Cascades on the Lattice

Kostas Orginos
College of William and Mary - JLab

LHP Collaboration

LHPC collaborators

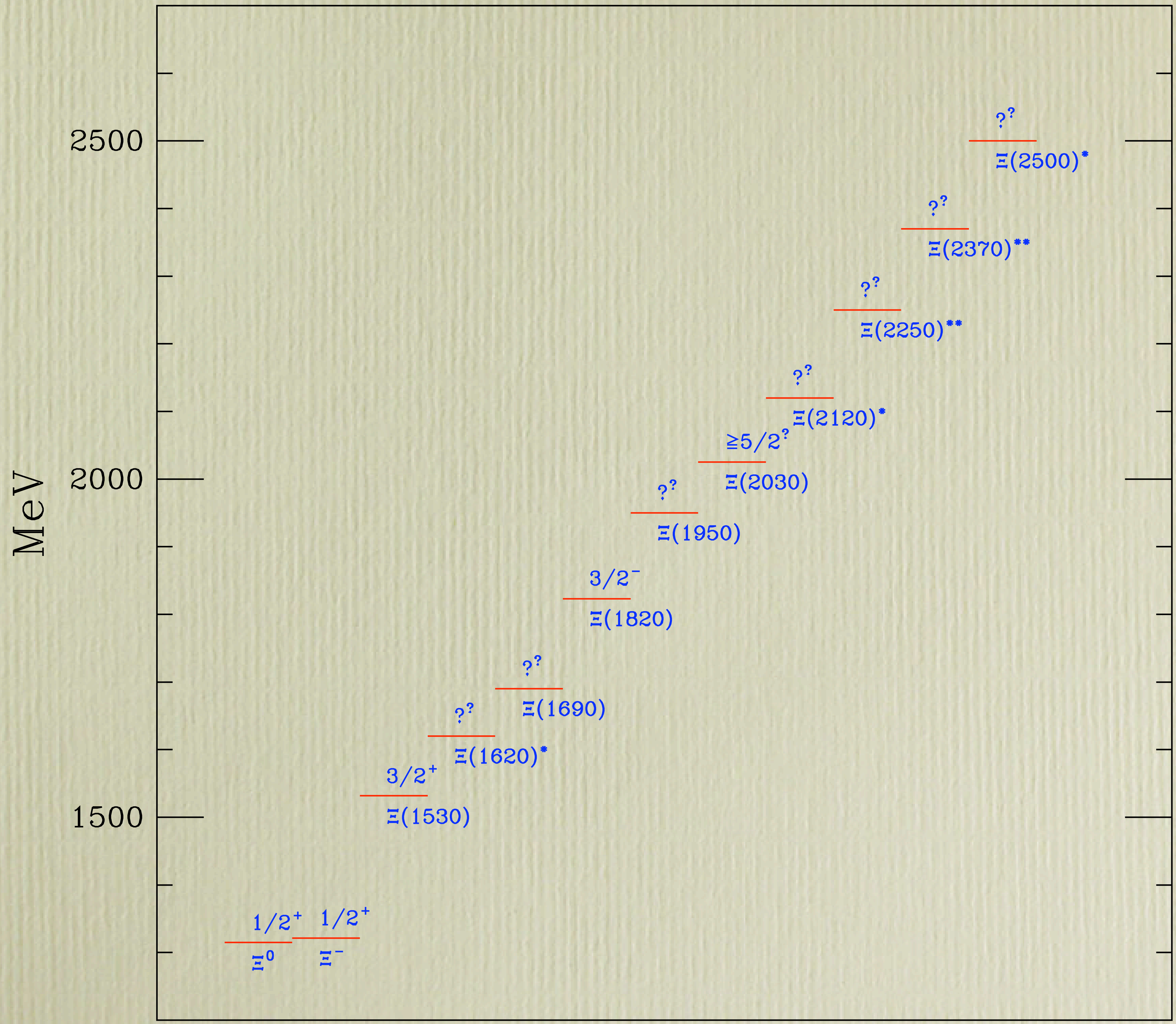
- R. Edwards (Jlab)
- G. Fleming (Yale)
- P. Hagler (Vrije Universiteit)
- C. Morningstar (CMU)
- J. Negele (MIT)
- A. Pochinsky (MIT)
- D. Renner (UofA)
- D. Richards (Jlab)
- W. Schroers (DESY)

Summary

- What can the Lattice do for you?
- How will we make it happen?
- What has been done?
- Some very preliminary results from LHPC

Thanks to D. Richards

Particle Data Group



Lattice QCD

- Spectrum calculation: simplest thing to do
- Strange quarks don't decay
  - stable cascades
- Better signal than protons (strange quark is heavy)
- Can vary quark masses
- Quantum numbers easy to identify

Difficulties

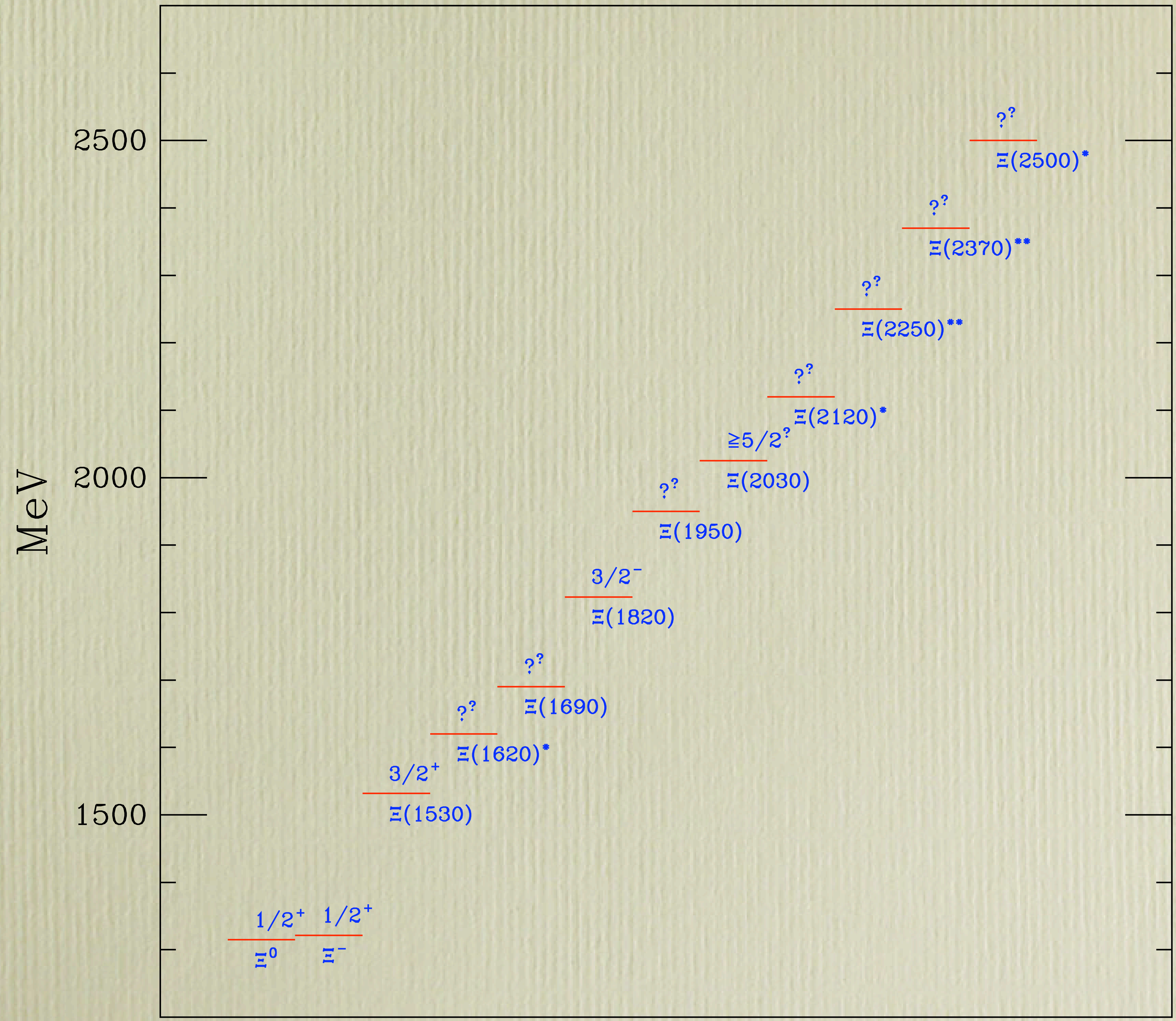
- Strong decays: Unstable particles
  - Finite volume techniques
  - Heavy quark masses: above threshold
- Broken rotational symmetry
  - Angular momentum not a good quantum number
- Vacuum polarization effects
  - Inefficient algorithms
  - mass of up and down quarks too light!
- Chiral symmetry and lattice fermions

Lattice Operators

G_1	H	G_2
7/2		7/2
	5/2	5/2
	3/2	
1/2		

hep-lat/050801 Basak et al.

Particle Data Group



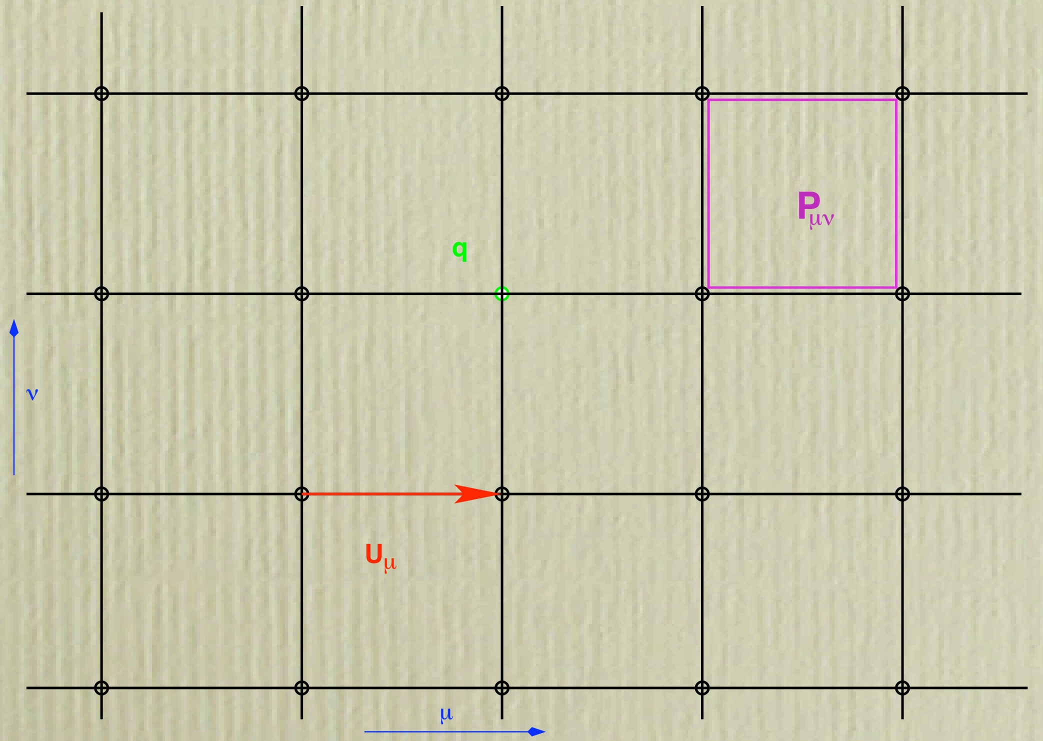
Lattice QCD

In continuous Euclidian space:

$$\mathcal{Z} = \int \mathcal{D}q\mathcal{D}\bar{q}\mathcal{D}A_\mu \, e^{-S[\bar{q},q,A_\mu]}$$

$$\langle \mathcal{O} \rangle = \frac{1}{\mathcal{Z}} \int \mathcal{D}q\mathcal{D}\bar{q}\mathcal{D}A_\mu \, \mathcal{O}(\bar{q}, q, A_\mu) \, e^{-S[\bar{q},q,A_\mu]}$$

Lattice regulator:



Gauge sector:

$$U_\mu(x) = e^{-iaA_\mu(x+\frac{\hat{\mu}}{2})}$$

Fermion sector:

$$\mathcal{Z} = \int dU \;\; \det(\Delta)^{n_f} \, e^{-\sum \frac{\beta}{N_c} ReTr[1-P_{\mu,\nu}(x)]}$$

Fermion doubling

Chiral symmetry breaking

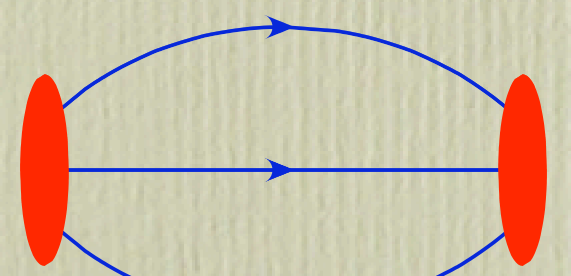
Spectrum

- Correlation functions

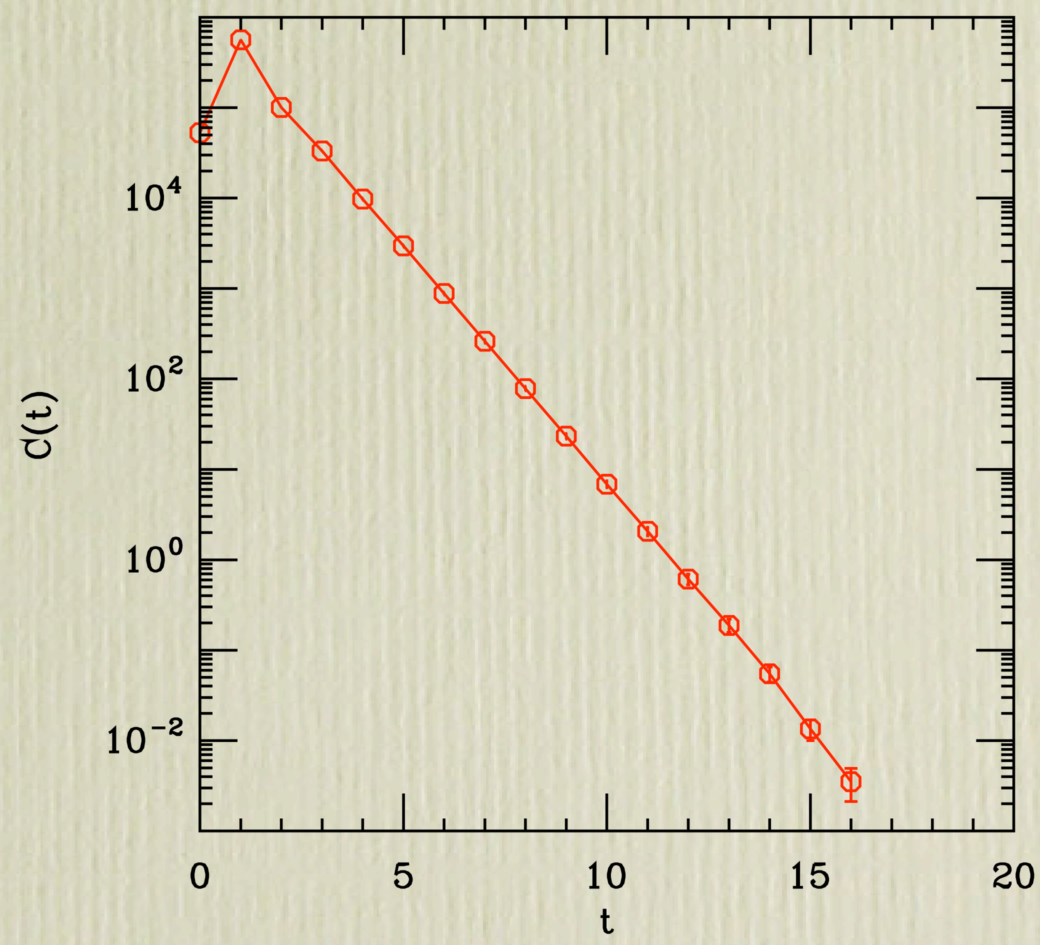
$$C(t) = \langle J(t)\bar{J}(0)\rangle$$

- J an interpolating field for some state

Proton



$$C(t) = Z_0 e^{-M_0 t} + \cdots$$



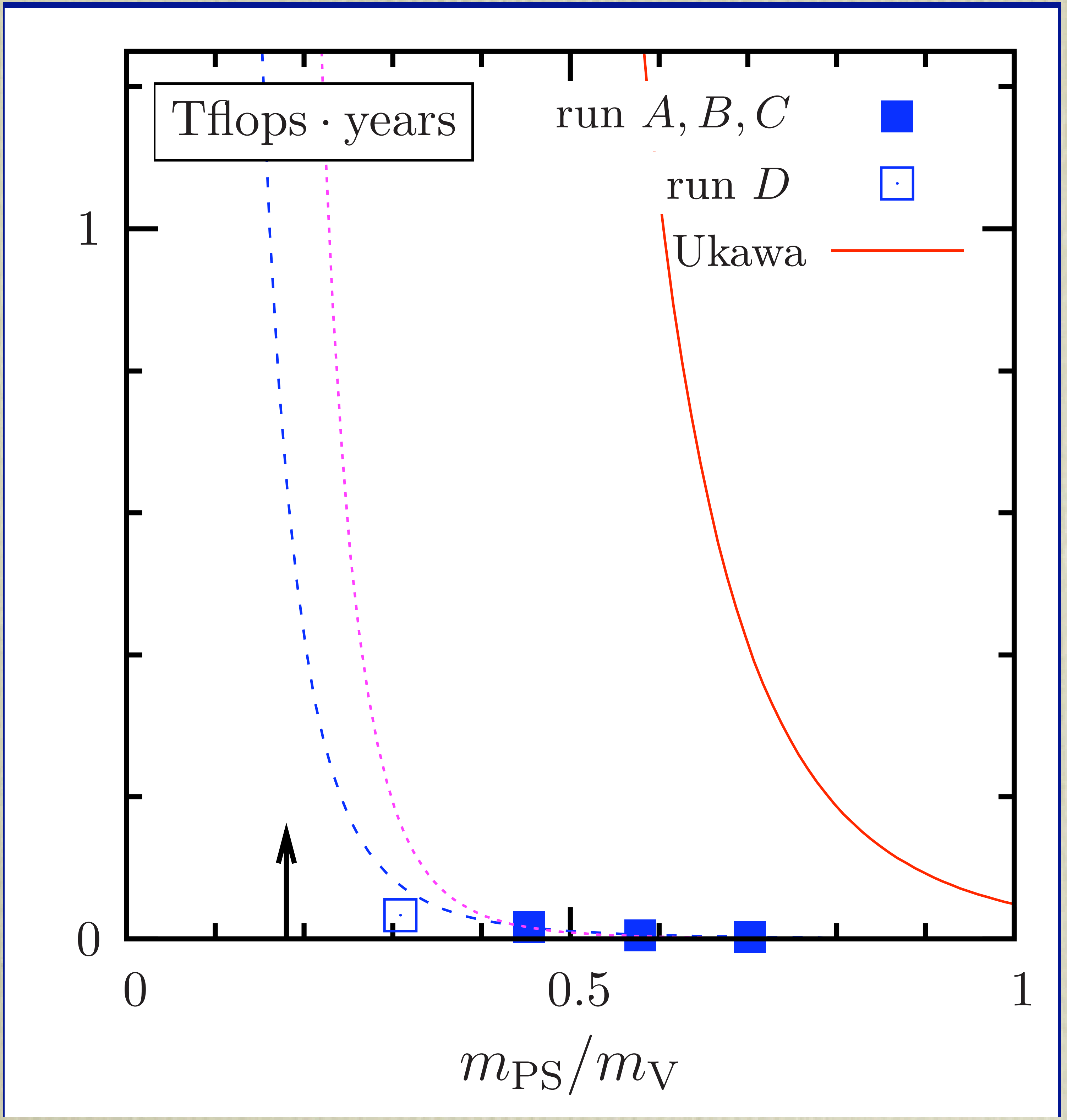
Need to do

- Continuum extrapolation
- Chiral extrapolation
- Infinite volume extrapolation
- In all cases use Effective field theory
- Scale setting
  - Heavy quark potential (Sommer scale)
  - Rho mass (bad choice)
  - Heavy quarkonia

What does it take

- 2+1 Dynamical flavors
  - 2 light (up down) 1 heavy (strange)
  - charm bottom top (treated in HQET as extrernal)
- Light quark masses $m_\pi < 400\text{MeV}$
  - Chiral extrapolations
  - Finite volume corrections
  - Numerical algorithm slows down (algorithm scaling $\sim \frac{1}{m_q^{2.5}}$)
- Continuum extrapolations
  - compute at several lattice spacings (algorithm scaling $\sim \frac{1}{a^7}$)

The Berlin Wall

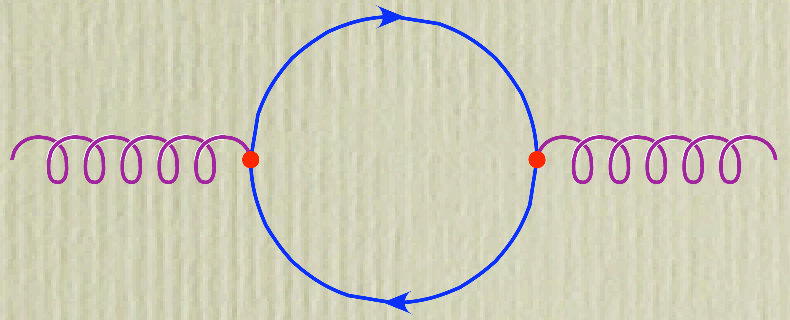


Urbach (ILFTN 3)

Queching

$$\mathcal{Z} = \int dU \;\; \det(\Delta)^{n_f} \; e^{-\sum \frac{\beta}{Nc} ReTr[1 - P_{\mu,\nu}(x)]}$$

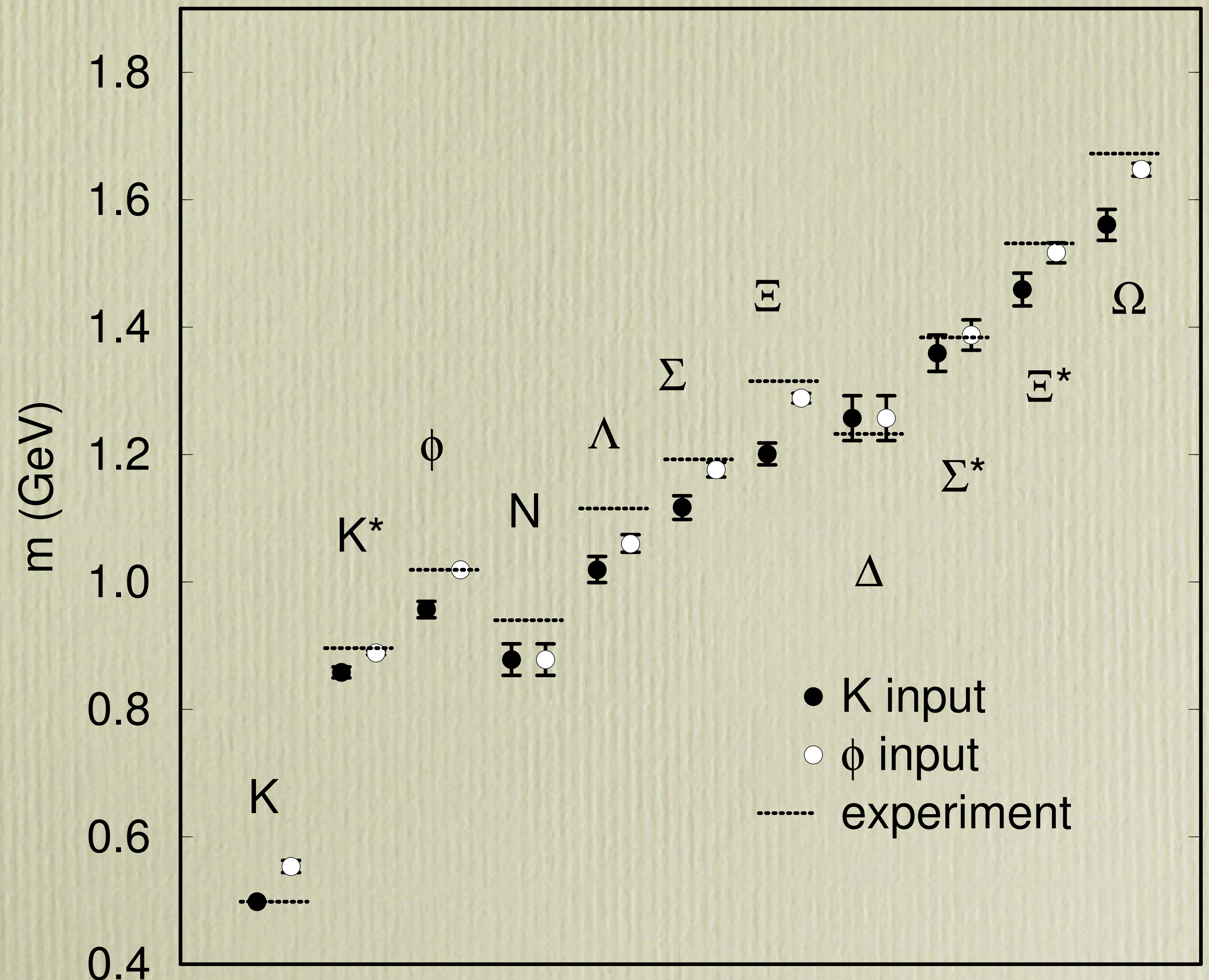
The computation simplifies if we ignore the fermion loops



$$\det(\Delta) = 1$$

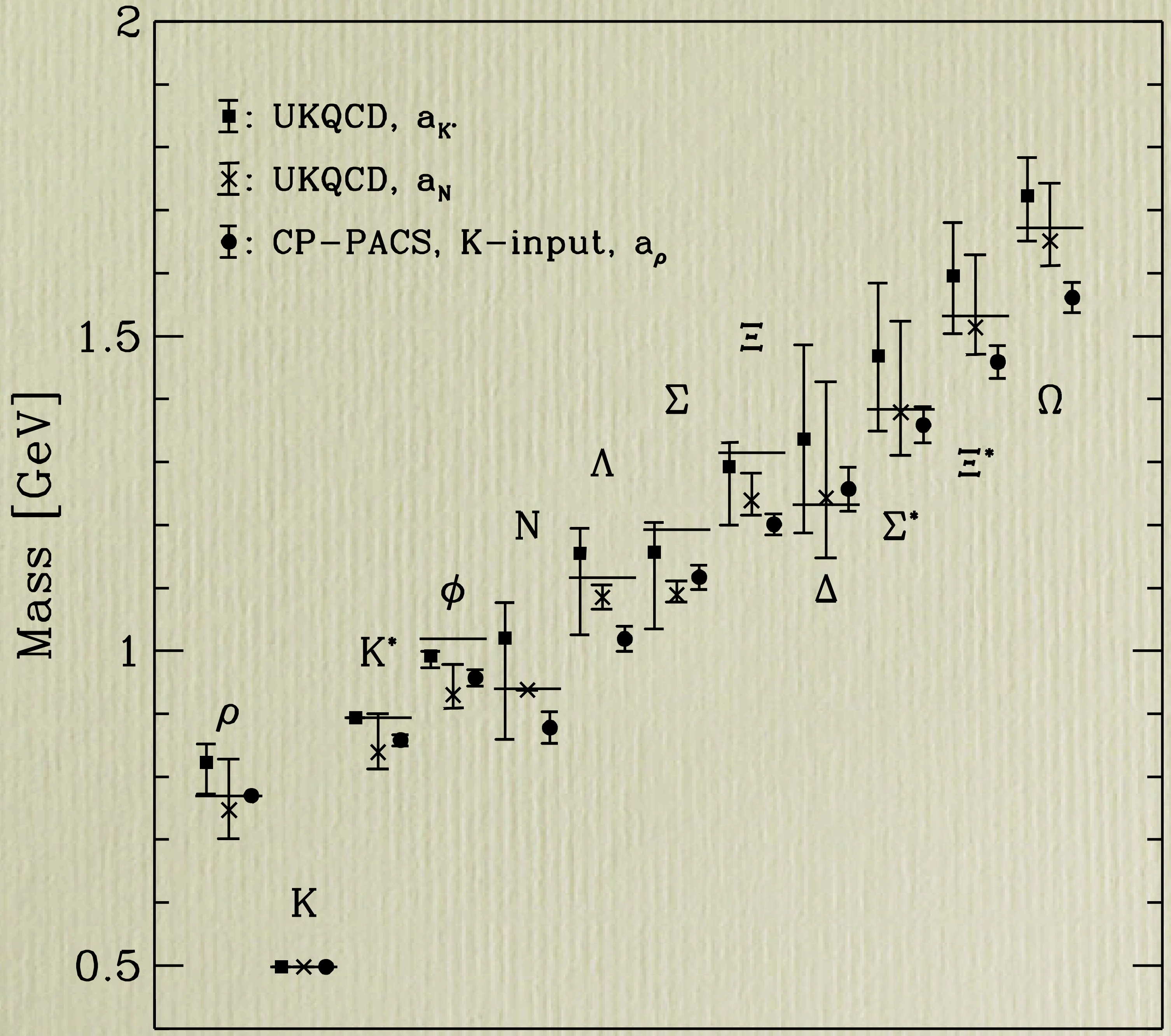
Uncontrolled “approximation”

Quenched spectrum



CP-PACS

Quenched Spectrum



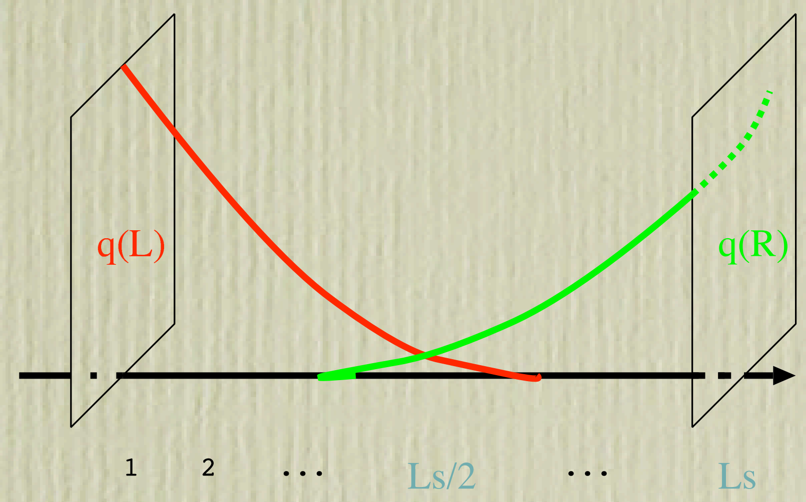
UKQCD

Recent Developments

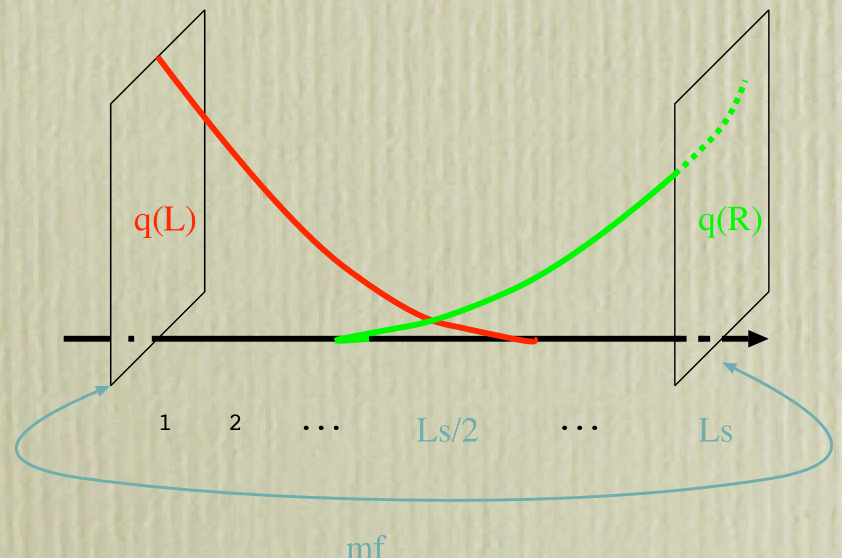
- Cheap dynamical fermions (Kogut-Susskind)
  - "Taste" breaking
  - Improved KS action (Asqtad $O(a^4, g^2 a^2)$) [KO, Sugar, Toussaint '99]
  - MILC has generated lattices: Ready to milk the MILC
- Chiral symmetry on the lattice ($O(a^2)$errors)
  - Domain wall fermions [Kaplan -- Shamir]
  - Overlap fermions [Neuberger, Narayanan]
  - Costly for dynamical: RBC now starting
  - Improvements:
    - Improved gauge actions [KO with RBC '02]
    - Mobius fermions [Brower, Neff, KO '04]
- Big Computers!

Domain Wall Fermions for QCD

Formulate the 5D Wilson fermions with mass $M \neq 0$ in $s \,\epsilon\, [1, L_s]$



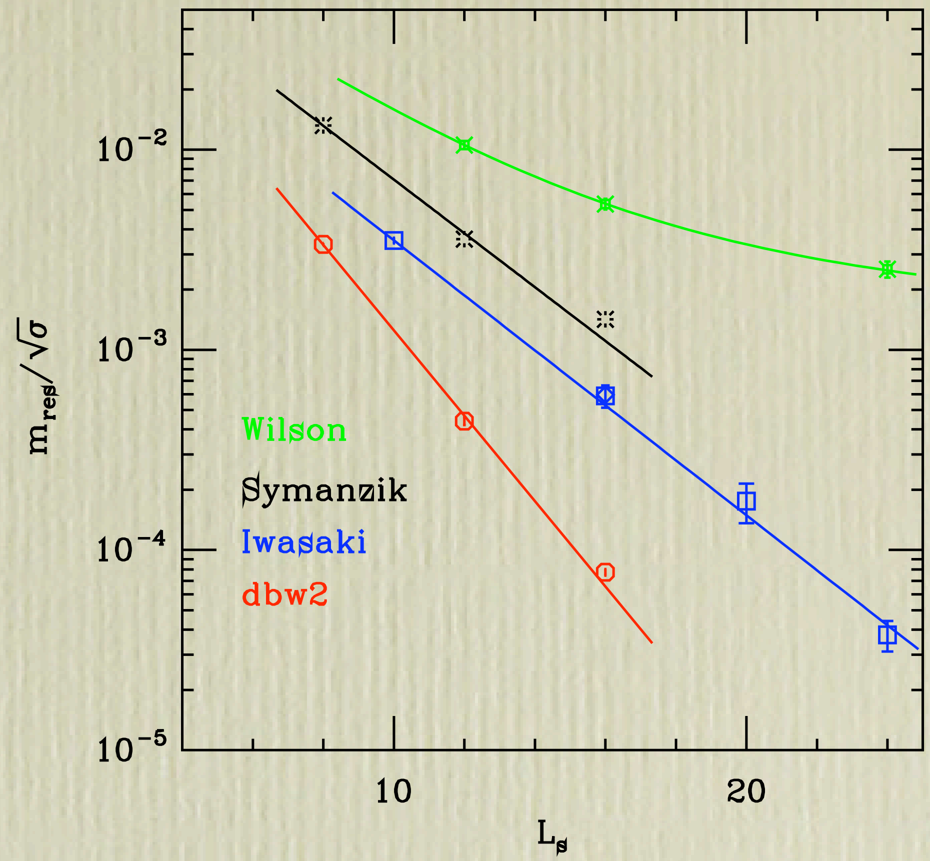
For $-2 < M < 0$, light chiral modes are bound on the walls.
Only one Dirac fermion without doublers remains.



Fermion mass is introduced by explicitly coupling m_f of the walls. [Shamir,Furman & Shamir]

Why Domain Wall Fermions

- Excellent chiral properties
  at finite lattice spacing:
  - $L_s \rightarrow \infty$ Exact chiral symmetry
  - L_s finite: Exponentially small chiral symmetry breaking
  - Gauge action affects chiral symmetry
    [KO with RBC hep-lat/0211023]
  - Chiral extrapolations

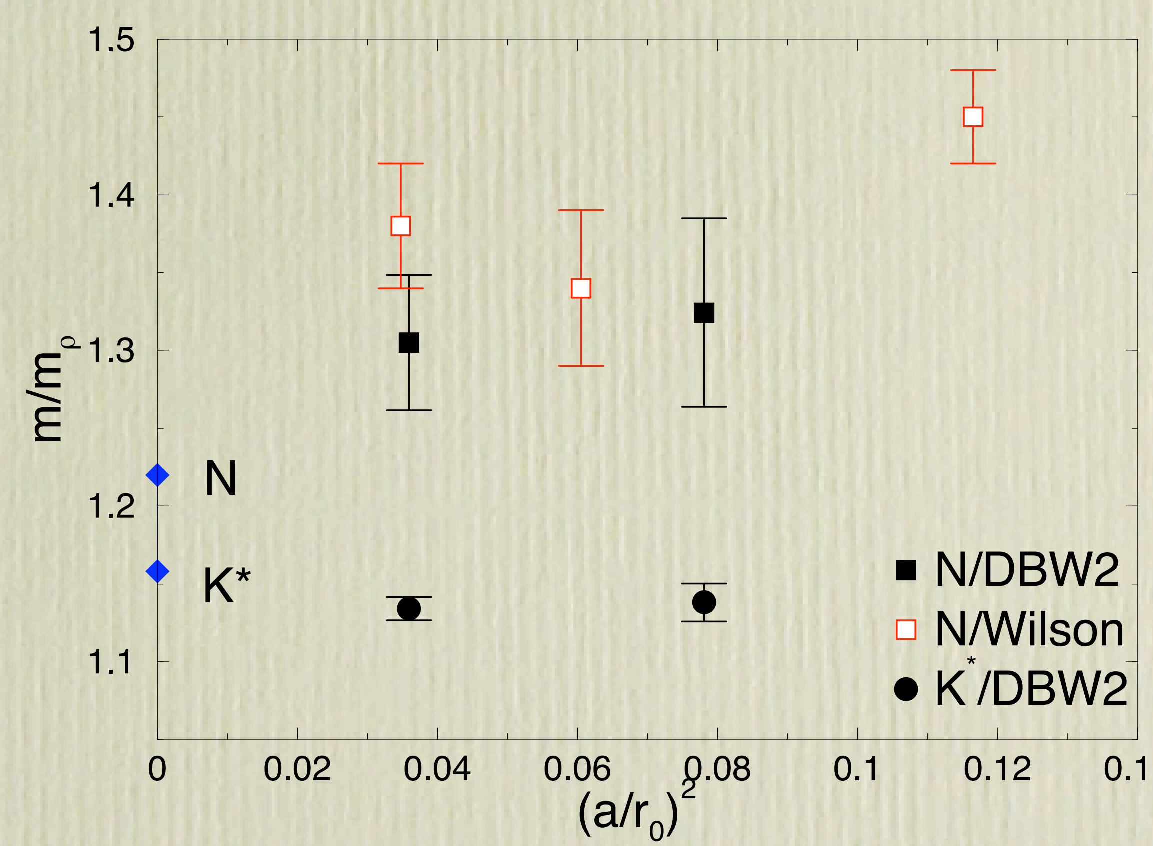


- Simpler renormalization due to symmetry

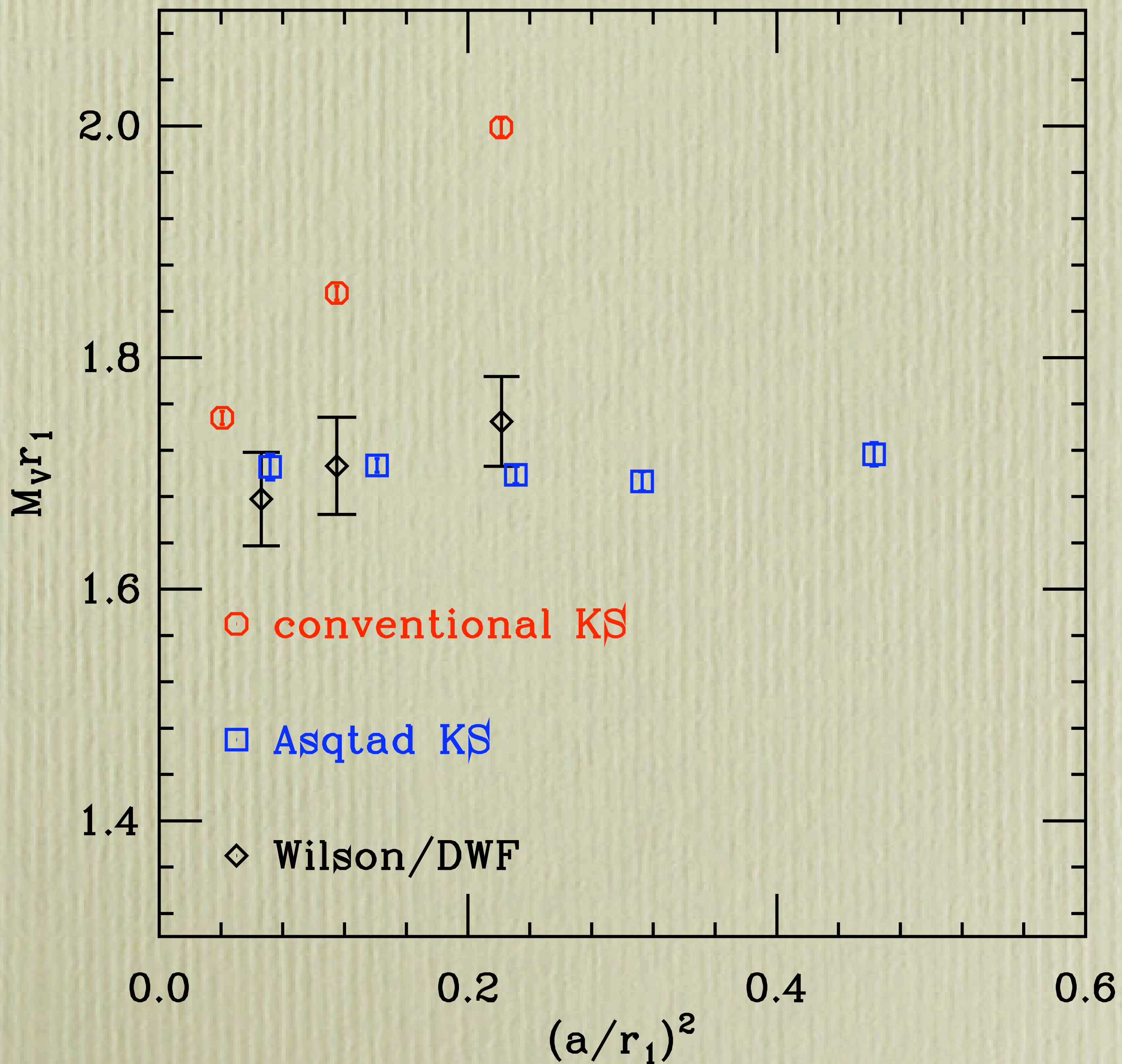
- Can work close to the chiral limit

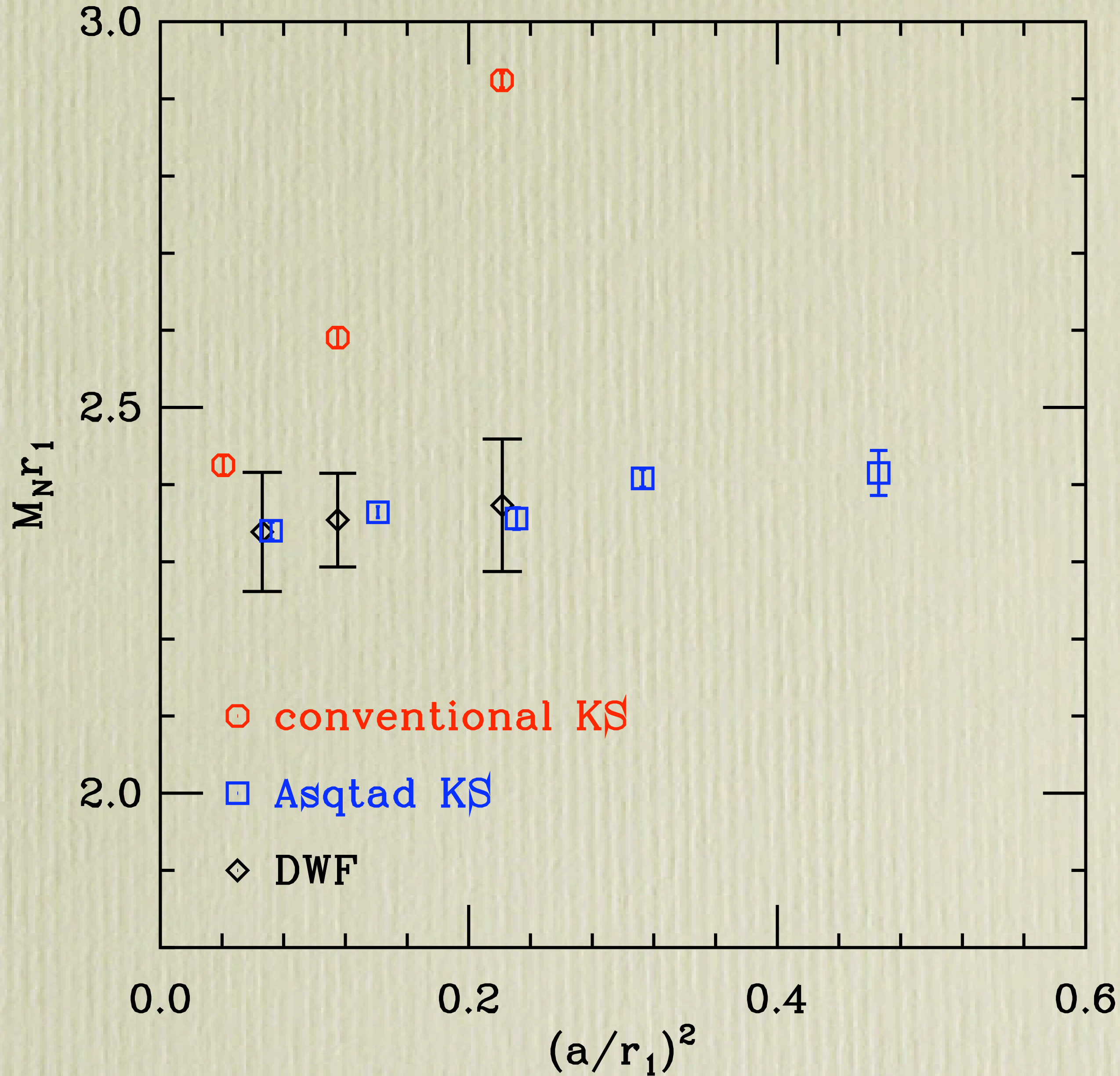
- Have $O(a^2)$ errors

- Excellent scaling properties



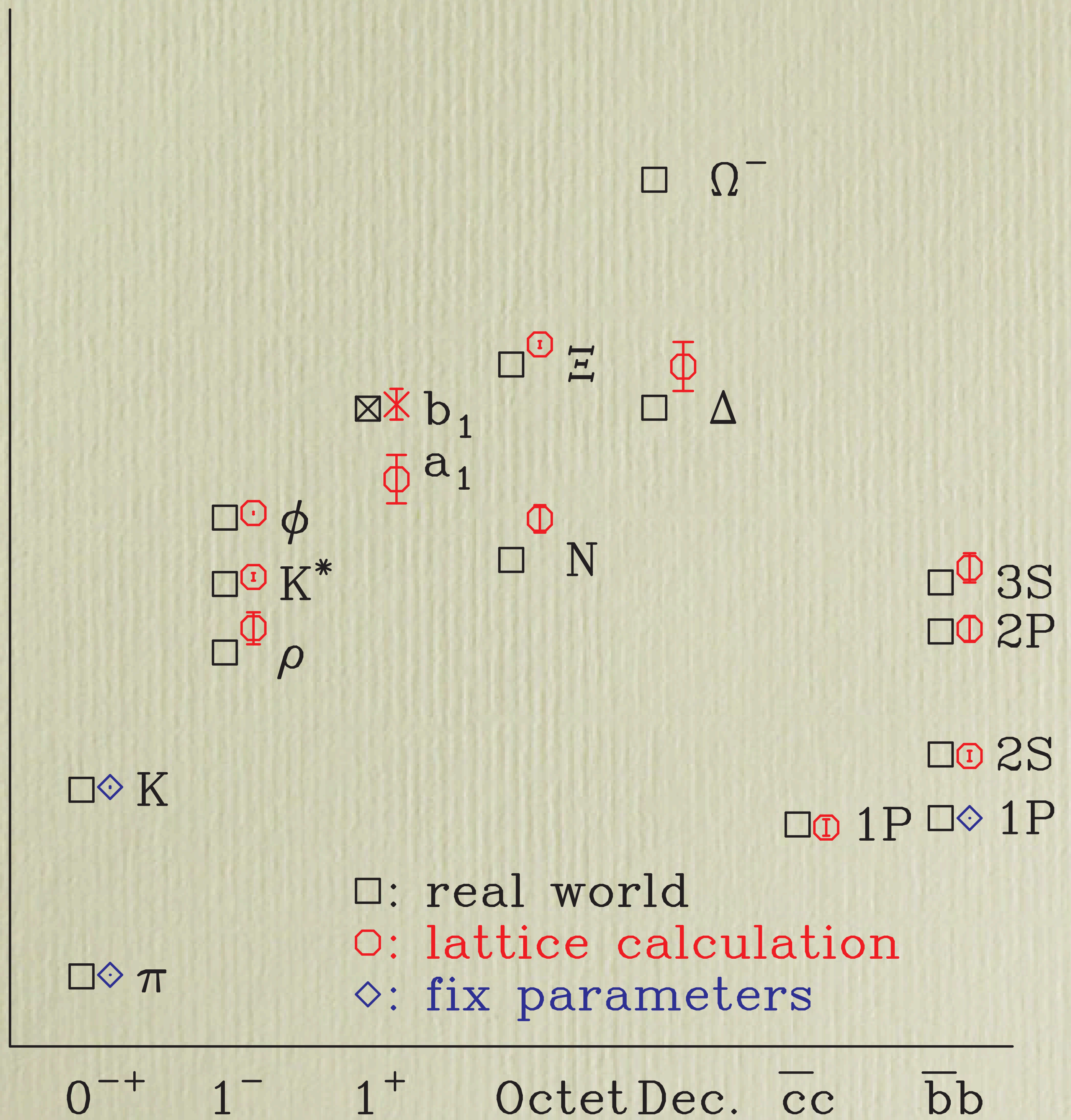
Scaling





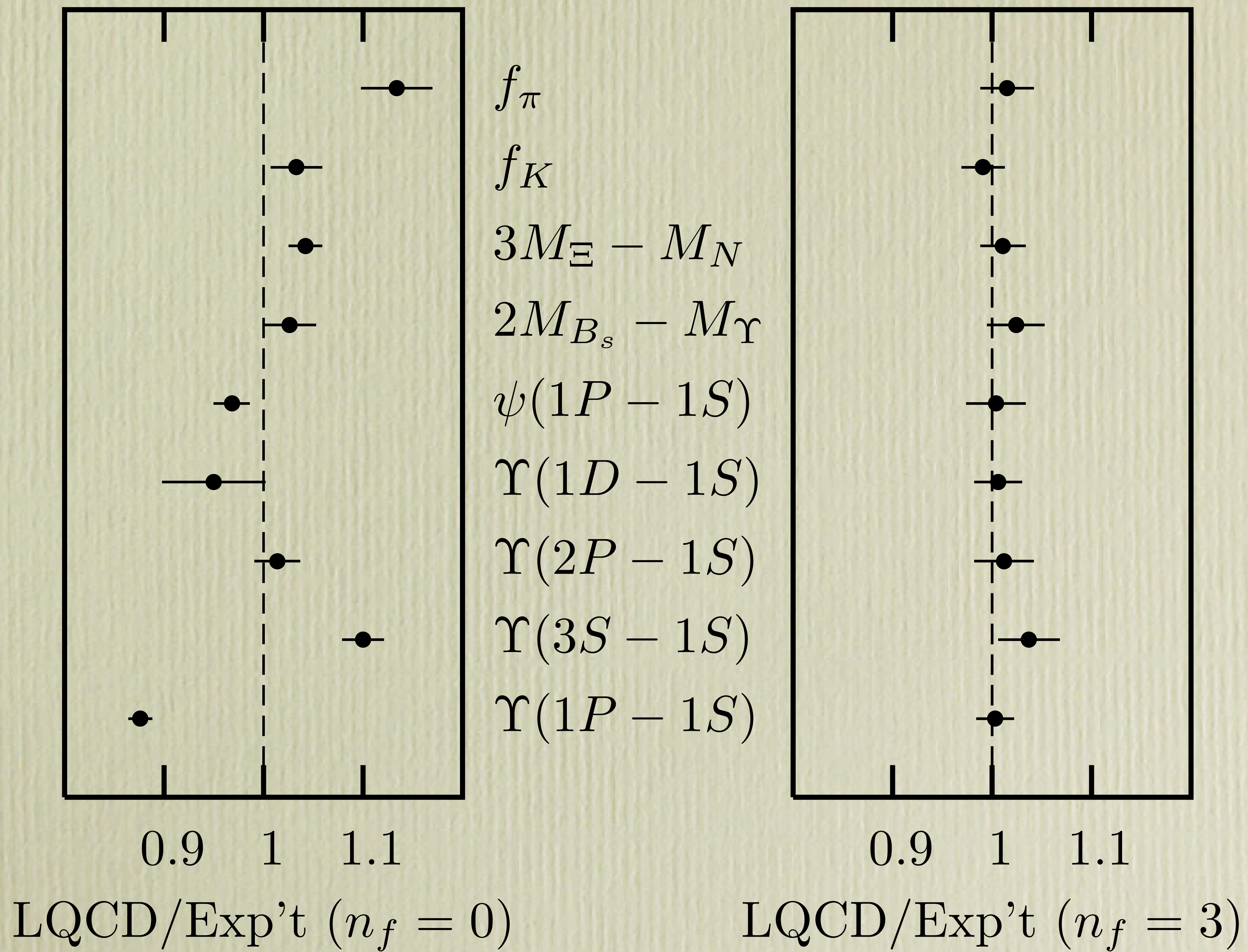
MILC and RBC data

Dynamical 2+1 flavors



MILC

Quenched vs Dynamical



MILC, HPQCD, UKQCD

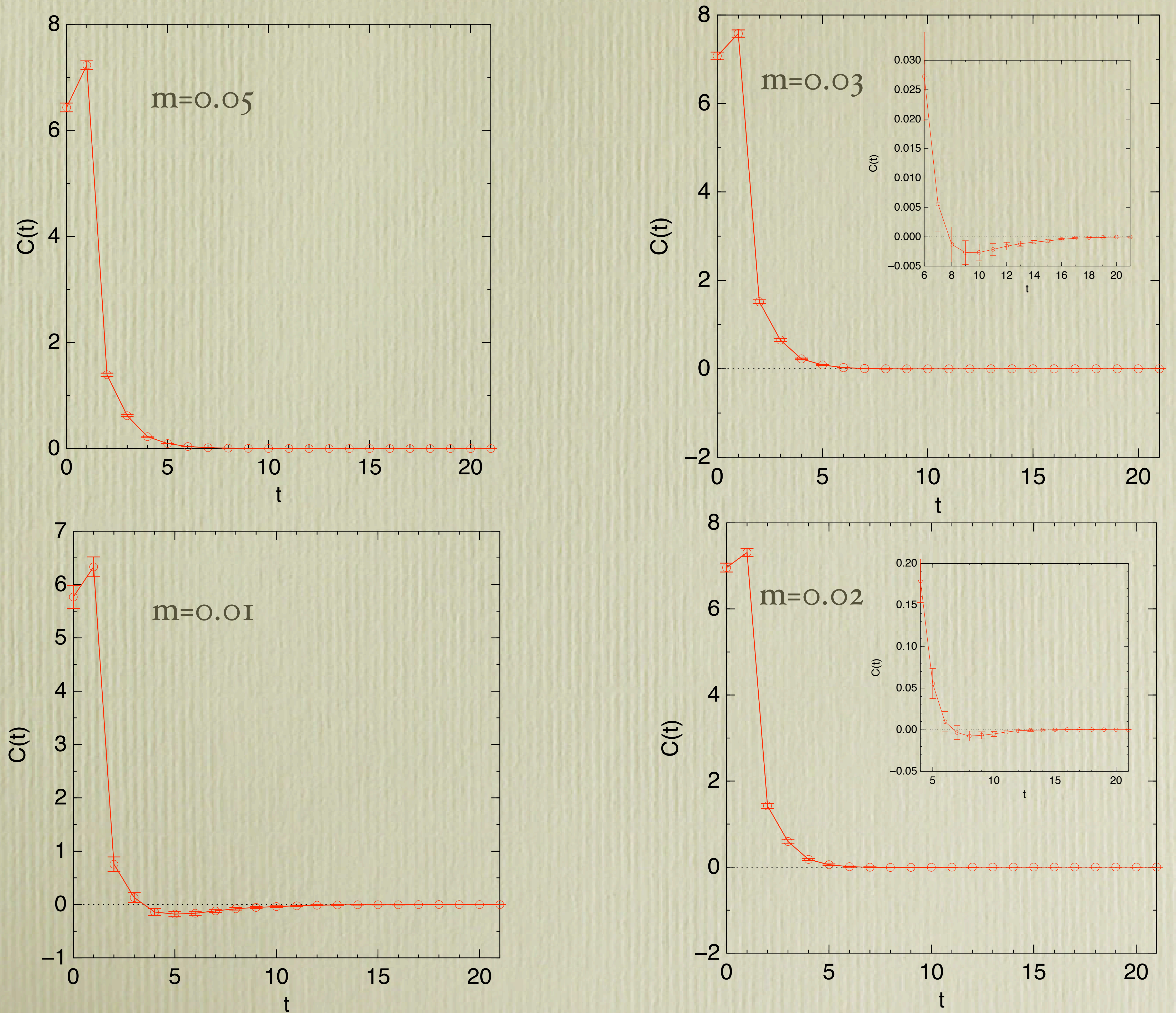
The LHPC program

- Domain wall fermions for valence (with hyp smeared links)
  - Chiral symmetry
  - Ward Identities
- Kogut-Susskind 2+1 Dynamical flavors
  - Improved KS action (Asqtad: $O(a^4, g^2 a^2)$) [KO, Sugar, Toussaint '99]
  - MILC has generated lattices: Ready to milk the MILC
- Light quark masses: Lightest pion $m_\pi \sim 250$MeV
- Volumes: 2.6 to 3.2 fm
- Future: Continuum extrapolation
  - MILC lattice spacings: a=0.125fm, 0.09fm
  - a=0.06fm in 1 - 2 years

The DWF quark masses

- Domain wall fermions for valence (hyp smeared links)
  - We tune the DWF quark mass to the staggered Goldstone pion
- Unitarity violation
- Baer et.al.: tune to the taste singlet for m_π
- Not clear it helps for other quantities (ex. f_π)
- Unitarity is restored in the continuum in any case

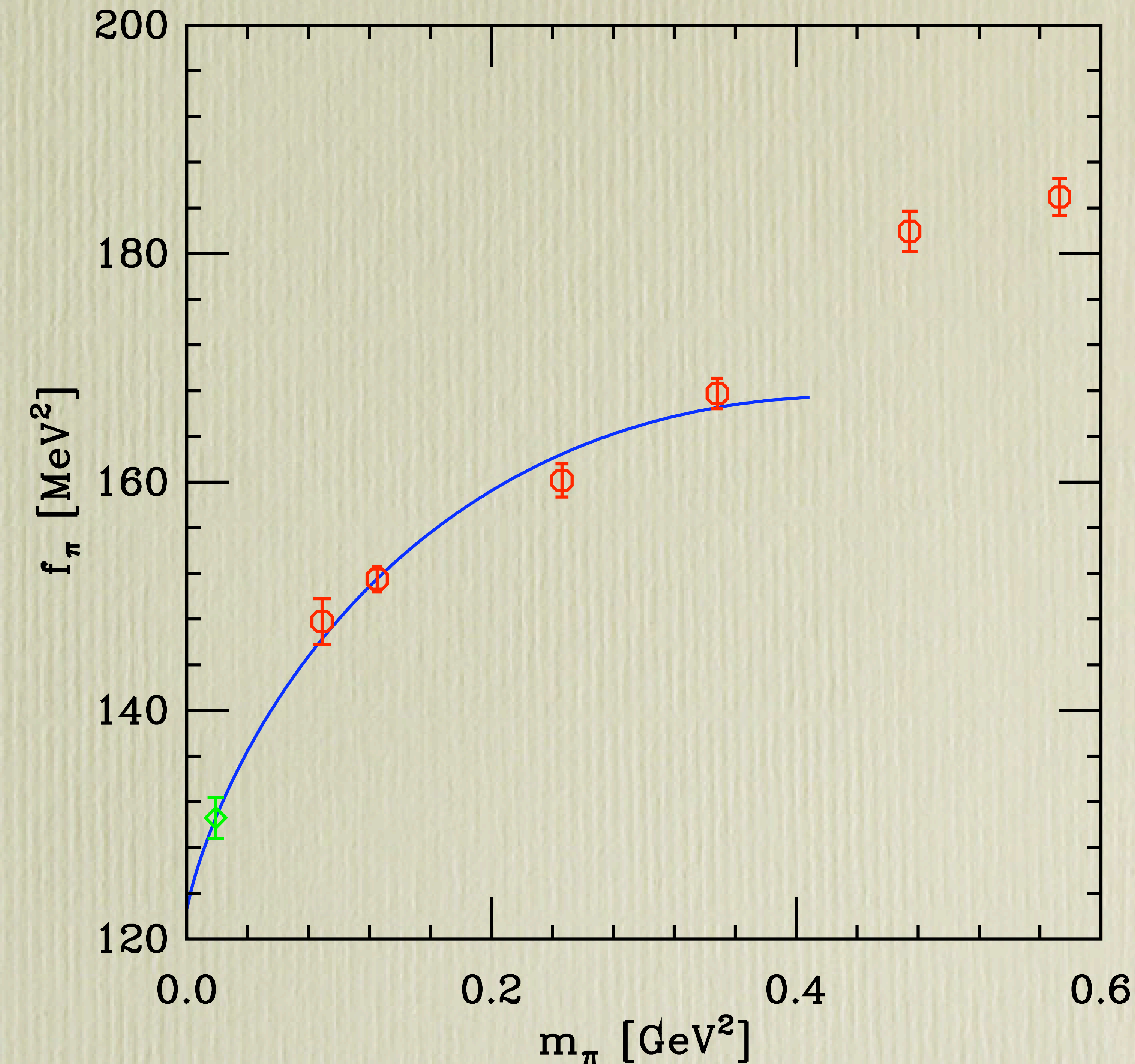
IsoVector scalar correlator



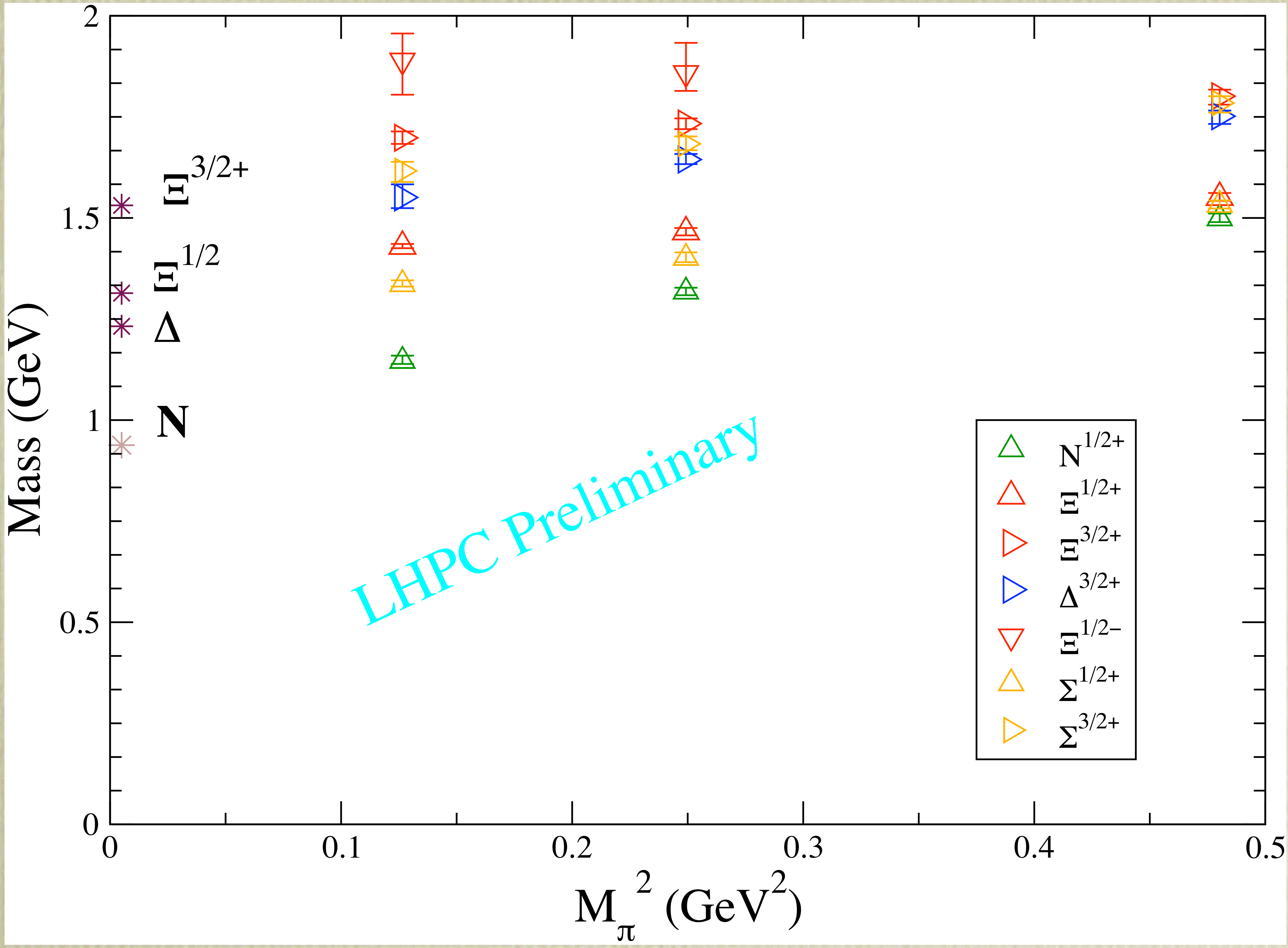
χPT calculation: Prelovsek LAT 05

Pion decay constant

- Fit the lower 4 points
- Scale used a = 0.125 fm
- One loop χPT extrapolation: 130.6(1.8)MeV
- Systematic error:
  - chiral extr. 3 MeV
  - 2% from scale setting
- χ^2/d.o.f. ~ 2
- Need mixed χPT of Baer et.al.

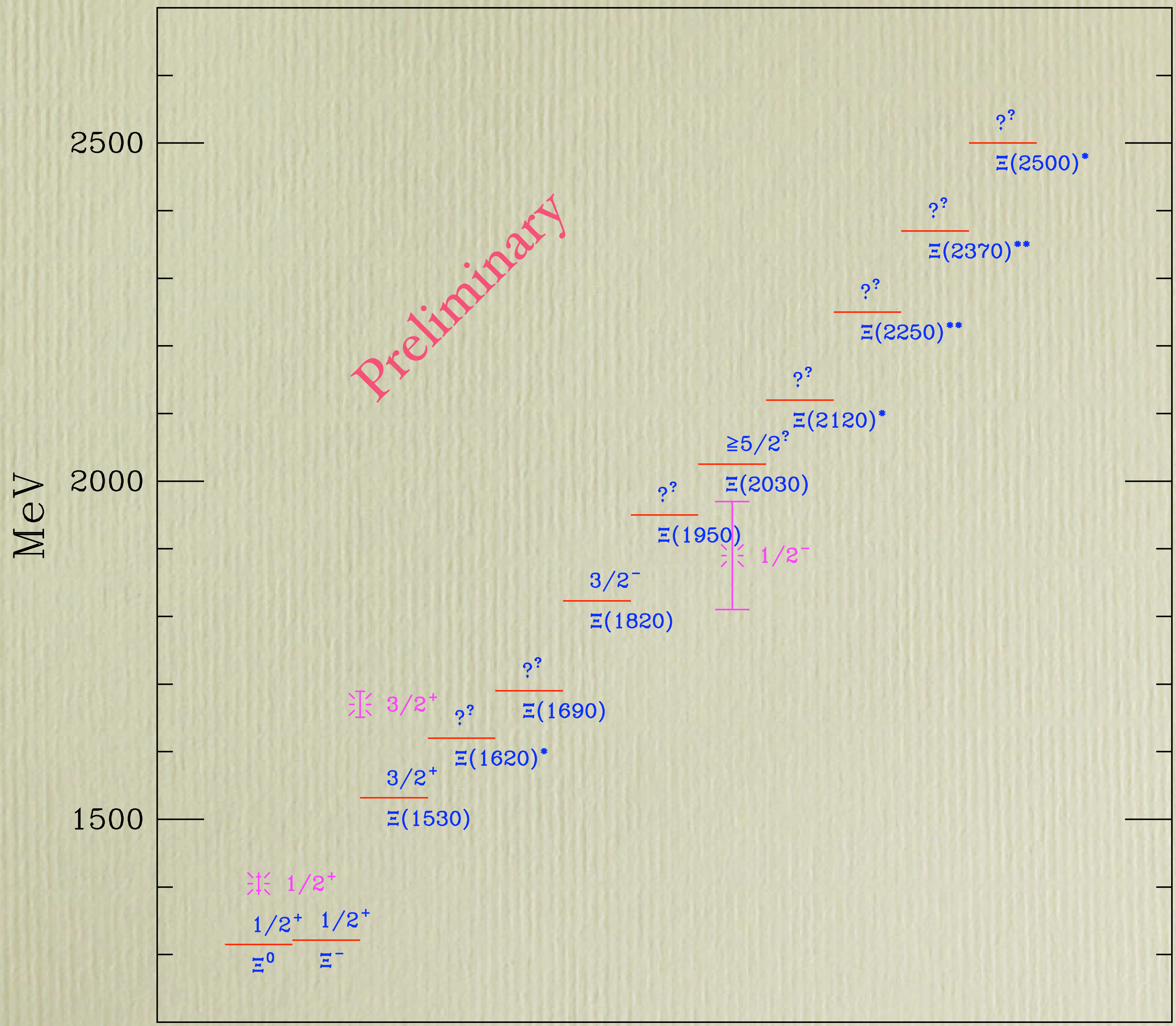


LHPC dwf on MILC



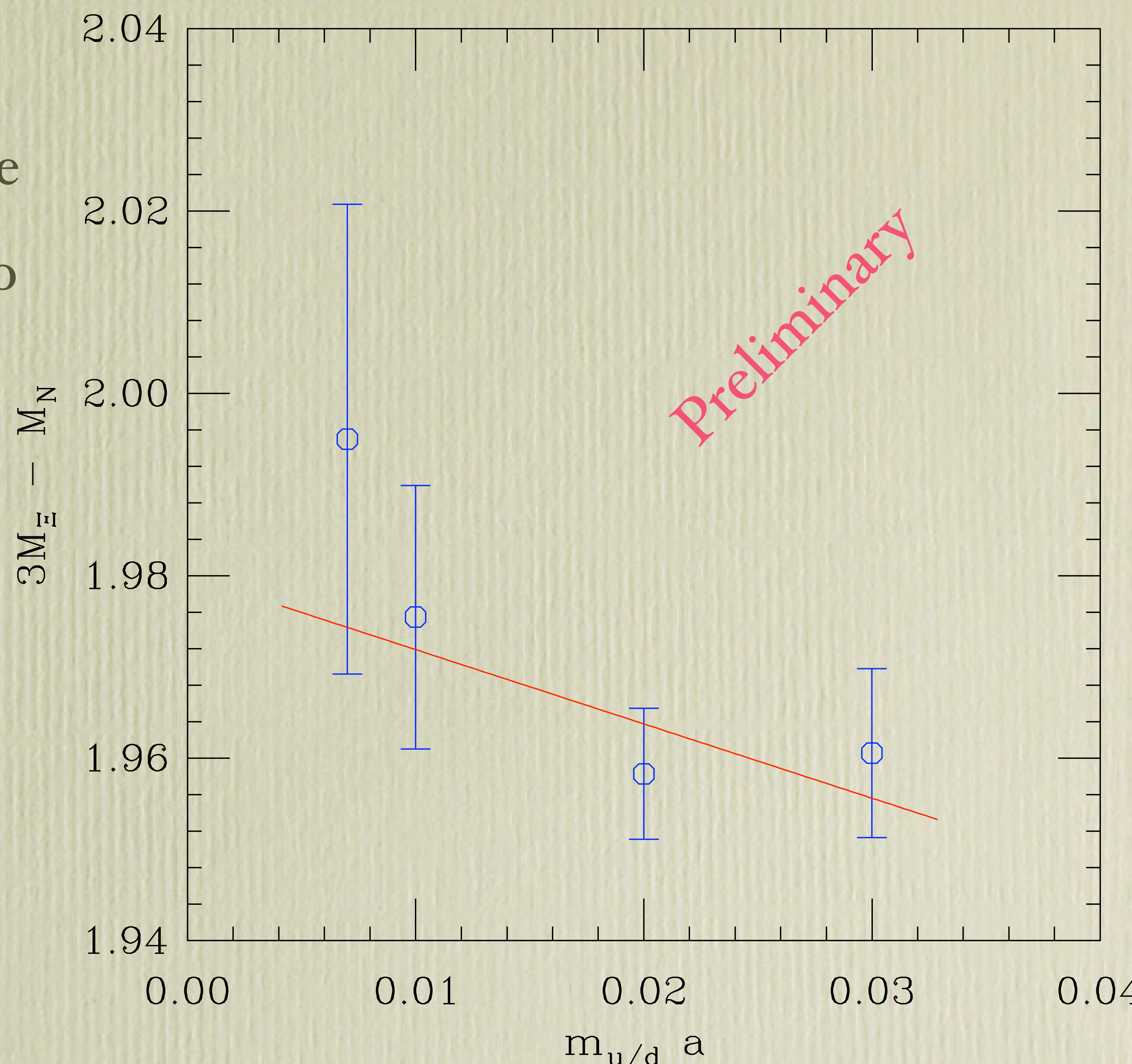
D. Richards

LHPC data vs Experiment

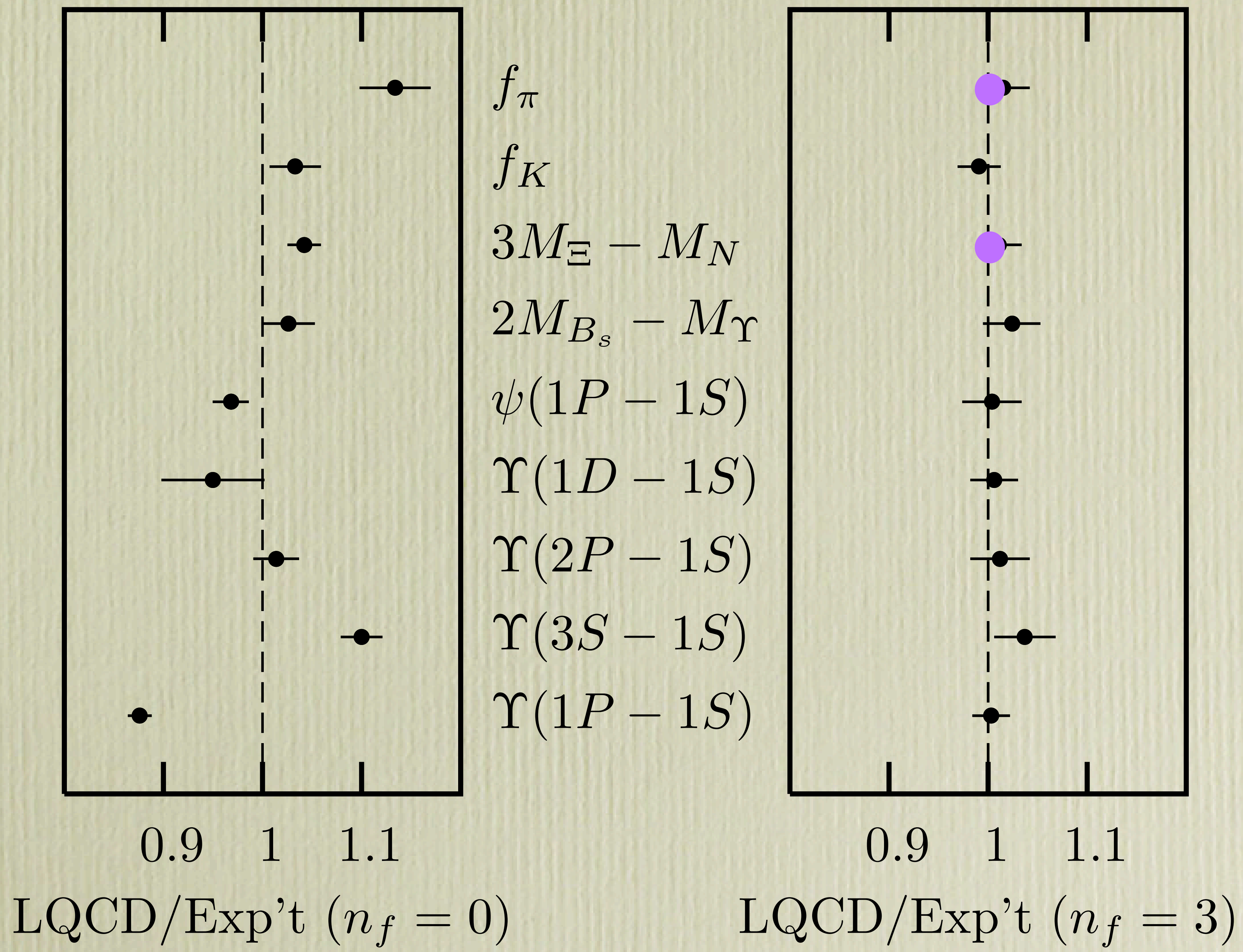


Cascade - Nucleon mass splitting

- Mild quark mass dependence
- Small systematic error due to chiral extrapolation
- Other systematice errors cancel
- Scale used a = 1588 MeV
- Latt./Exp. = 1.006(8)



Quenched vs Dynamical



LHPC: preliminary (no errorbars)

MILC, HPQCD, UKQCD

Conclusions

- Lattice QCD can be very helpful in studying the cascade spectrum
- Not much has been done up to now
- The "gold plated" observable $3M_{\Xi} - M_N$ is well reproduced (MILC and LHPC).
- LHPC: Need to work on statistics and extrapolations
- Finer lattice spacing is on the way