Mapping the Spectrum of Light Quark Mesons and Gluonic Excitations with Linearly Polarized Photons

Phenomenology

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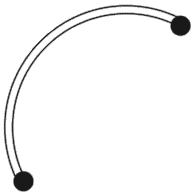
PAC 30

Models of Gluonic Excitations

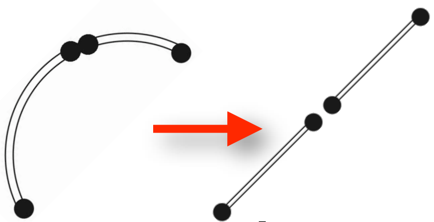
- the flux-tube model has historically dominated the field
- has a rather complete phenomenological coverage
  - *mass spectrum estimates* (Isgur & Paton)



$$\delta m \sim \left\langle \frac{1}{r} \right\rangle \qquad m_{\mathcal{H}} \sim 2\,\mathrm{GeV}$$

$$1^{-+}, 0^{+-}, 2^{+-}$$ + *non-exotics*

  - *hadronic decay widths* (Isgur, Kokoski, Close, Page ...)

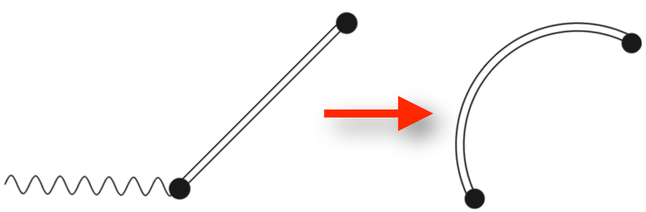


⇒ *"S+P" rule*

$\pi_1 \to \pi\, b_1$

$\pi_1 \not\to \pi\, \rho$

  - *photocouplings* (Close & JJD)



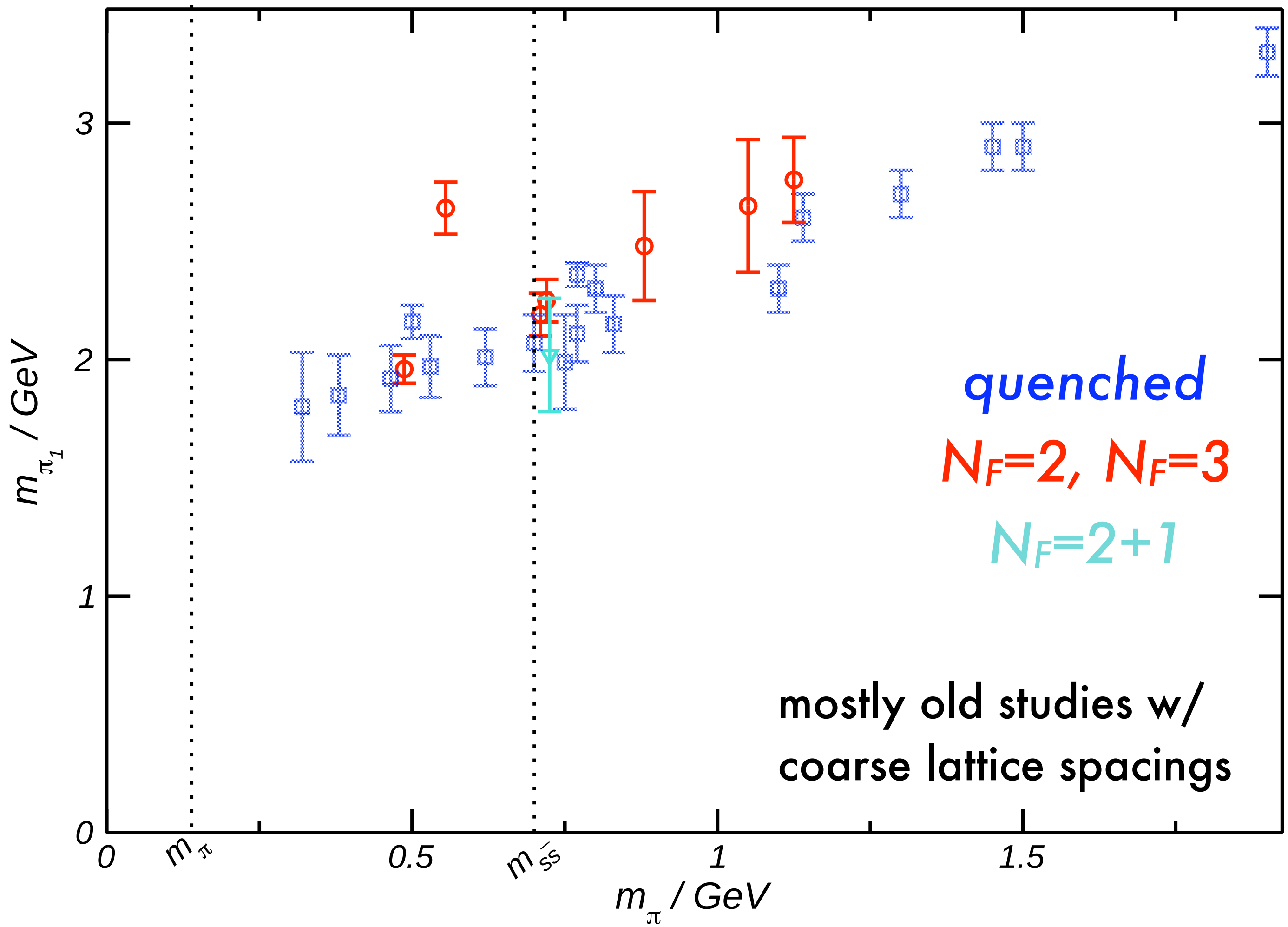
$$\frac{A_{\mathcal{H}}}{A_{\mathcal{C}}} \sim \frac{\sqrt{b}}{m_q} \sim \mathcal{O}(1)$$

Lattice QCD

- lattice QCD is, in principle, a controlled approximation to QCD
- computational power limits
  - the fineness of the lattice spacing $a \gtrsim 0.06\,\mathrm{fm}$
  - the size of the box $L \lesssim 3\,\mathrm{fm}$
  - the light quark mass $m_\pi \gtrsim 250\,\mathrm{MeV}$
- in the years before and during *GlueX* expect to see all the flux-tube model predictions tested using lattice QCD

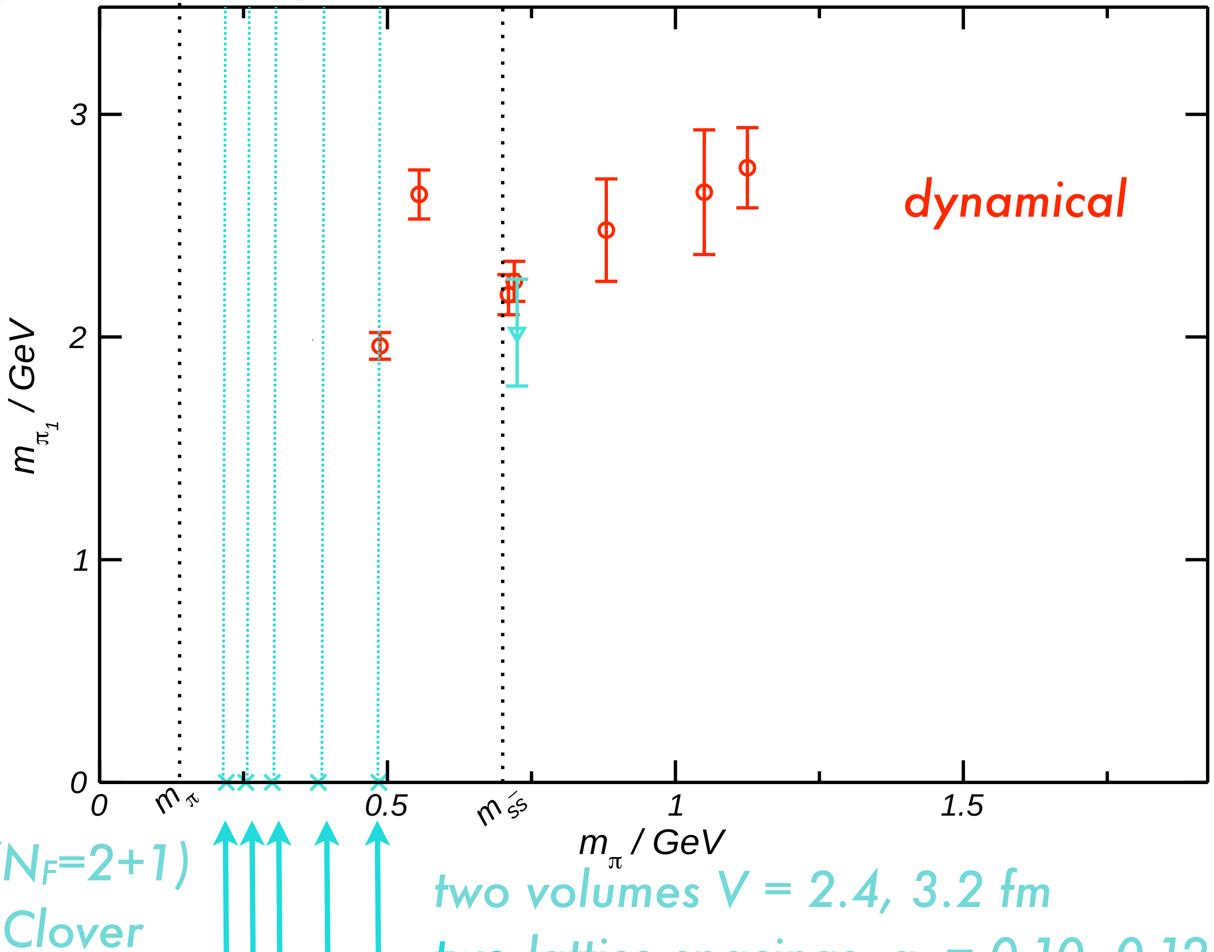
Lightest 1^{-+} from Lattice QCD

- summary of world simulation data



Lightest 1^{-+} from Lattice QCD

- *JLab* effort over next two years will significantly improve this picture



dynamical (N_F=2+1)
anisotropic Clover

two volumes V = 2.4, 3.2 fm
two lattice spacings, a_s = 0.10, 0.125 fm

$1/a_t$ = 6 GeV

Wider Meson Spectrum

- *GlueX* will be a meson spectrometer of broad scope
- *JLab* lattice QCD spectrum program has same aim
  - excited states in a given J^{PC} via variational method

e.g. baryon sector work by LHPC claims 9 excited states !

  - large set of J^{PC} using big operator set

$$\bar{\psi}\Gamma\psi$$

$$\bar{\psi}\Gamma\, \overleftrightarrow{D}_{\mu}\, \psi$$

$$\bar{\psi}\Gamma\, \overleftrightarrow{D}_{\mu}\overleftrightarrow{D}_{\nu}\, \psi$$

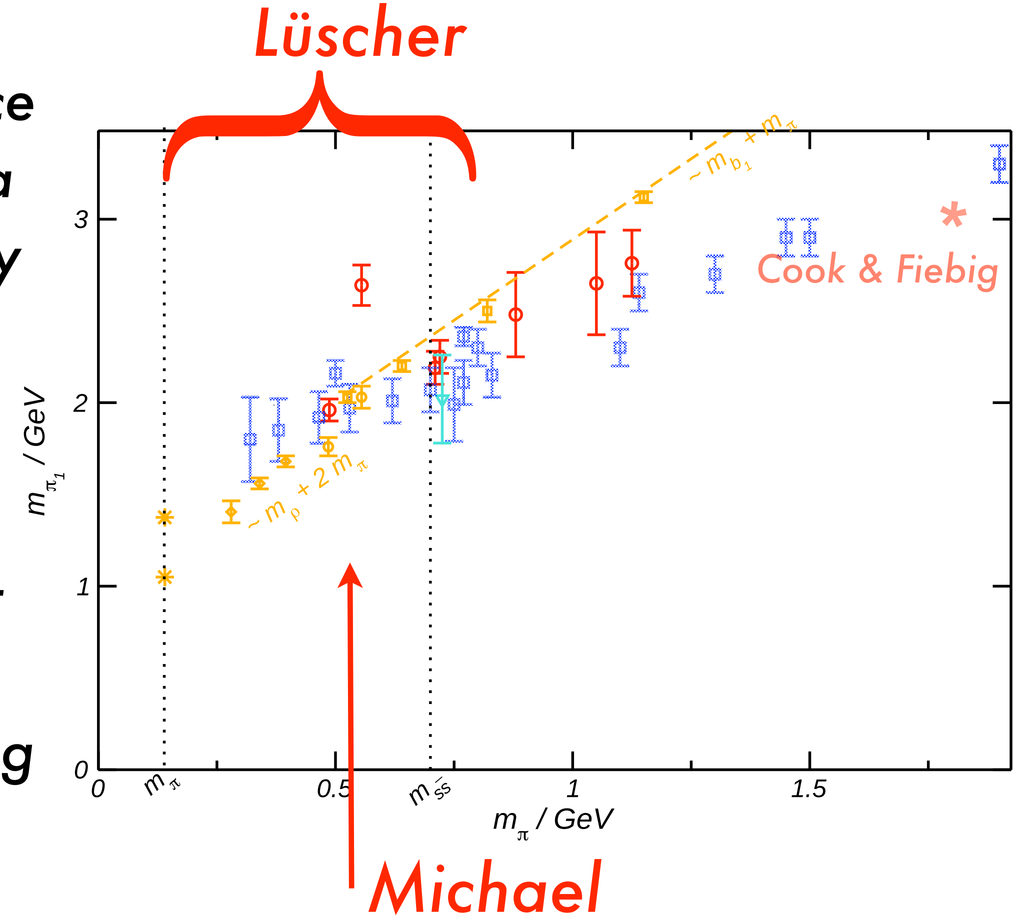
$$\bar{\psi}\Gamma F^{\mu\nu}\psi$$

Hadronic Decays

- challenging topic in lattice QCD, currently two approaches
  - *Lüscher method*

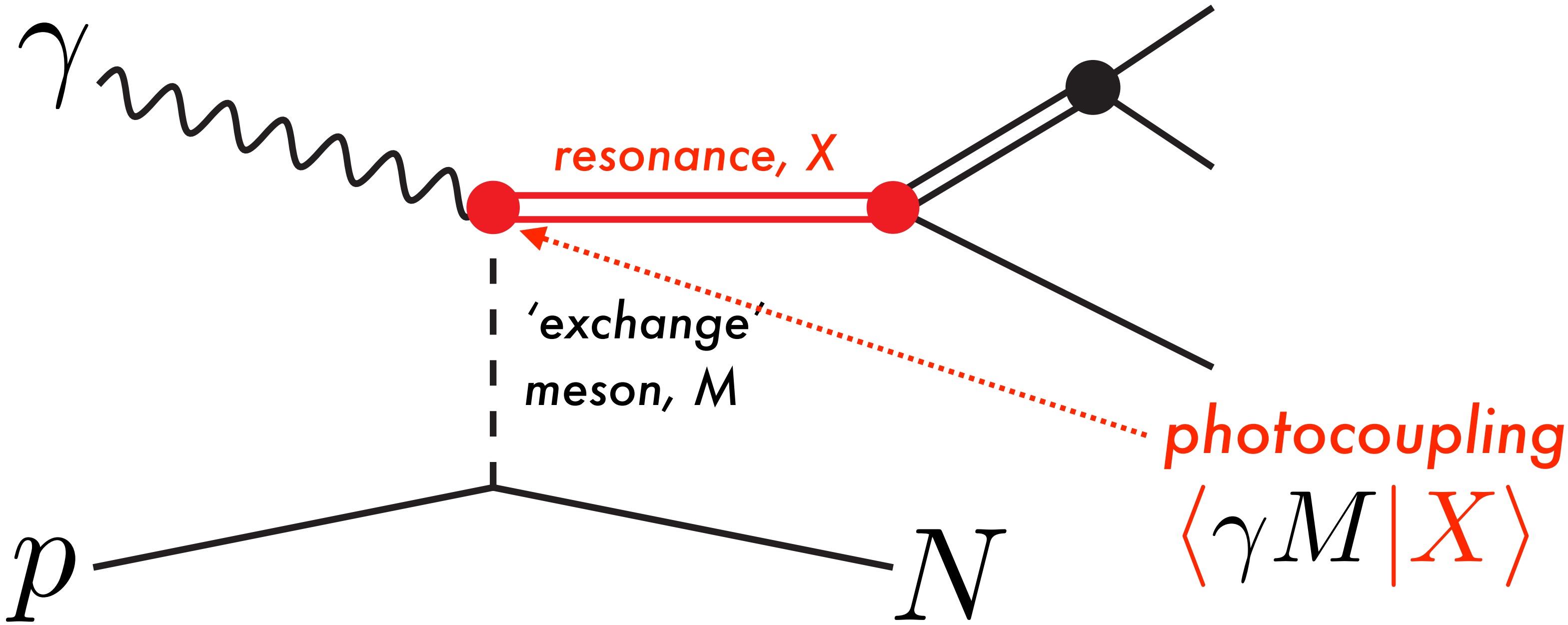
    uses the volume dependence of energy levels to extract a phase shift & hence a decay width
  - *Michael method*

    tunes the quark mass to put the two-particle decay at threshold & extracts a strong coupling



Photocouplings

- GlueX will photoproduce mesons



- couplings virtually unknown even for conventional mesons - clear target for Lattice QCD *predictions*

Photocouplings

- work is underway - initially in comparison to the good charmonium radiative transition data

PHYSICAL REVIEW D **73**, 074507 (2006)

Radiative transitions in charmonium from lattice QCD

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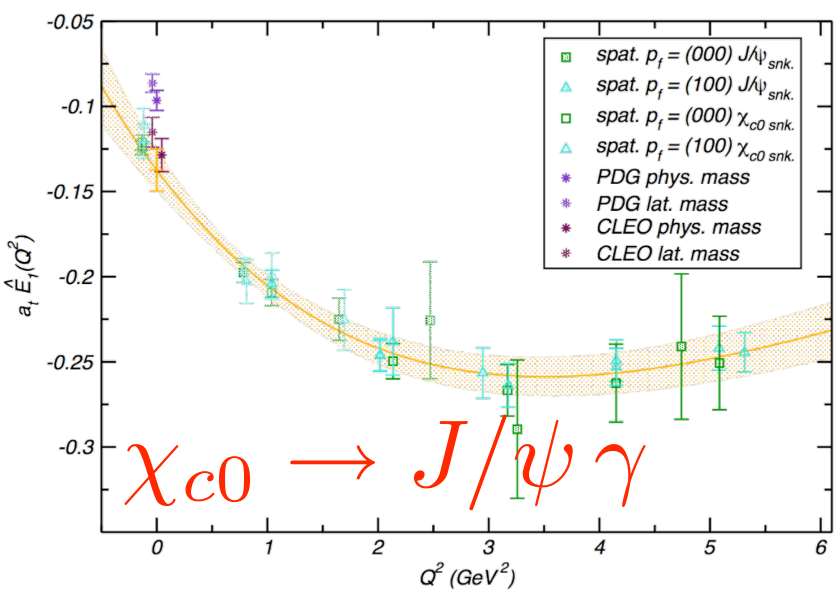
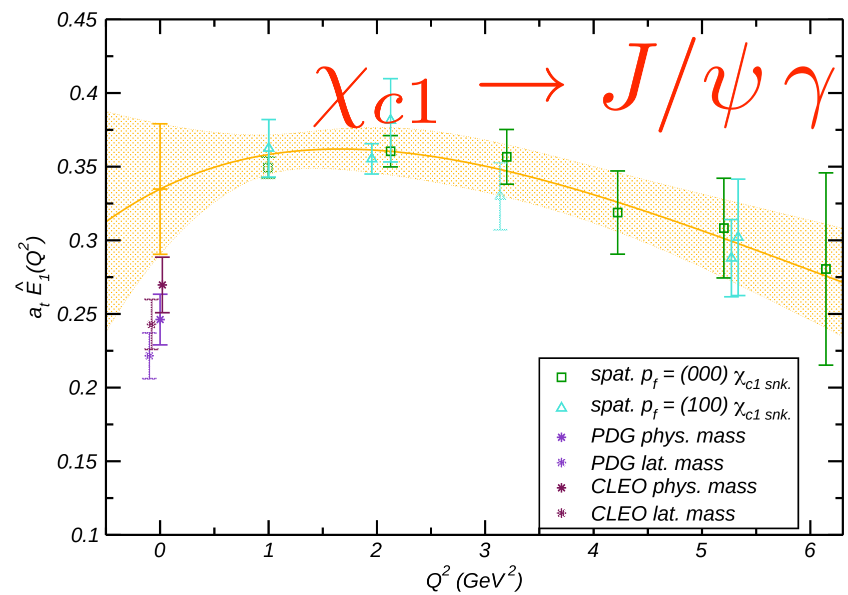




Phenomenology of PWA / Reactions

- 'bump-hunting' in cross-section data will not suffice
- partial wave analysis is the required tool

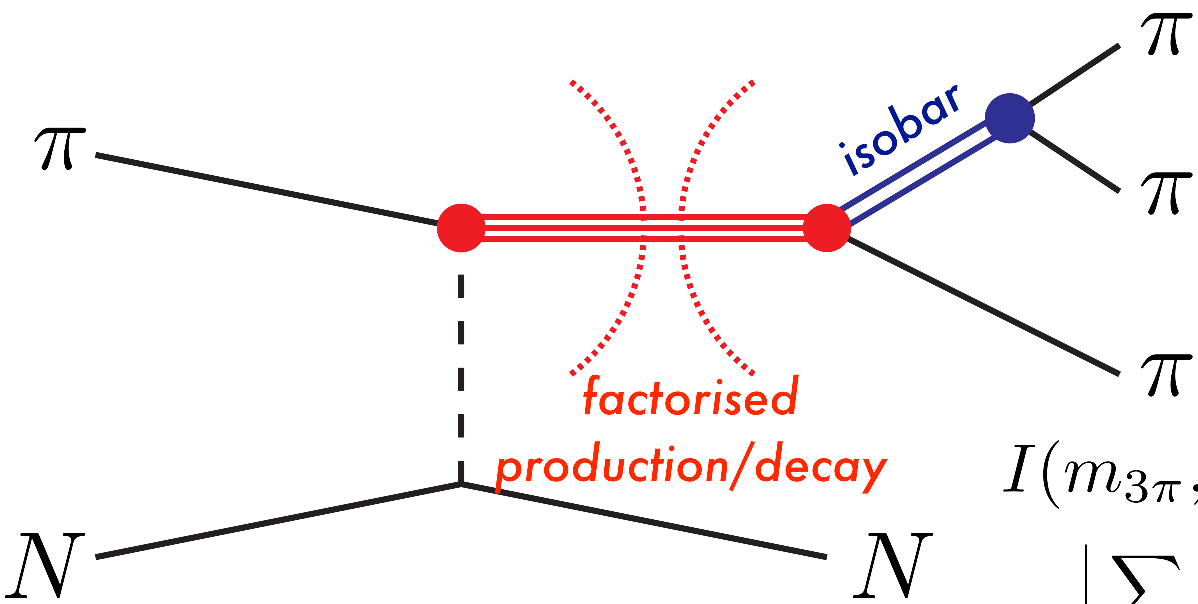
- considerable experience within the *GlueX* collaboration, analyzing data from
  - *E852*
  - *CLAS*
  - *Crystal Barrel*

- new, independent, code development at *IU* and *CMU*

see e.g. *www-meg.phys.cmu.edu/~pwa*

Phenomenology of PWA

- conventional analyses of multi-particle final states adopt isobar model, e.g. in $\pi N \to \pi\pi\pi N$



$$I(m_{3\pi}, t, \ldots) = \left| \sum_{\text{wave}} C_{\text{wave}}(m_{3\pi}, t) A_{\text{wave}}(\ldots) \right|^2$$

prod. decay

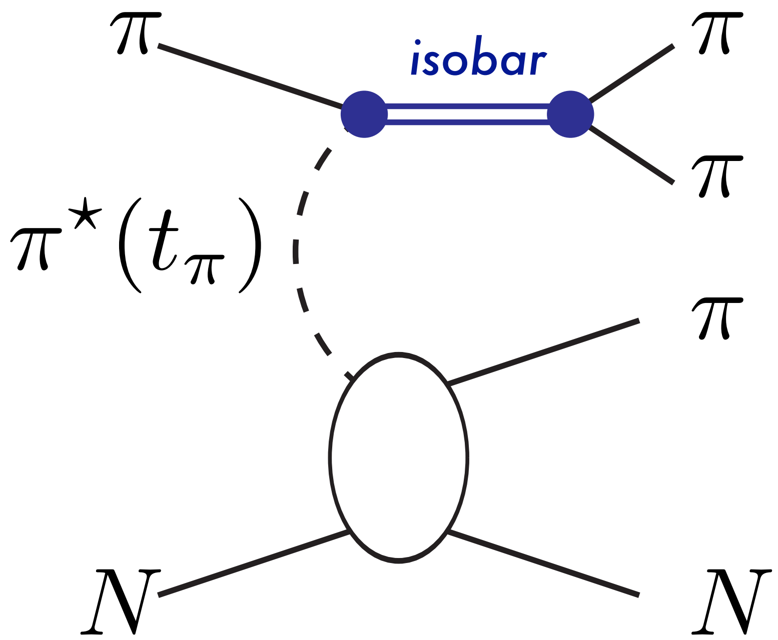
- simplifies analysis considerably
- but not totally general

$$A_{\text{wave}} = P_{\text{isobar}}(m_{2\pi}) D(\theta_1, \phi_1) D(\theta_2, \phi_2)$$

fixed isobar propagator

Beyond the Isobar Model

- known since the beginning of multiparticle analysis that 'factorised' assumption can be violated
  - e.g. the Deck effect



$$\pi \longrightarrow \pi^\star + \mathrm{isobar}$$

'diffractive dissociation'

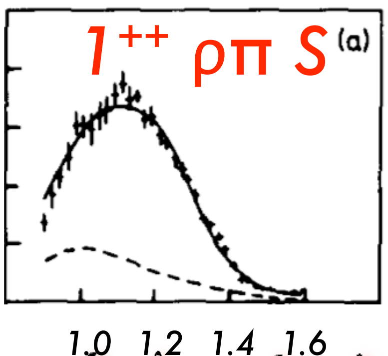
$$\pi^\star N \longrightarrow \pi N$$

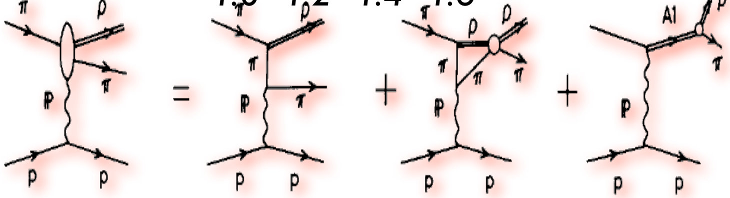
'quasi on-shell scattering'

- modeling this diagram one gets a threshold peak in the *isobar* - π *S*-wave

Deck Effect in $\pi N \to \pi\pi\pi N$

- to fit data phenomenologists have assumed that isobar-model *(factorized)* analysis puts most of the Deck amplitude in the right partial wave
- then have plausible explanations for
  - 'distorted' line-shape of a_1 meson

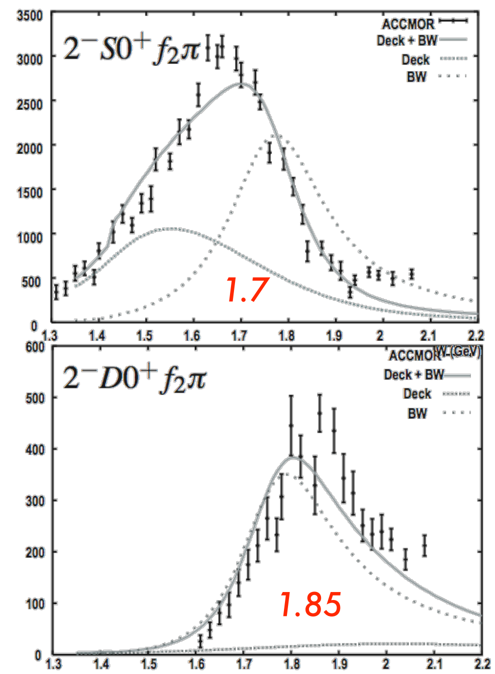




$$D_R = D\left[r e^{i\delta} \sin\delta + e^{i\delta} \cos\delta\right]$$

BW ~~BW~~

shifted π_2 peak in $f_2\pi$ *S*, *D*-waves



Deck Effect & Isobar Model

- we don't know exactly how the isobar model distributes the non-factorized Deck amplitude amongst 'isobar partial waves'
- it may be that some amplitude from a strong wave ends up in a minor wave - *real physics 'leakage'*
- slightly modified version of Deck will appear in photoproduction - added complication/benefit of polarization?
- future efforts will attempt more varied amplitude analyses

GlueX Theory Support

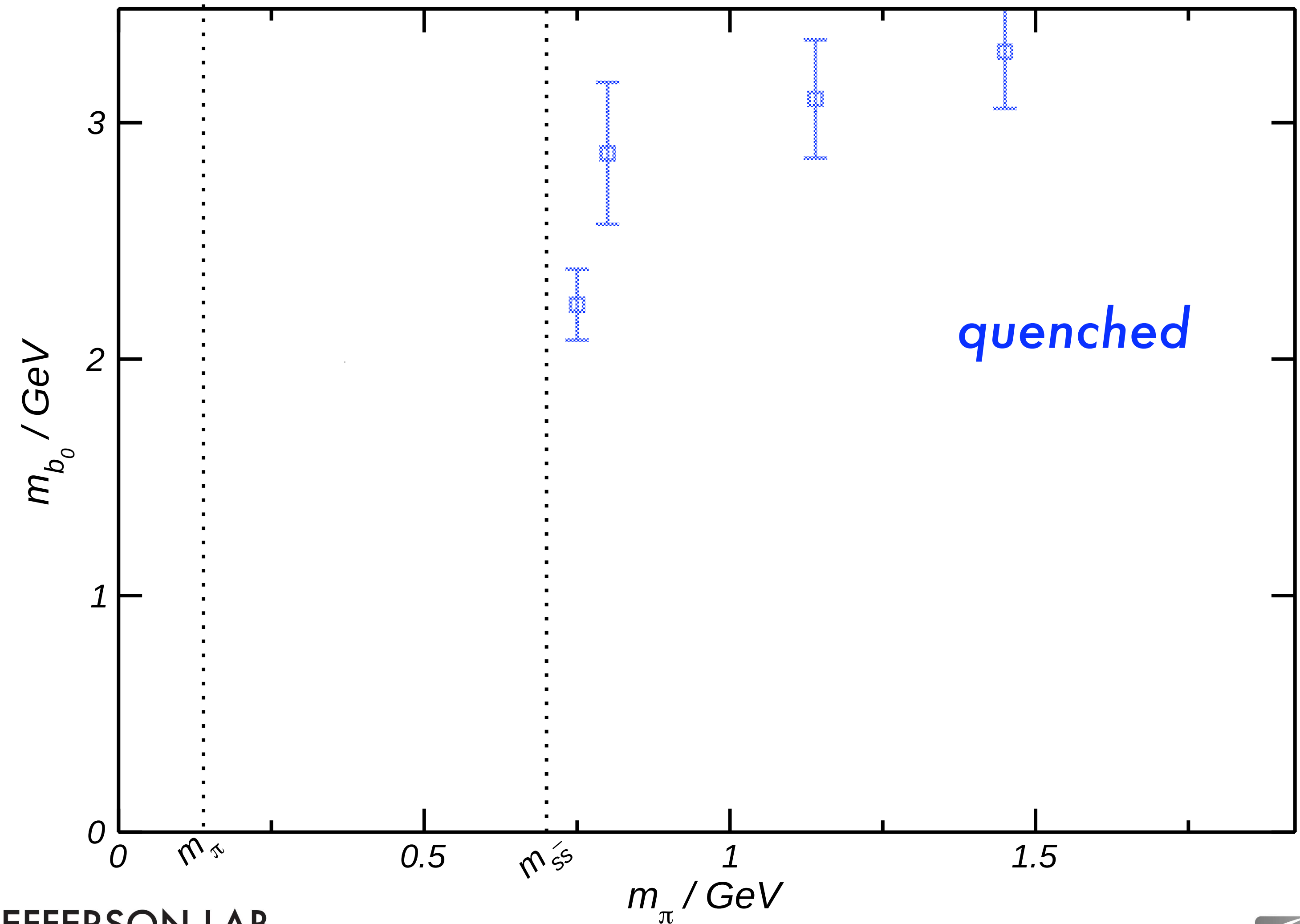
- *GlueX* relevant theory/phenomenology work is thriving
  - lattice QCD now addressing relevant model predictions
  - increased interest in amplitude analysis set to make *GlueX* results definitive

extra sildes

- for the inquisitive

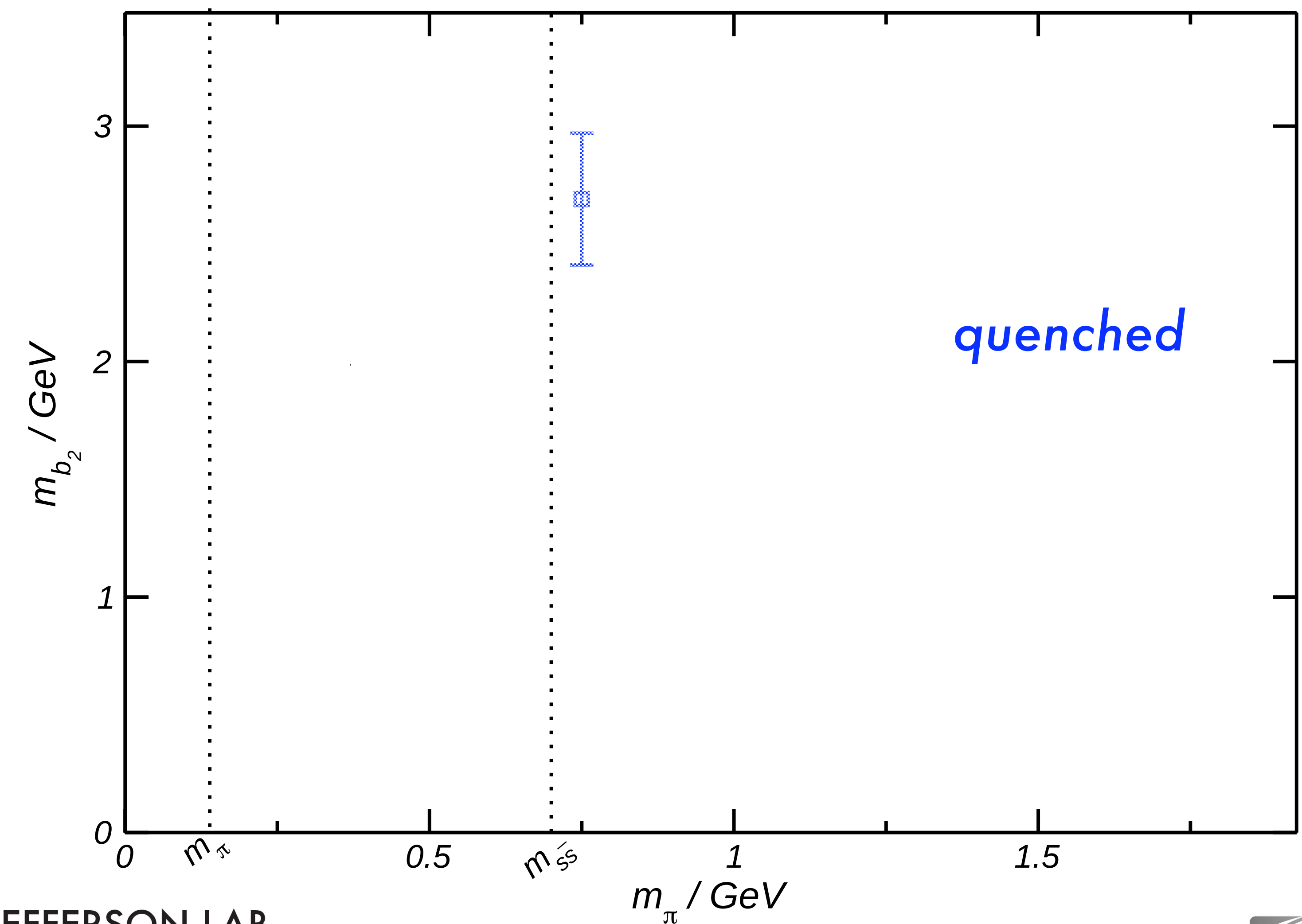
Lightest 0^{+-} from Lattice QCD

- summary of world simulation data



Lightest 2^{+-} from Lattice QCD

- summary of world simulation data



Lattice QCD & model testing

- quark masses will decrease in the future, but even now we can make good use of lattice data
- we can compare lattice QCD calculations with ‘heavier’ quarks vs model calculations with ‘heavier’ quarks

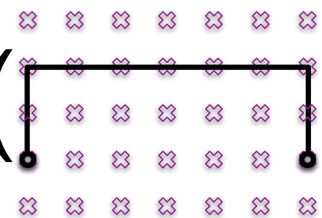
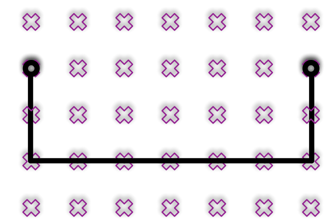
UKQCD ‘96

Lacock & Michael

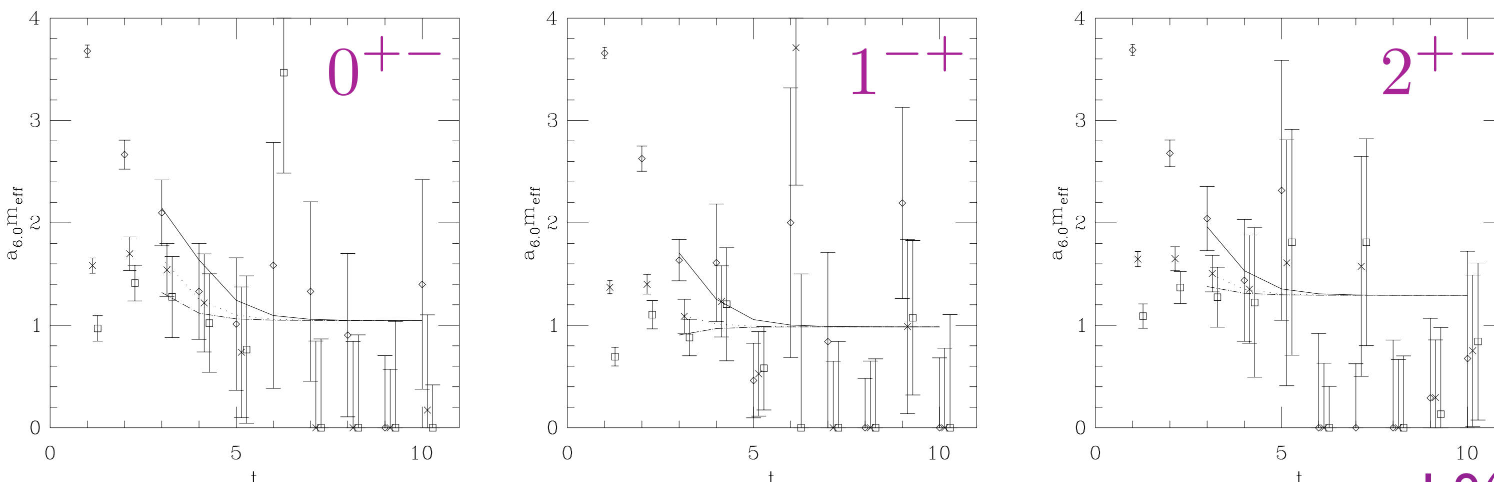
$m_\pi \sim 700$ MeV

- ★ $16^3 \times 48$, β=6.0 clover (a ~ 0.1 fm) , m ~ m_s

quenched

hyb. int. field ~ $(1+\gamma_4)\cdot$ ( — )

70 cfgs.

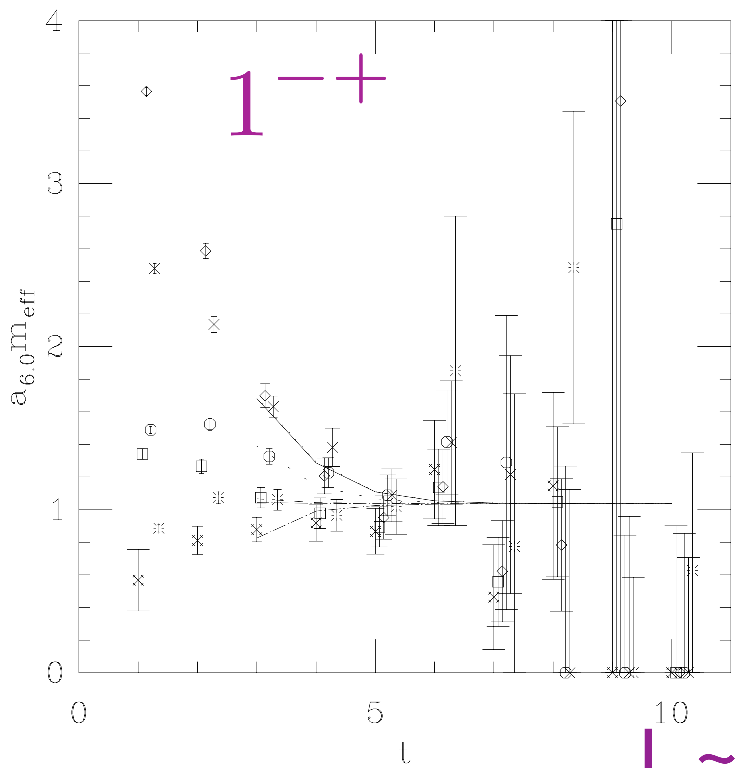


1.9(5) GeV

UKQCD '97

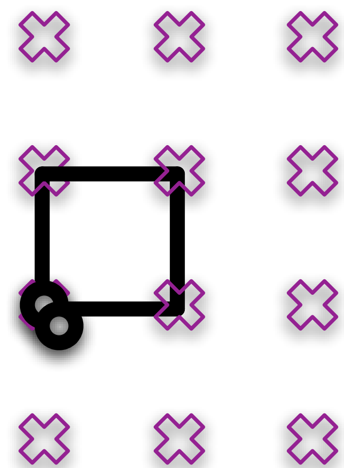
Lacock, Michael, Boyle & Rowland

350 cfgs.



$L \sim 1.6$ fm

also include



find these are noisy

$m \sim m_s$

0^{+-} 2.20(13) GeV

1^{-+} 1.99(13) GeV

2^{+-} 2.52(20) GeV

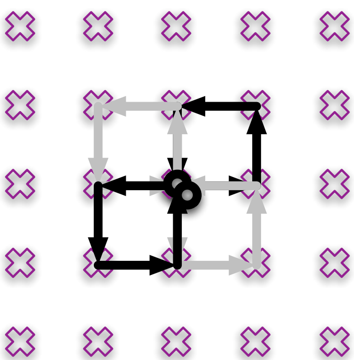
CSSM '05

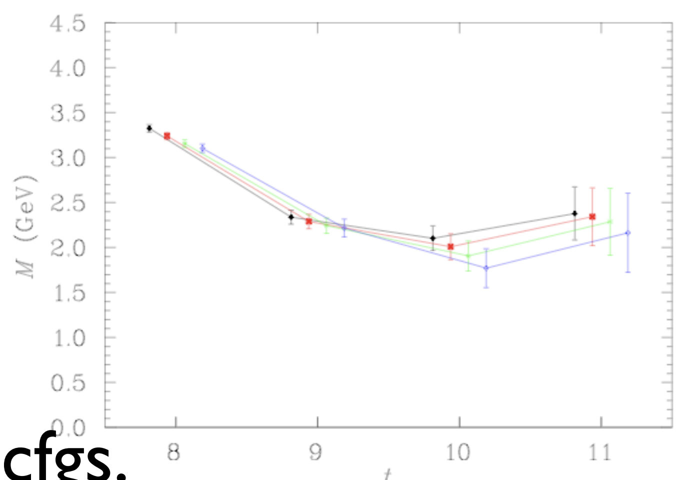
Hedditch et al.

quenched

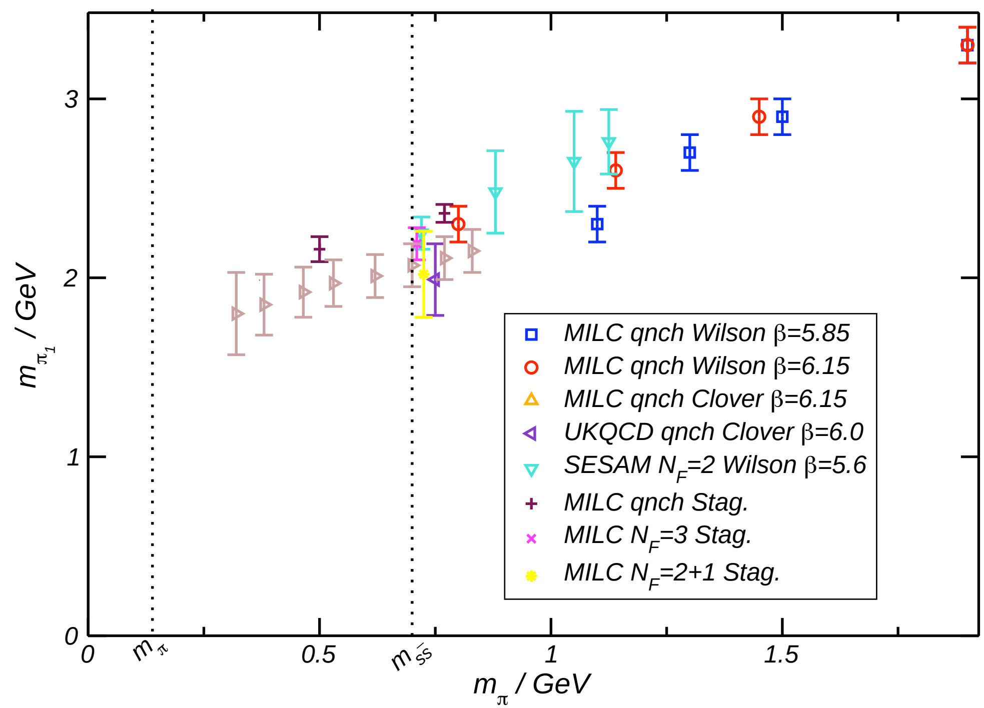
L ~ 2.5 fm

★ 20^3x40, FLIC, m_π > 320 MeV (a ~ 0.128 fm)

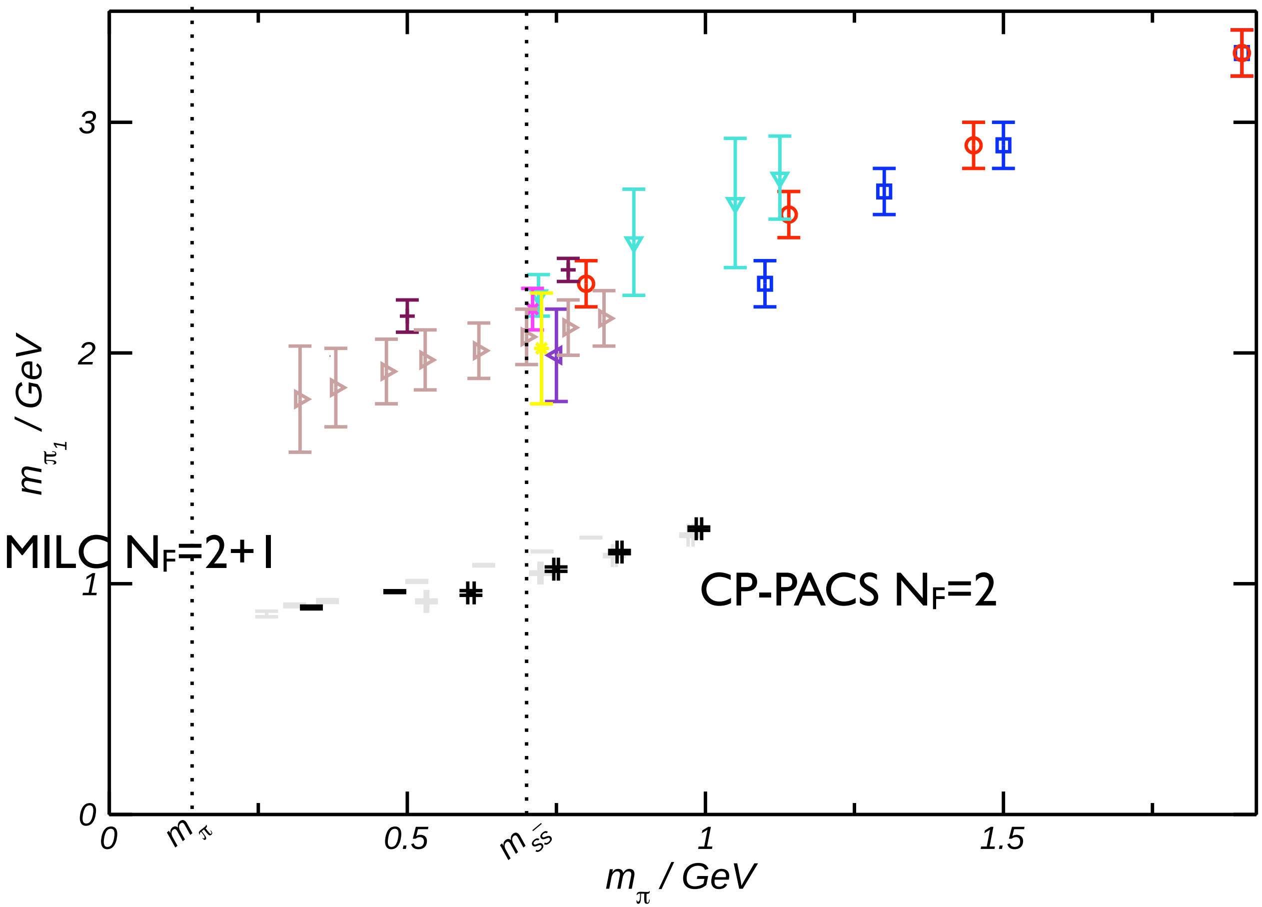




~350 cfgs.



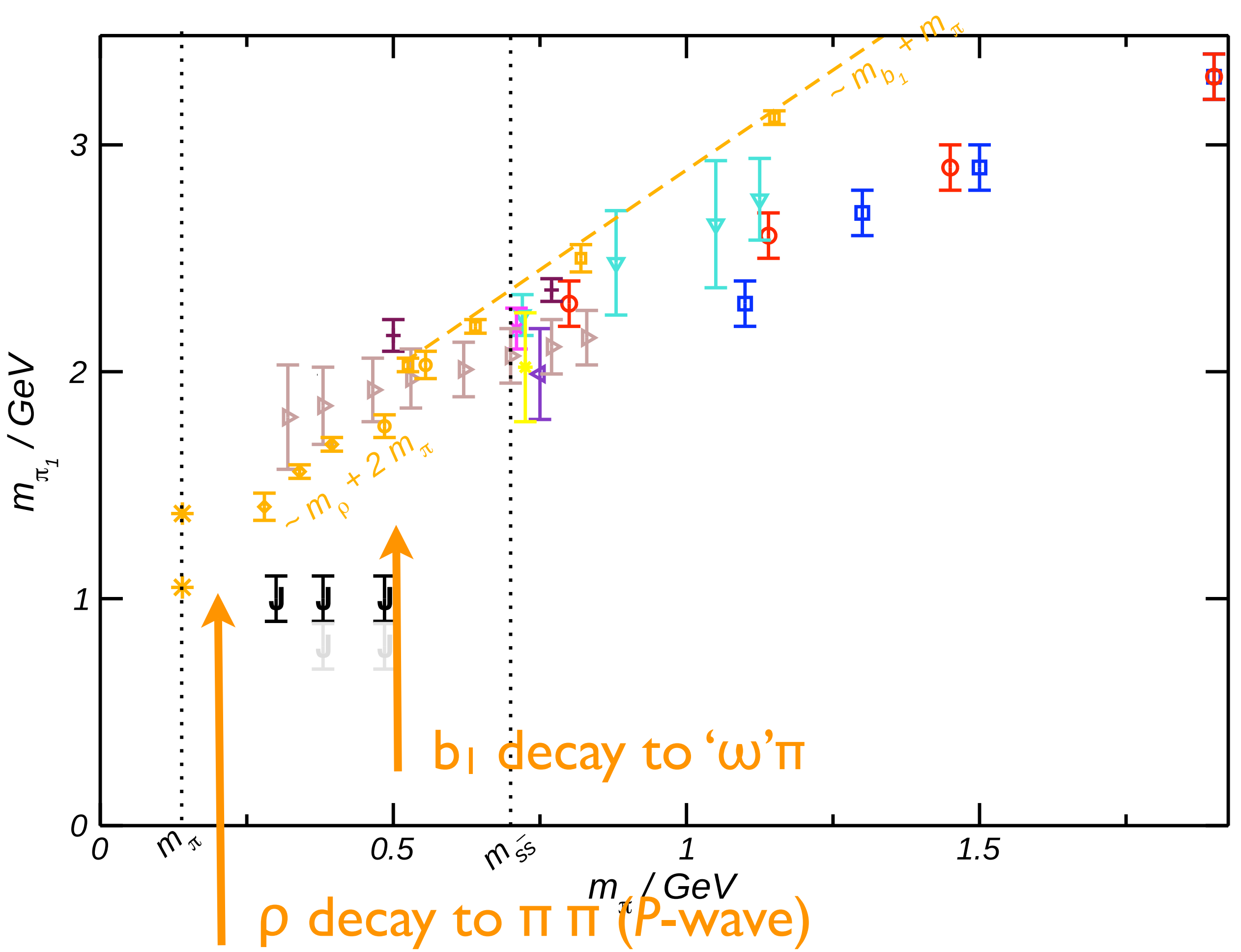
π_1 vs ρ



state of the art is rather different

lightest 1^{-+} ?

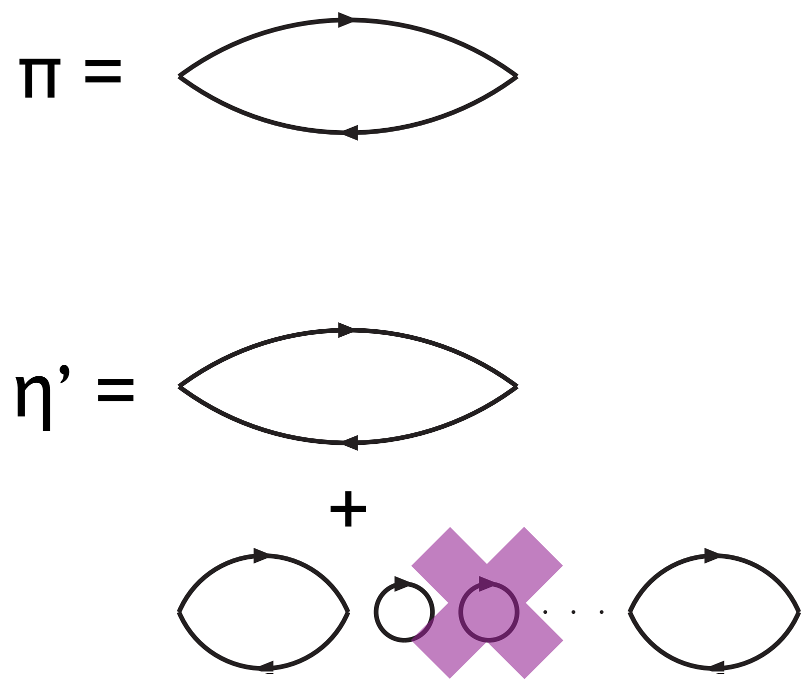
★ multi-hadron states lightest at low pion mass



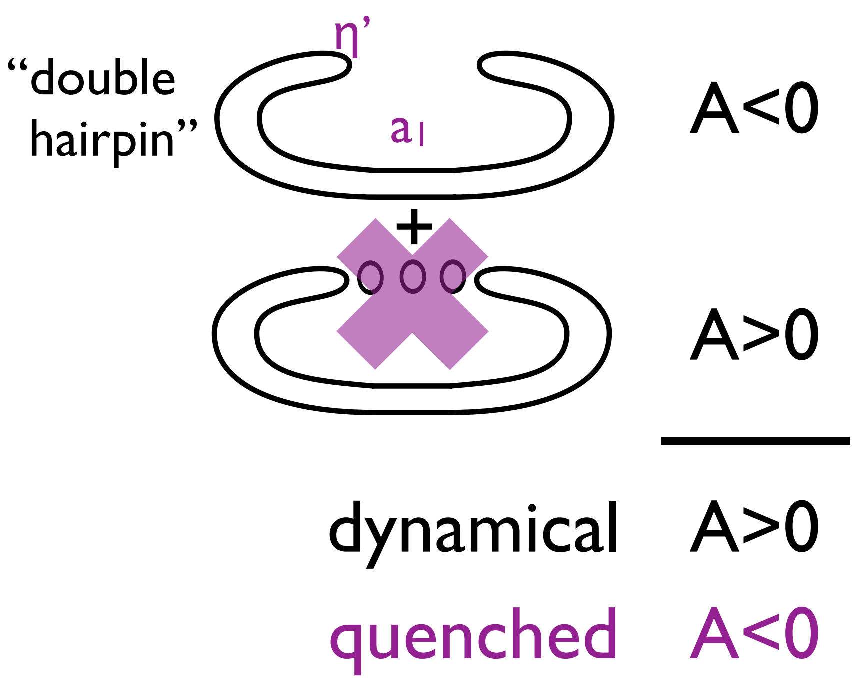
quenched at low m_π ?

- ★ extra caution required - theory is non-unitary
  - ★ shows up strongly with the η' meson

quenched η' is degenerate with the π

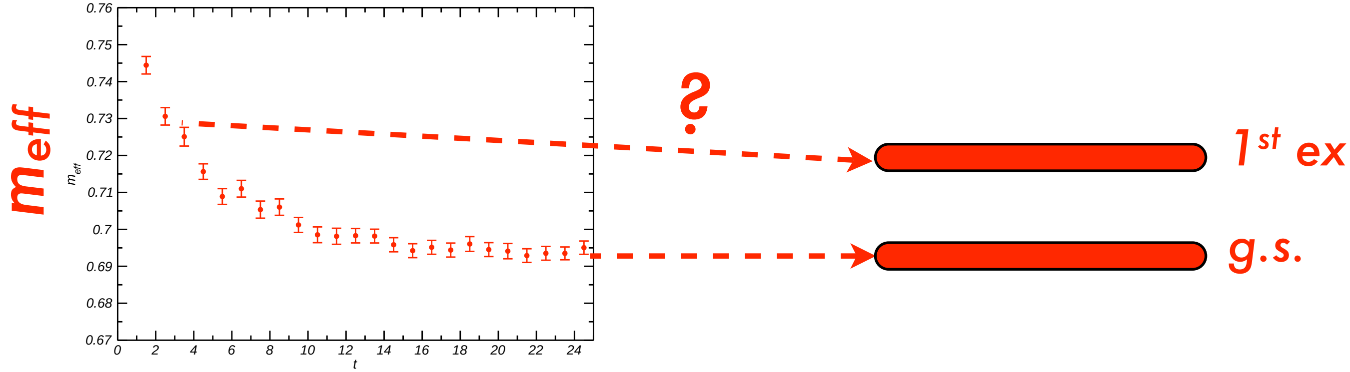


a_1 η' state lightest at low m_π

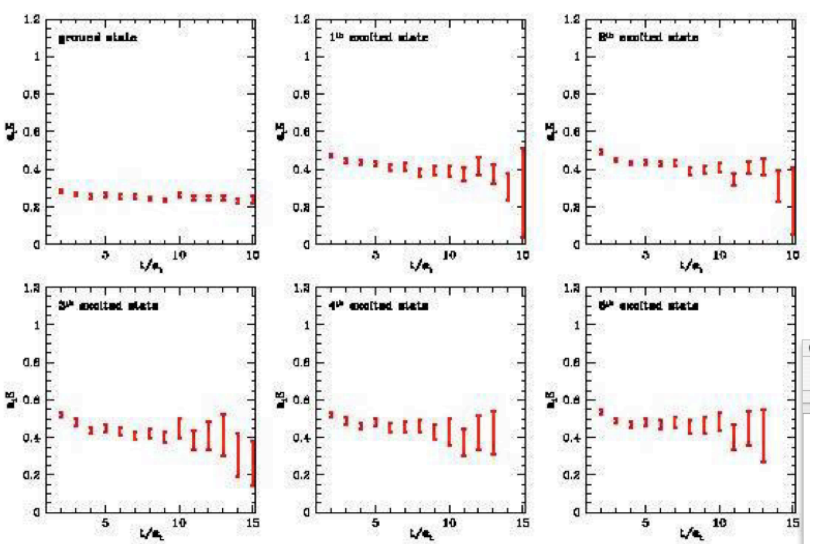


Variational Method

- traditional method



- variational method



e.g. baryon sector
work by LHPC
9 excited states !