mesons coupling to photons

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collaborations with:
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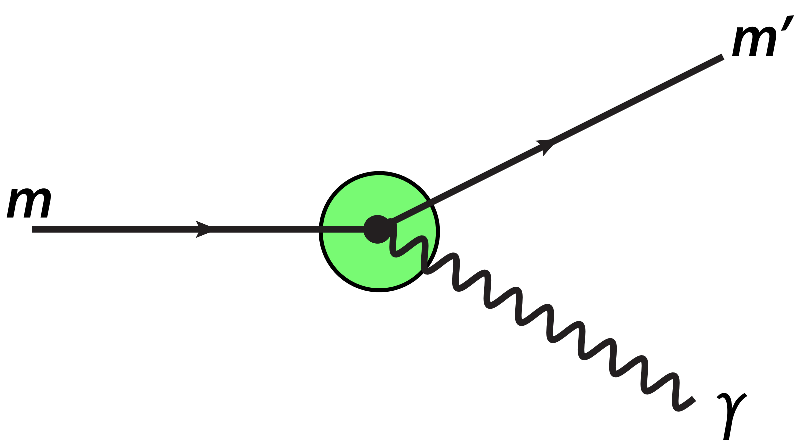
David Richards (JLab)
Ermal Rrapaj (ODU u.grad)
Christopher Thomas (JLab)

recent work under the auspices of the
Hadron Spectrum Collaboration

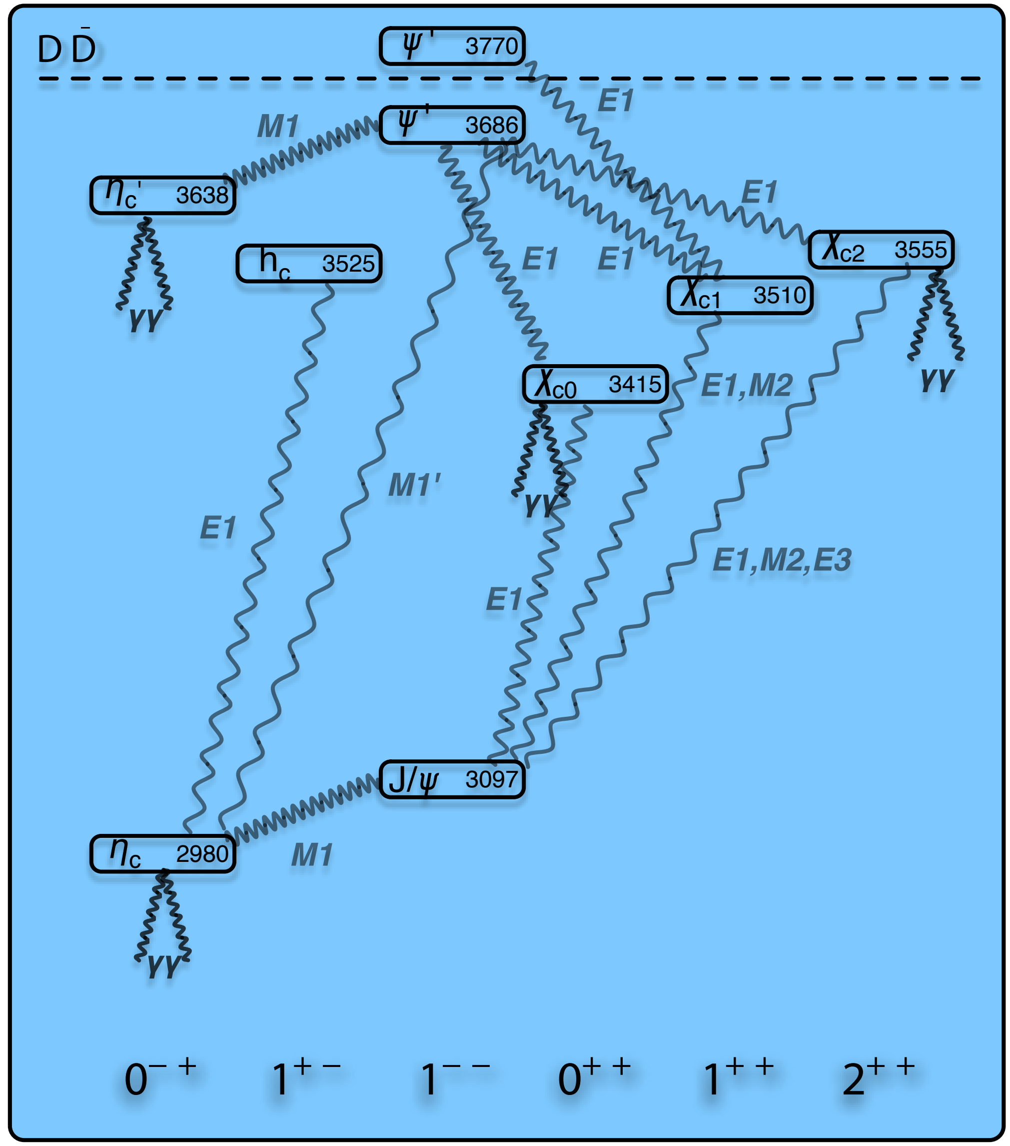
PRD 79 094504 (2009)
PRD 78 094504 (2008)
PRD 77 034501 (2008)
PRL 97 172001 (2006)
PRD 73 074507 (2006)

couplings in decay



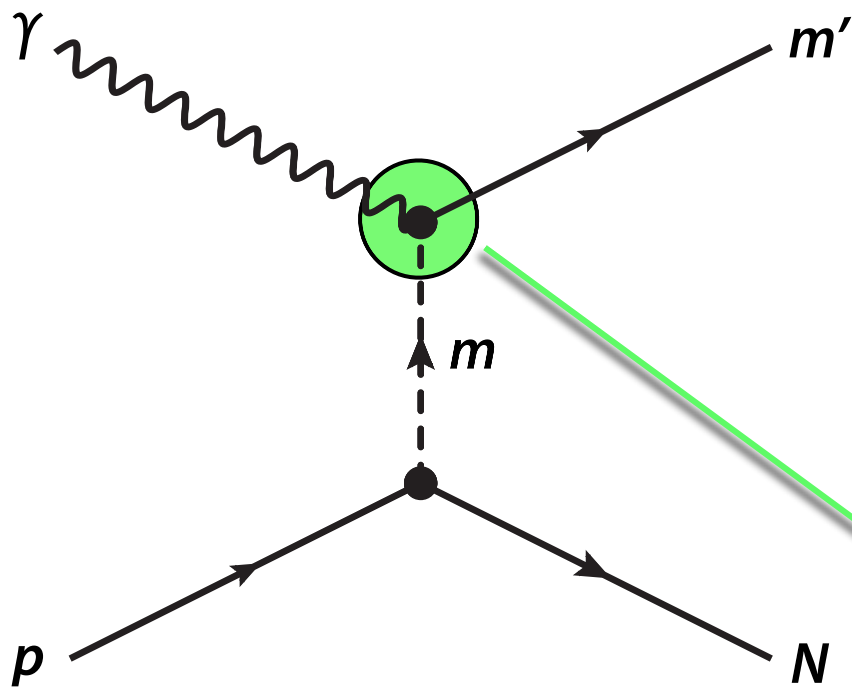
radiative transitions

CLEO-c, BES III



no longer up to date

couplings in production



peripheral photoproduction

GlueX

basic object: $\langle \gamma\, m' | m \rangle$

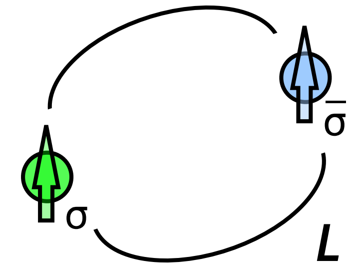
$$\langle m' | \bar{\psi}\gamma^{\mu}\psi | m \rangle \langle \gamma | A_{\mu} | 0 \rangle$$

QCD matrix element

“quark model” bound state approach

$$\langle m' | \bar{\psi}\gamma^\mu\psi | m \rangle$$

how do we compute this?



‘traditional’ approach - quark model:

e.g. $q\bar{q}$ in a $^{2S+1}L_J$ eigenstate

$$|m\rangle \sim \int d^3\vec{q}\ \varphi(|\vec{q}|) Y_L(\hat{q})\ |q_\sigma(\vec{q});\ \bar{q}_{\bar{\sigma}}(-\vec{q})\rangle$$

explicit ‘educated guess’ at meson structure

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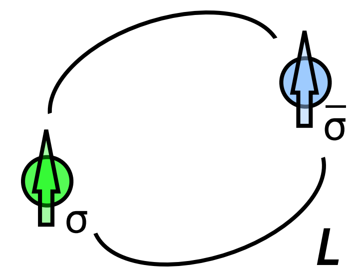

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what about more exotic possibilities, e.g. explicit gluonic field - "hybrid mesons"?

requires more modeling - 'guess' how QCD behaves (e.g. flux-tube model, constituent gluon models ...)

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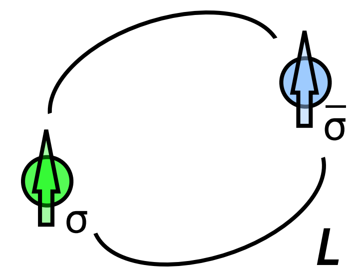

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for light quarks - "constituent quarks" as degrees-of-freedom ?

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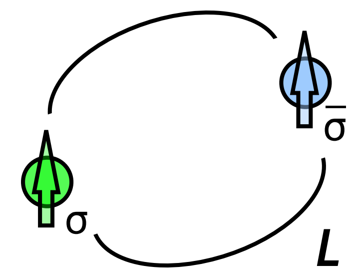

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... will NOT do this
... try 'direct' QCD calculation
... and compare

couplings from QCD

extract from three-point correlators

$$C(t_f, t, t_i) = \big\langle 0 \big| \Phi'(t_f)\, \big[\bar{\psi}\gamma^\mu\psi\big](t)\, \Phi(t_i) \big| 0 \big\rangle$$

composite ***QCD*** operators with meson quantum numbers

couplings from QCD

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e.g. vectors can be 'made' with

$$\bar{\psi}\gamma^i\psi \qquad \bar{\psi}\overleftrightarrow{D}^i\psi \qquad \epsilon_{ijk}\,\bar{\psi}\gamma^5\overleftrightarrow{D}^j\overleftrightarrow{D}^k\psi$$

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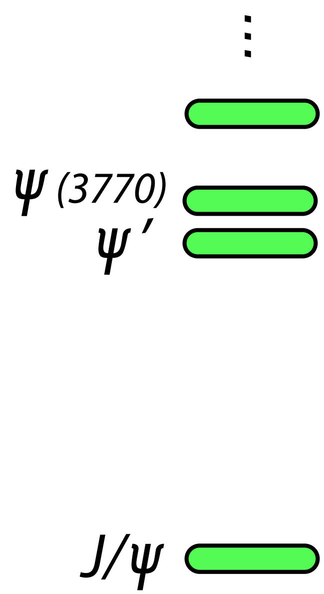
each operator will have different 'overlap' on to the tower of vector states



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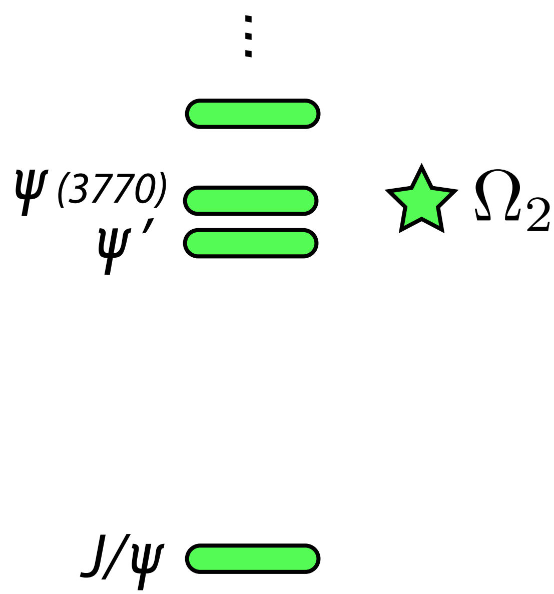

some ***linear combination*** of the operators is ***optimal*** for a certain state

$$\Omega_{\mathfrak{n}} = v_1^{\mathfrak{n}}\Phi_1 + v_2^{\mathfrak{n}}\Phi_2 + \ldots$$

in lattice QCD ?

lattice QCD computes *N*-point correlators by numerical estimation of the path integral

i'm hiding a lot here - can't explain lattice field theory in this talk - sorry

question is - can we reliably extract the spectrum and photon couplings using a (relatively) small number of composite operators ?

just try it!

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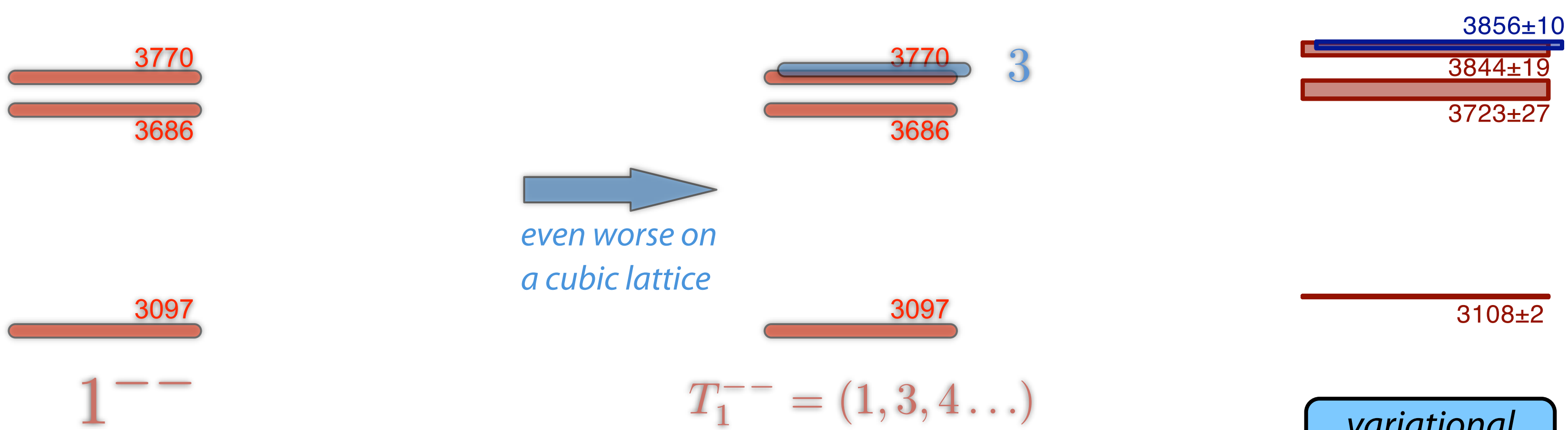
e.g. charmonium vector spectrum using ~10 operators



variational solution

the 'honesty' slide

first attempt - little systematic control

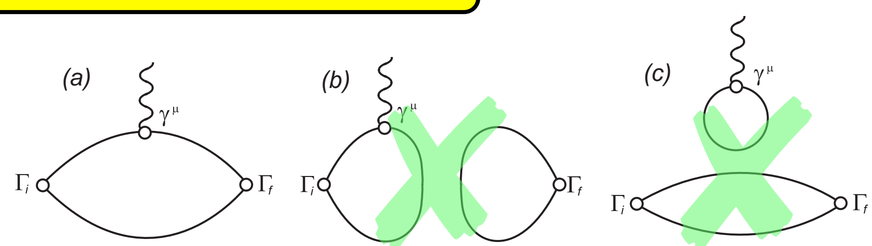
quenched - no light quarks at all (like most quark models)

"nothing is decaying !"

one lattice spacing $\boldsymbol{a = 0.1}$ ***fm*** (anisotropic, $\boldsymbol{a_t = 0.033}$ ***fm***)

box possibly too small for highly excited states (***1.2 fm***)

only connected diagrams



OZI justification ?

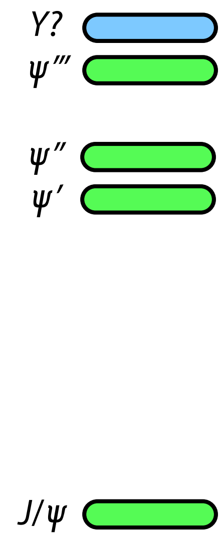
allowed us to get ***high statistics*** (1000 gauge field configs) and most importantly to 'try things out'

Monte-Carlo - statistical error from finite number of samples

all of these 'lattice issues' are systematically improvable: see papers by ***Fermilab/MILC*** & ***HPQCD***

vector states

Level	Mass/MeV	Suggested state	Model assignment
0	3106(2)	J/ψ	1^3S_1
1	3746(18)	$\psi'(3686)$	2^3S_1
2	3846(12)	ψ_3	Lattice artifact
3	3864(19)	$\psi''(3770)$	1^3D_1
4	4283(77)	ψ(“4040”)	3^3S_1
5	4400(60)	Y?	Hybrid

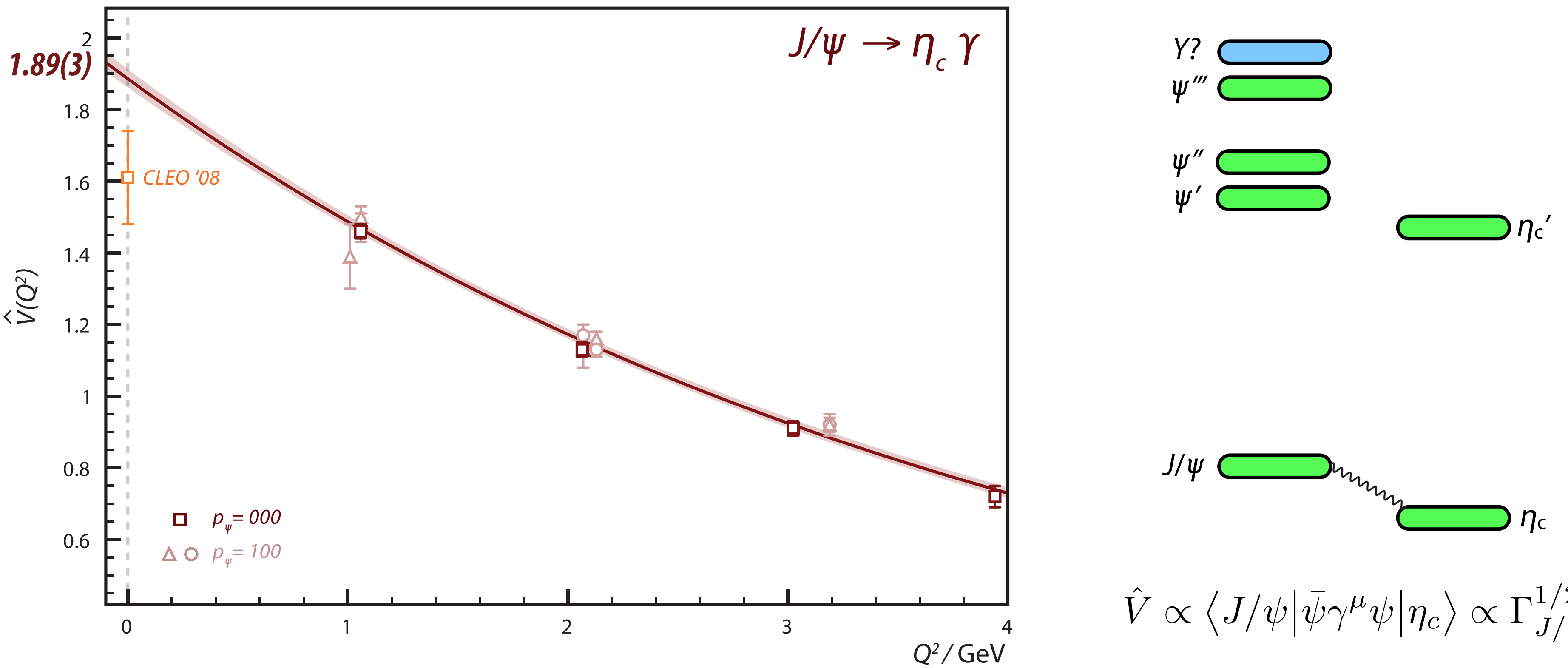


masses systematically high:
quenched?
finite volume?

vacuum matrix elements compared to potential model : ***PRD78:094504 (2008)***

can isolate excited states - now consider radiative transitions involving these

vector - pseudoscalar (M1)



$$\hat{V} \propto \langle J/\psi | \bar{\psi}\gamma^\mu \psi | \eta_c \rangle \propto \Gamma^{1/2}_{J/\psi \to \eta_c \gamma}$$

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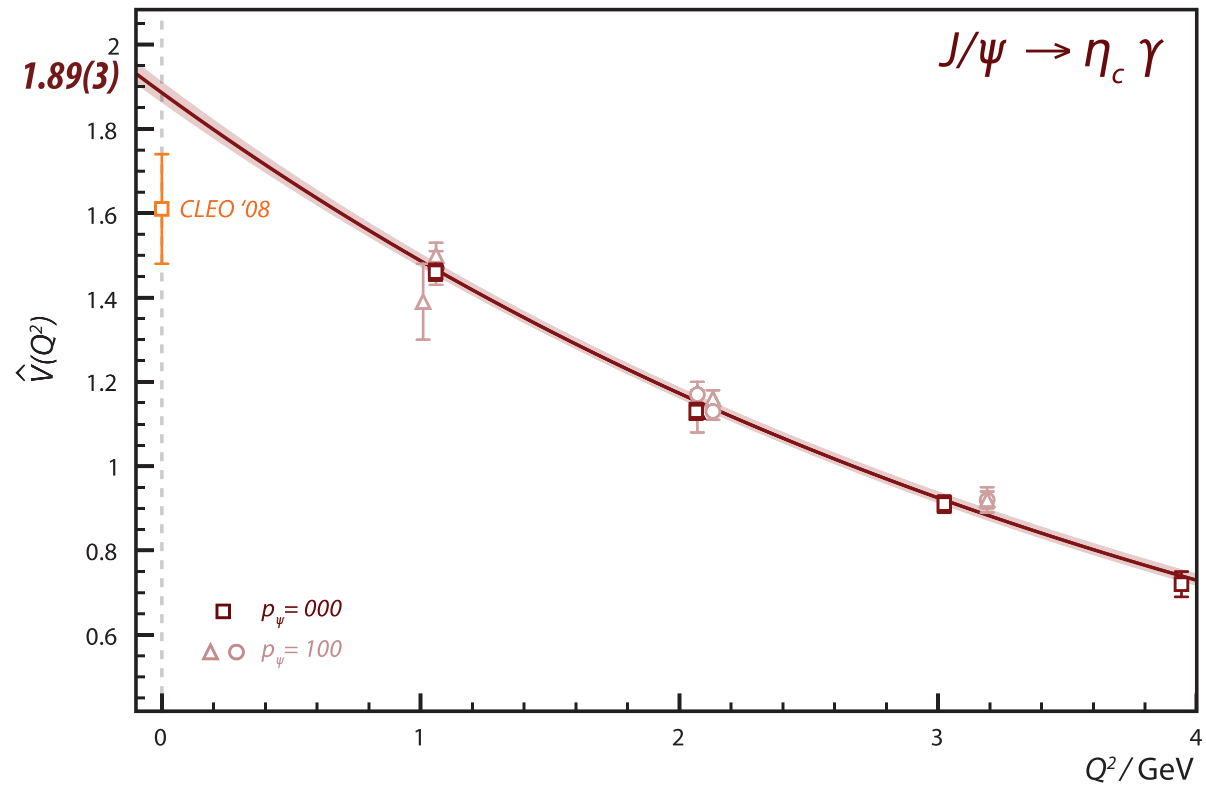

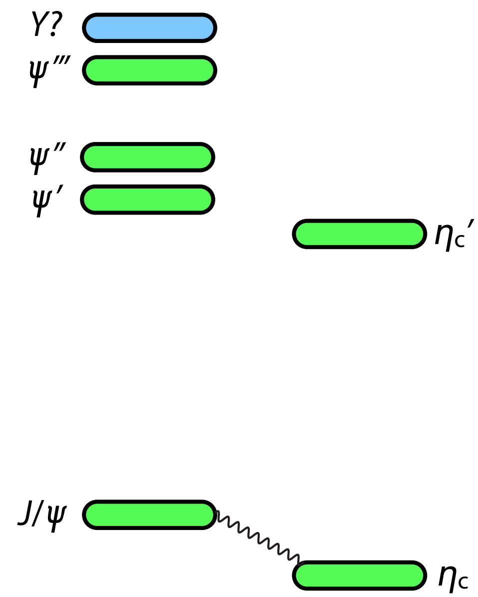

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in quark-potential models:

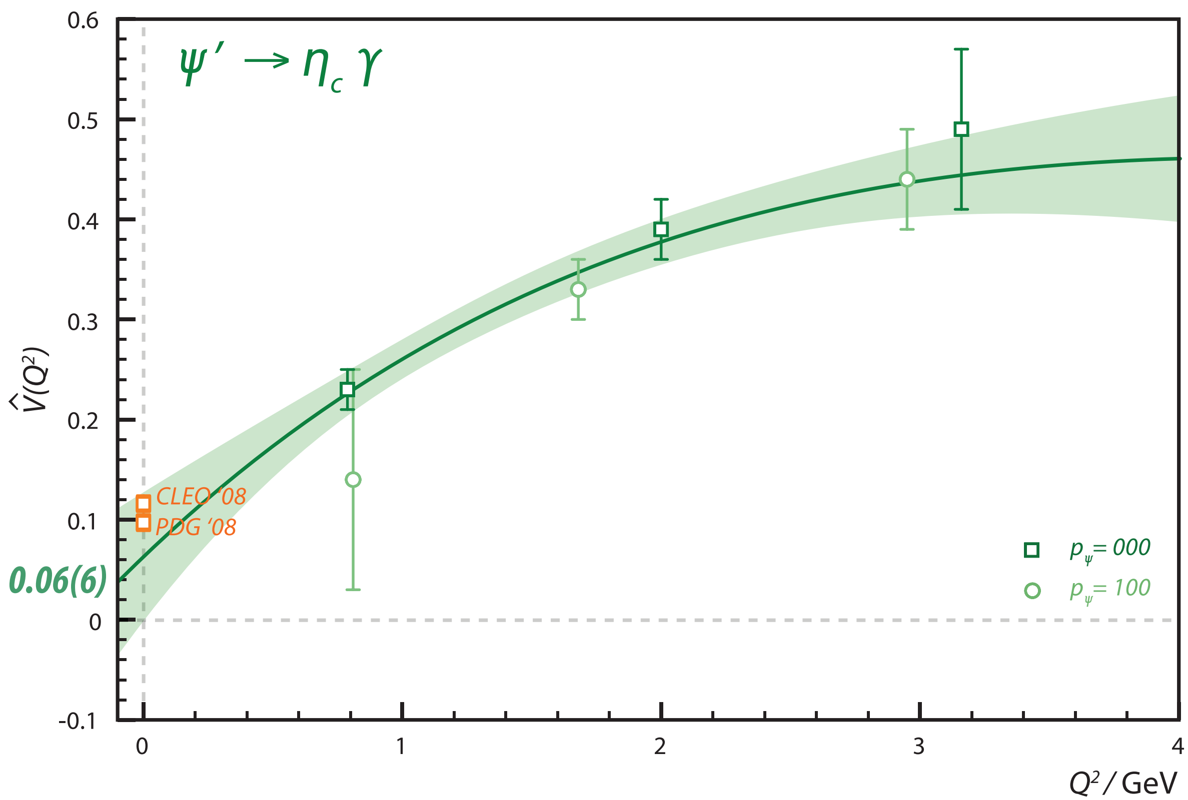
quark spin flip ~ $\dfrac{\sigma}{m_c}$

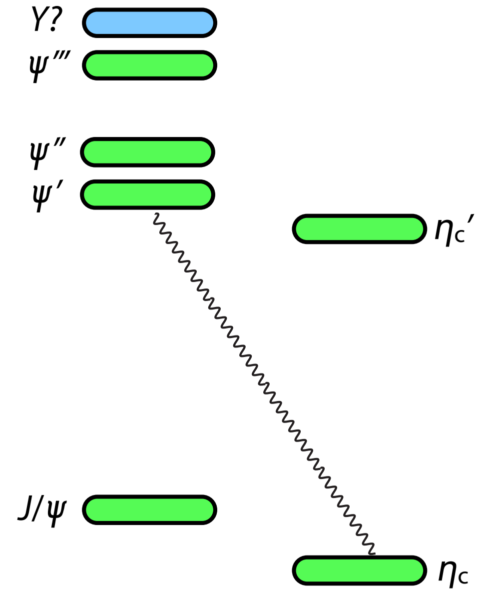
$$V \sim \frac{1}{m_c} \int r^2 dr\, R_f(r) j_0(|\vec{q}|r) R_i(r)$$

'Higher Charmonia' (Barnes, Godfrey, Swanson)

Γ ~ 2.4 - 2.9 keV vs. exptal (***CLEO-c***) = 1.85(30) keV

vector - pseudoscalar (M1)





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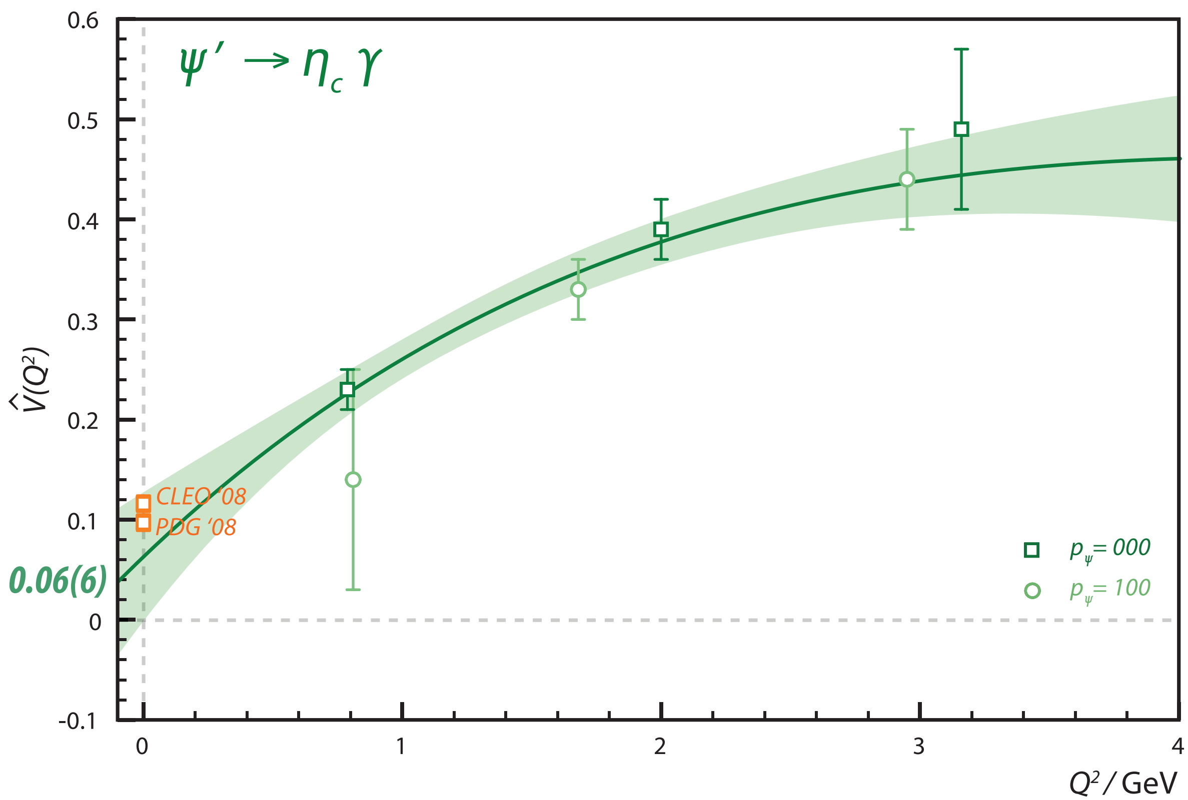
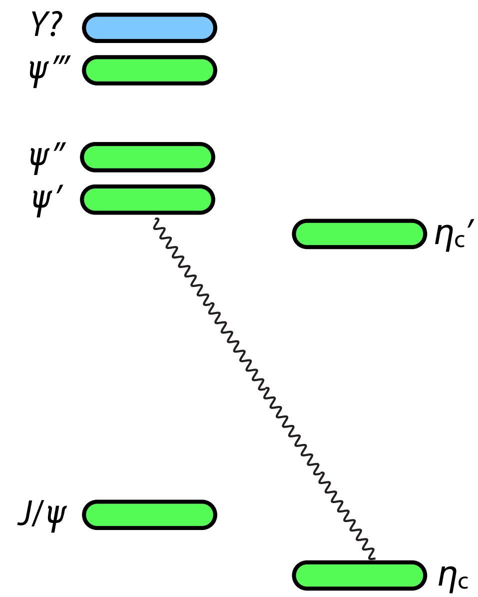




in quark-potential models:

'hindered' : orthogonal (***2S***, ***1S***) wavefunctions

$$V \sim \frac{1}{m_c} \int r^2 dr\, R_f(r) \left(1 + \mathcal{O}(|\vec{q}|^2 r^2)\right) R_i(r)$$

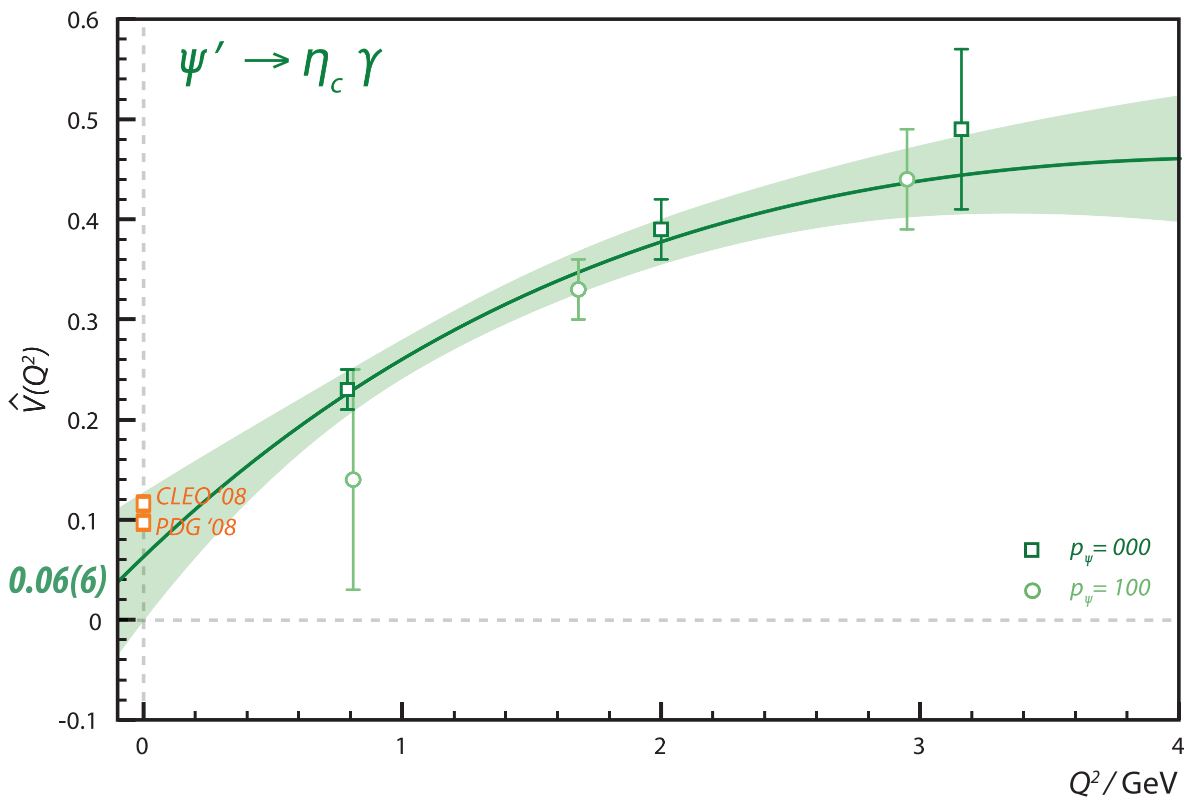
relativistic corrections at the same order

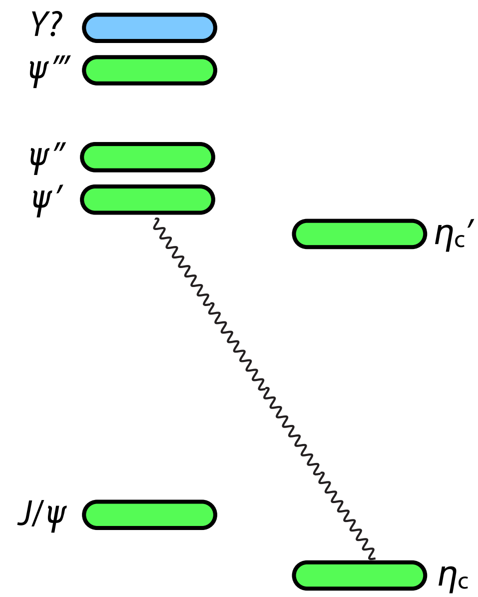
frame (in)dependence of non-rel wavefunctions

'Higher Charmonia'
(Barnes, Godfrey, Swanson)

Γ ~ 4 - 10 keV vs. exptal (***CLEO-c***) = 1.37(20) keV

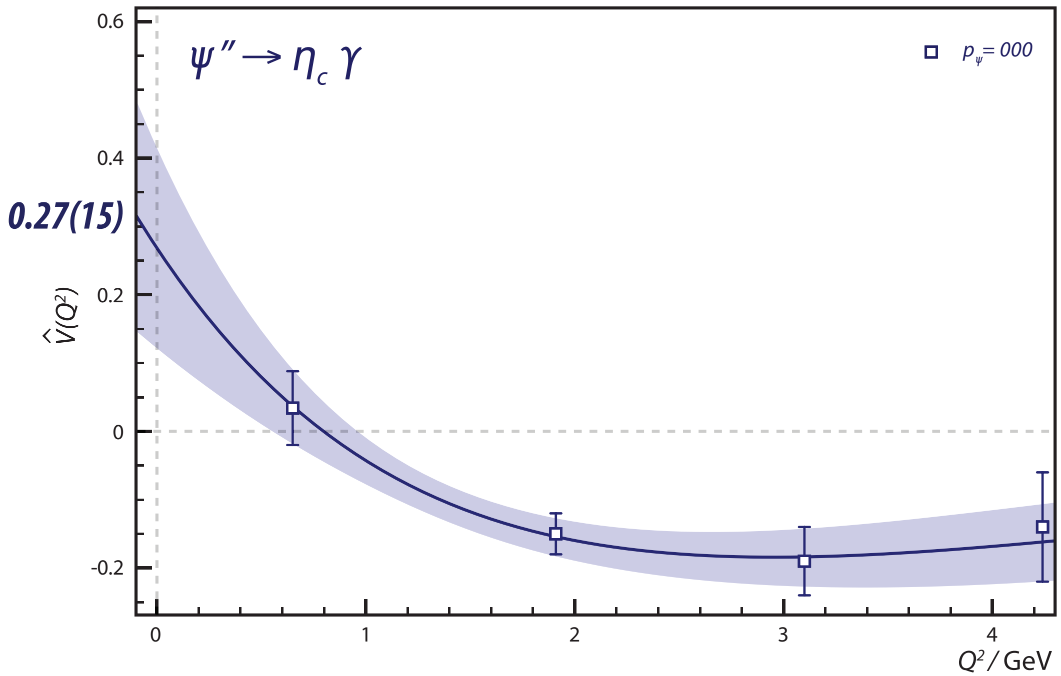
vector - pseudoscalar (M1)

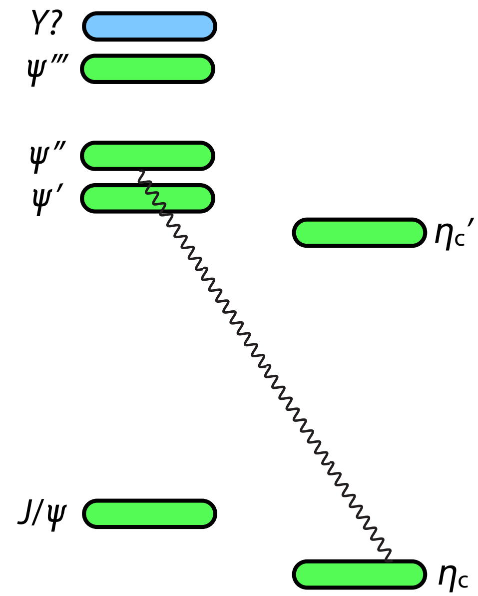




first lattice QCD extraction of a radiative transition involving an excited meson

vector - pseudoscalar (M1)





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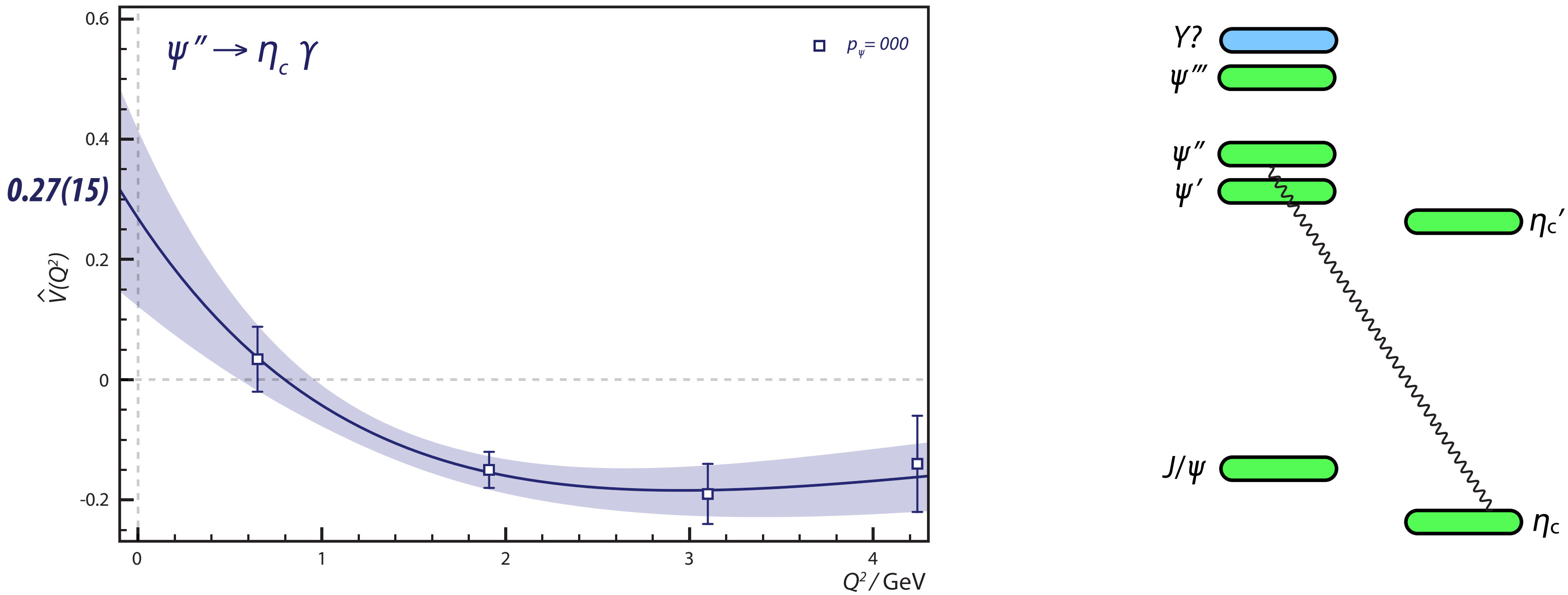

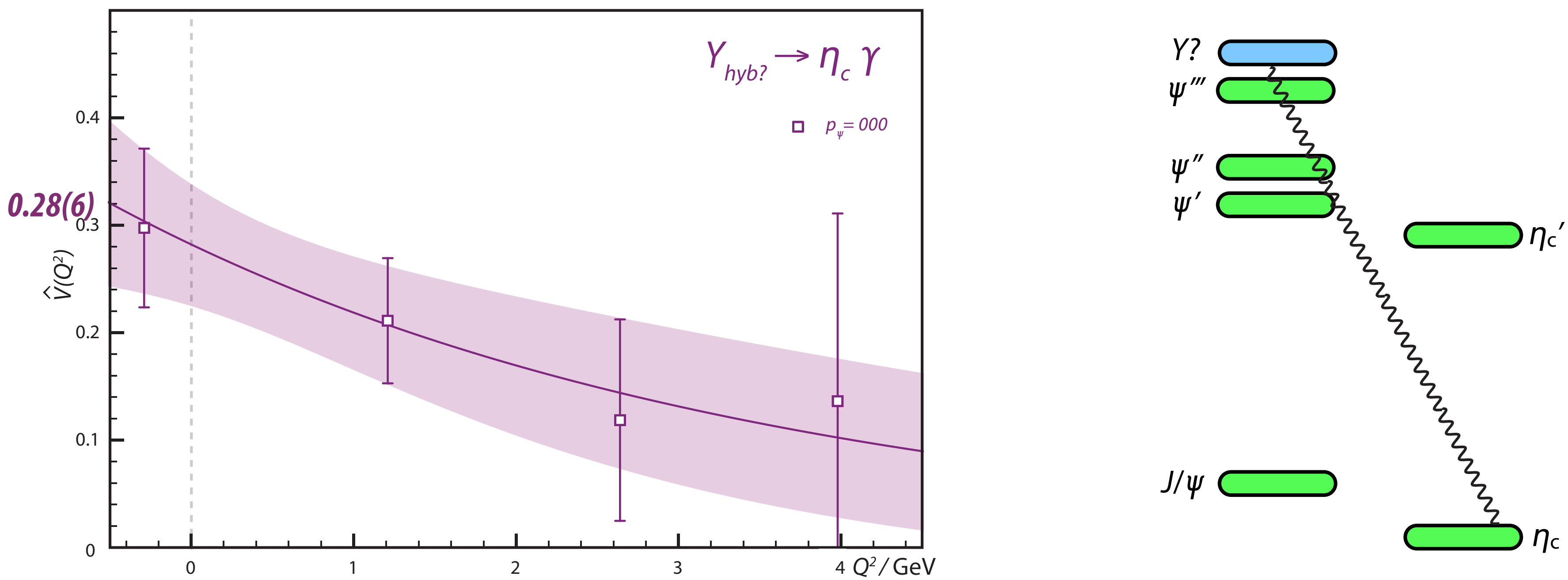

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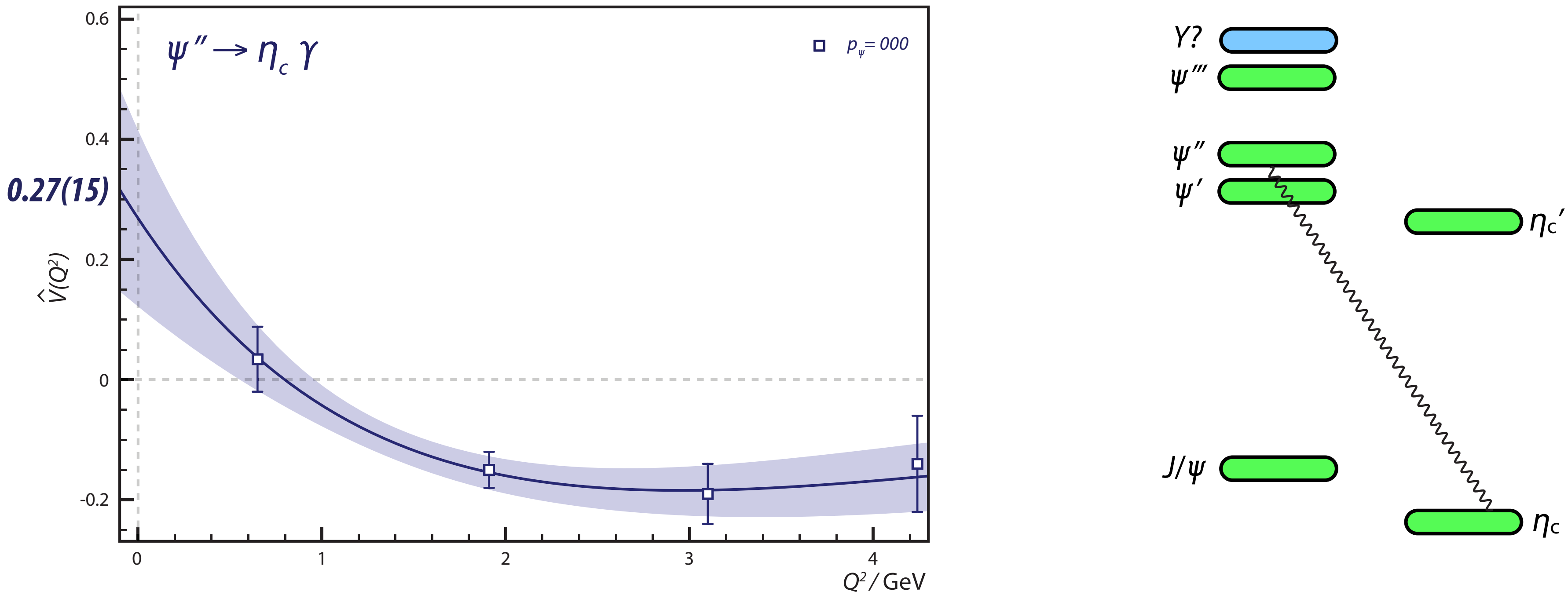
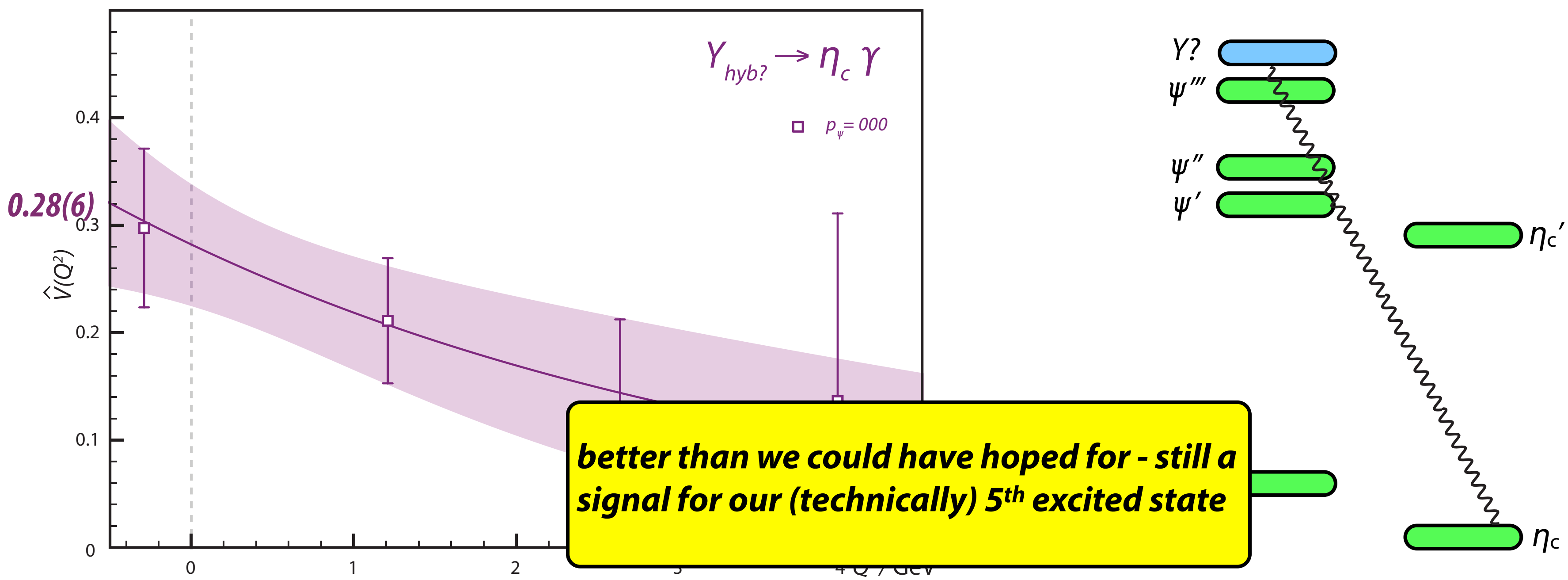
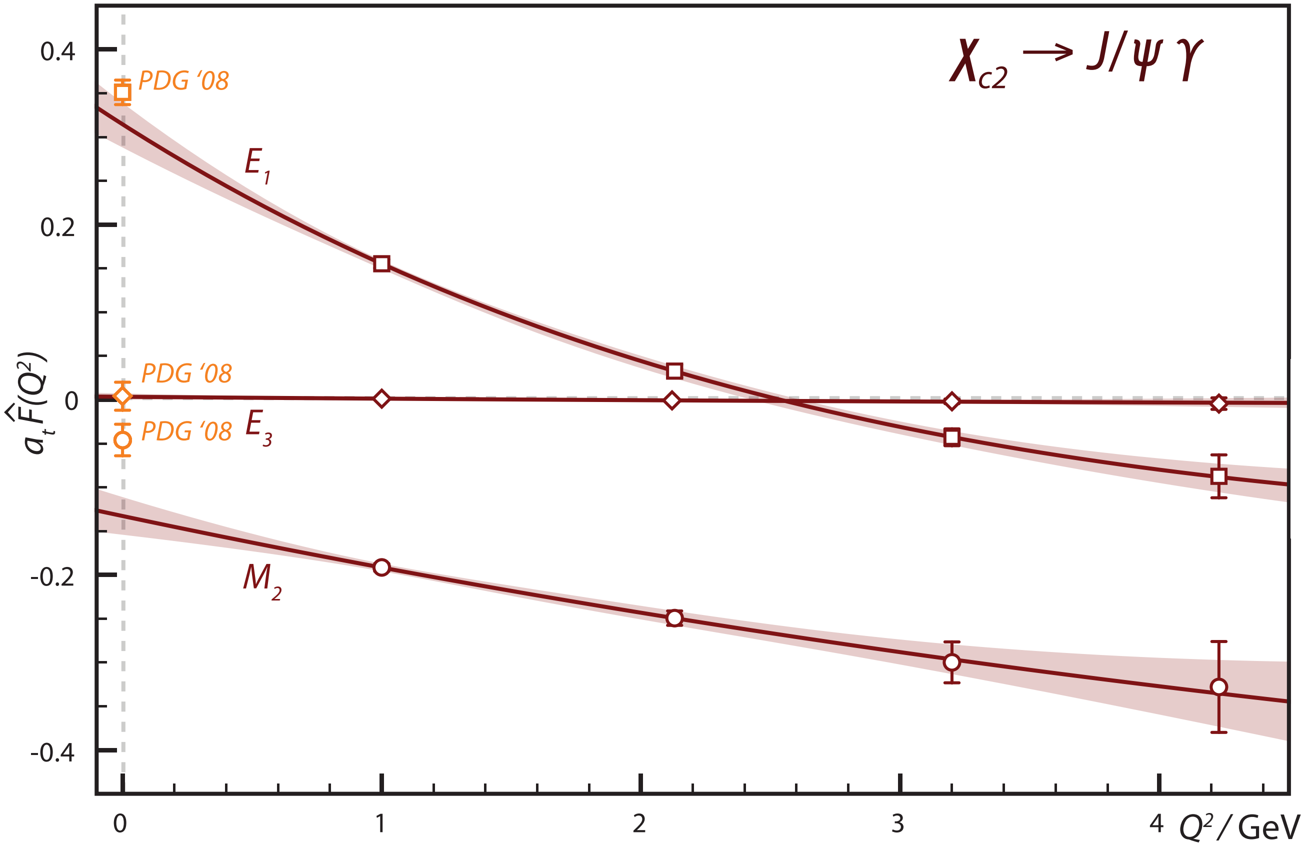
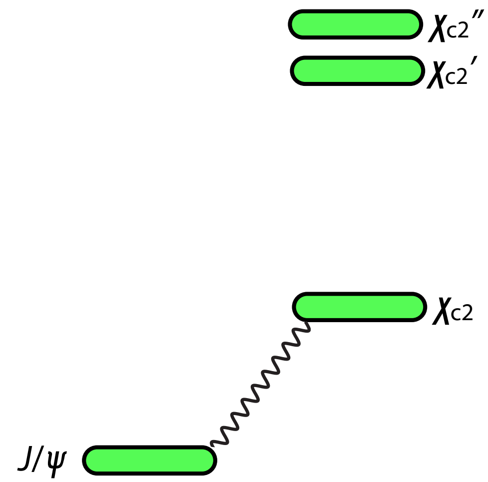




better than we could have hoped for - still a signal for our (technically) 5th excited state

tensor - vector (E1,M2,E3)





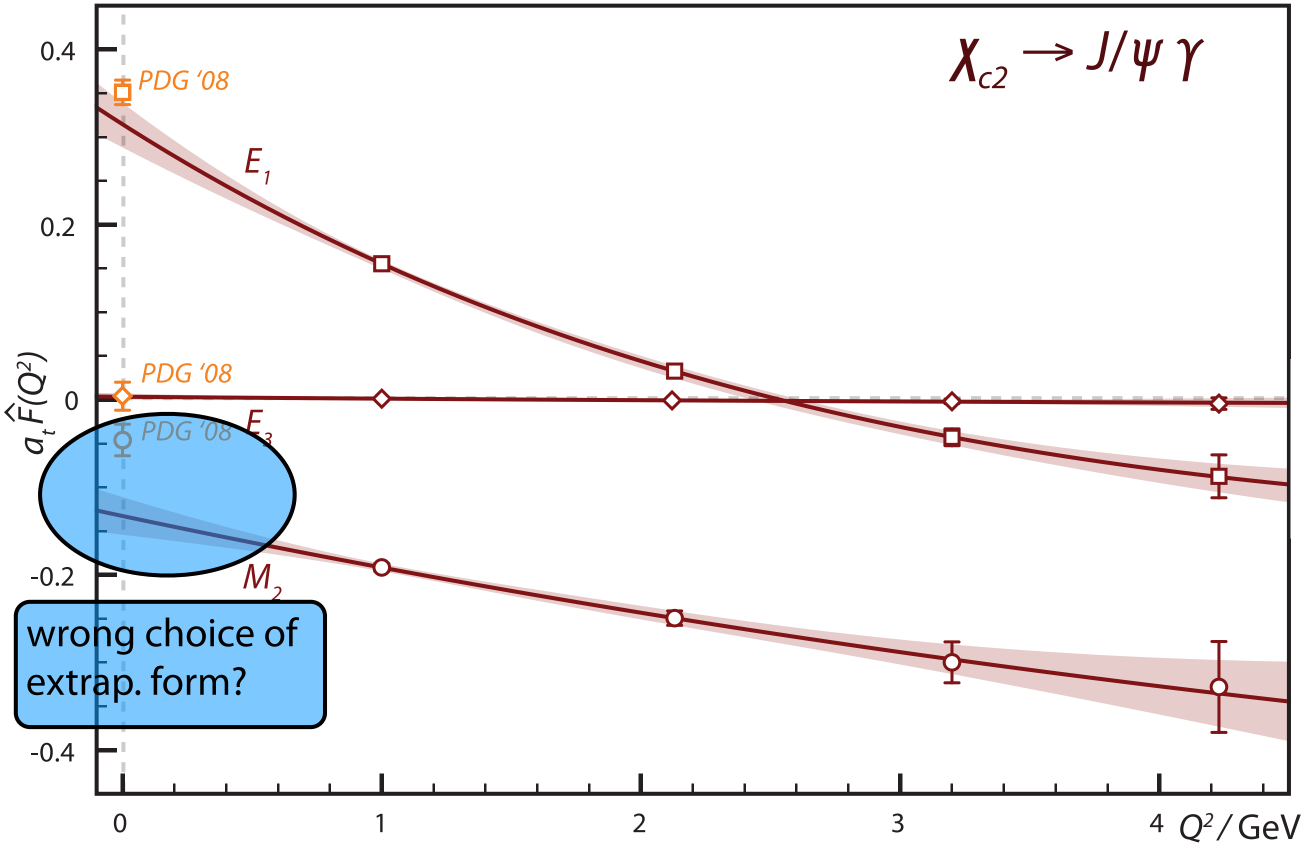
experimental results from angular dependence of radiative decay events

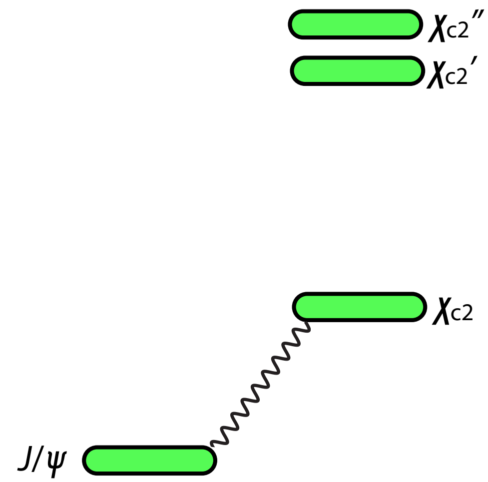
suppressed magnetic quadrupole of right sign, but too large in magnitude

electric octopole consistent with zero

relativistic correction in quark models
- rather model dependent

tensor - vector (E1,M2,E3)





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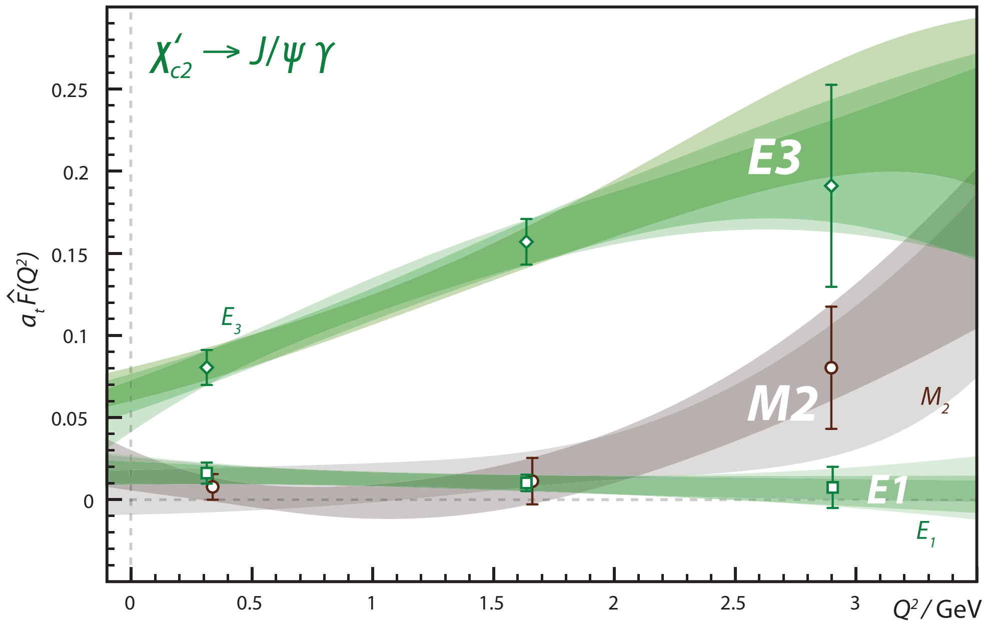
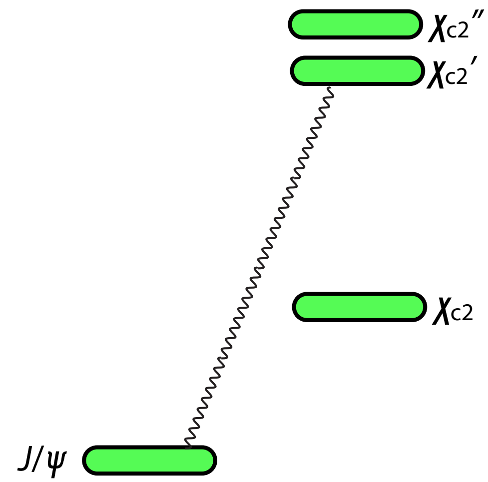
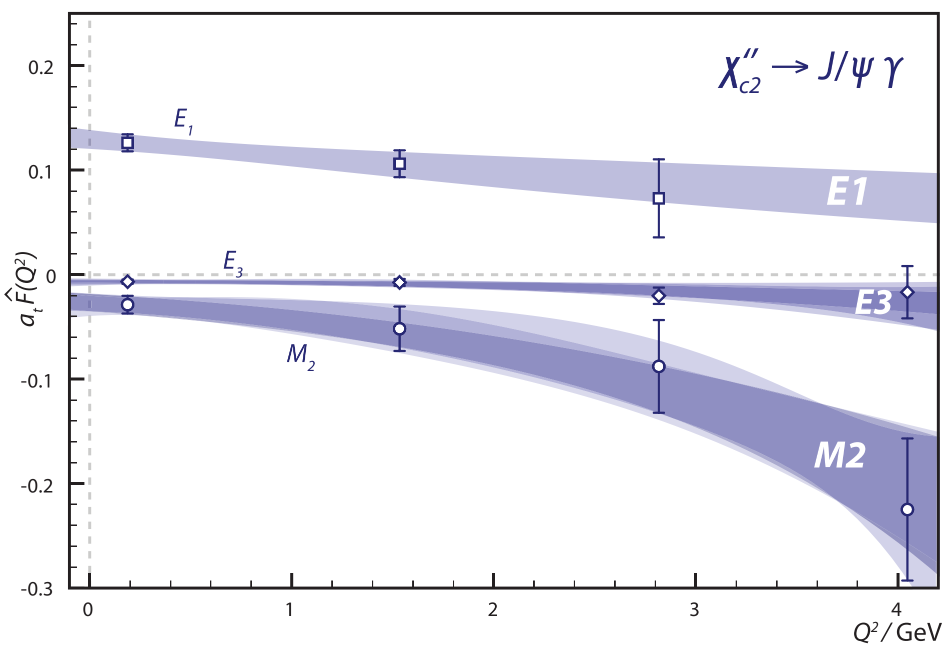


E1≈0, E3 ≠ 0

$m = 4115(28)$ MeV





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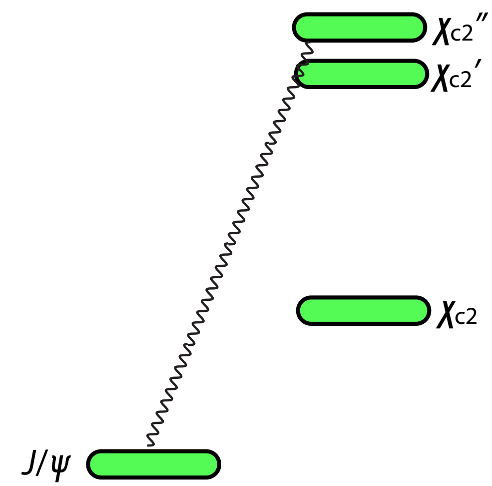

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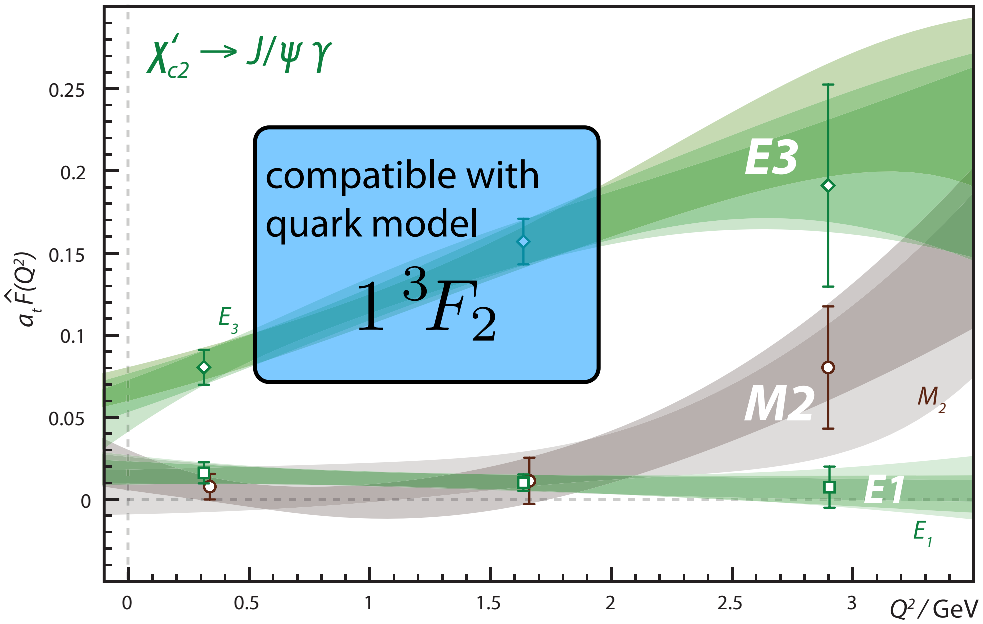

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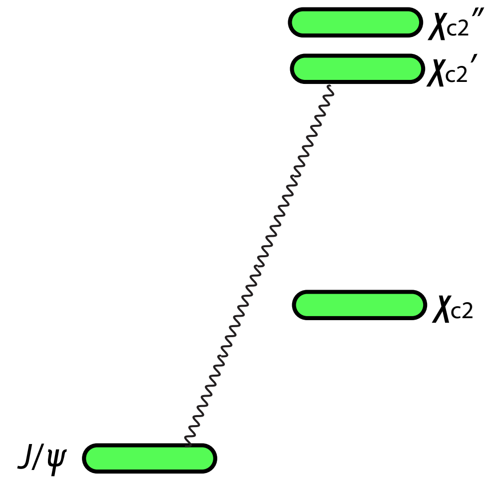

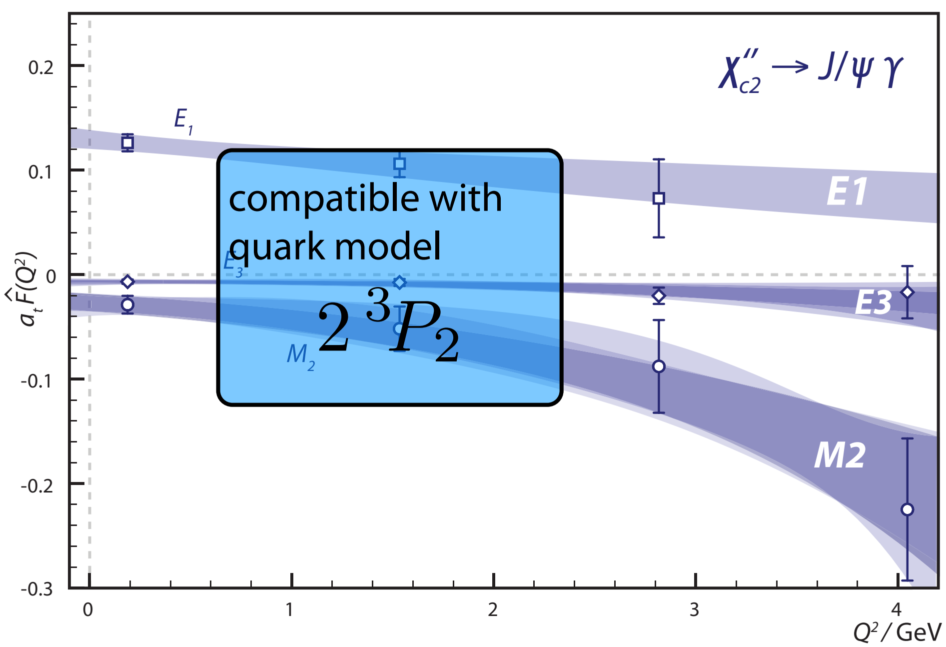

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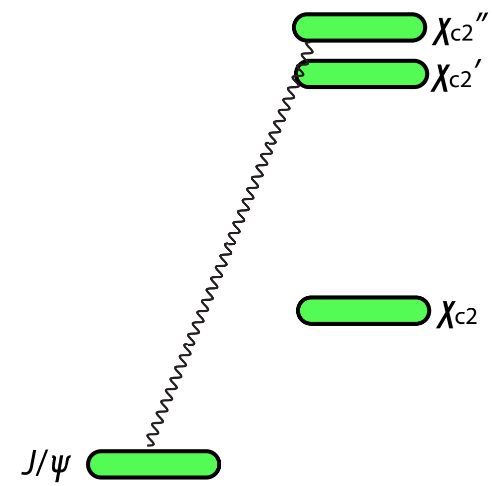
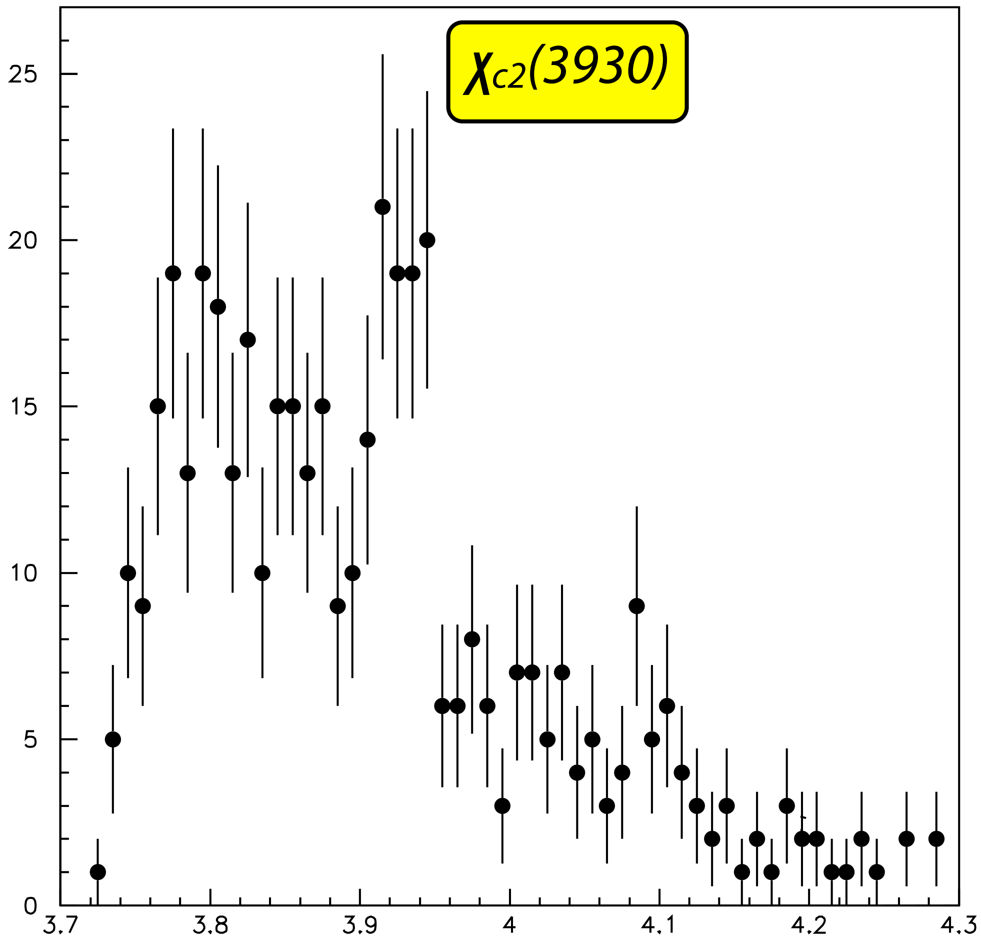
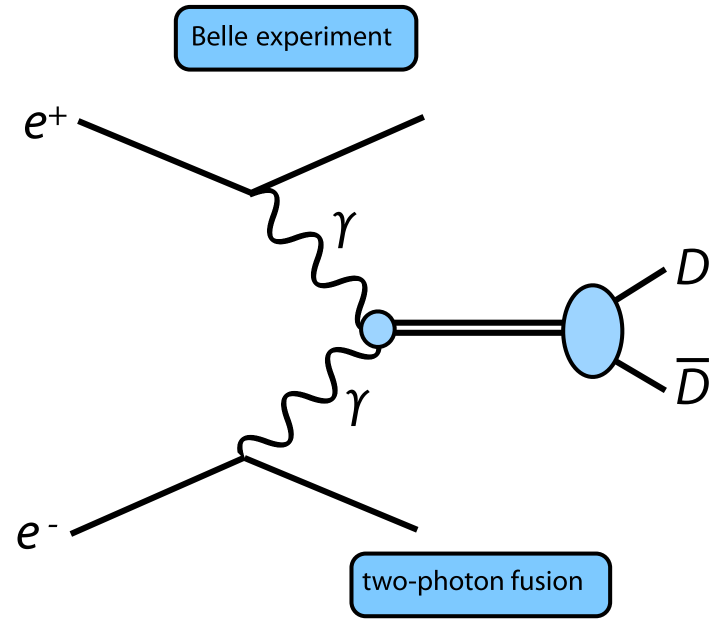


excited tensor states?

Belle $\gamma\gamma \longrightarrow D\bar{D}$





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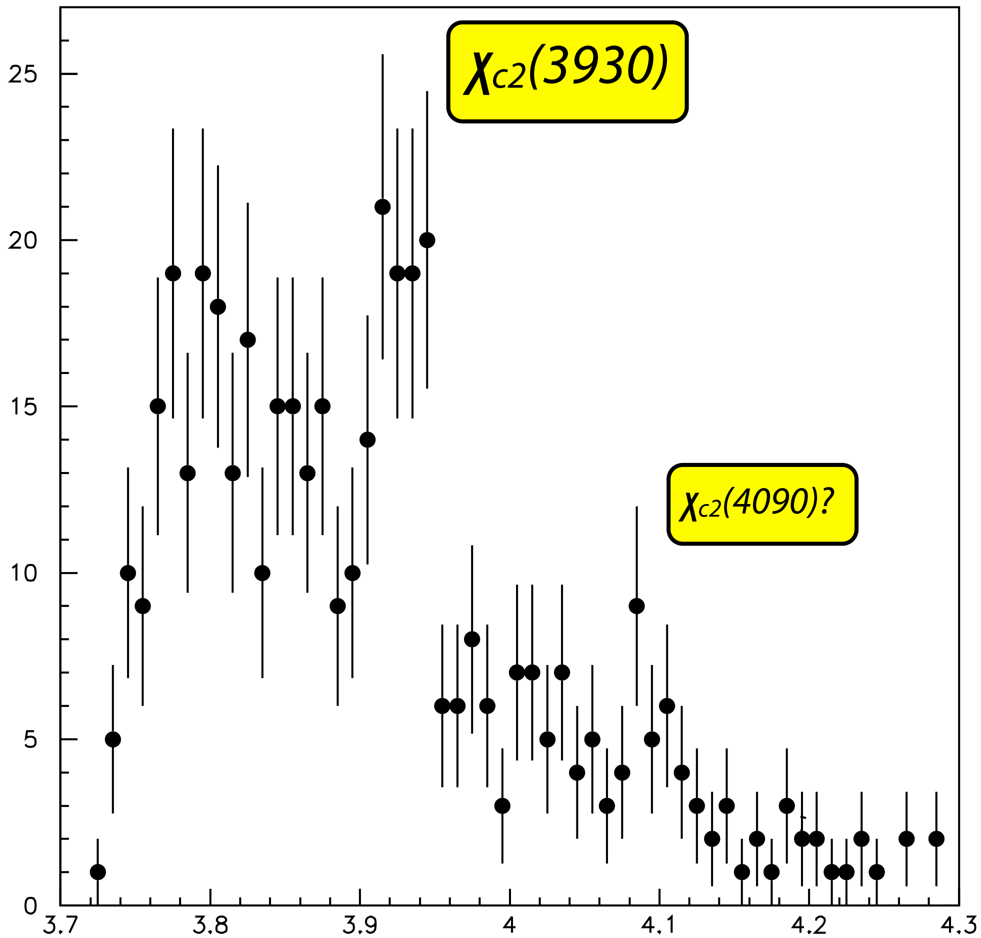
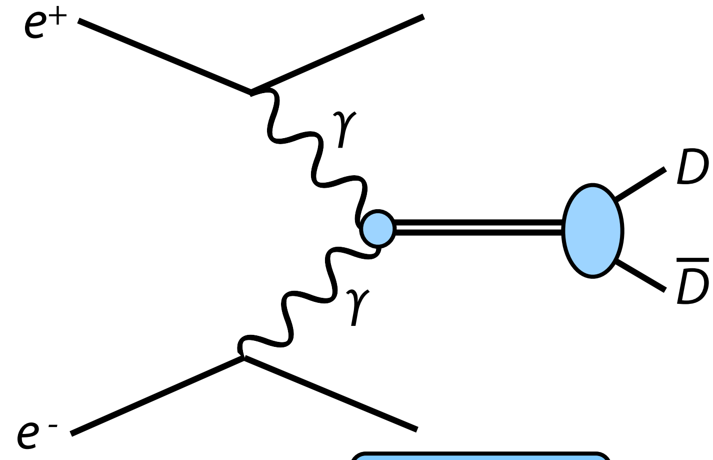


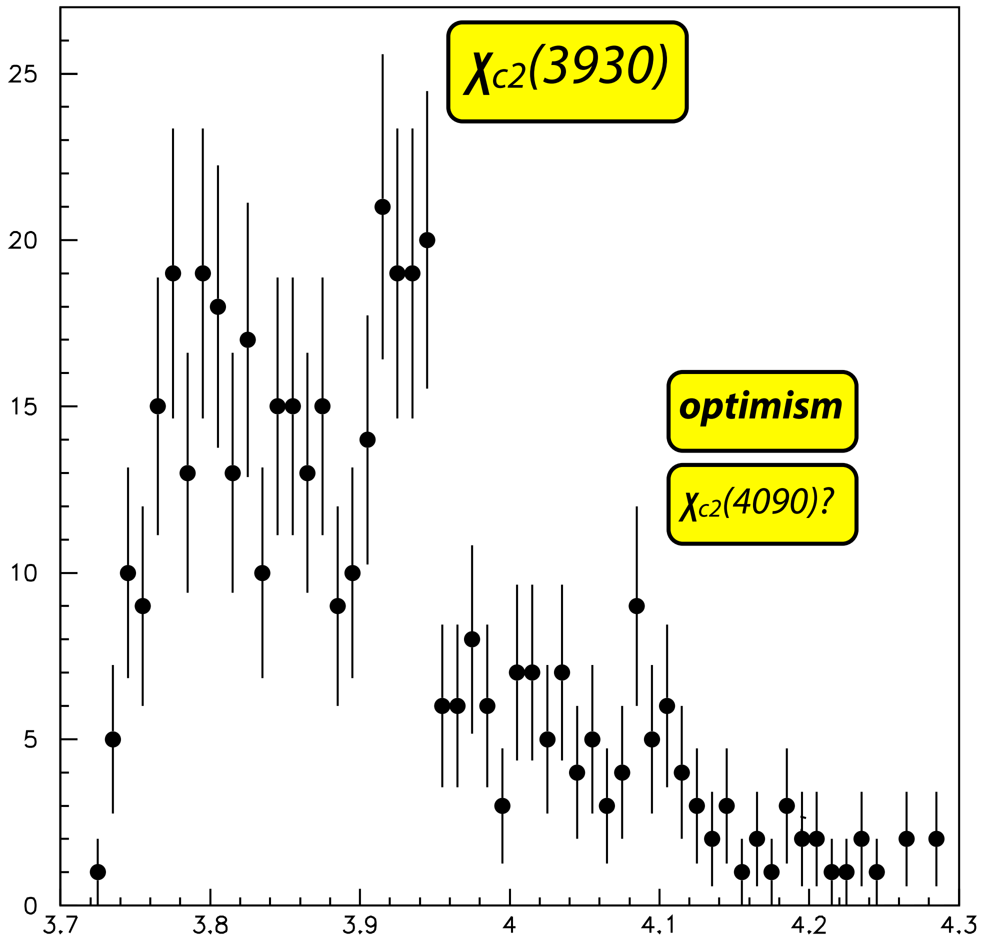
Belle experiment

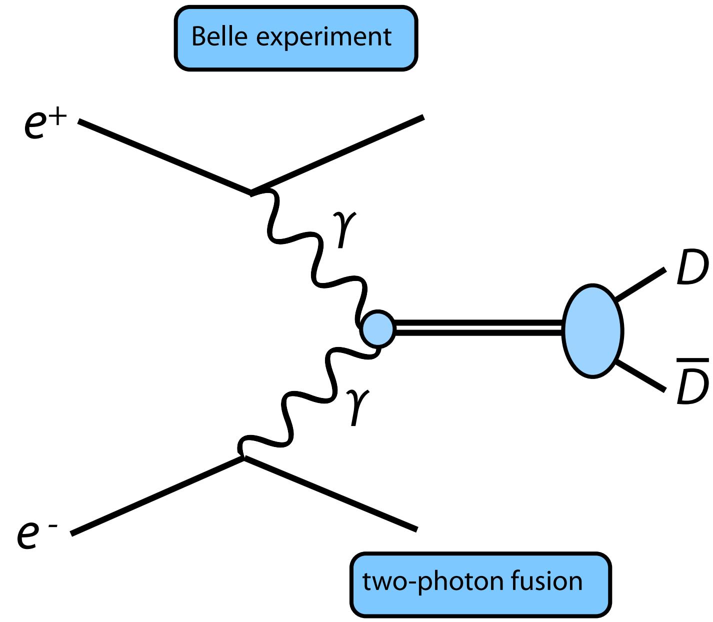


two-photon fusion

excited tensor states?

Belle $\gamma\gamma \to D\bar{D}$





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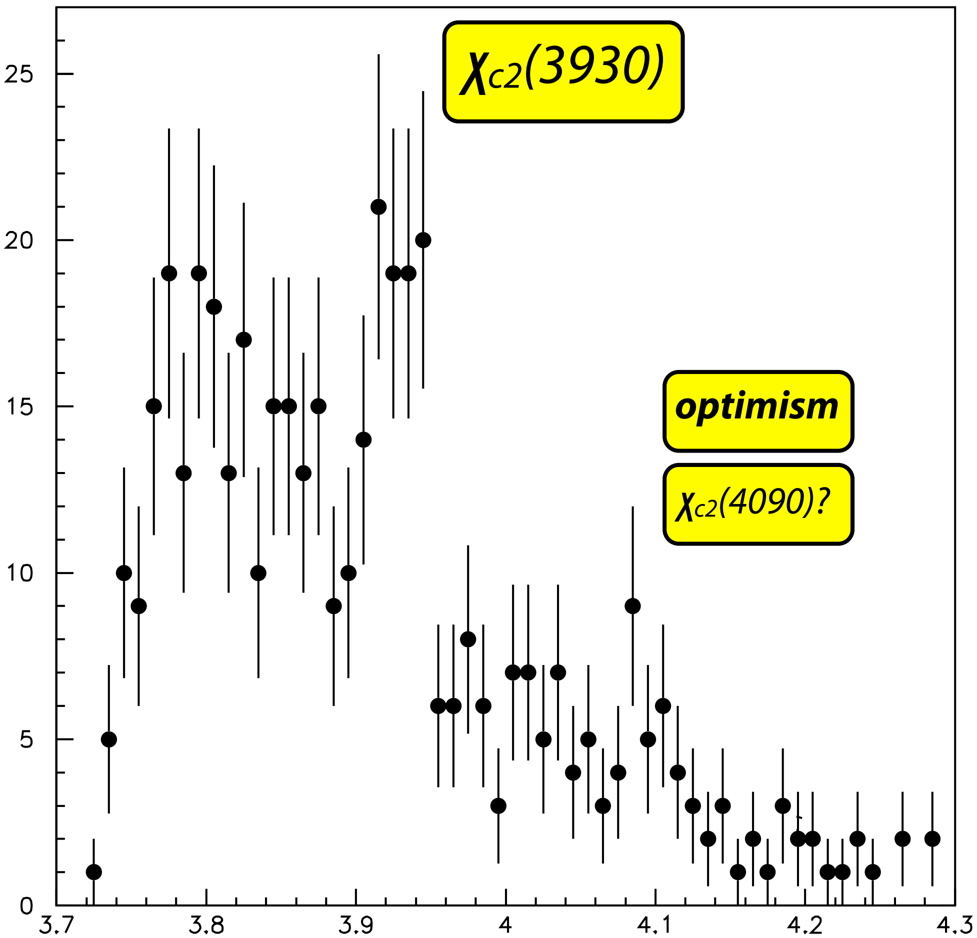
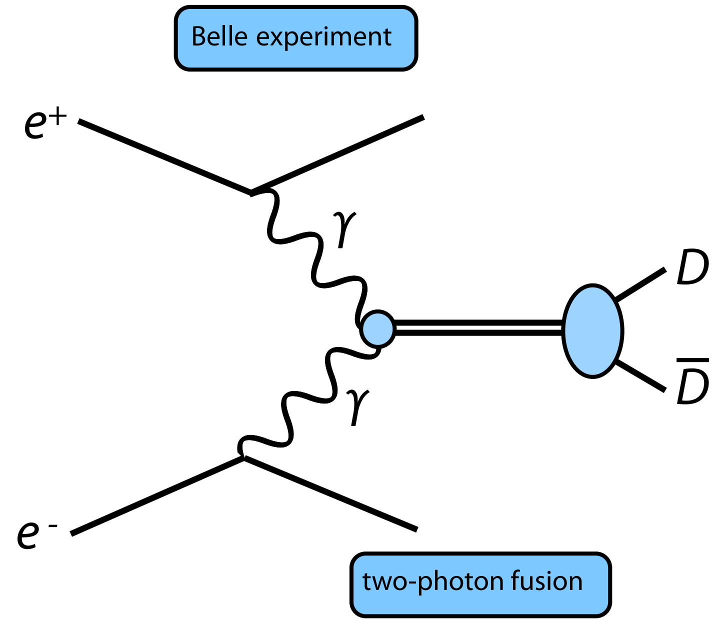


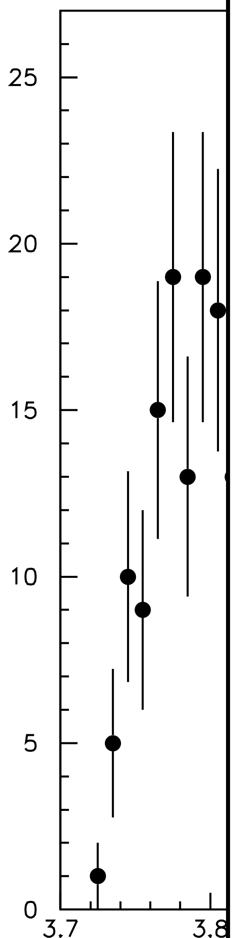


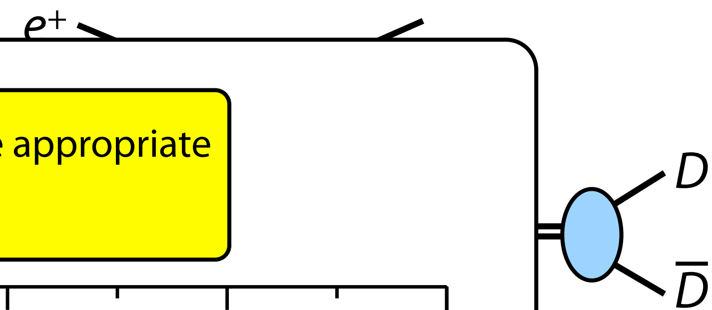
our calculation finds the F -wave lighter - may be artifact of small box 'squeezing'

excited tensor states?

Belle $\gamma\gamma \rightarrow D\bar{D}$

Belle experiment





sion

e lighter -
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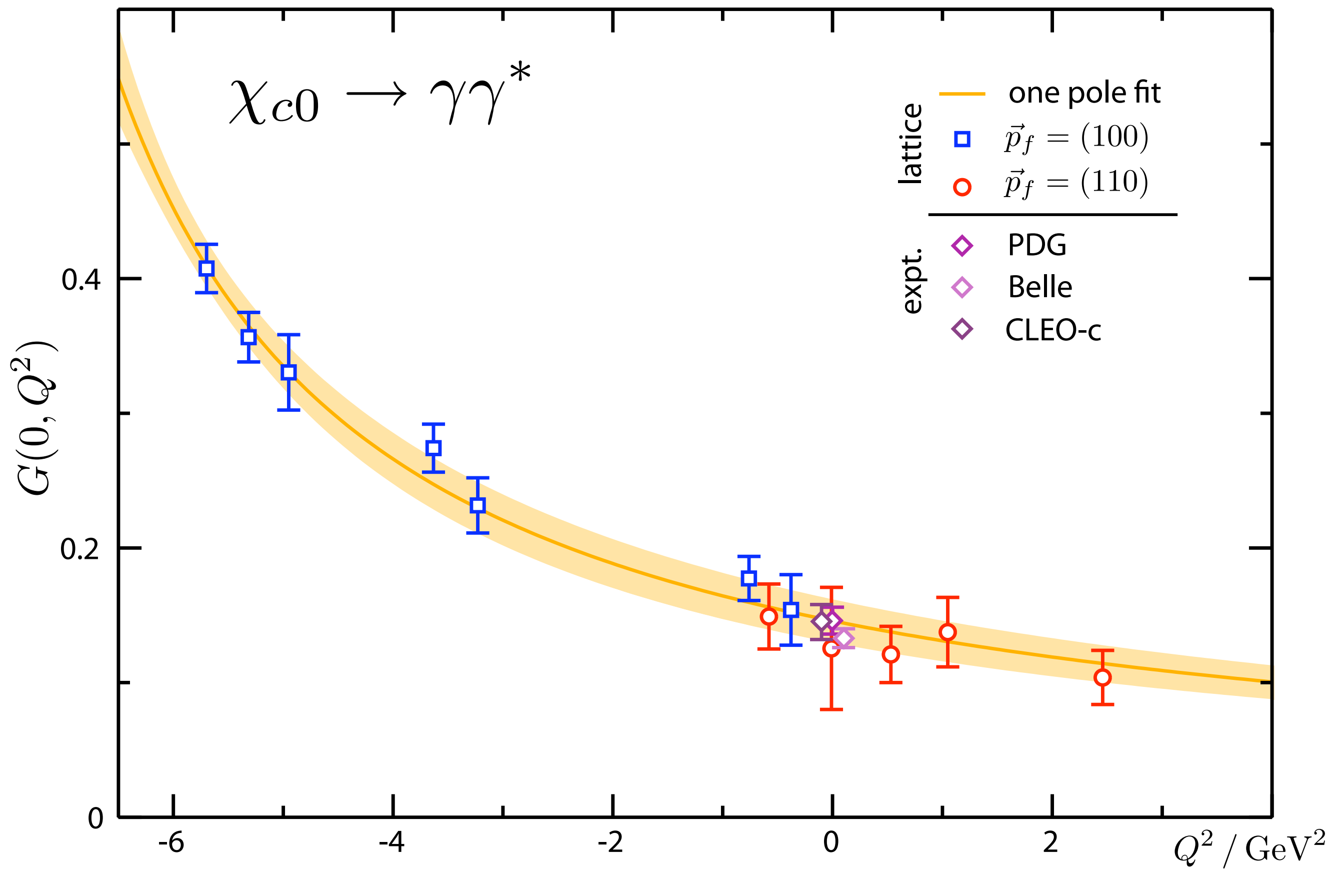
we have the technology to do the appropriate two-photon coupling calculation



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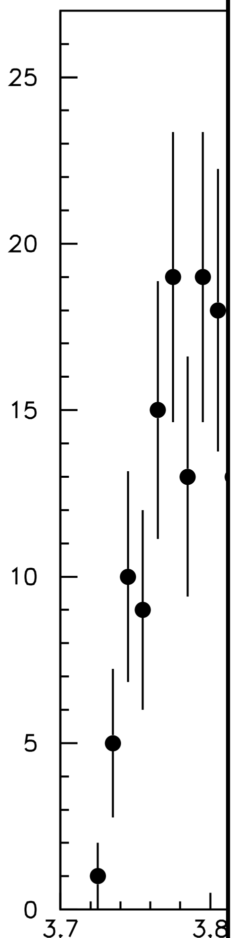

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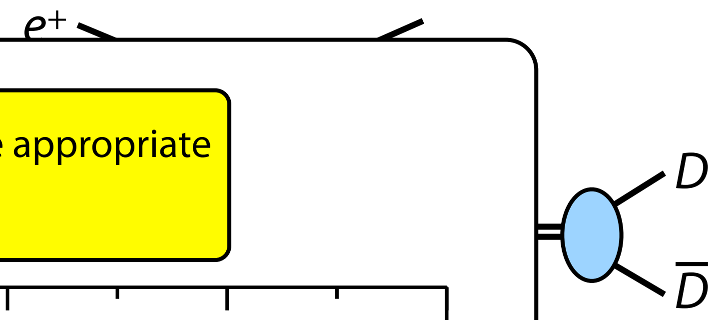

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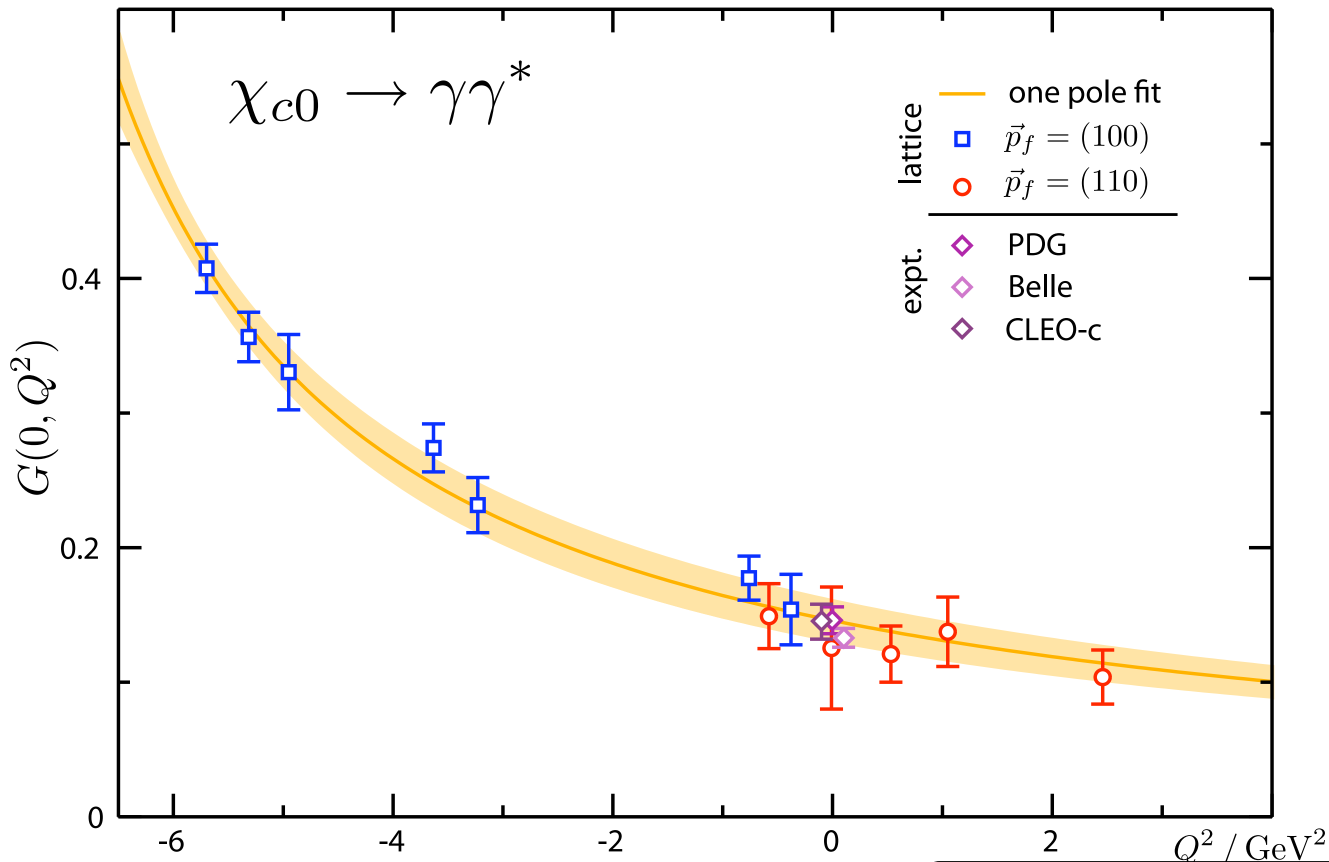

technology - yes
personnel - no

exotics

$J^{PC}=1^{-+}$ not accessible to $c\bar{c}$ pair

we find state at about 4.3 GeV

HYBRID MESON:
excited gluonic field

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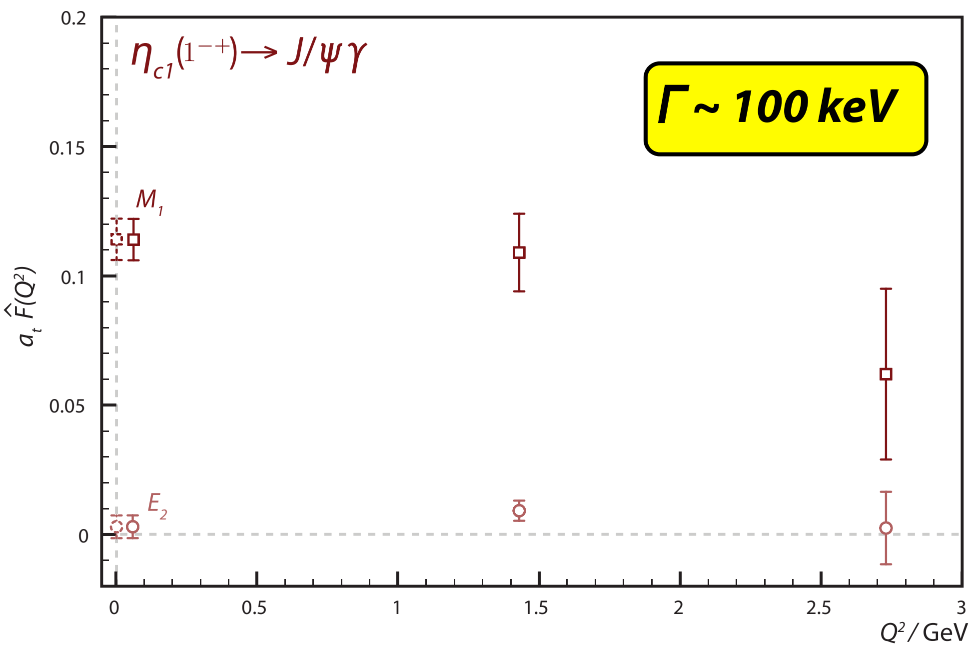
$\eta_{c1} \rightarrow J/\psi\ \gamma$

magnetic dipole transition



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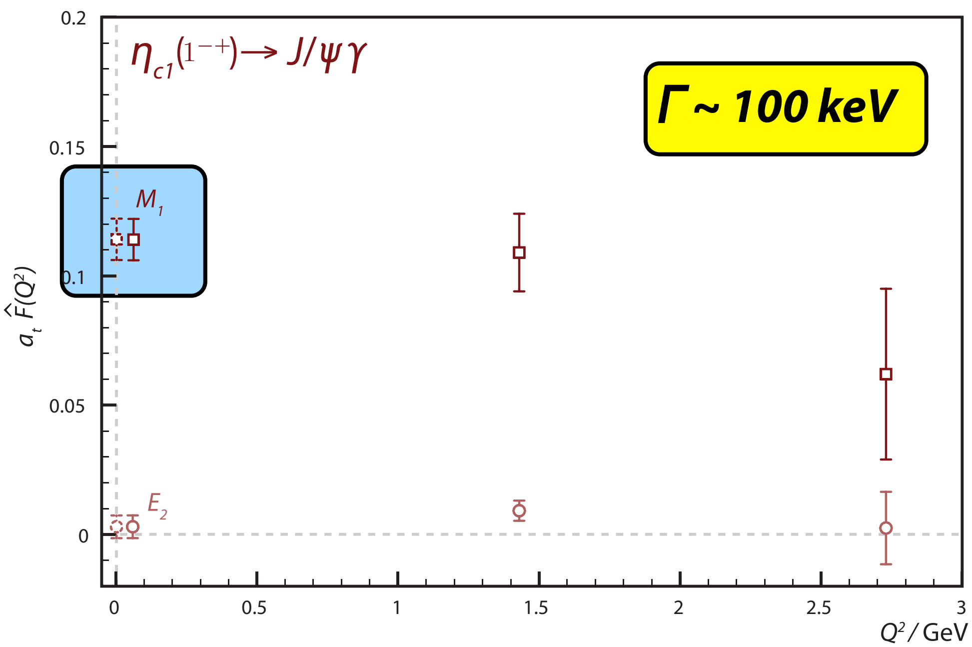

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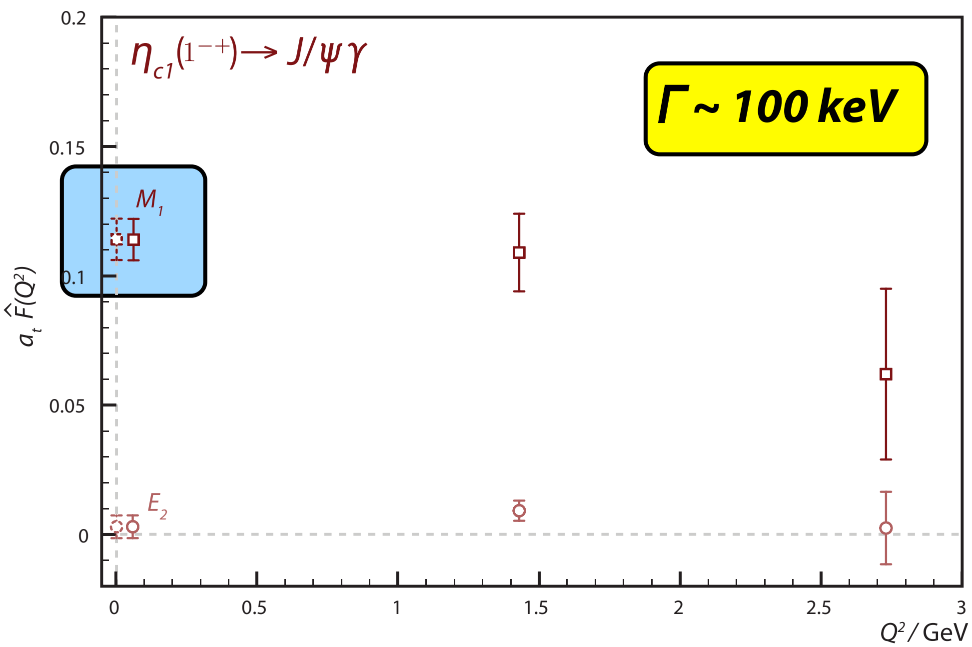

Γ ~ 100 keV

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

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

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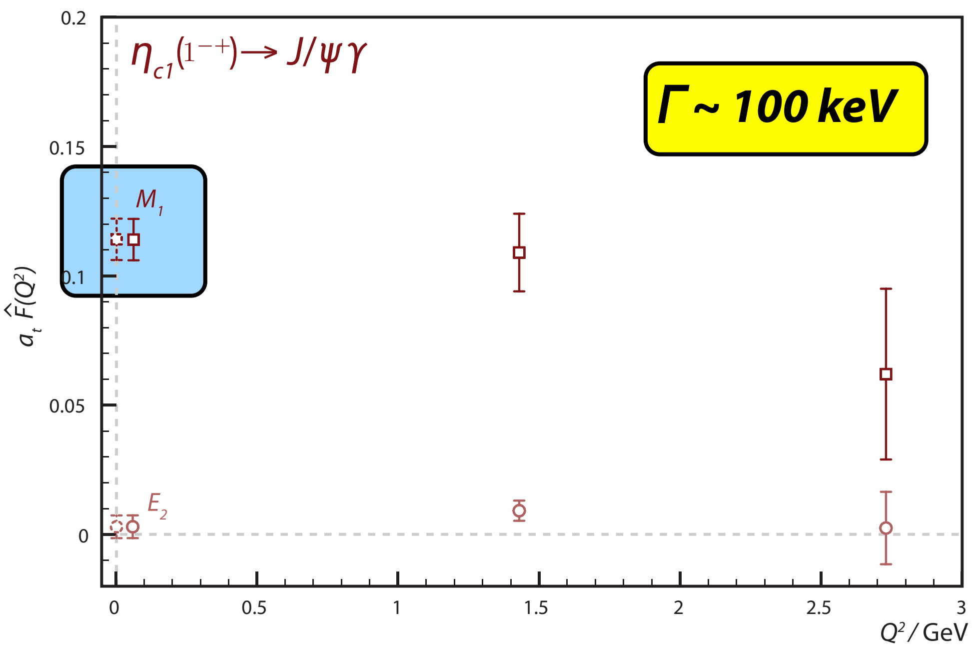

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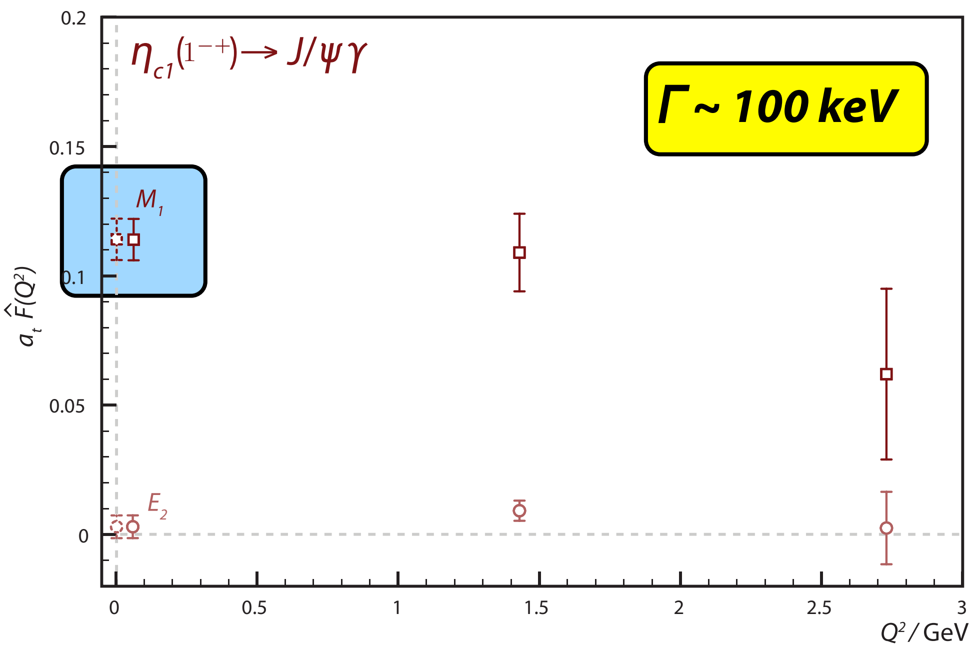

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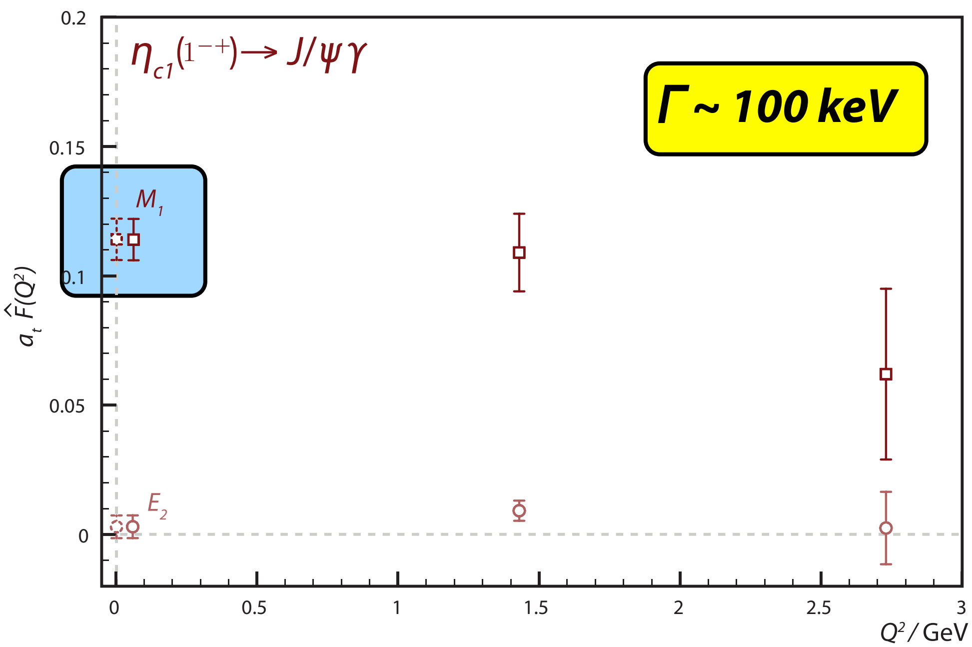

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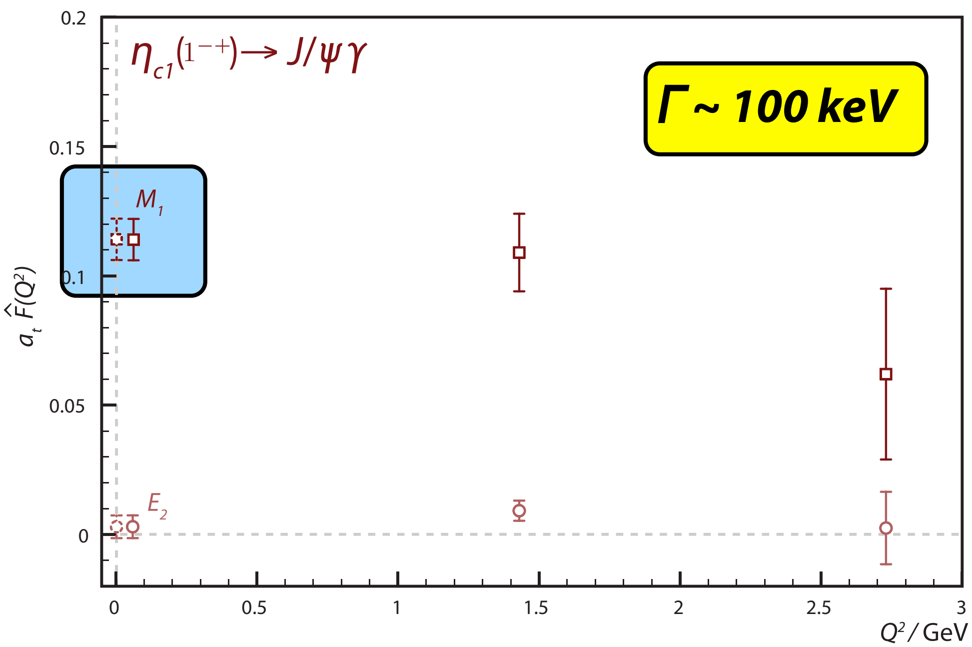

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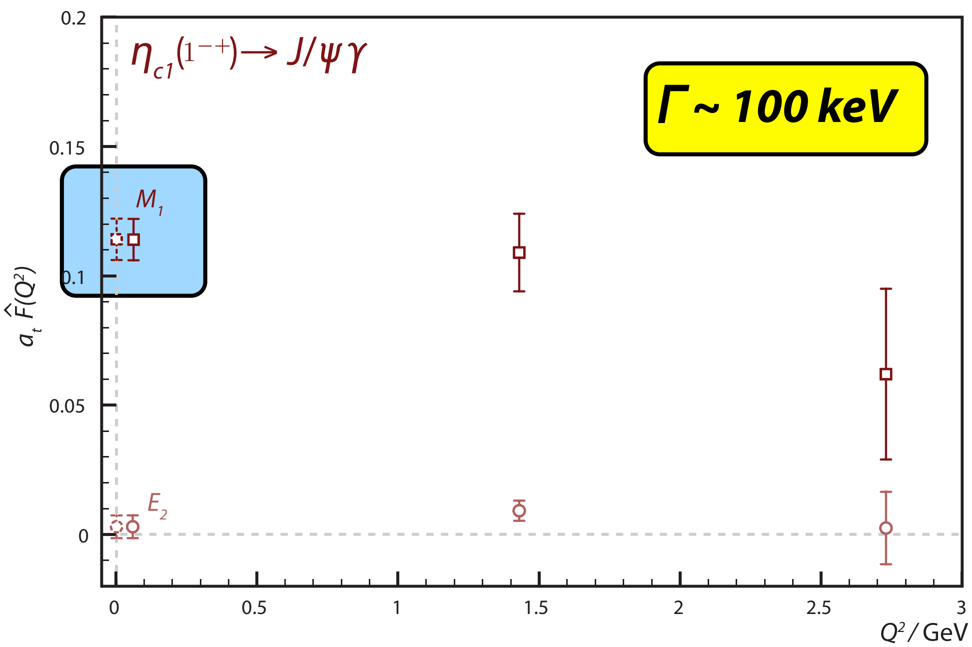

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first QCD information about hybrid meson photocouplings

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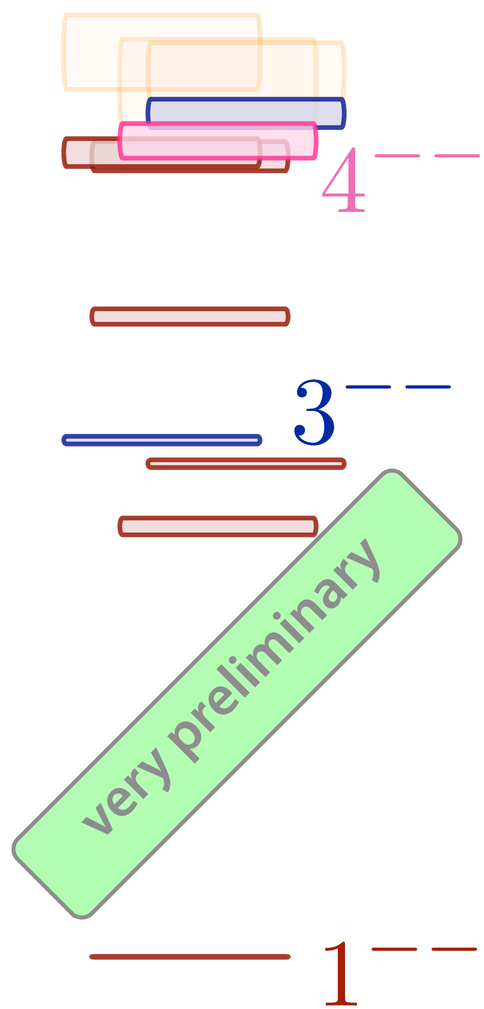
e.g. flux-tube model, Coulomb gauge ...

light mesons & GlueX

now efforts pointed toward lighter quarks

initially dynamical three-flavour calculations - three copies of the strange quark

$T_1^{--} \quad (1,3,4\ldots)$



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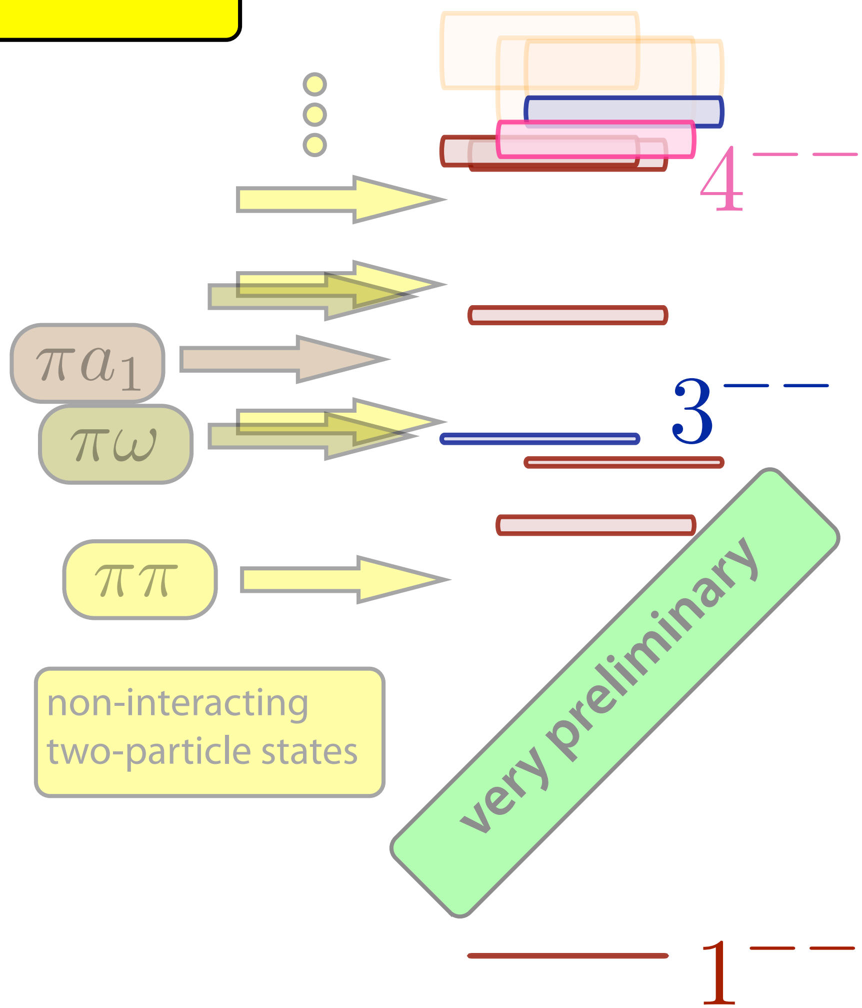

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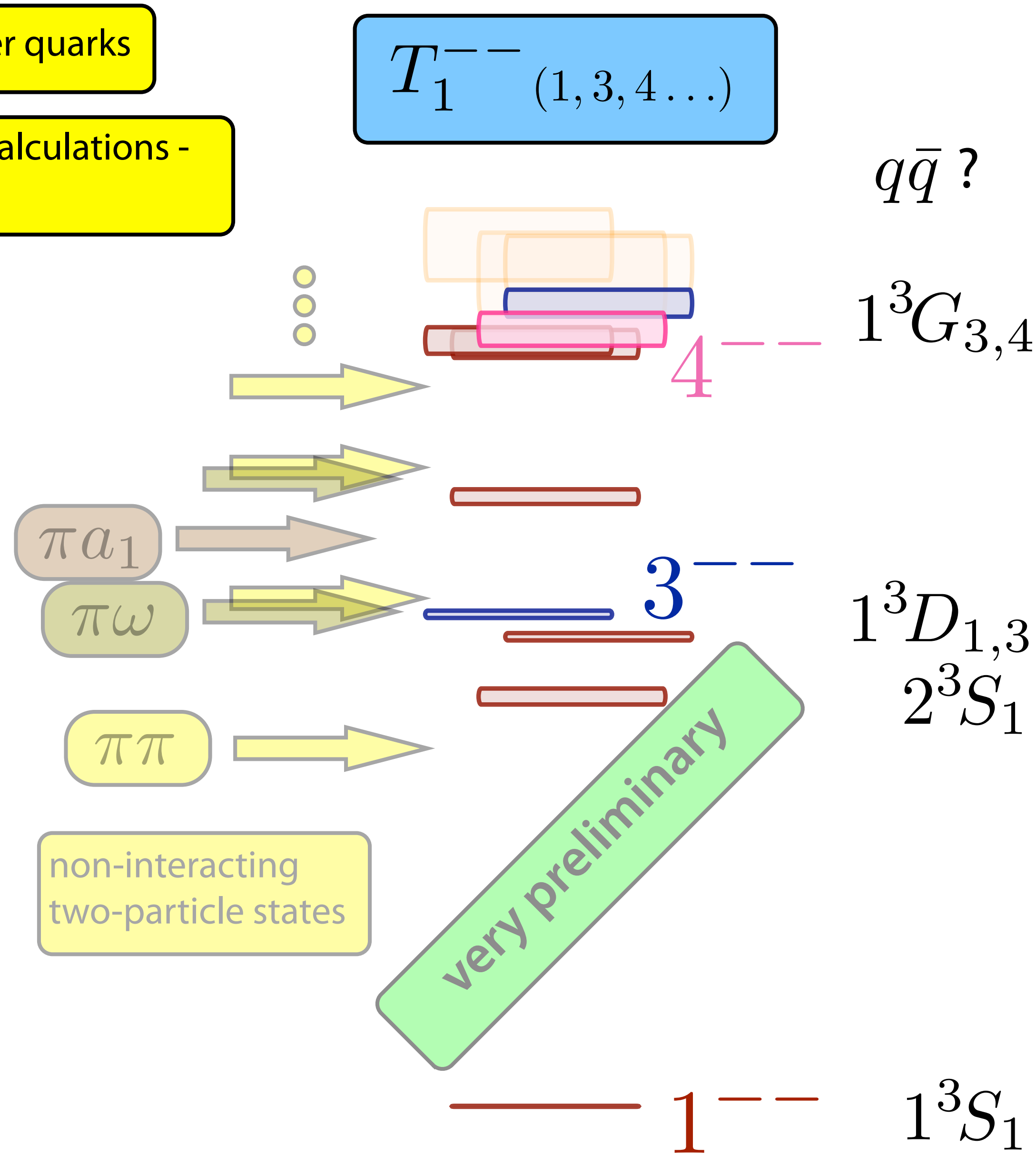

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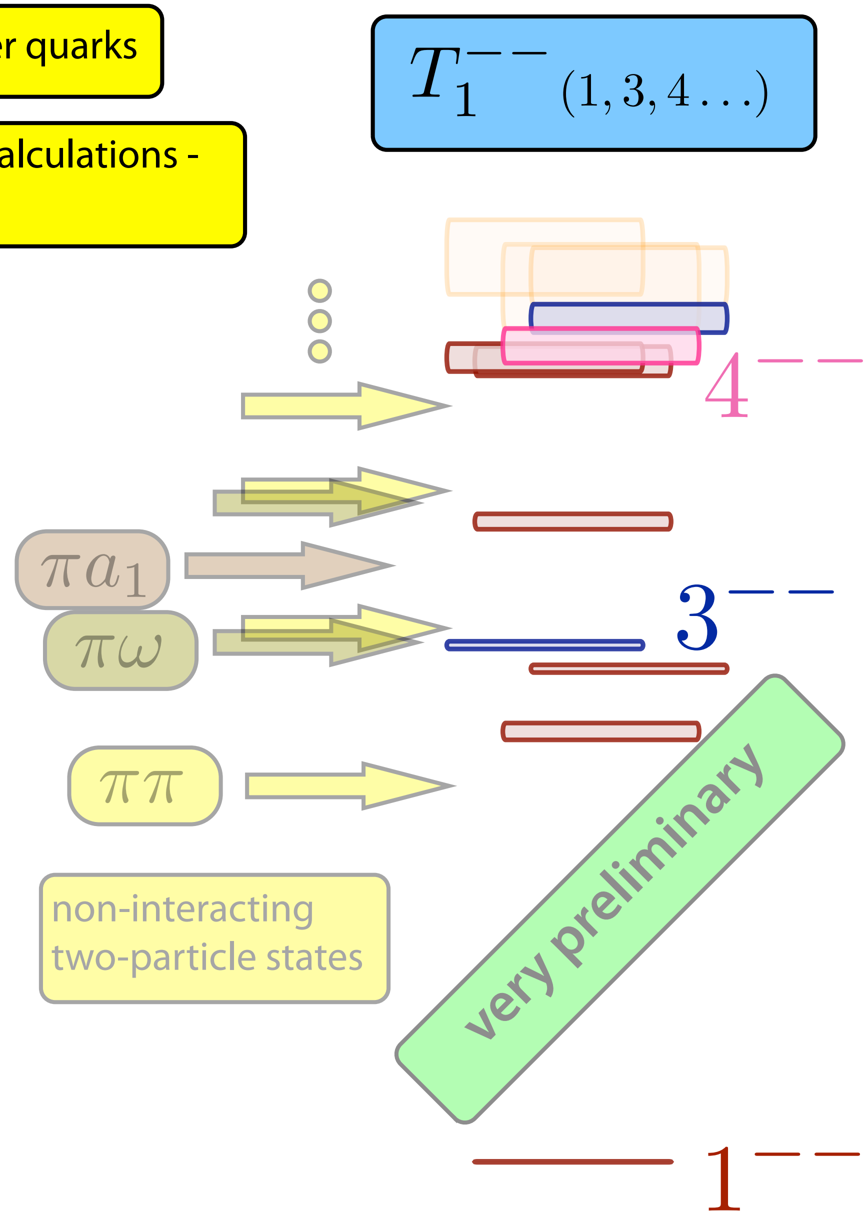

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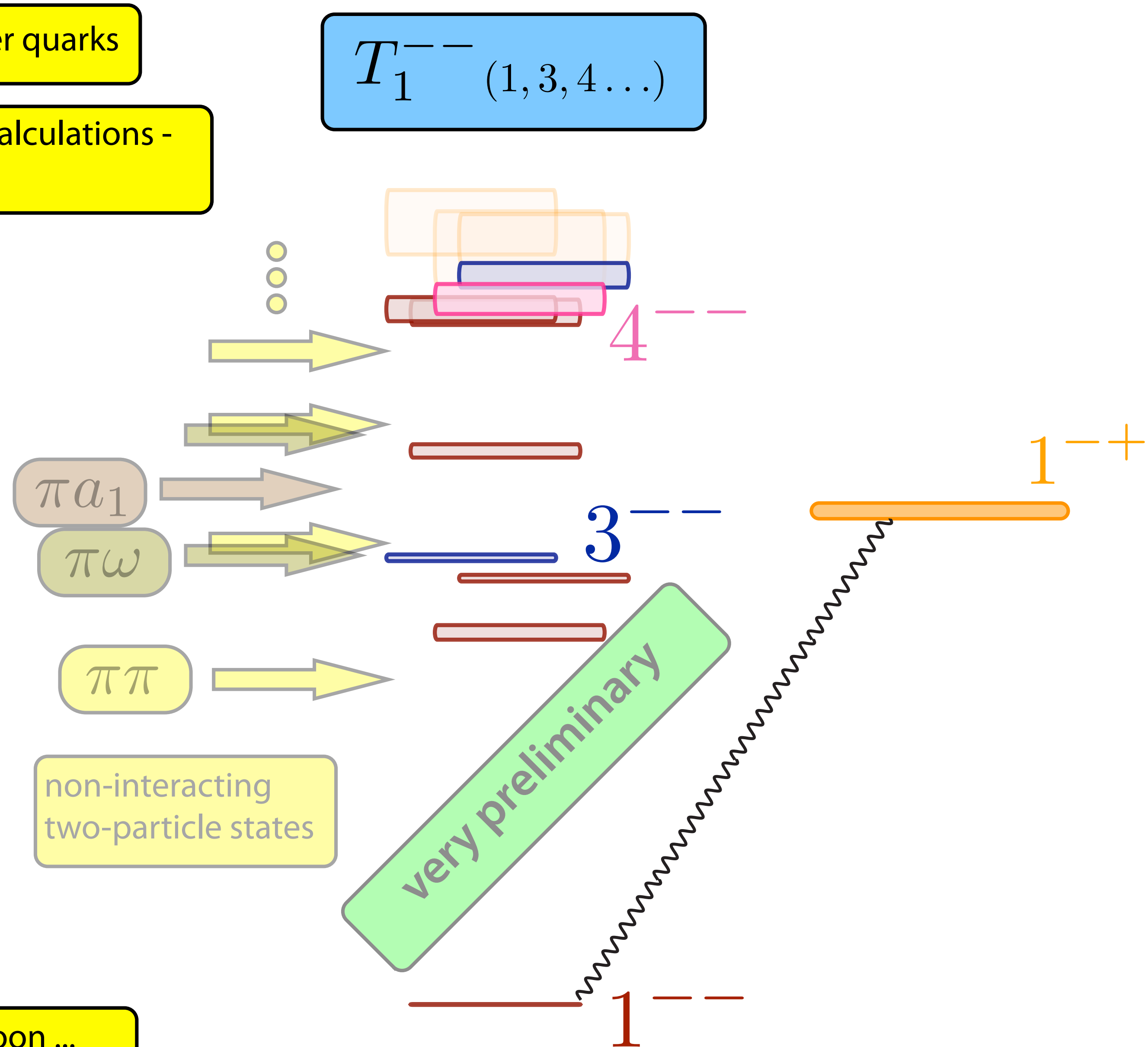

photocoupling estimates soon ...

summary

reliable techniques for extraction of excited states in lattice field theory

now applied to radiative matrix element calculations

initial trials with quenched studies of charmonium - compare with potential models

I have emphasized the exceptions - but actually potential models agree rather well with many results I have not presented

exotic (hybrid?) to conventional meson radiative transitions are large

if this is duplicated in light meson sector, bodes well for GlueX