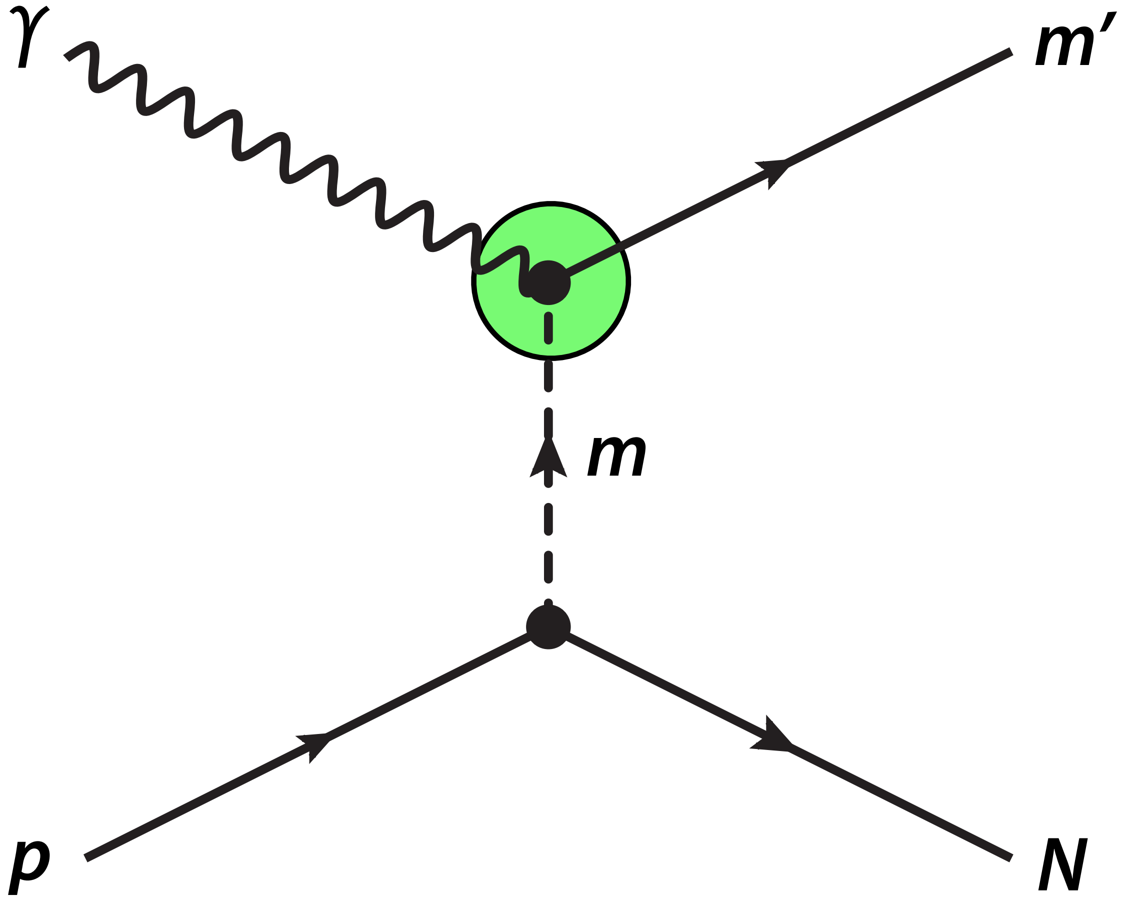
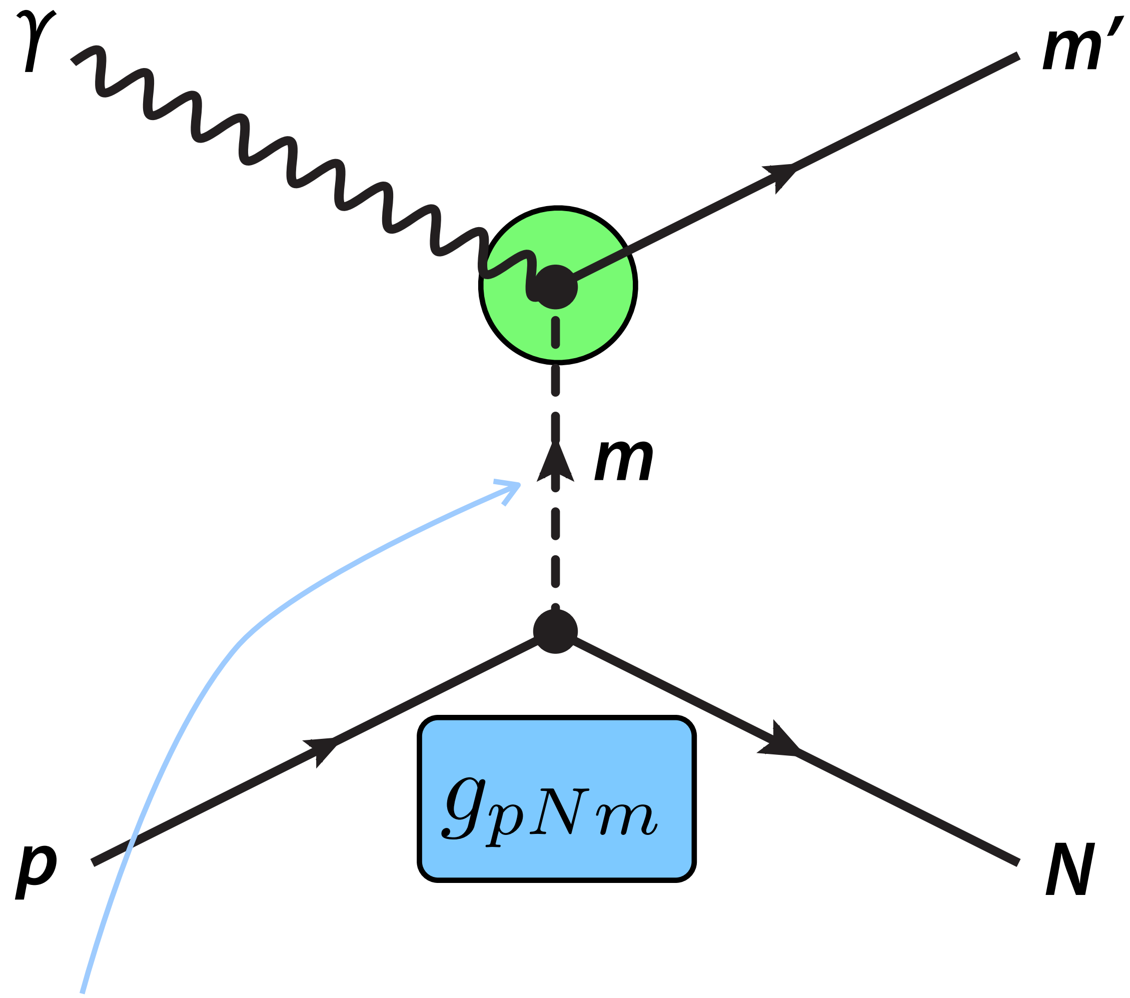
photocoupling phenomenology



* *basic picture*
* *review model results*
* *first hints from QCD*

meson photocouplings



g_{pNm}

$$\frac{1}{t - m^2}$$

$$\mathcal{P}_{\mathcal{R}}(t)$$

simplest picture: all ***GlueX*** rates proportional to photocouplings:

$$\langle \gamma\, m' | m \rangle$$

particularly interested in exotic couplings, e.g.:

$$\langle \gamma \pi | \pi_1 \rangle$$

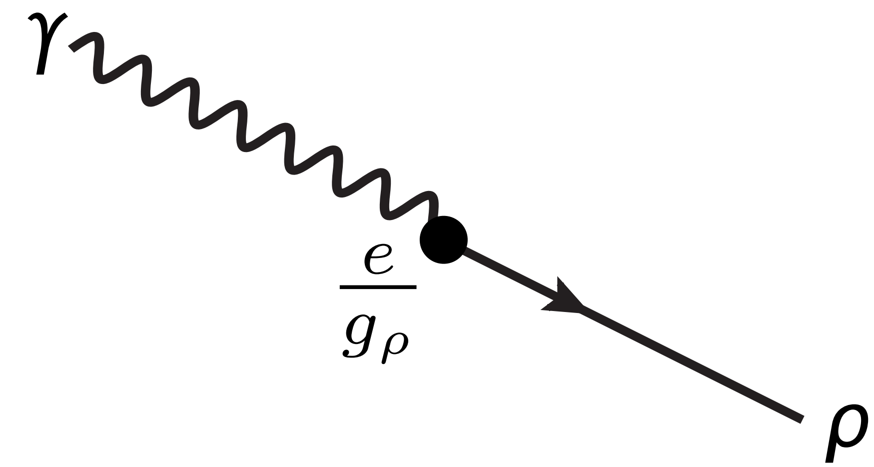
$$\langle \gamma \rho | \pi_1 \rangle$$

$$\langle \gamma \mathbb{P} | b_2 \rangle$$

$$\vdots$$

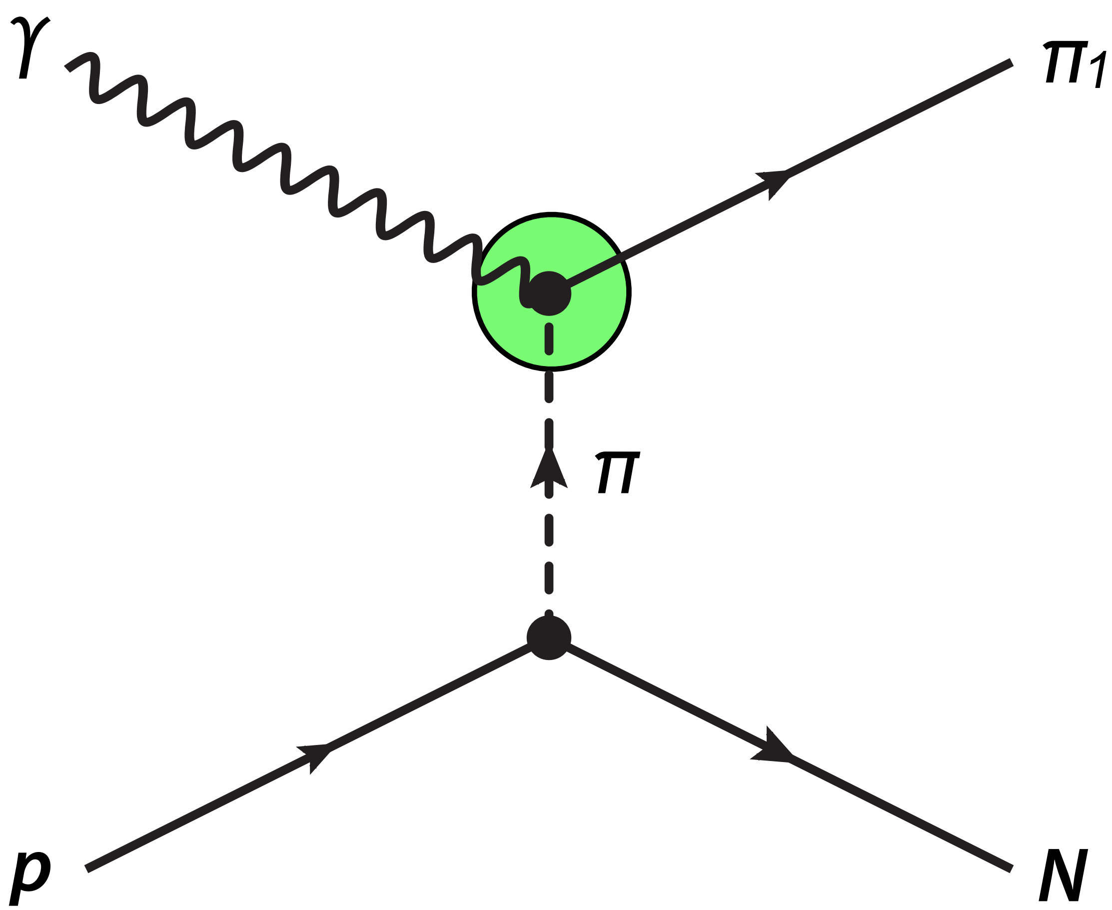
hadron-level models

use hadronic coupling & *VMD* to estimate photocoupling

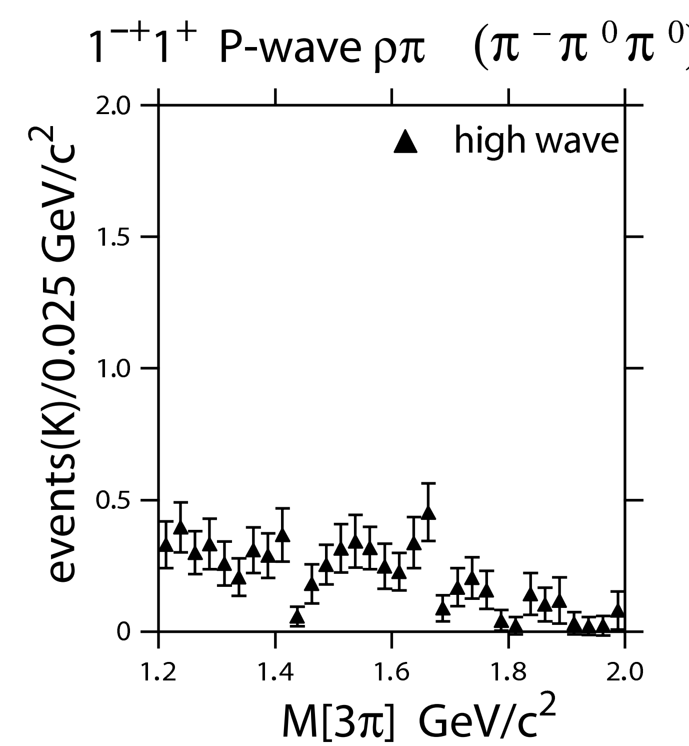


e.g. $$\Gamma(\pi_1 \to \gamma\pi) = \frac{e^2}{g_\rho^2} \cdot \Gamma(\pi_1 \to \rho\pi)$$

e.g. Szczepaniak & Swat



requires knowledge of the hadronic width !
IU analysis of ***E852*** data suggests this might not be large ?

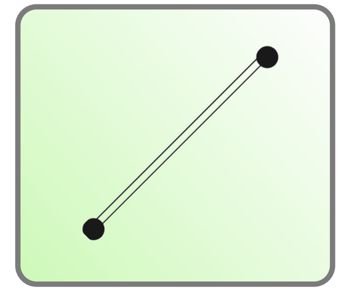


flux-tube model

quantum mechanical many-body model

constituent quarks $\tilde{q}$
gluonic field forms a tube between quarks

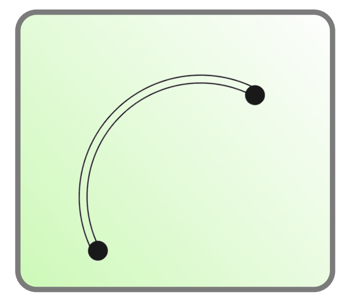
conventional mesons - tube in ground state



$$M = m_q + m_{\bar{q}} + \langle V_0(r_{q\bar{q}}) \rangle$$

non-exotic J^{PC}

hybrid mesons - tube in excited oscillatory state



$$M = m_q + m_{\bar{q}} + \langle V_1(r_{q\bar{q}}) \rangle$$

$$\delta M \sim \left\langle \frac{\pi}{r} \right\rangle \sim 1\,\mathrm{GeV}$$

excited tube carries $J^{PC} = 1^{\pm\mp}$.
gives 'degenerate' mesons
$$0^{+-},\ 1^{-+},\ 2^{+-}$$
and more non-exotics

in this picture exotics have $S_{q\bar{q}} = 1$

coulomb gauge

quantum mechanical many-body model

constituent quarks $\tilde{q}$
gluon obtains an effective mass

Szczepaniak, Guo et al (for heavy quarks [charm])

lightest exotic - 1^{-+} with $S_{q\bar{q}} = 1$.

non-exotic - 1^{--} with $S_{q\bar{q}} = 0$.

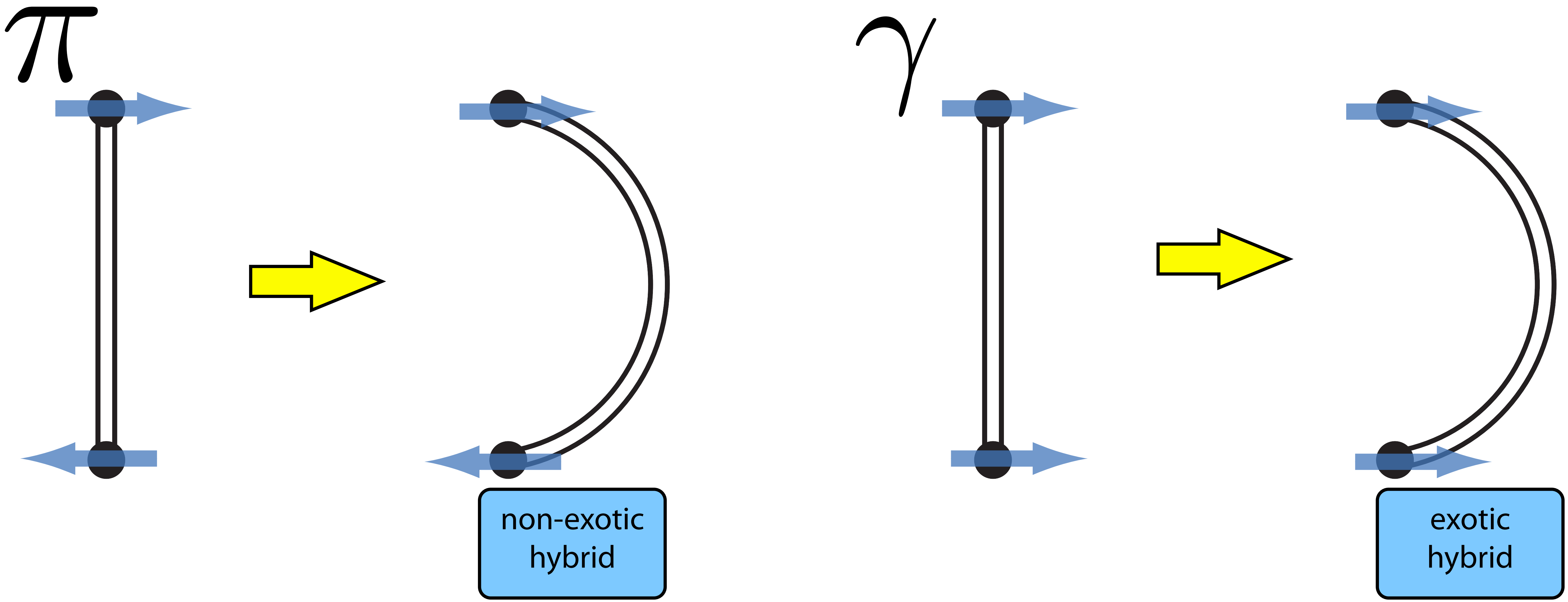
heavier exotic 2^{+-} .

so we should be careful, flux-tube model patterns are not general

quark-level models

the spin argument for photoproduction vs. pion production

proposed that if 'projectile' has same spin configuration, exotic hybrids preferred



this is really just a hand-wave, not a microscopic model - doesn't say anything about how the *t*-channel exchange excites the tube

doesn't mean it isn't correct !

generalities

ELECTRIC DIPOLE TRANSITIONS

neutrals - C-parity good

$$(\eta, \pi^0)\ \gamma_{E1} \longrightarrow (h_1, b_1)$$
$$(\omega, \rho^0)\ \gamma_{E1} \longrightarrow (f_J, a_J)$$
$$(f_J, a_J)\ \gamma_{E1} \longrightarrow (\omega_J, \rho_J)$$

no exotics here

charged - C-parity broken

$$\pi^{\pm}\ \gamma_{E1} \longrightarrow (b_1, a_1)^{\pm}$$
$$\rho^{\pm}\ \gamma_{E1} \longrightarrow (b_J, a_J)^{\pm}$$
$$a_J^{\pm}\ \gamma_{E1} \longrightarrow (\rho_J, \pi_J)^{\pm}$$

π_1, b_0, b_2, ρ_0 are exotic

MAGNETIC DIPOLE TRANSITIONS

$$(\eta, \pi^0)\ \gamma_{M1} \longrightarrow (\rho, \omega)$$
$$(\omega, \rho^0)\ \gamma_{M1} \longrightarrow (\eta_J, \pi_J)$$
$$(f_J, a_J^0)\ \gamma_{M1} \longrightarrow (h_J, b_J)$$

π_1, b_0, b_2 are exotic

$$\pi^{\pm}\ \gamma_{M1} \longrightarrow (\rho, \pi_1)^{\pm}$$
$$\rho^{\pm}\ \gamma_{M1} \longrightarrow (\rho_J, \pi_J)^{\pm}$$
$$a_J^{\pm}\ \gamma_{M1} \longrightarrow (b_J, a_J)^{\pm}$$

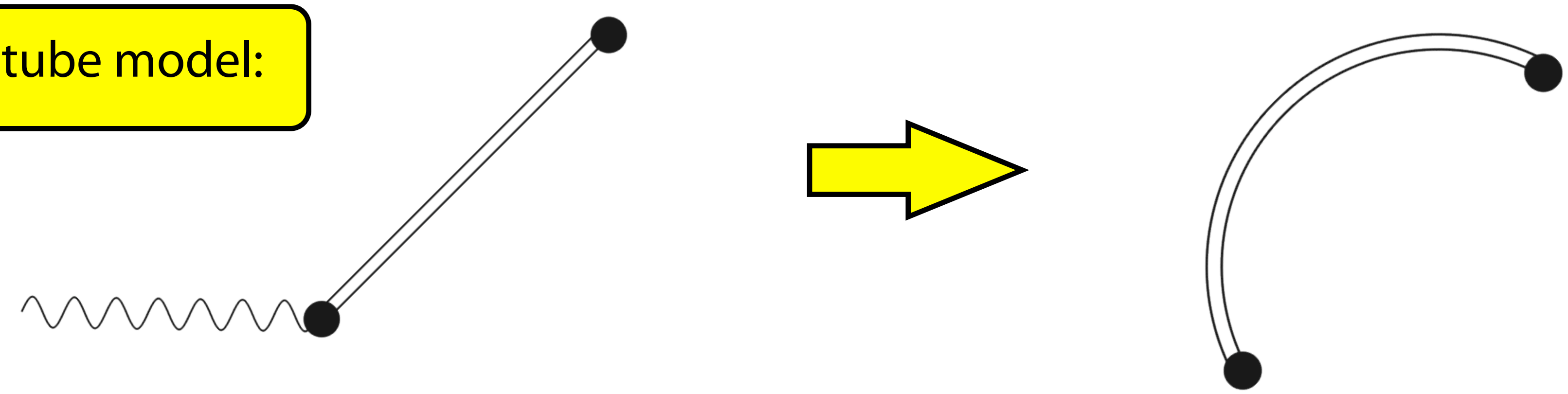
π_1, b_0, b_2 are exotic

quark-level models

Dudek & Close '03, '04

in microscopic models these may not all be allowed

explicit calculations in flux-tube model:



many-body quantum mechanics calculation

ELECTRIC DIPOLE TRANSITIONS

(no spin flip)

$$\pi[\,{}^1S_0]\;\gamma_{E1} \longrightarrow (b_1[\,{}^1P_1], a_1[\,{}^1\mathcal{H}_1])$$

$$\rho[\,{}^3S_1]\;\gamma_{E1} \longrightarrow (a_J[\,{}^3P_J], b_J[\,{}^3\mathcal{H}_J])$$

ρ exchange - $b_{0,2}$

$$a_J[\,{}^3P_J]\;\gamma_{E1} \longrightarrow (\rho_J[\,{}^3(S,D)_J], \pi_J[\,{}^3\mathcal{H}_J])$$

a_J exchange - π_1

treating a pion as a $q\bar{q}$ bound state !

quark-level models

ELECTRIC DIPOLE TRANSITIONS

expt: $$\Gamma(b_1^+ \to \pi\gamma) = 230(60)\,\mathrm{keV}$$

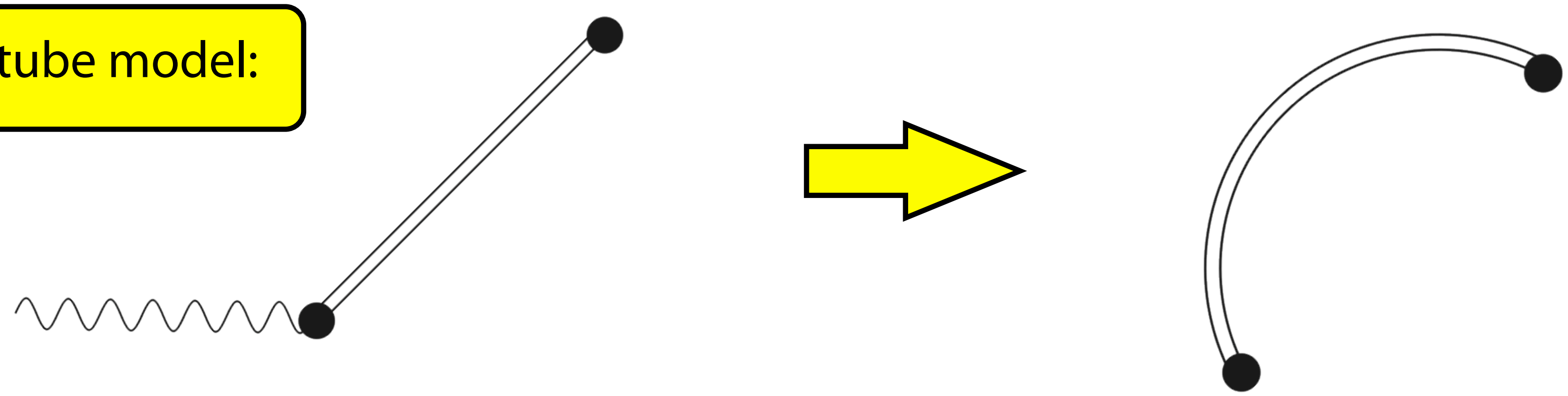
model: $$\Gamma(b_{JH}^+ \to \rho^+\gamma) = 2300(800)\,\mathrm{keV}$$

$$\Gamma(\pi_{1H}^+ \to a_2^+\gamma) = 90\,\mathrm{keV}$$

quark-level models

in microscopic models these may not all be allowed

explicit calculations in flux-tube model:



many-body quantum mechanics calculation

MAGNETIC DIPOLE TRANSITIONS

for conventionals - pure spin-flip

$$\sim \frac{\sigma}{m}$$

$$\Gamma(\rho^+ \to \pi^+\gamma) = 68(7)\,\mathrm{keV}$$

$$\Gamma(J/\psi \to \eta_c\gamma) \sim 2\,\mathrm{keV}$$

for hybrids - novel mechanism - tube absorbs the ang. mom.

light meson predictions are sensitive to approximations

$$\Gamma(\eta_{c1} \to J/\psi\gamma) \sim 30 - 60\,\mathrm{keV}$$

unpublished Dudek DPhil. thesis

QCD

lattice QCD as reliable approximation?

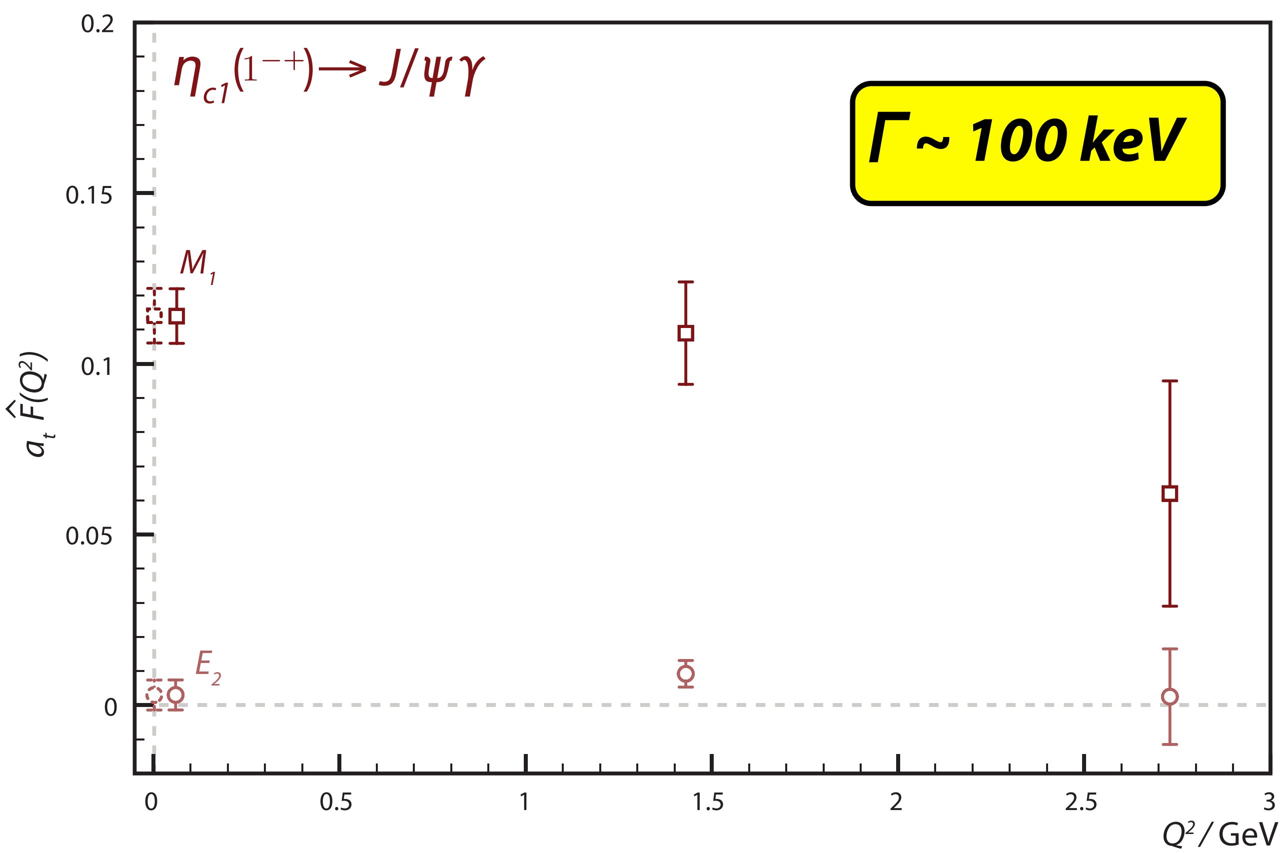
Exotic and excited-state radiative transitions in charmonium from lattice QCD.
Jozef J. Dudek (Jefferson Lab & Old Dominion U.) , Robert Edwards, Christopher E. Thomas (Jefferson Lab) . JLAB-THY-09-949, Feb 2009. 33pp.
e-Print: **arXiv:0902.2241** [hep-ph]

first attempt to extract photocouplings with exotics - no 'model' assumptions

in charmonium initially - lighter quark calculations running now

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

magnetic dipole transition



compare with $J/\psi \to \eta_c \gamma$ ~ 1 keV

quark spin flip ~ $\dfrac{\sigma}{m_c}$

perhaps this is not spin-flip?

$^3\mathcal{H}_1 \to {}^3S_1\gamma$

supports models in which the exotic has $S_{q\bar{q}} = 1$

QCD

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

magnetic dipole transition

$\Gamma \sim 100$ keV

now try something ***really naive***:

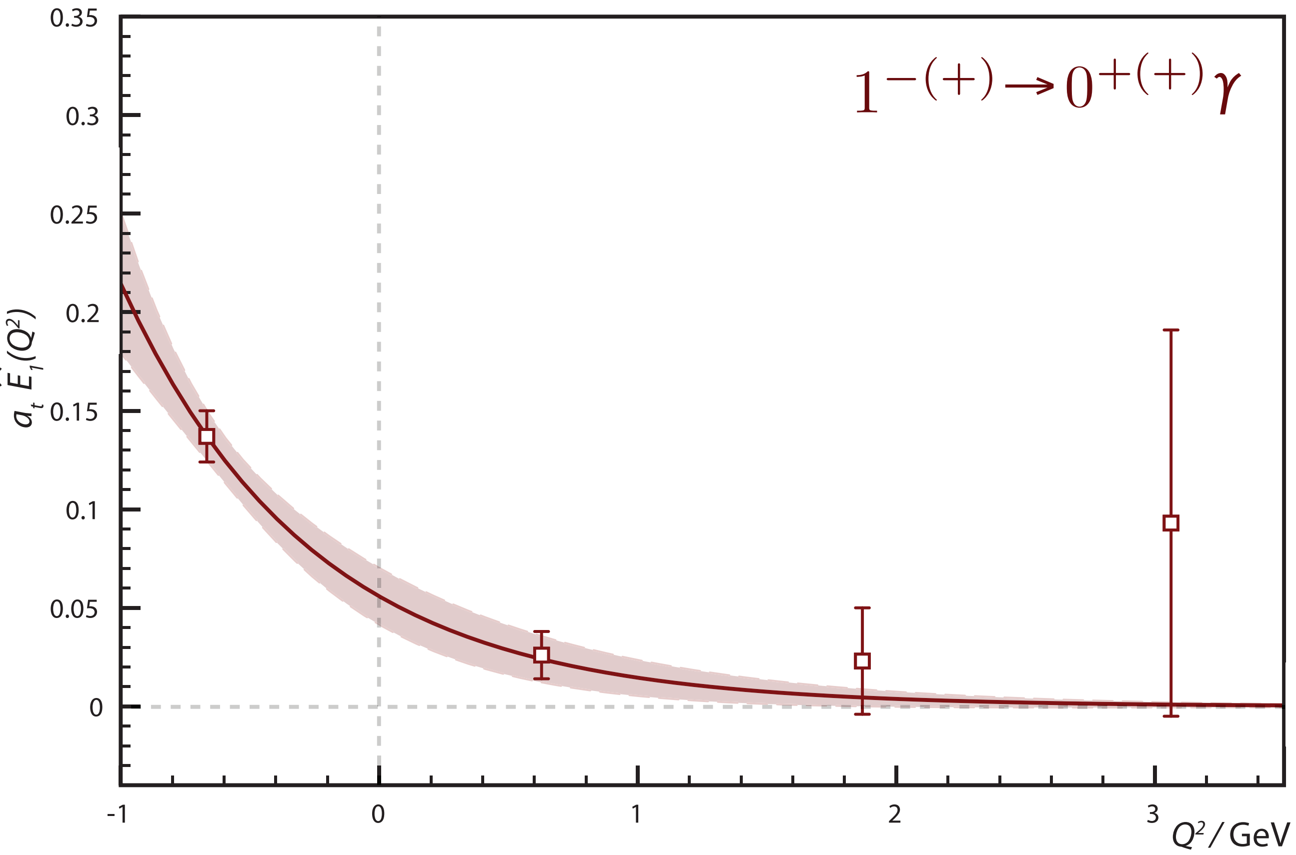
$$\frac{|\vec{q}|^{-3}\Gamma(\pi_1 \to \rho\gamma)}{|\vec{q}|^{-3}\,\Gamma(\rho \to \pi\gamma)} \stackrel{?}{=} \frac{|\vec{q}|^{-3}\Gamma(\eta_{c1} \to J/\psi\gamma)}{|\vec{q}|^{-3}\,\Gamma(J/\psi \to \eta_c\gamma)}$$

~ 0.1

but if we divide only by ***q*** ***~ 7***

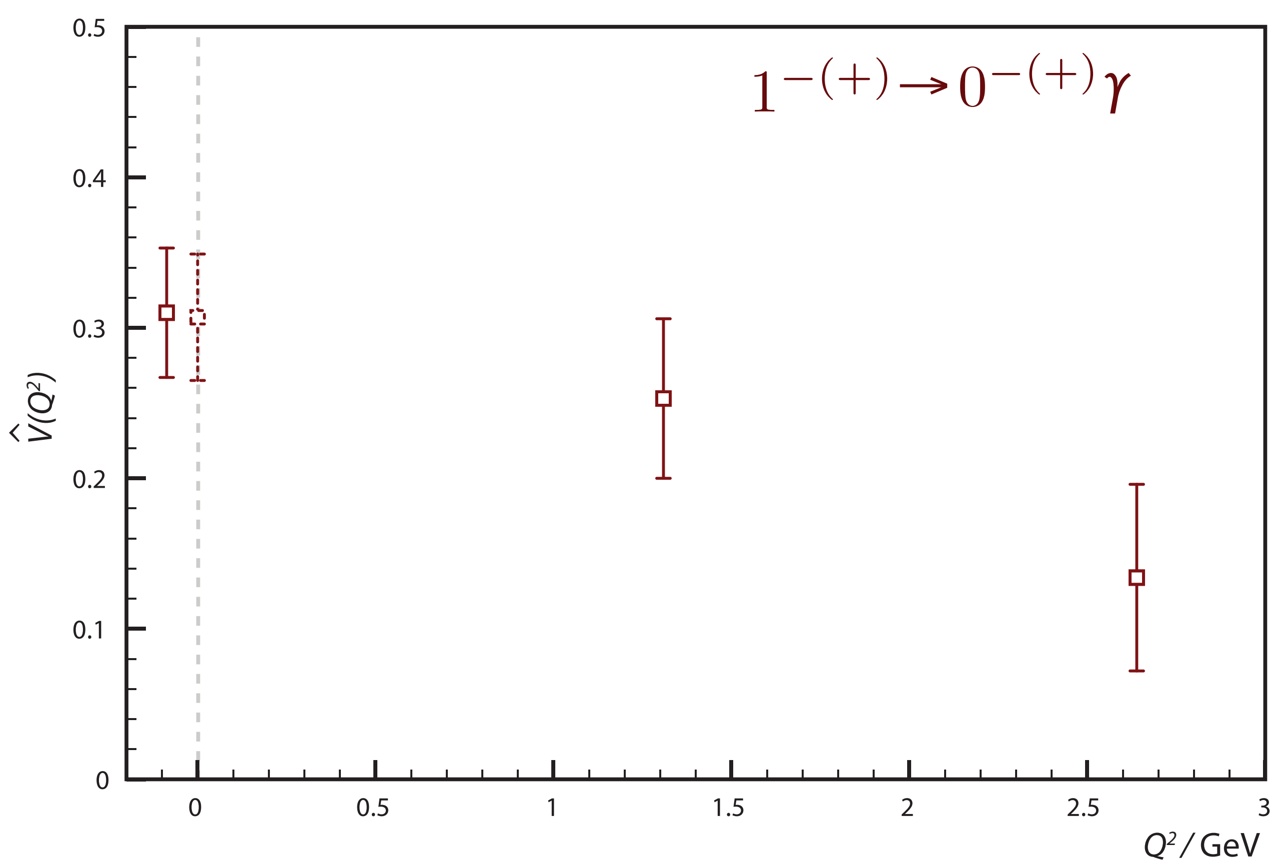
we do need to do the calculation with lighter quarks

exotics



compare with ***0.12*** for $\psi \to \chi_{c0}\gamma$

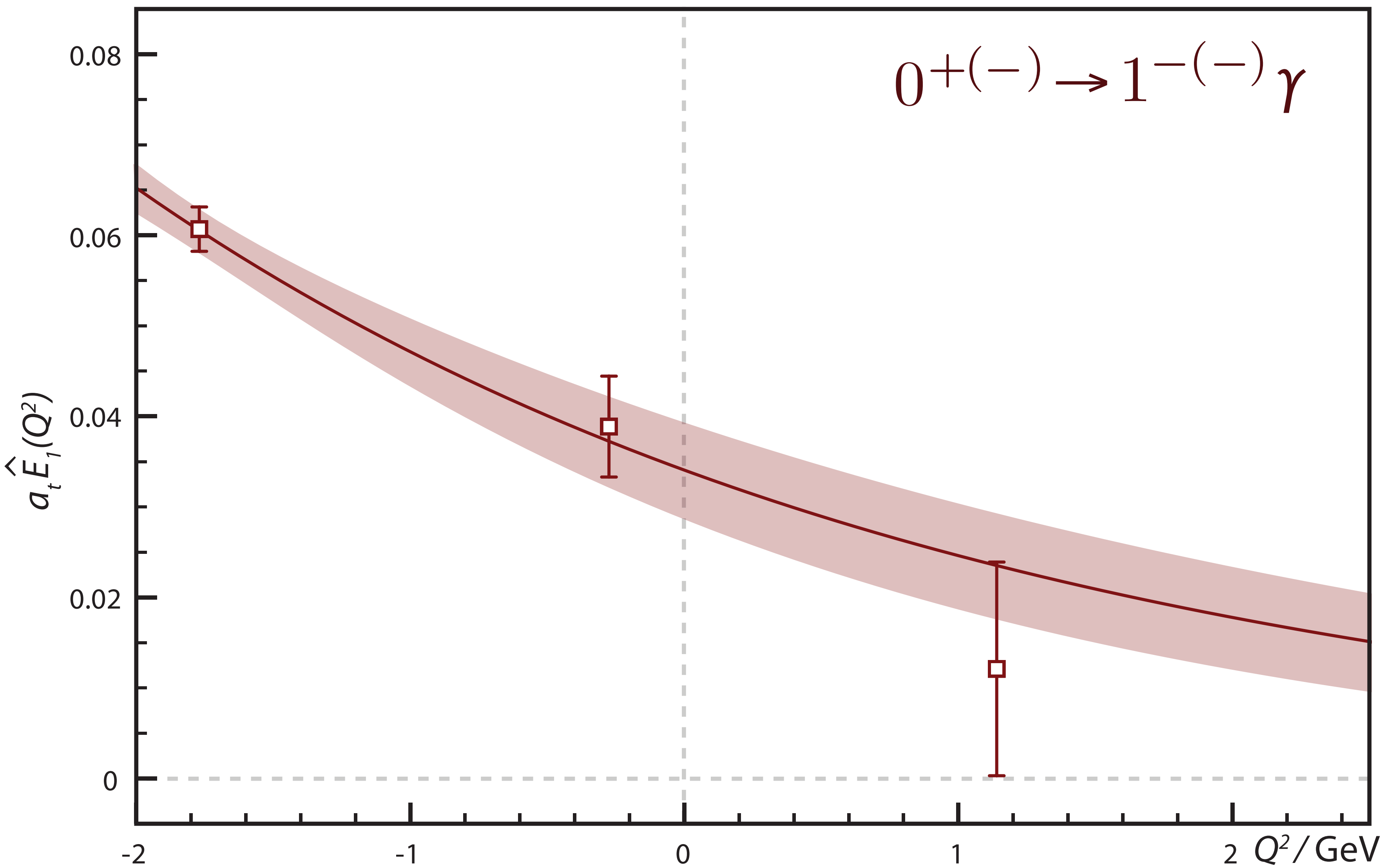
comparable - $(S_{q\bar{q}} = 1) \to (S_{q\bar{q}} = 1)$



compare with ***1.9*** for $\psi \to \eta_c\gamma$

suppressed - $(S_{q\bar{q}} = 1) \to (S_{q\bar{q}} = 0)$

exotics



compare with ***0.12*** for $\psi \rightarrow \chi_{c0} \gamma$

comparable - $(S_{q\bar{q}} = 1) \rightarrow (S_{q\bar{q}} = 1)$

now?

currently starting similar calculations with lighter quarks

right now: trying to extract a meson spectrum with:

three light quark flavours, but all at the ***strange quark mass***

will then attempt to extract photocouplings

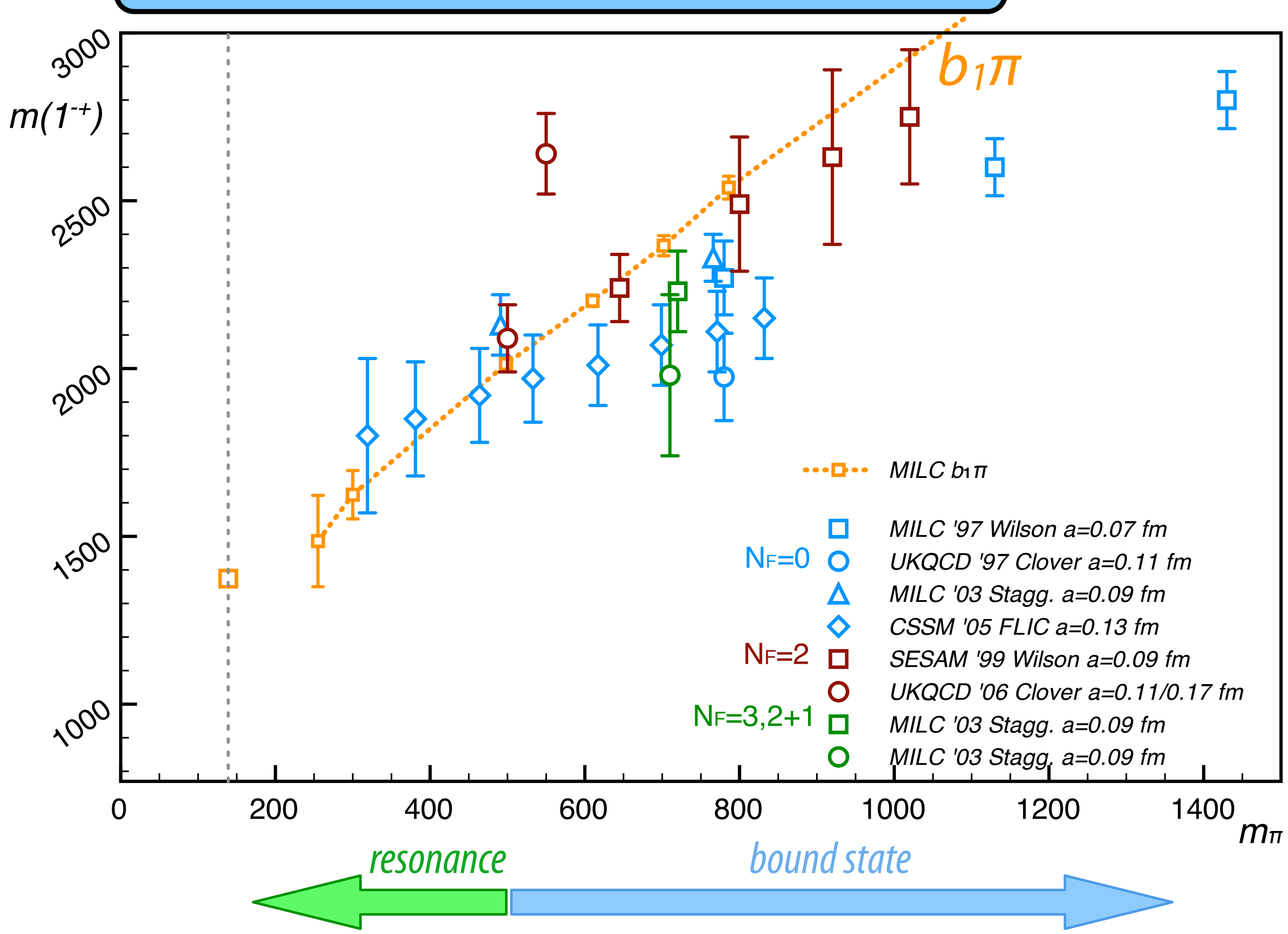
if this works, we'll push down the quark masses

we will hit some serious theoretical challenges - how do we reliably extract 'resonances'

EXOTIC J^{PC}

will need these techniques for realistic extraction of exotic resonance parameters

extant lattice results for lightest 1^{-+} state

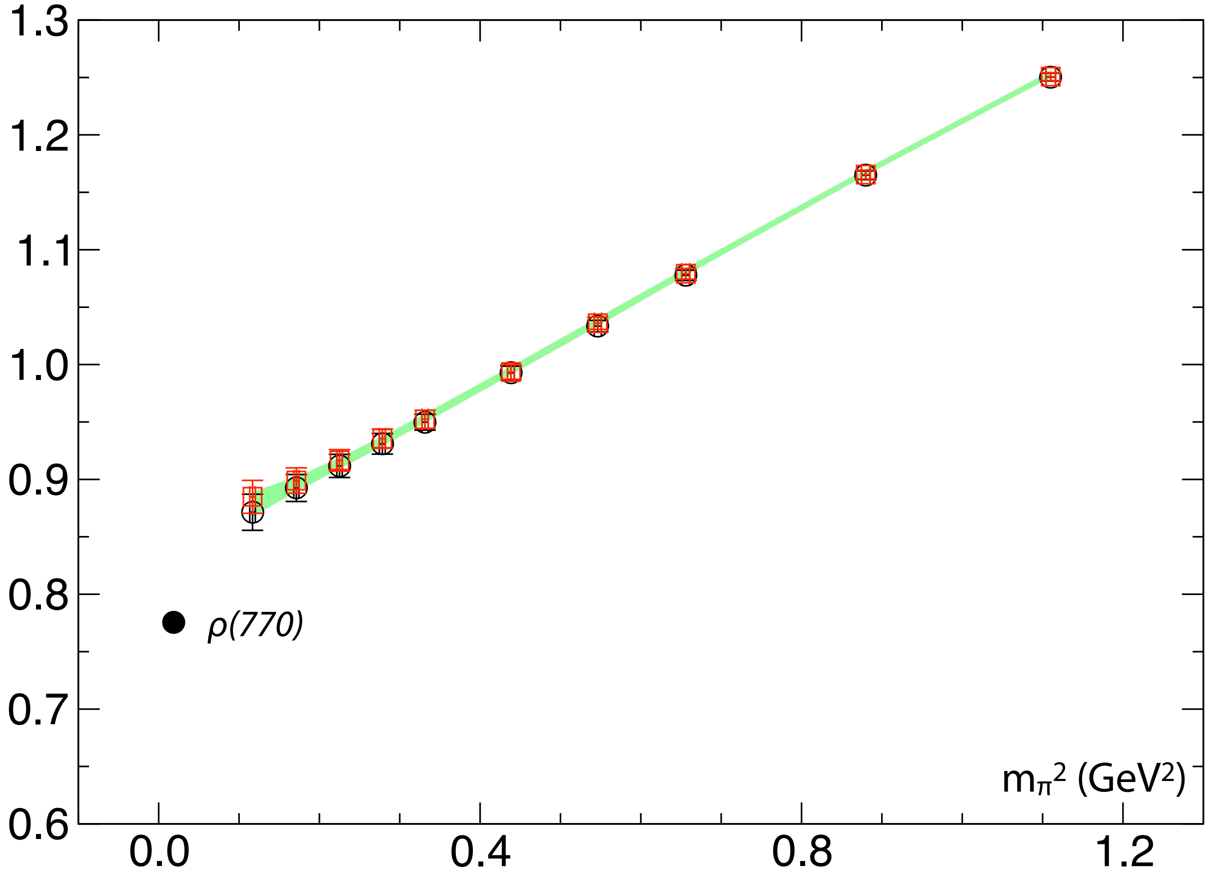


S-wave $b_1\pi$ state lightest below around $m_\pi \sim 600$ MeV ?

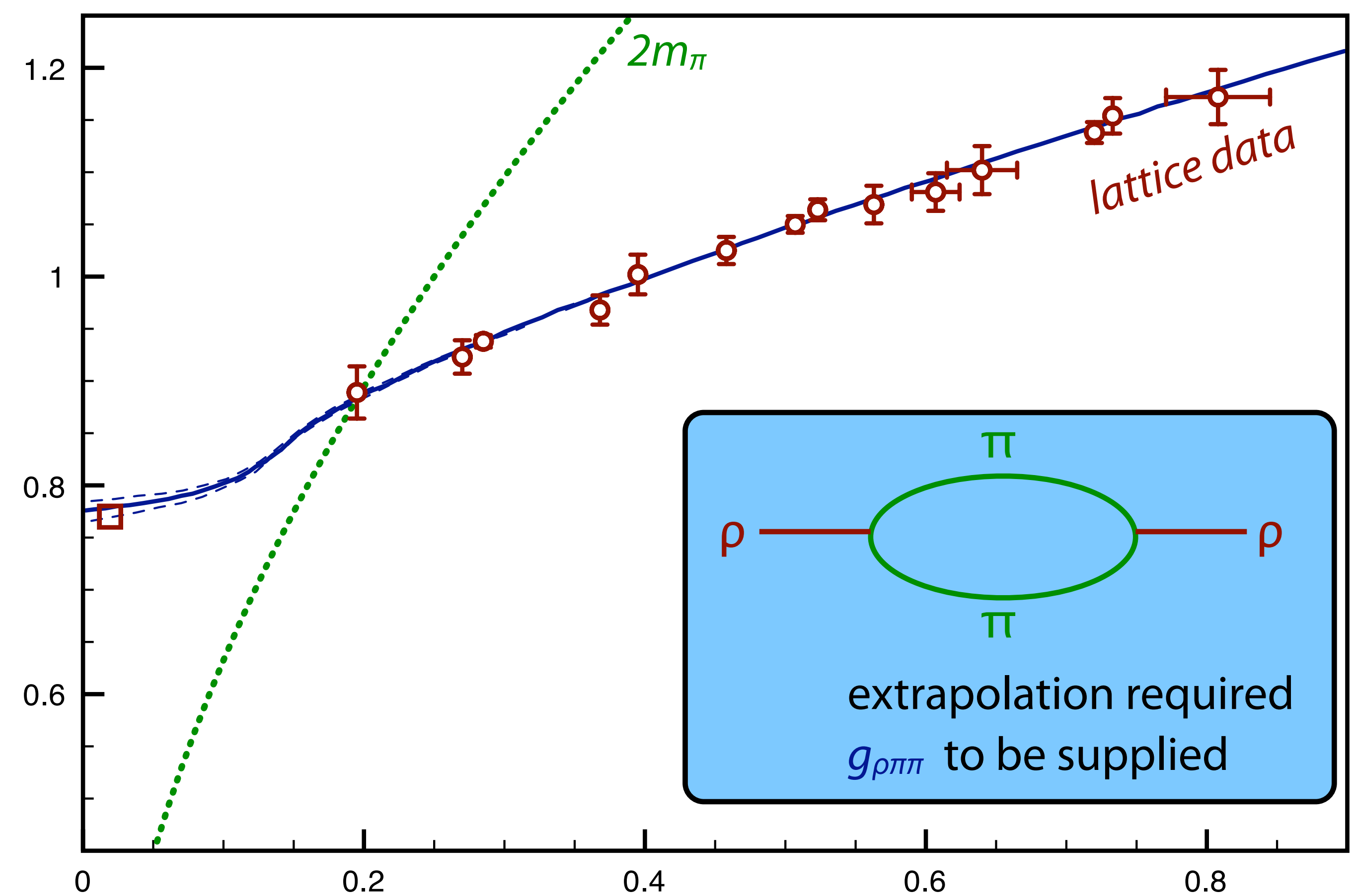
challenging calculations!

LATTICE QCD - RESONANCES, NOT BOUND STATES

notice that the data does not appear to be extrapolating to the physical ρ mass



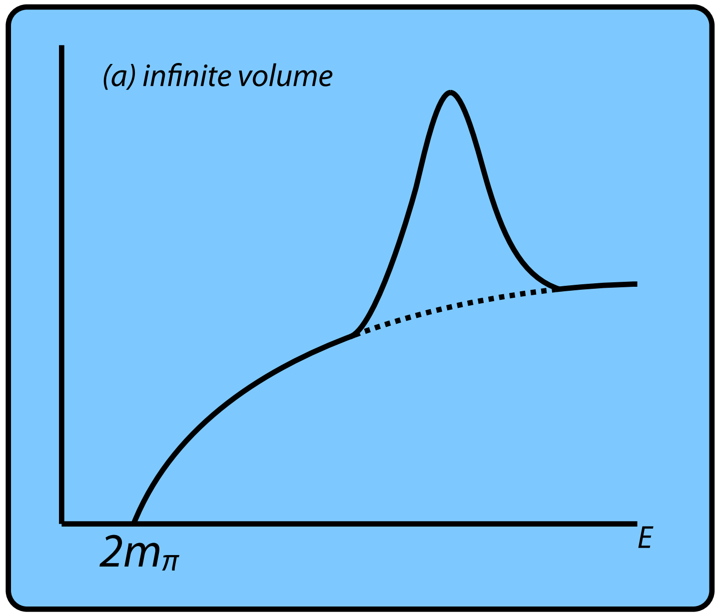
also observed in dynamical (unquenched) calculations



at low quark masses the lightest vector meson is a resonance in $\pi\pi$

RESONANCES IN FINITE VOLUME

what does the QCD vector spectrum look like?

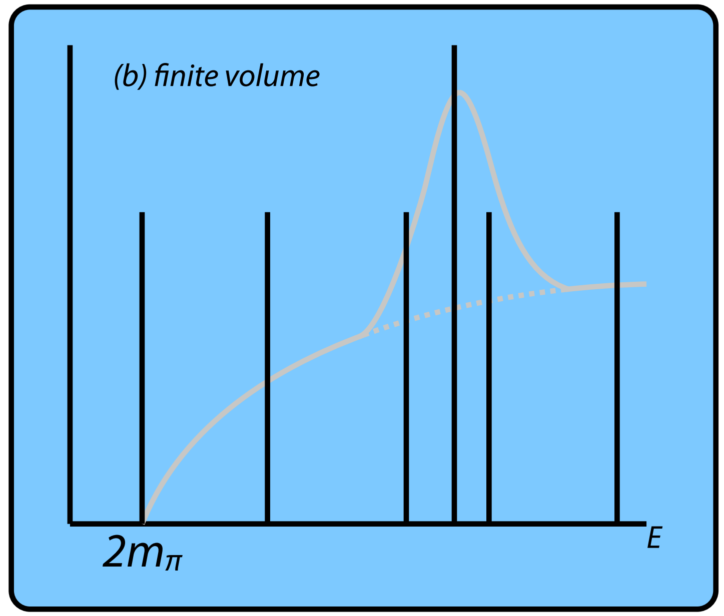


in ***infinite volume***, a continuous spectrum of $\pi\pi$ states

$$E(p) = 2\sqrt{m_\pi^2 + p^2}$$

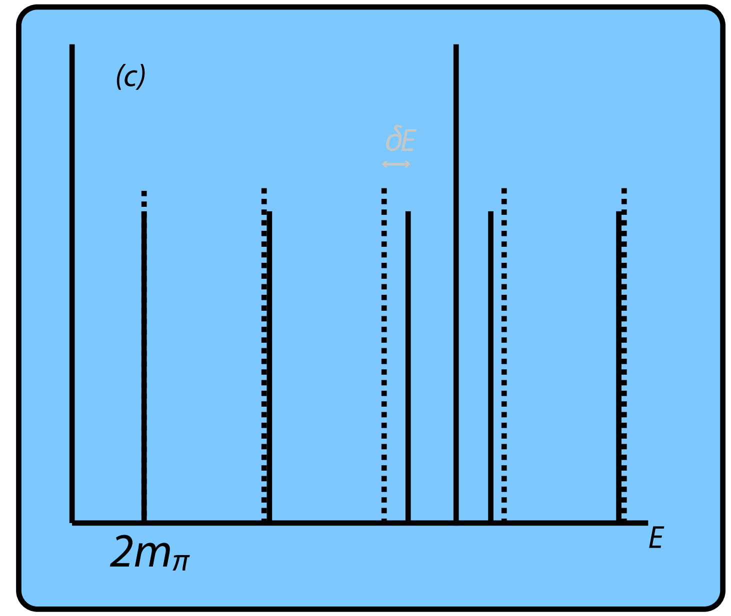
resonance embedded in a continuum of multi-particle states

$$C(\tau) = \int dE\, W(E)\, e^{-E\tau}$$



in ***finite volume***, a discrete spectrum of states

$$C(\tau) = \sum_N W_N e^{-E_N \tau}$$



non-interacting two-particle states have known energies

$$E(p) = 2\sqrt{m_\pi^2 + n\left(\frac{2\pi}{L}\right)^2}$$

deviation from free energies depends upon the interaction and contains information about the scattering phase shift

$\delta E(L) \leftrightarrow \delta(E)$: Lüscher method

RESONANCES IN FINITE VOLUME

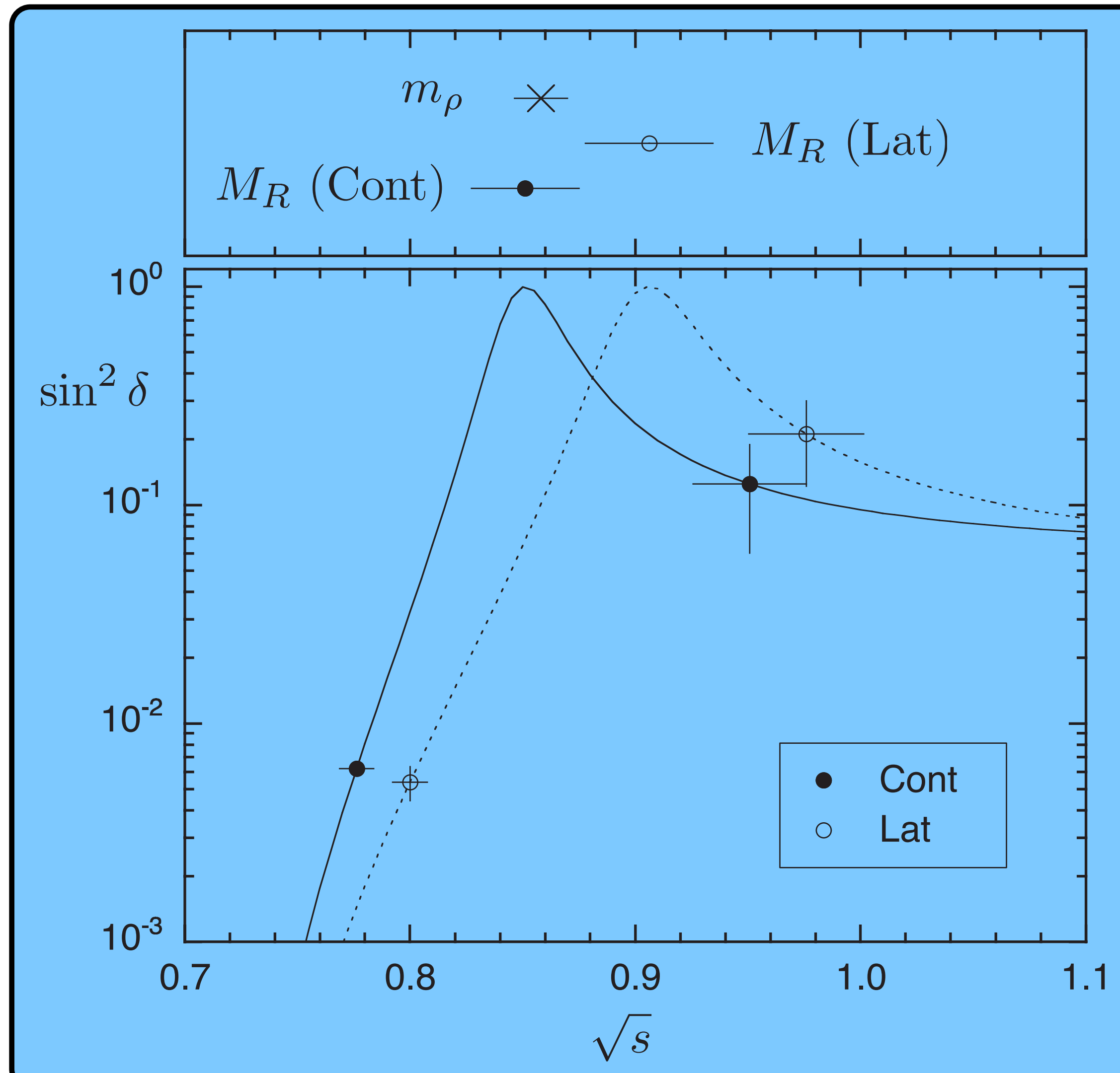
becoming feasible to consider this in actual calculations

$m_\rho/m_\pi \sim 2.4$ $a \sim 0.2$ fm $L\, m_\pi \sim 4$

CP-PACS

at a single lattice volume, computed a correlator matrix using two operators:

1. a "ρ-like", $q\bar{q}$ at the origin operator
2. a "ππ-like", separated $q\bar{q}$-$q\bar{q}$ operator



(barely constrained) Breit-Wigner fit to the extracted phase shift

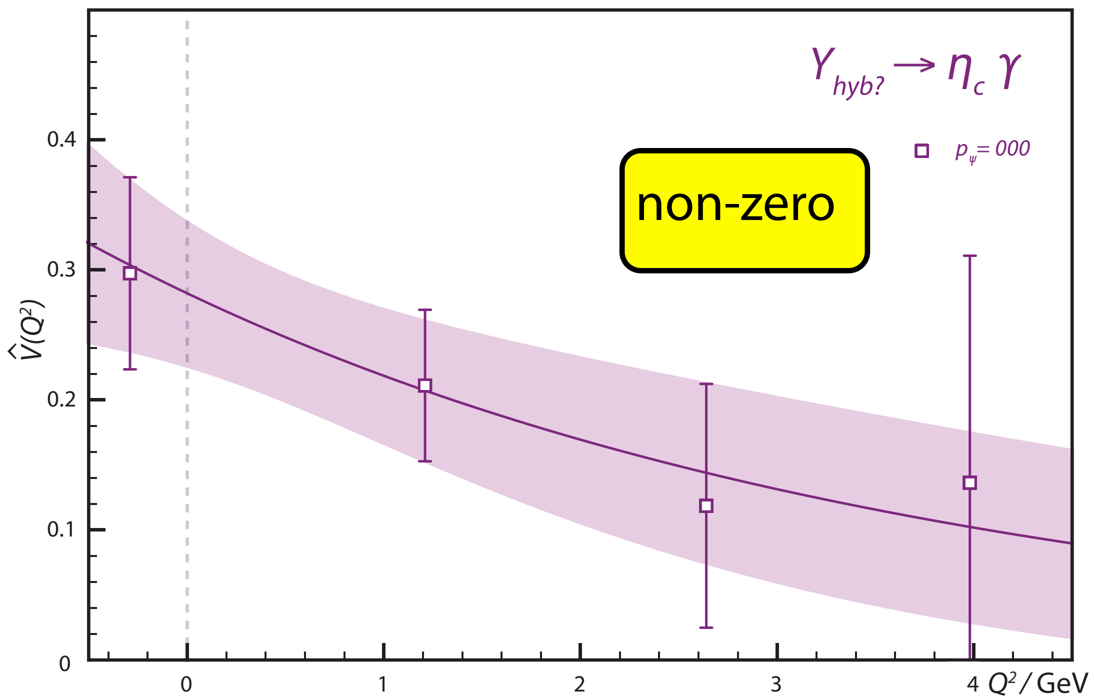
appears to be possible to take advantage of finite volume to study resonances

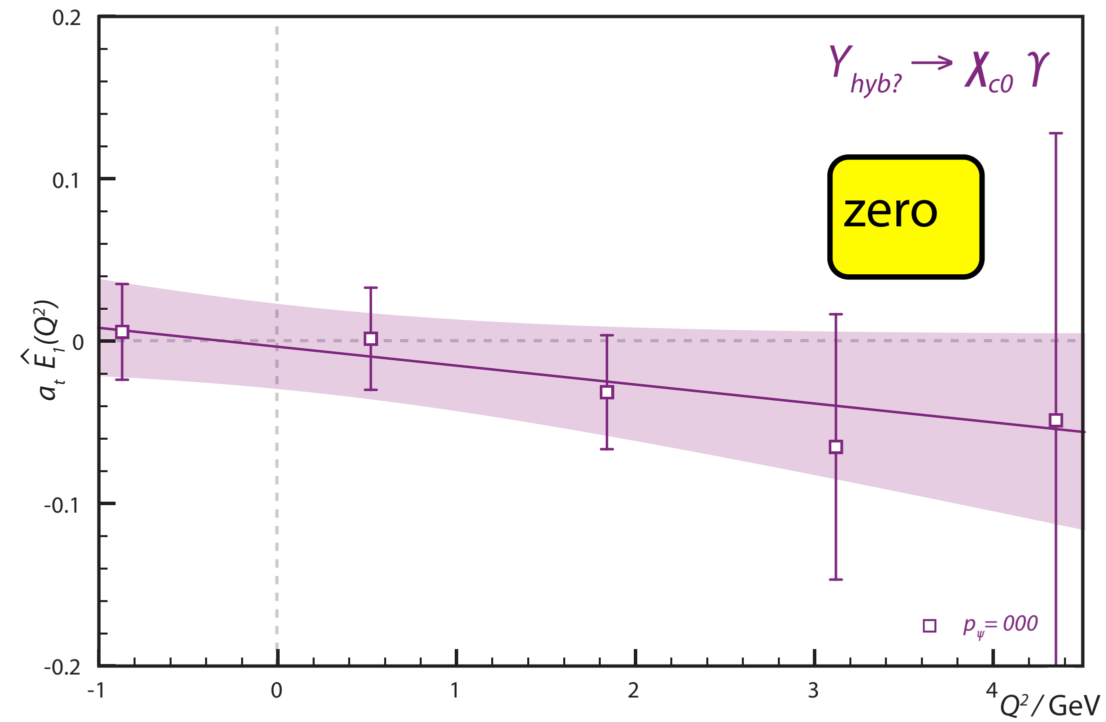
non-exotic hybrid ?

a state in the vector channel (*1*⁻⁻)

m ~ 4.4 GeV

has hybrid-like properties - large overlap with 'gluonic' operators





suggests a spin-singlet $(S_{q\bar{q}} = 0)$ non-exotic hybrid

Y(4260) → *ππ J/ψ* so not a good candidate for $(S_{q\bar{q}} = 0)$