The GlueX Experiment and Lattice QCD

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LHP '06

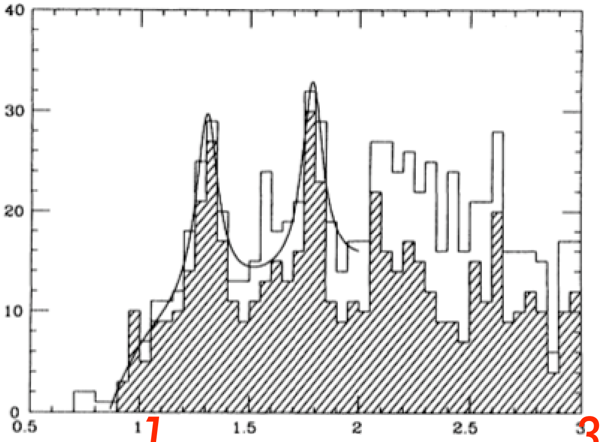
The Physics of GlueX

- *GlueX* will explore the meson spectrum with a mass reach over 2.5 GeV
- major feature is the search for exotic quantum-numbered mesons
  - e.g. $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-} \ldots$ not accessible to a fermion-antifermion state
  - likely origin for such states in QCD is *hybrid mesons* - i.e. quark-antiquark states with excited gluonic field

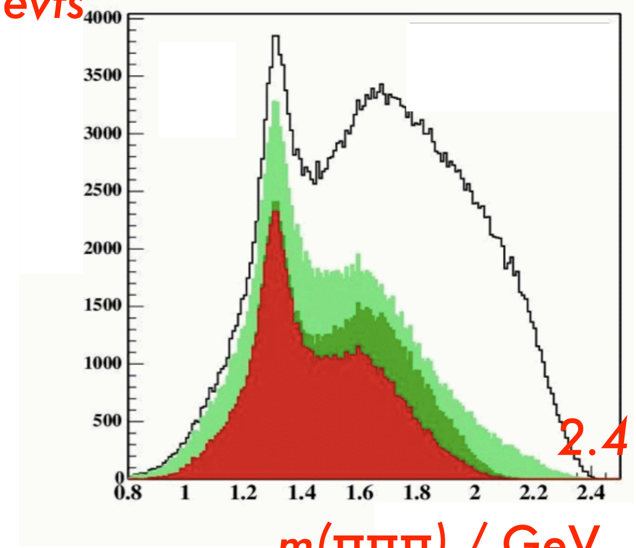
The GlueX Experiment

- GlueX will use real 9 GeV photons to photoproduce mesons
- virtually no data on photoproduction of meson resonances exists

SLAC bubble chamber
19 GeV photons (1991)

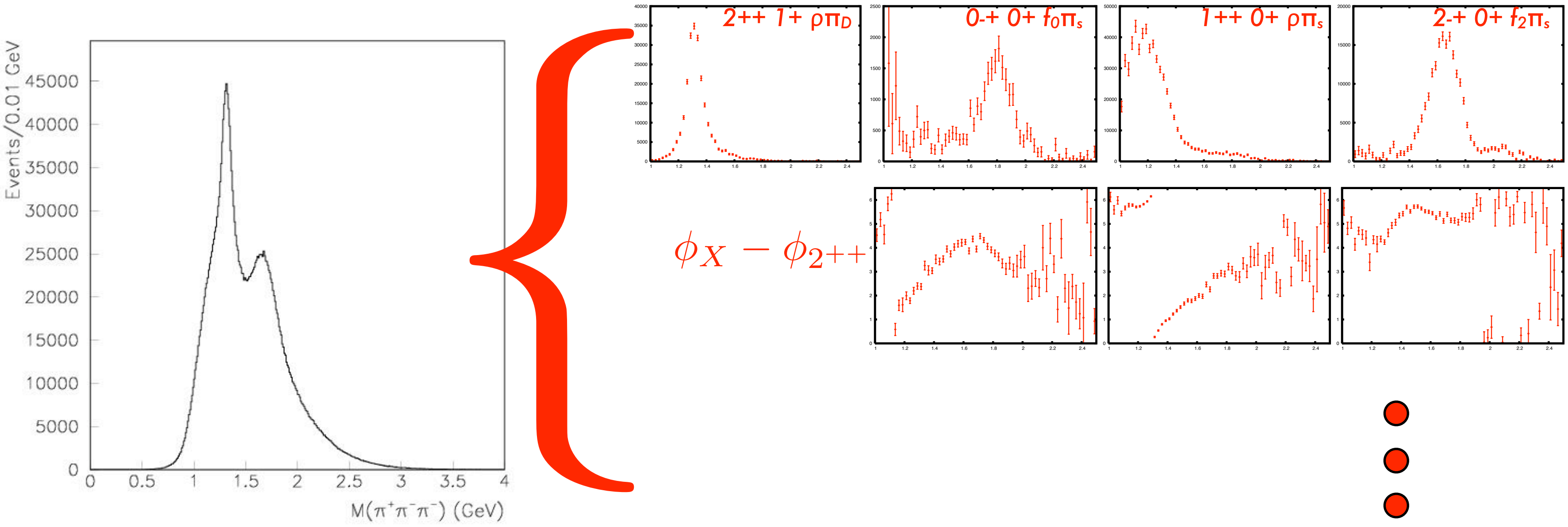


CLAS
5.5 GeV photons (2005)



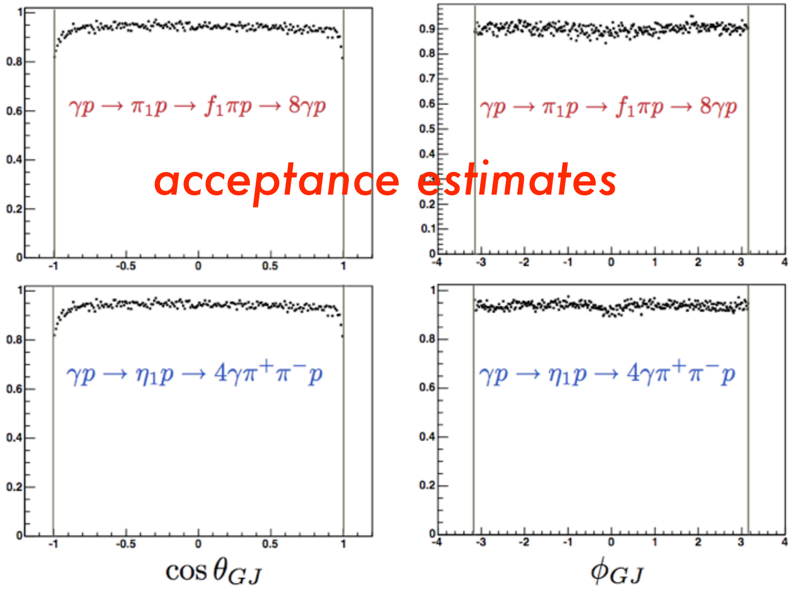
GlueX Details

- *GlueX* will hugely surpass these statistics
  - *10^6* πππ events per *10* MeV bin in *3 months* running
  - ~ *1* PetaByte per year
- detector designed to have good coverage over full *4*π
  - aids the required Partial Wave Analysis

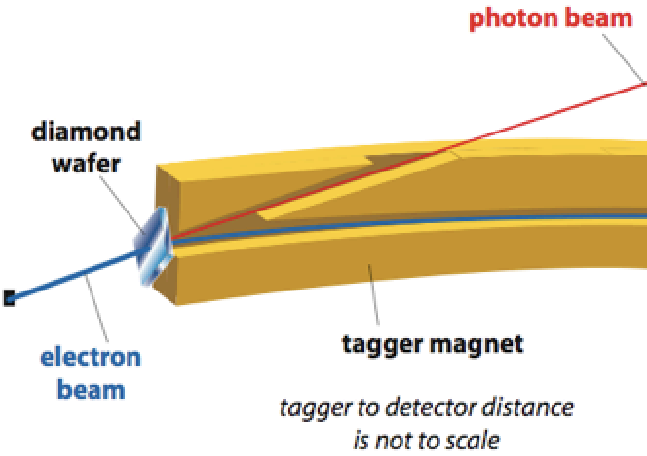


reducing model dependence actively researched

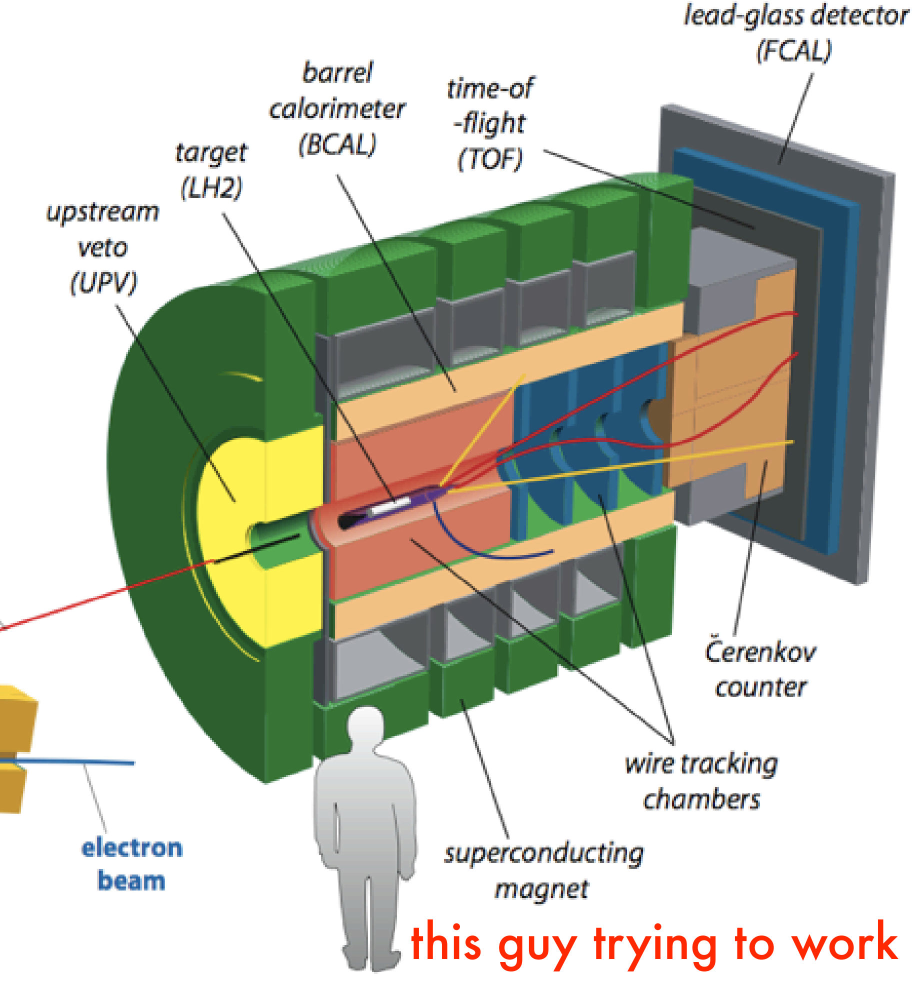
GlueX Photon Beam & Detector



acceptance estimates



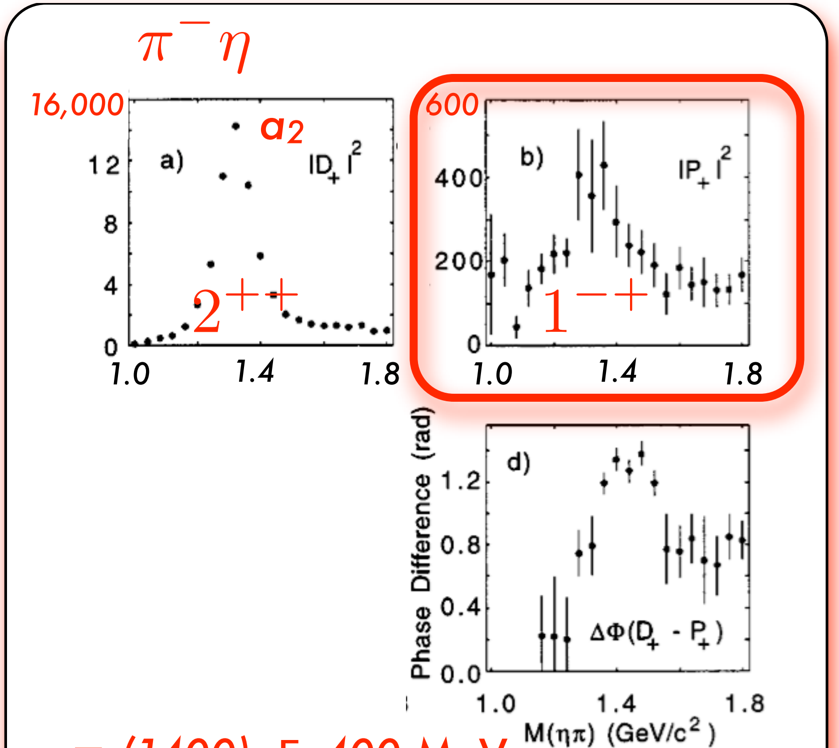
tagger to detector distance is not to scale



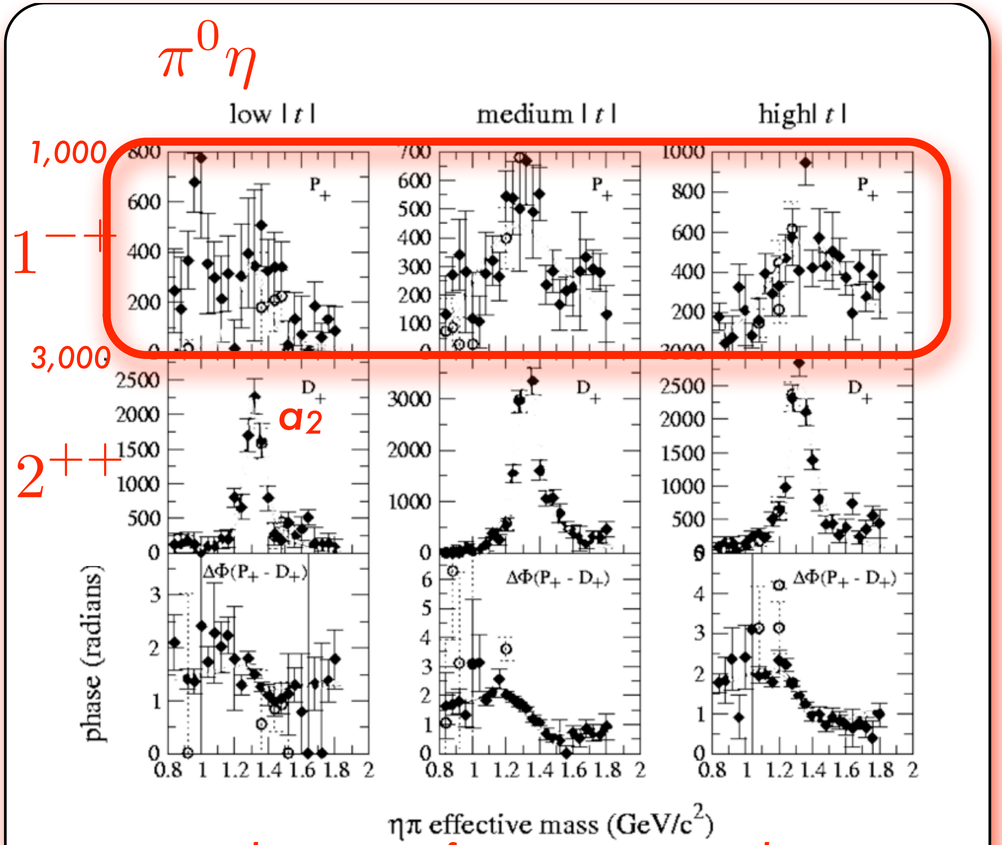
this guy trying to work out who stole the other half of the detector

Exotics in Experiment

- bulk of relevant exotic searches done by *E852* using a 18 GeV pion beam & dominantly 1^{-+}
  - $\pi p \to \pi \eta N$



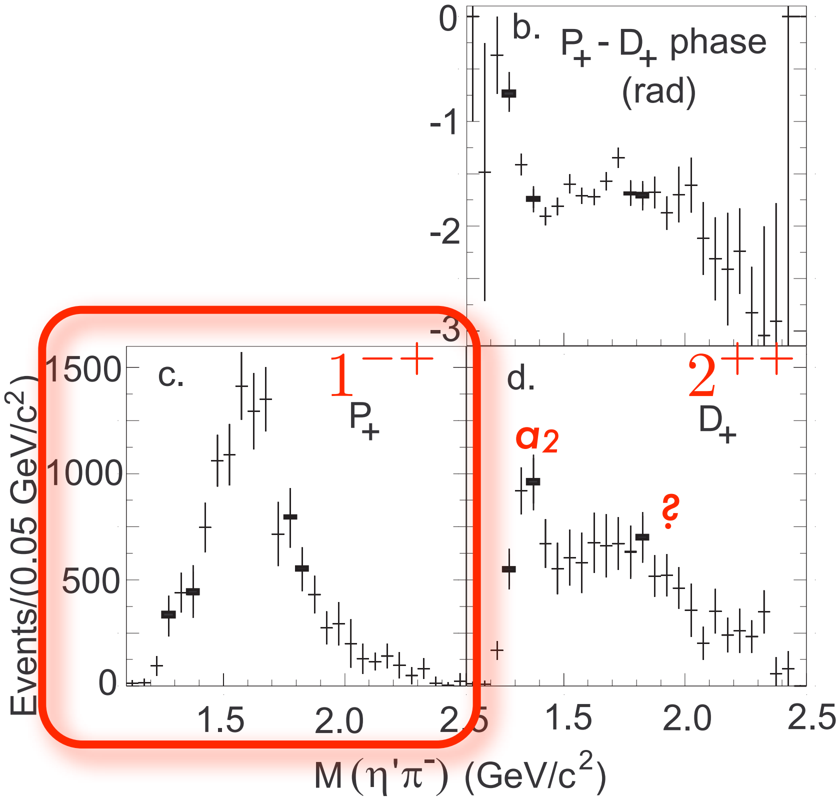
$\pi_1(1400)$, $\Gamma\sim400$ MeV or non-resonant interaction ?



no clear sign of a resonance in the P-wave intensity

Exotics in E852

$$\pi p \rightarrow \pi^- \eta' p$$



broad enhancement in *P*-wave intensity

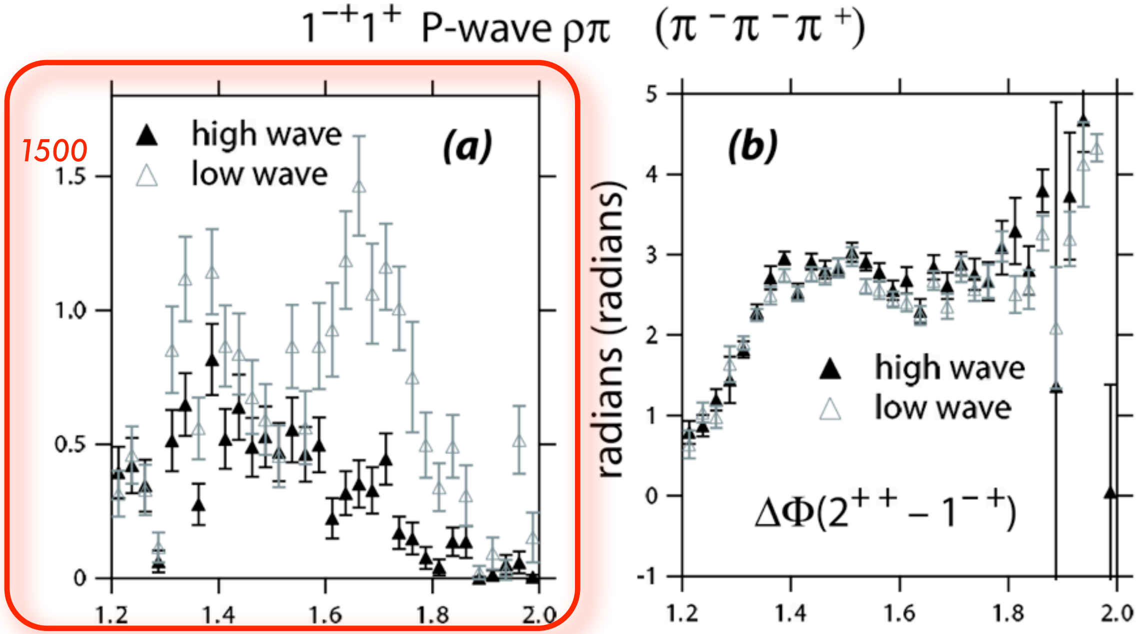
D-wave structure not understood so phase comparison unconstrained

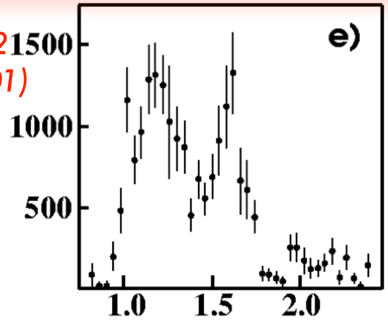
taken at face value, intensity gives $\pi_1(1600)$, Γ~350 MeV

non-resonant origin cannot be ruled out

Exotics in E852

- two analyses of $\pi p \to \pi\pi\pi p$, more recent has higher statistics



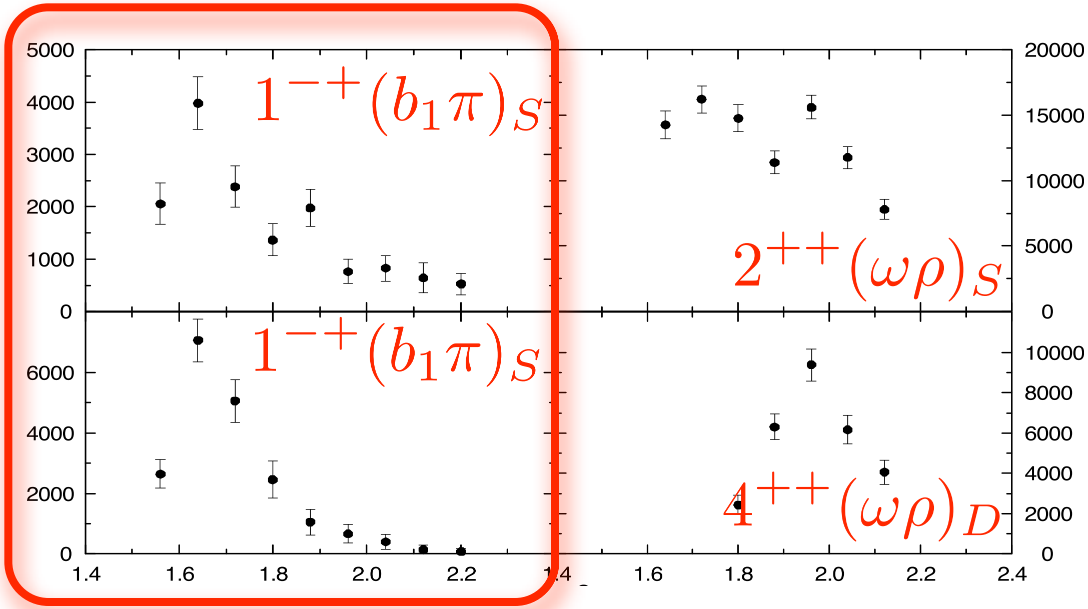


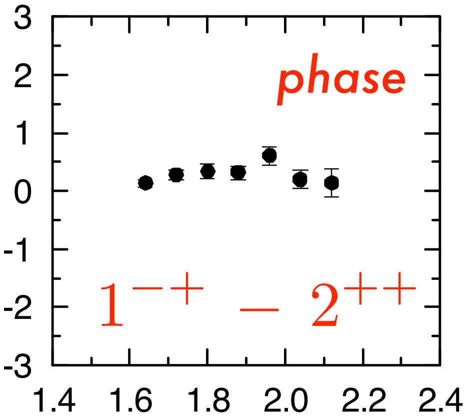
grey points use a more truncated wave-set lacking some 2^{-+} waves

claimed explanation of difference is π₂(1670) missing waves being assigned to exotic wave by PWA

E852 Exotics cont...

$\pi p \rightarrow \pi\pi\pi\pi\pi p$



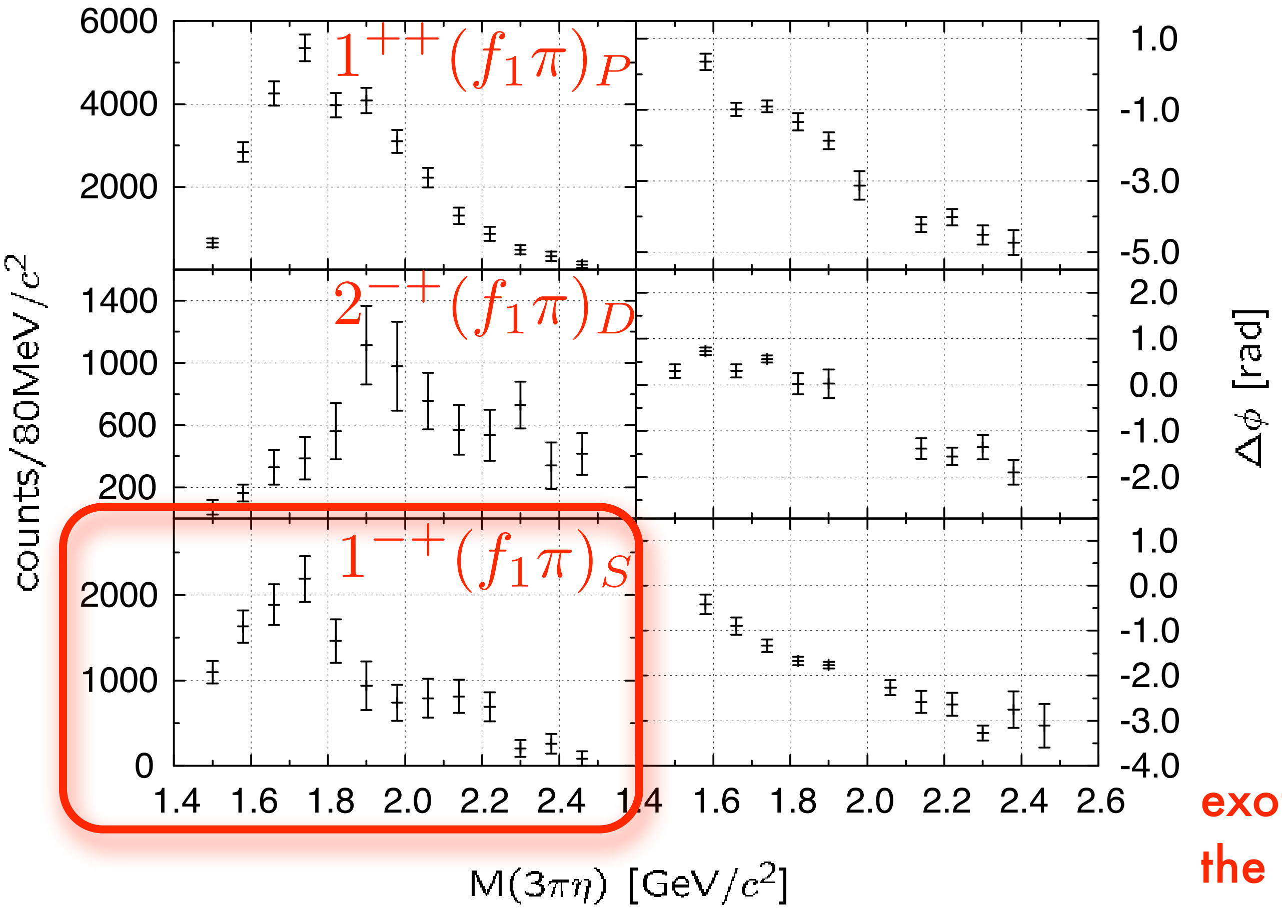


exotic enhancement in the 1.65 GeV region

low event statistics limit the PWA to a small number of waves

E852 Exotics cont...

$\pi p \rightarrow \eta\pi\pi\pi p$



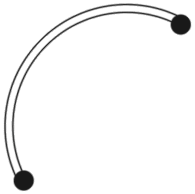
exotic enhancement in the 1.7 GeV region

Exotics in Experiment

- *E852* results suggestive, but situation unclear overall
- *GlueX* poised to continue the good work of hybrid-hunting with a new production mechanism and much greater statistics

Models of Gluonic Excitations

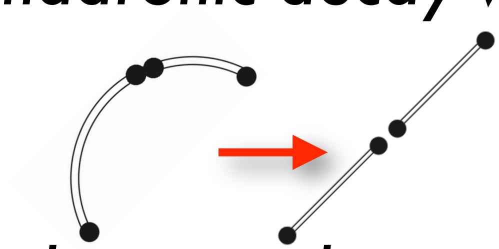
- the flux-tube model has historically dominated the field
- has a rather complete phenomenological coverage
  - *mass spectrum estimates* *(Isgur & Paton)*



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

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

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

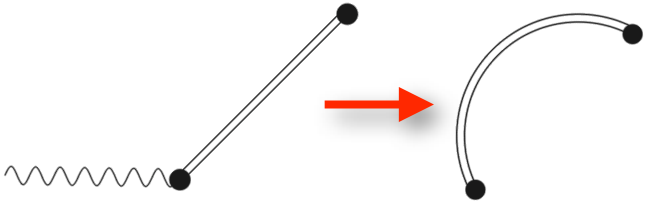


$\Rightarrow$ *"S+P" rule*

$\pi_1 \to \pi\, b_1$

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

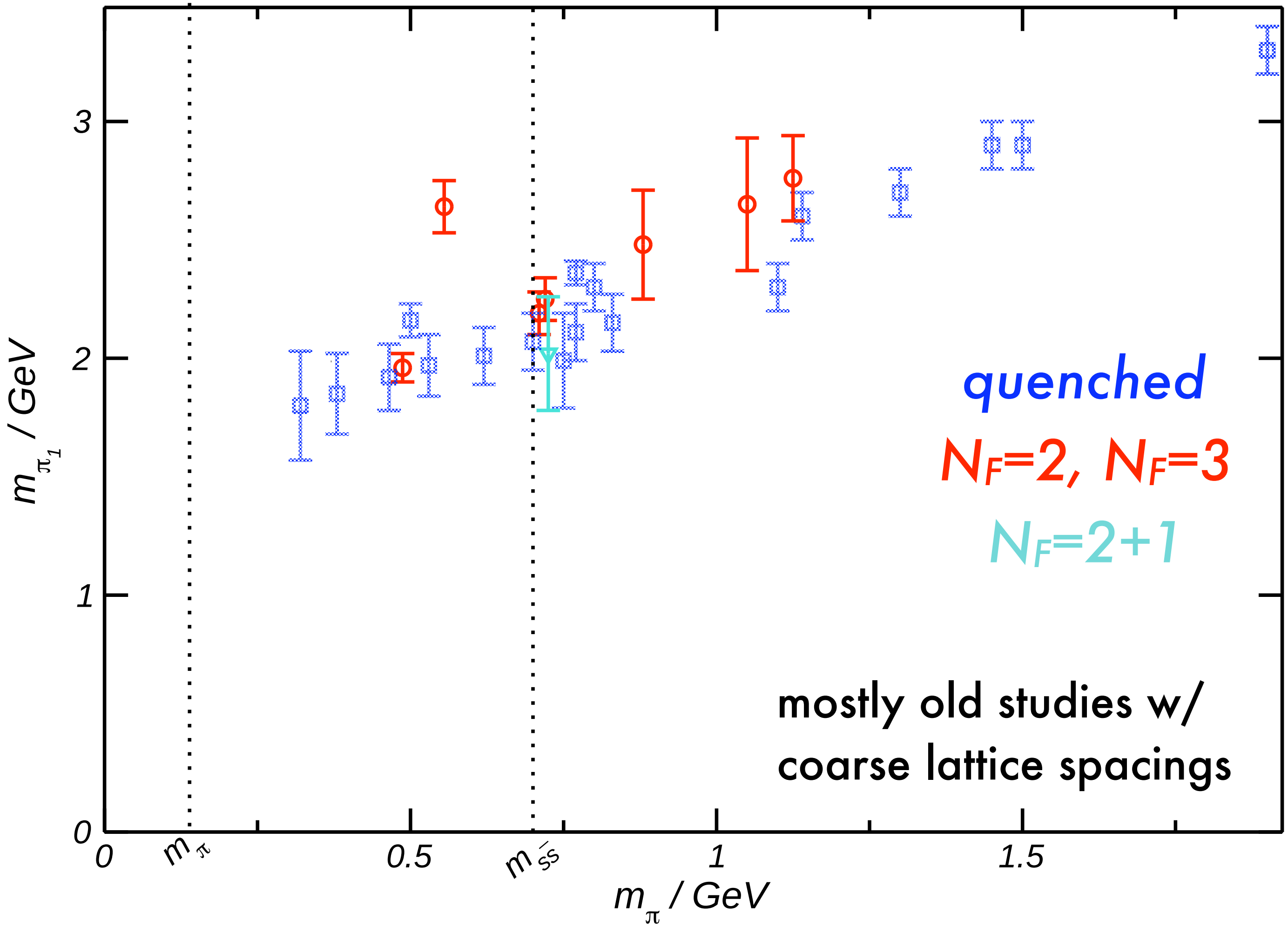
  - *photocouplings* *(Close & JJD)*



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

Lightest 1^{-+} from Lattice QCD

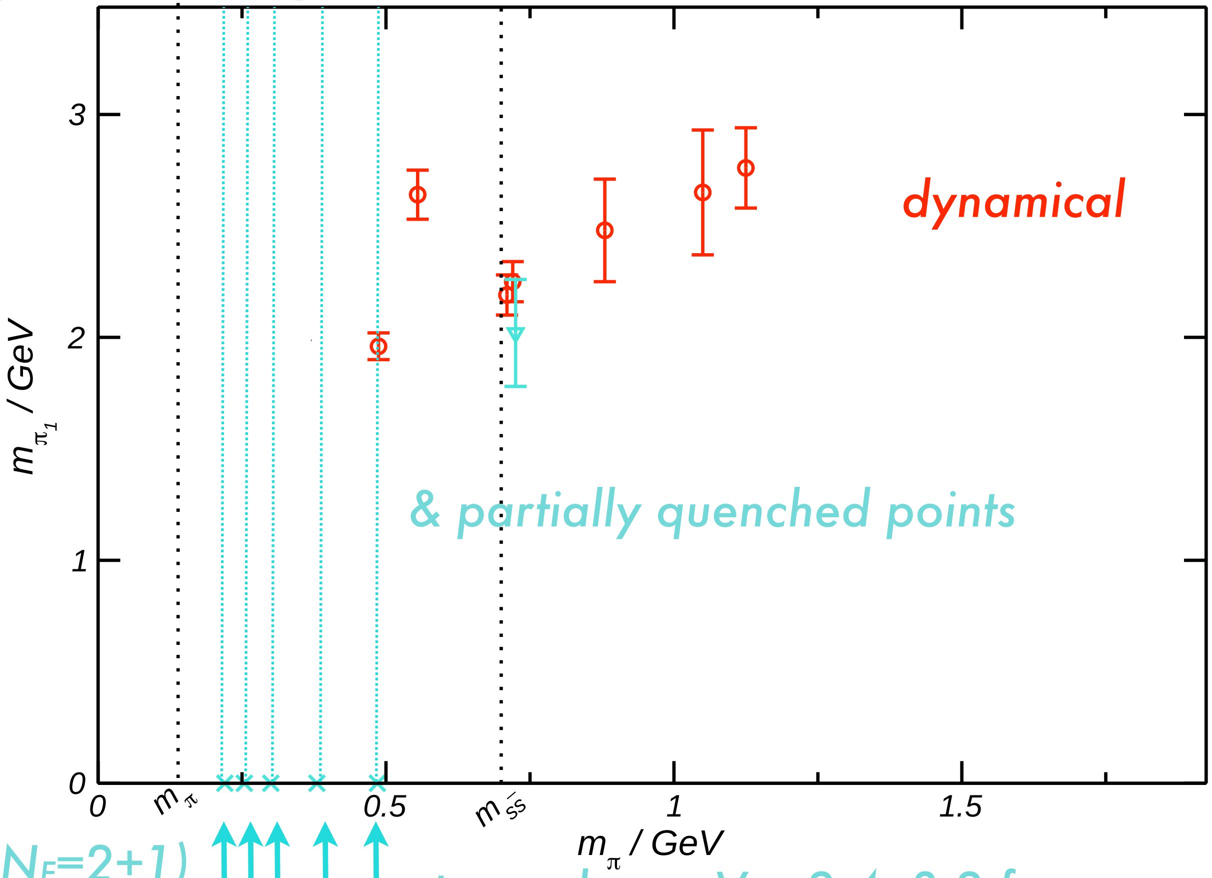
- summary of world simulation data



mostly old studies w/ coarse lattice spacings

Lightest 1^{-+} from Lattice QCD

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



dynamical

& partially quenched points

dynamical (N_F=2+1)
anisotropic Clover

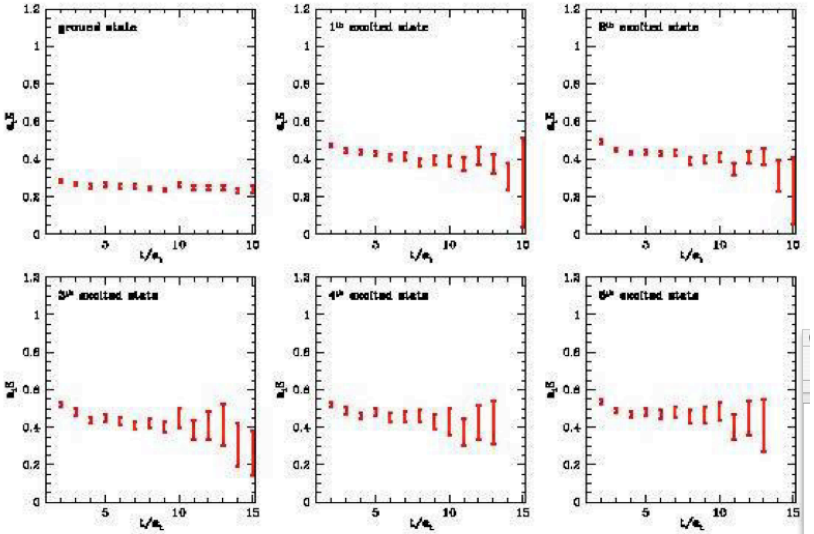
two volumes V = 2.4, 3.2 fm
two lattice spacings, a_s = 0.10, 0.125 fm

$1/a_t$ = 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 !



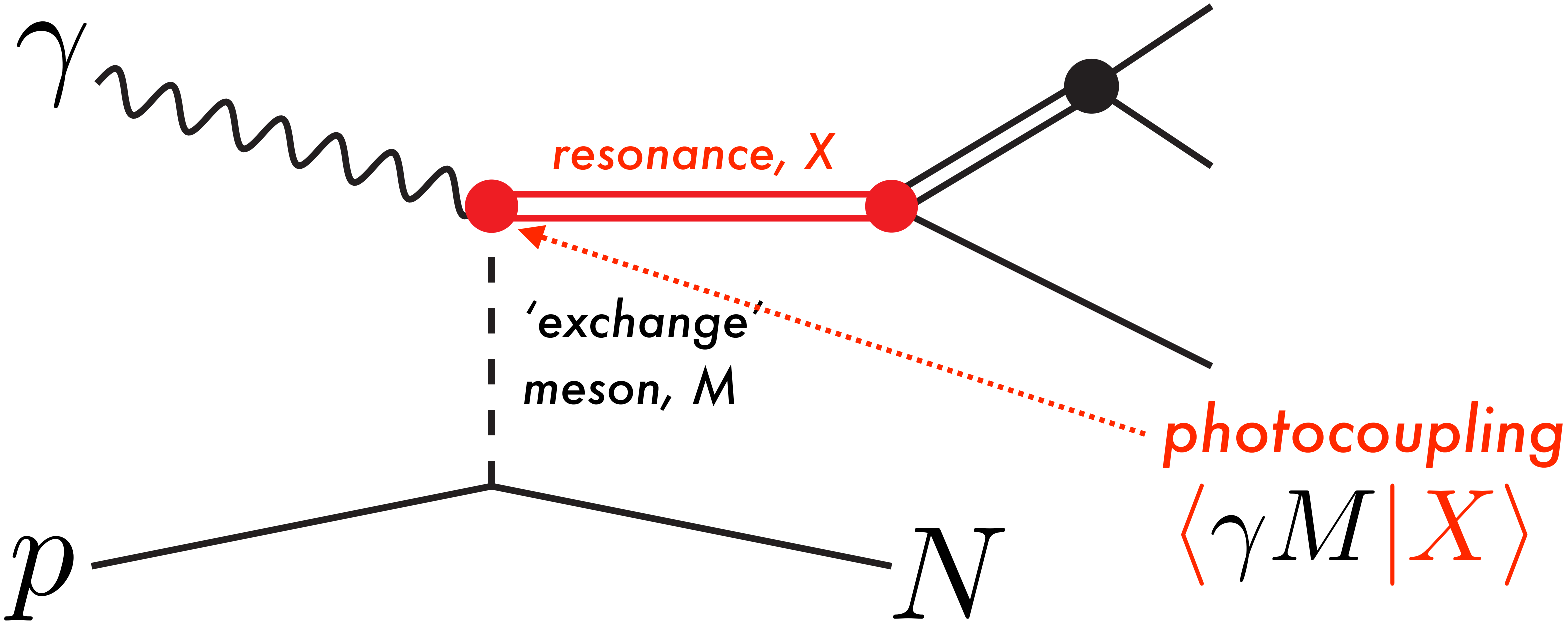
  - large set of J^{PC} using big operator basis

$$\bar{\psi}\Gamma\psi \qquad \bar{\psi}\Gamma \overleftrightarrow{D}_\mu \psi \qquad \bar{\psi}\Gamma \overleftrightarrow{D}_\mu \overleftrightarrow{D}_\nu \psi \qquad \bar{\psi}\Gamma F^{\mu\nu}\psi$$

+ two-meson style operators

Photocouplings

- *GlueX* will photoproduce mesons



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

Lattice Method

- three-point functions with vector current

$$\Gamma(t_f, t; \vec{p}_f, \vec{q}) = \sum_{\vec{x},\vec{y}} e^{-i\vec{p}_f\cdot\vec{x}} e^{i\vec{q}\cdot\vec{y}} \, \langle \varphi_f(\vec{x}, t_f) j^\mu(\vec{y}, t) \varphi_i(\vec{0}, 0) \rangle$$

$$\sim \sum_{n,m} e^{-\boxed{E_{f_n}}(t_f - t)} \boxed{\langle 0|\varphi_f(0)|f_n(\vec{p}_f)\rangle}$$

$$\boxed{\times \langle f_n(\vec{p}_f)|j^\mu(0)|i_m(\vec{p}_i)\rangle}$$

$$\times \boxed{\langle i_m(\vec{p}_i)|\varphi_i(0)|0\rangle} e^{-\boxed{E_{i_n}} t}$$

covariant transition matrix element to be extracted

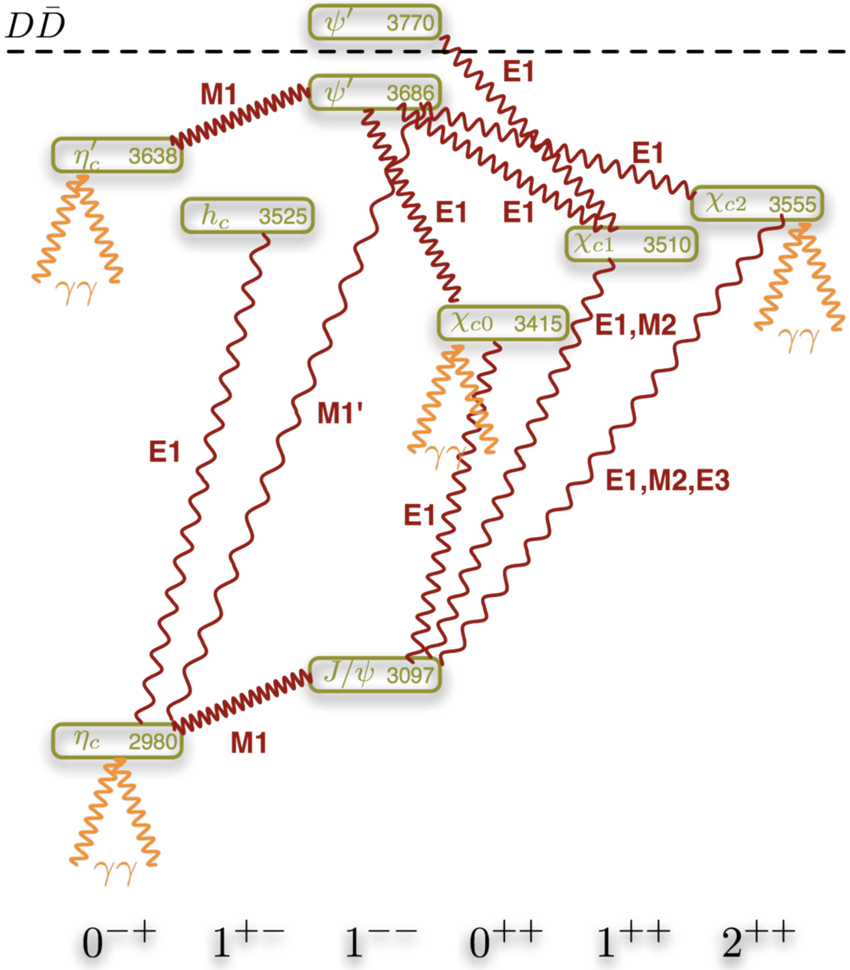
energies and overlap factors extracted from fits to two-point functions

three-point function calculation performed via a sequential-sink construction

smeared $\bar{\psi}\Gamma\psi$ interpolators

Charmonium

- before calculating with light quarks for *GlueX* we'd like to test the technology
- charmonium is ideal
  - excellent expt$^{\underline{al}}$ data
  - near-stable states
  - quenched might be 'tolerable'



quenched aniso. ξ=3
$1/a_t \sim 6$ GeV

DWF ($m_c a_t \sim 0.15$)

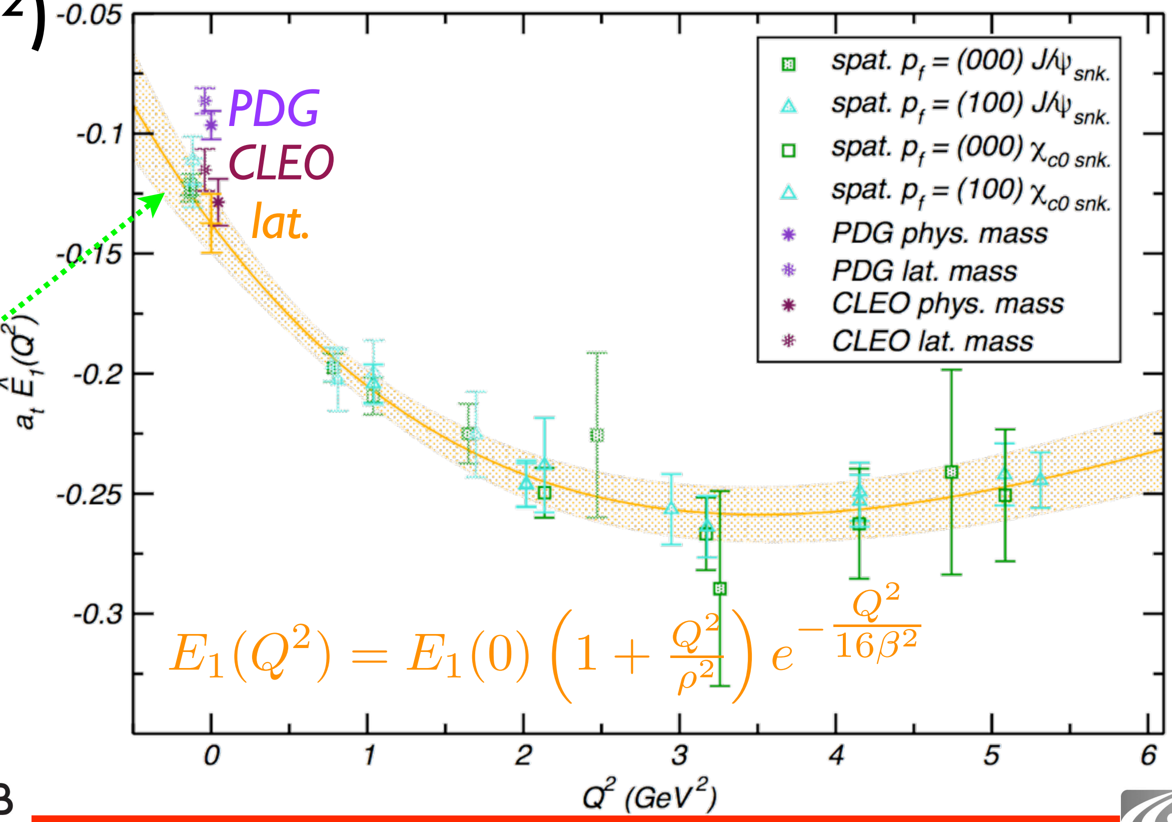
300 cfgs.

$\chi_{c0} \to J/\psi\gamma$

- transverse $E_1(Q^2)$ and longitudinal $C_1(Q^2)$

$$\langle S(\vec{p}_S)|j^\mu(0)|V(\vec{p}_V,r)\rangle = \Omega^{-1}(Q^2)\bigg(E_1(Q^2)\Big[\Omega(Q^2)\epsilon^\mu(\vec{p}_V,r) - \epsilon(\vec{p}_V,r).p_S\big(p_V^\mu p_V.p_S - m_V^2 p_S^\mu\big)\Big]$$
$$+\frac{C_1(Q^2)}{\sqrt{q^2}} m_V \epsilon(\vec{p}_V,r).p_S\Big[p_V.p_S(p_V+p_S)^\mu - m_S^2 p_V^\mu - m_V^2 p_S^\mu\Big]\bigg)$$

$E_1(Q^2)$



$$E_1(Q^2) = E_1(0)\left(1+\frac{Q^2}{\rho^2}\right)e^{-\frac{Q^2}{16\beta^2}}$$

not used in the fit

$\chi_{c1} \to J/\psi\gamma$

- **transverse $E_1(Q^2)$, $M_2(Q^2)$ and longitudinal $C_1(Q^2)$**

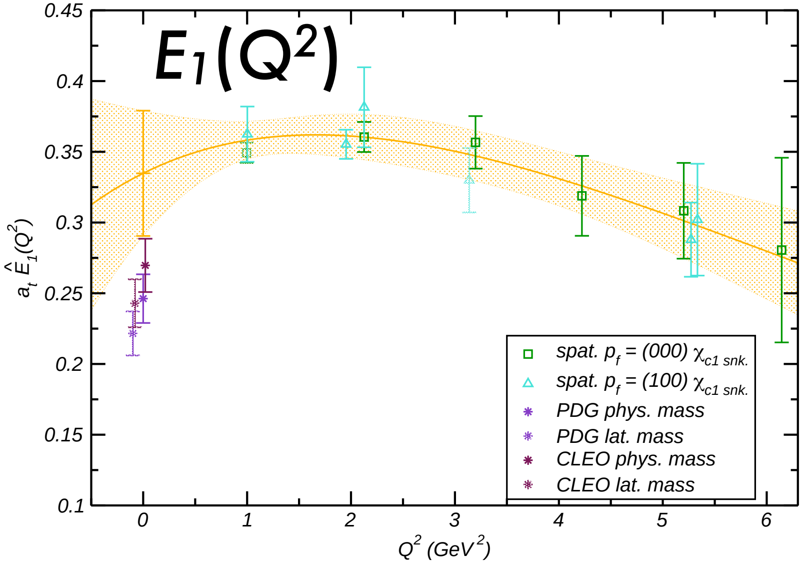
$$\langle A(\vec{p}_A, r_A)|j^\mu(0)|V(\vec{p}_V, r_V)\rangle = \frac{i}{4\sqrt{2}\Omega(Q^2)}\epsilon^{\mu\nu\rho\sigma}(p_A - p_V)_\sigma \times$$

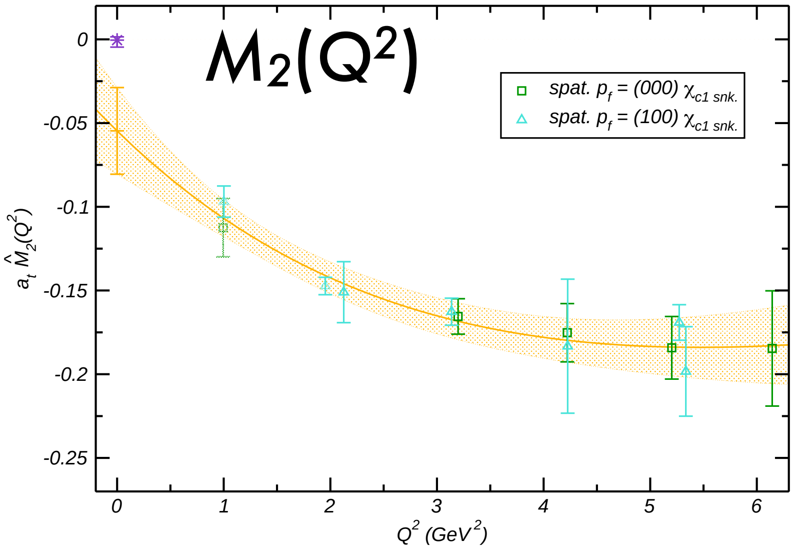
$$\times \Bigg[E_1(Q^2)(p_A + p_V)_\rho \Big(2m_A[\epsilon^*(\vec{p_A}, r_A).p_V]\epsilon_\nu(\vec{p_V}, r_V) + 2m_V[\epsilon(\vec{p}_V, r_V).p_A]\epsilon^*_\nu(\vec{p_A}, r_A)\Big)$$

$$+ M_2(Q^2)(p_A + p_V)_\rho \Big(2m_A[\epsilon^*(\vec{p_A}, r_A).p_V]\epsilon_\nu(\vec{p_V}, r_V) - 2m_V[\epsilon(\vec{p}_V, r_V).p_A]\epsilon^*_\nu(\vec{p_A}, r_A)\Big)$$

$$+ \frac{C1(Q^2)}{\sqrt{q^2}}\Big(- 4\Omega(Q^2)\epsilon^*_\nu(\vec{p}_A, r_A)\epsilon_\rho(\vec{p}_V, r_V)$$

$$+ (p_A + p_V)_\rho \Big[(m_A^2 - m_V^2 + q^2)[\epsilon^*(\vec{p}_A, r_A).p_V]\ \epsilon_\nu(\vec{p}_V, r_V) + (m_A^2 - m_V^2 - q^2)[\epsilon(\vec{p}_V, r_V).p_A]\ \epsilon^*_\nu(\vec{p}_A, r_A)\Big]\Big)\Bigg].$$





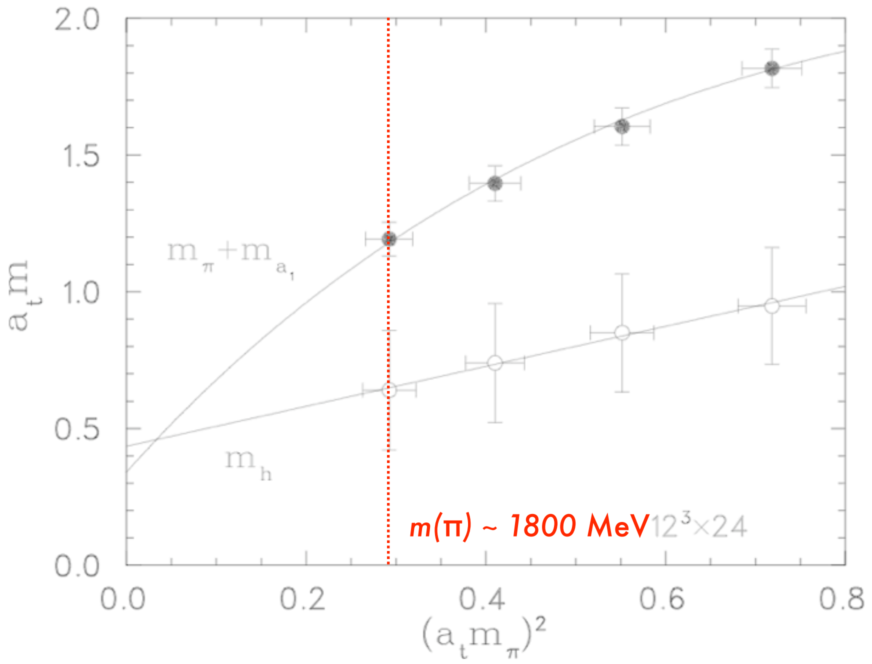
Summary

- *GlueX* is a major component of the *JLab 12* GeV upgrade
- will exceed total world meson production data in a few years
- search for exotic mesons a main focus

- *JLab* lattice QCD program aligned with *GlueX* aims
- dynamical 2+1 anisotropic Clover lattices to be used for spectrum, decay and photocoupling studies at low pion masses

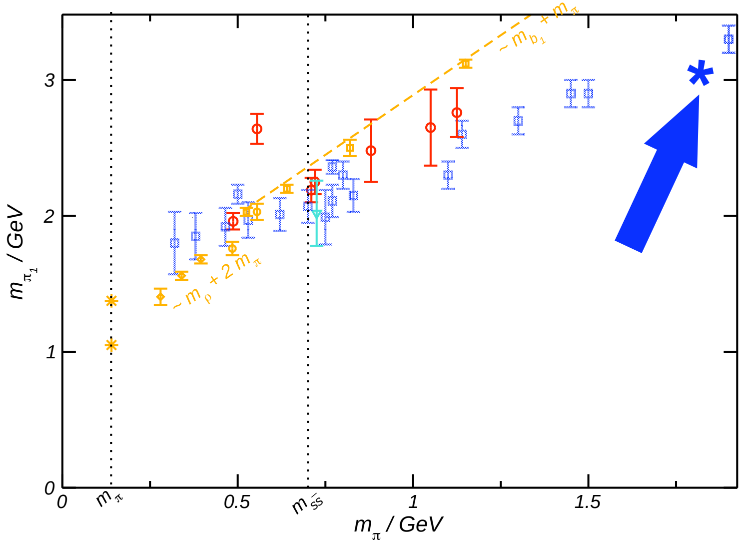
Hadronic Decays

- some recent lattice progress on this important topic
- Lüscher method study : Cook & Fiebig
    - use volume dependence where $m(\pi) + m(b_1) < m(\pi_1)$ or $m(\pi) + m(a_1) < m(\eta_1)$



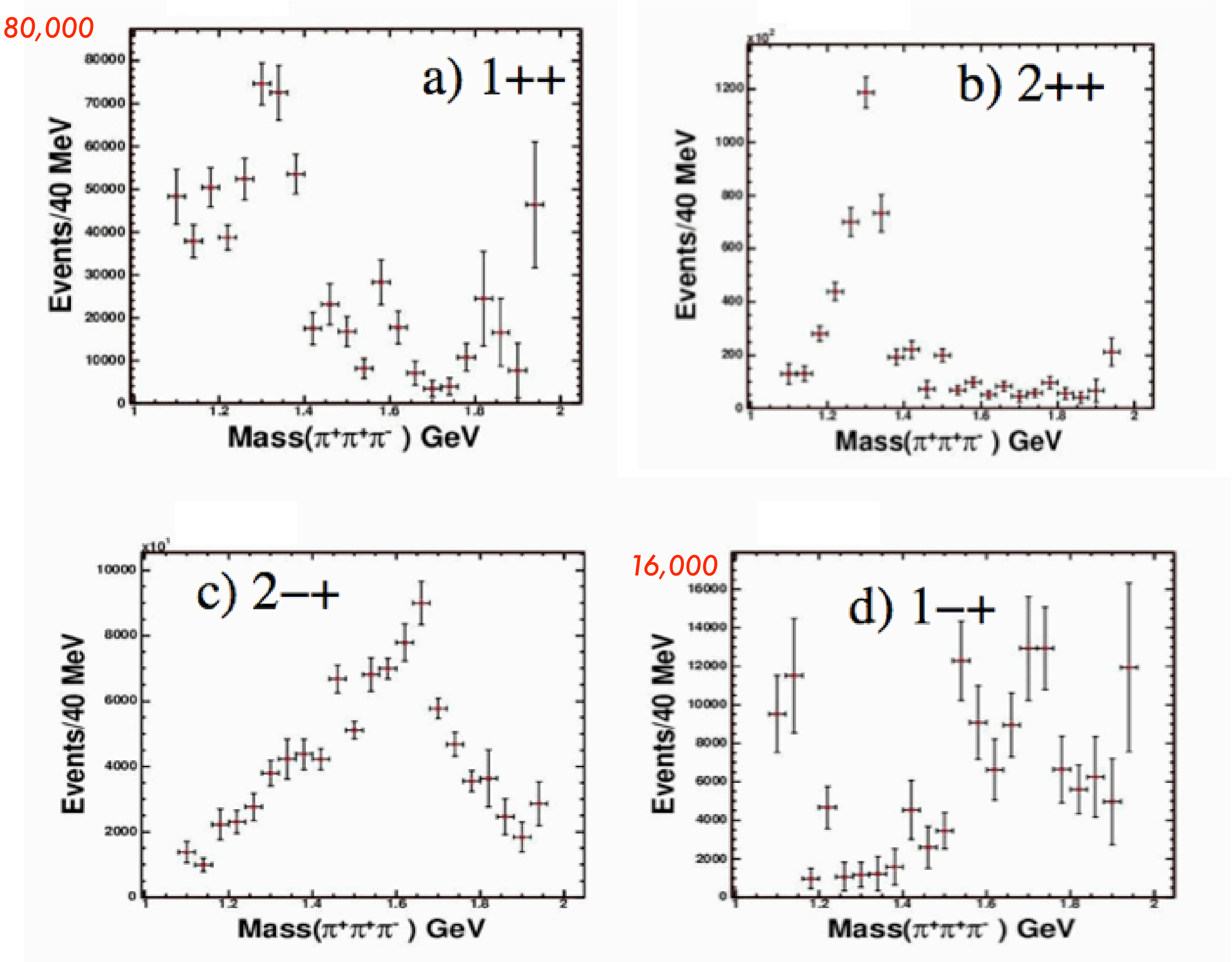
m(π) ~ 1800 MeV

very large extrapolation to level crossing



quenched 10^3x24 & 12^3x24 with Wilson quarks

CLAS PWA



80,000

16,000

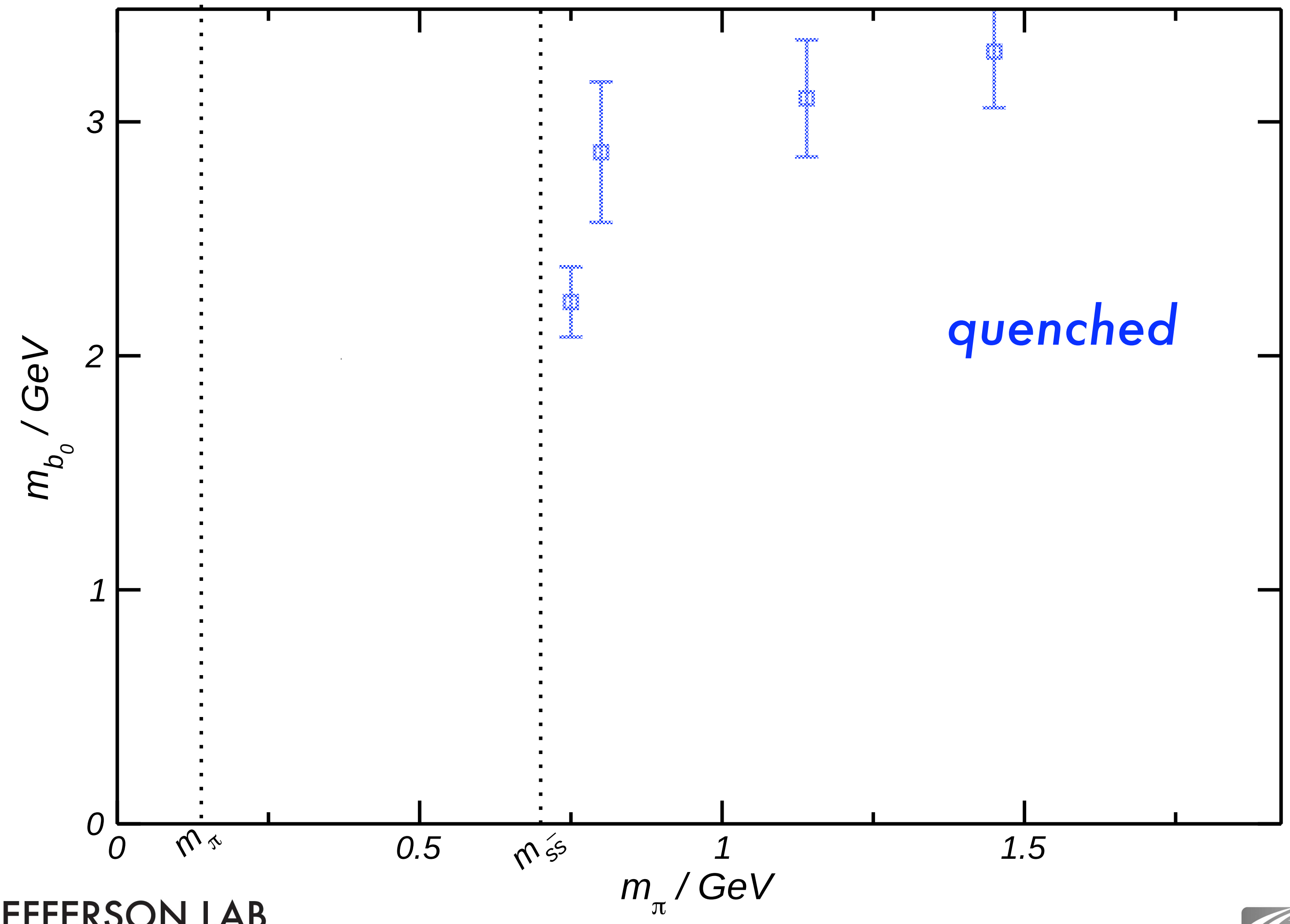
exotic maybe 1-2% of 1++ in pion prod, appears to be about 20% here

Hadronic Decays cont.

- some recent lattice progress on this important topic
- alternative approach due to Michael & McNeile
  - tune quark masses to $m(\pi) + m(b_1) \approx m(\pi_1)$

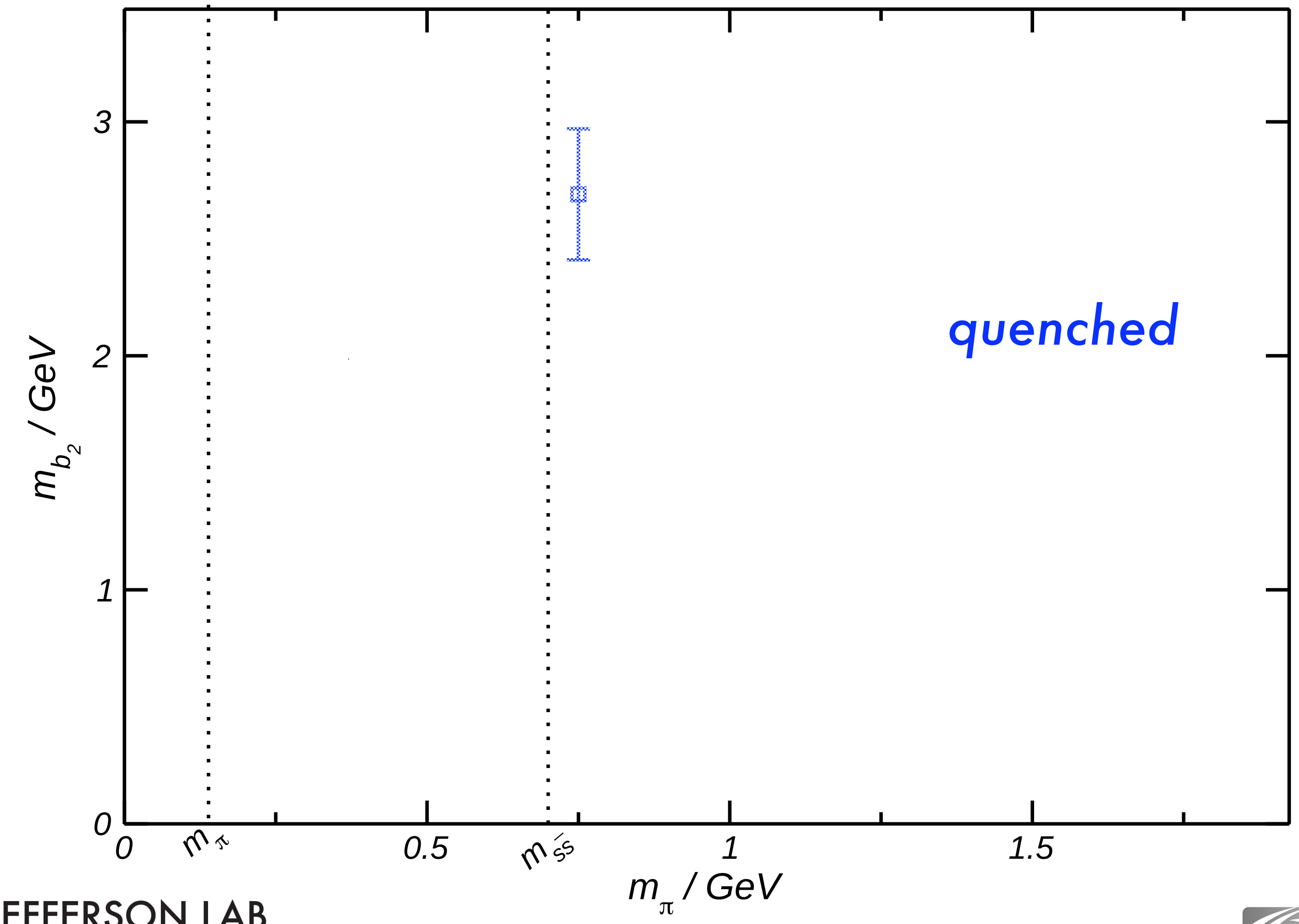
Lightest 0^{+-} from Lattice QCD

- summary of world simulation data



Lightest 2^{+-} from Lattice QCD

- summary of world simulation data

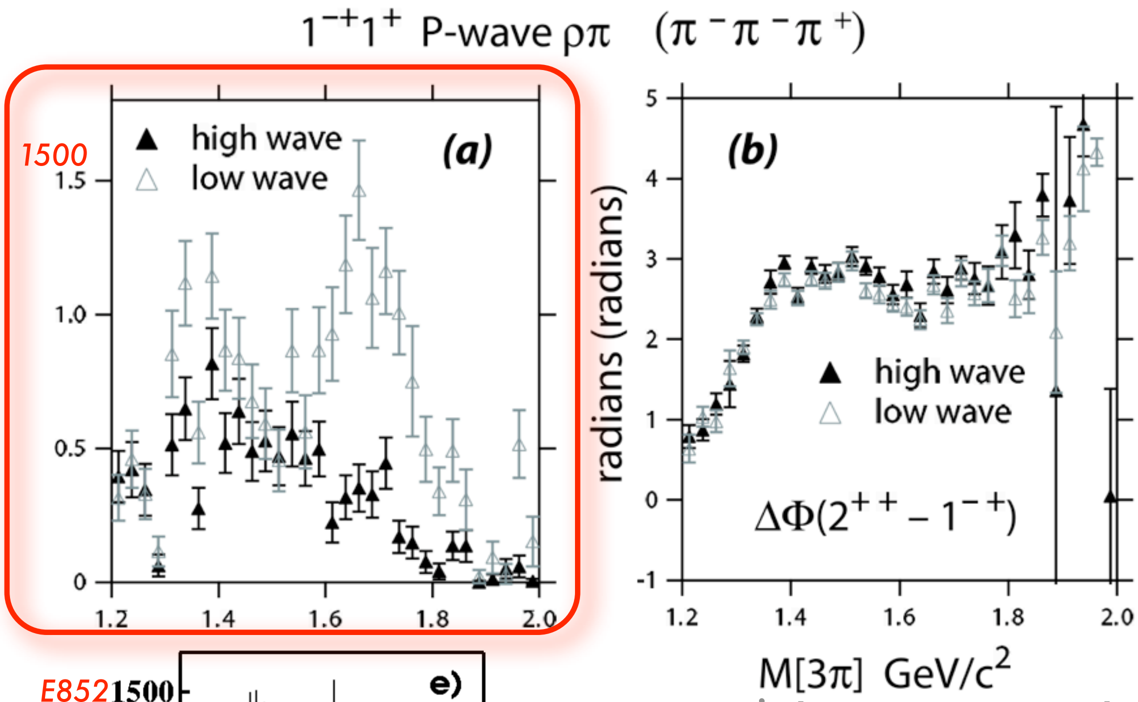


Lattice QCD & model testing

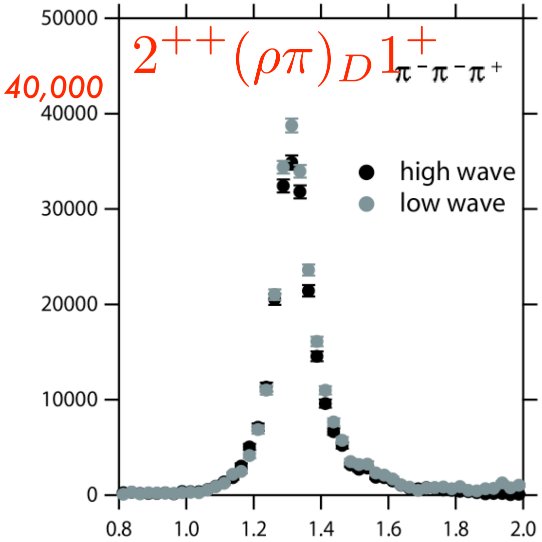
- quark masses will decrease in the future, but even now we can make good use of lattice data
- we can compare lattice QCD calculations with ‘heavier’ quarks vs model calculations with ‘heavier’ quarks

Exotics in E852

- two analyses of $\pi p \to \pi\pi\pi p$, more recent has higher statistics

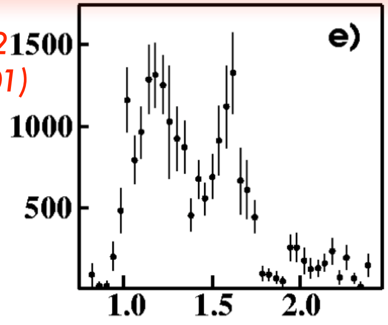


1500



$2^{++}(\rho\pi)_D 1^+$

40,000



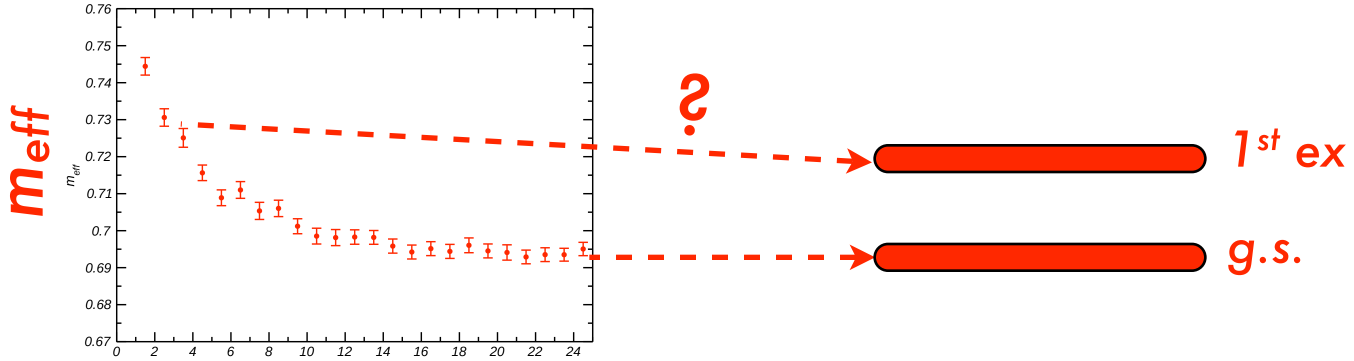
E852
(2001)

grey points use a more truncated waveset lacking some 2^{-+} waves

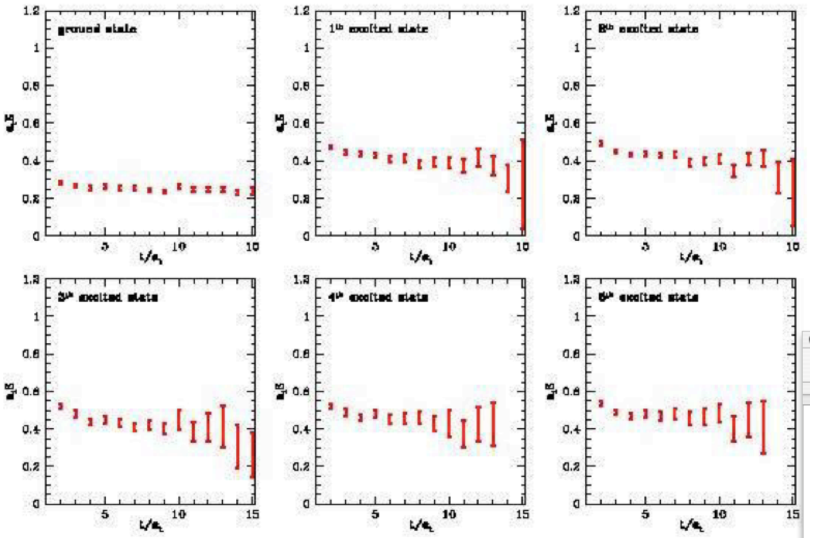
claimed explanation of difference is $\pi_2(1670)$ leaking into exotic wave

Variational Method

- traditional method



- variational method



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