Radiative Transitions in Charmonium

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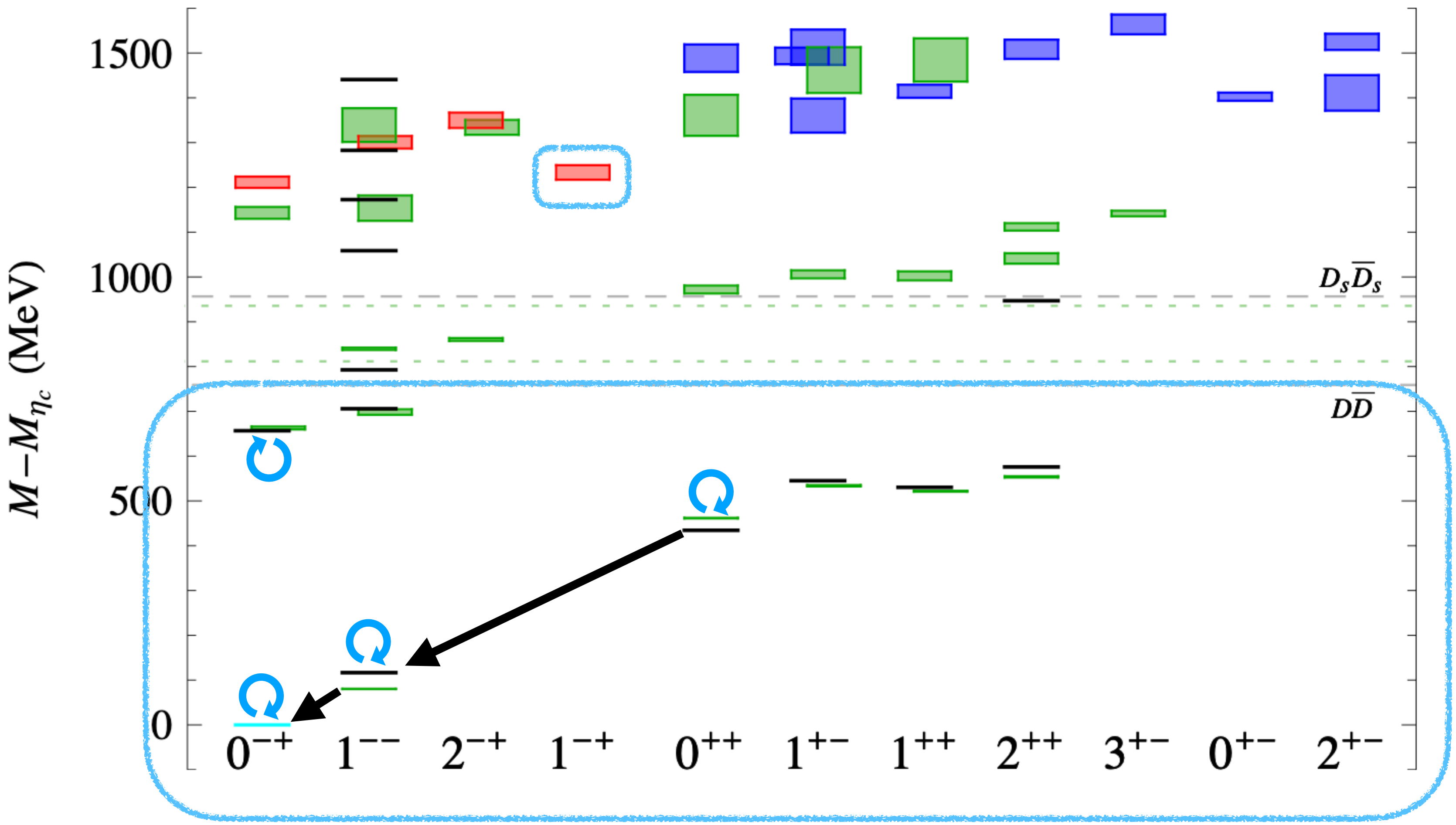
hadspec

Calculation Details

- Work performed on a single anisotropic lattice with Wilson clover fermions
- $N_f = 2 + 1, \quad m_\pi = 391\,\text{MeV}, \quad a_t \sim 0.12\,\text{fm}, \quad \xi = a_s/a_t \sim 3.5, \quad m_\pi L \sim 4.8$
- Finite volume, momentum quantised $\mathbf{p} \sim \frac{2\pi}{L}\mathbf{n}$
- Couple to c quark only, can access $A \to A\gamma$ form factors
- Compute using $\mathcal{O}(a)$ improved current
- Correlators computed in the distillation framework [0905.2160]
- Previous work on Radiative Transitions by HadSpec in $l\bar{l}$ sector [1501.07457]

Spectroscopy Summary [1204.5425]

… on the lattice used in this study



Correlators

- We want form factors, these can be accessed through correlators

$$\langle 0|\Omega_f(\Delta t) j^\mu(t) \Omega_i^\dagger(0)|0\rangle = \sum_{n_i,n_f} \frac{1}{2E_{n_i}} \frac{1}{2E_{n_f}} e^{-E_{n_f}(\Delta t - t)} e^{-E_{n_i} t} \langle 0|\Omega_f(0)|n_f\rangle \langle n_f|j^\mu(0)|n_i\rangle \langle n_i|\Omega_i^\dagger(0)|0\rangle$$

$$\Omega_{n_i}^\dagger|0\rangle = 2E_{n_i}|n_i\rangle + \sum_{j\neq i} \varepsilon_j |n_j\rangle$$

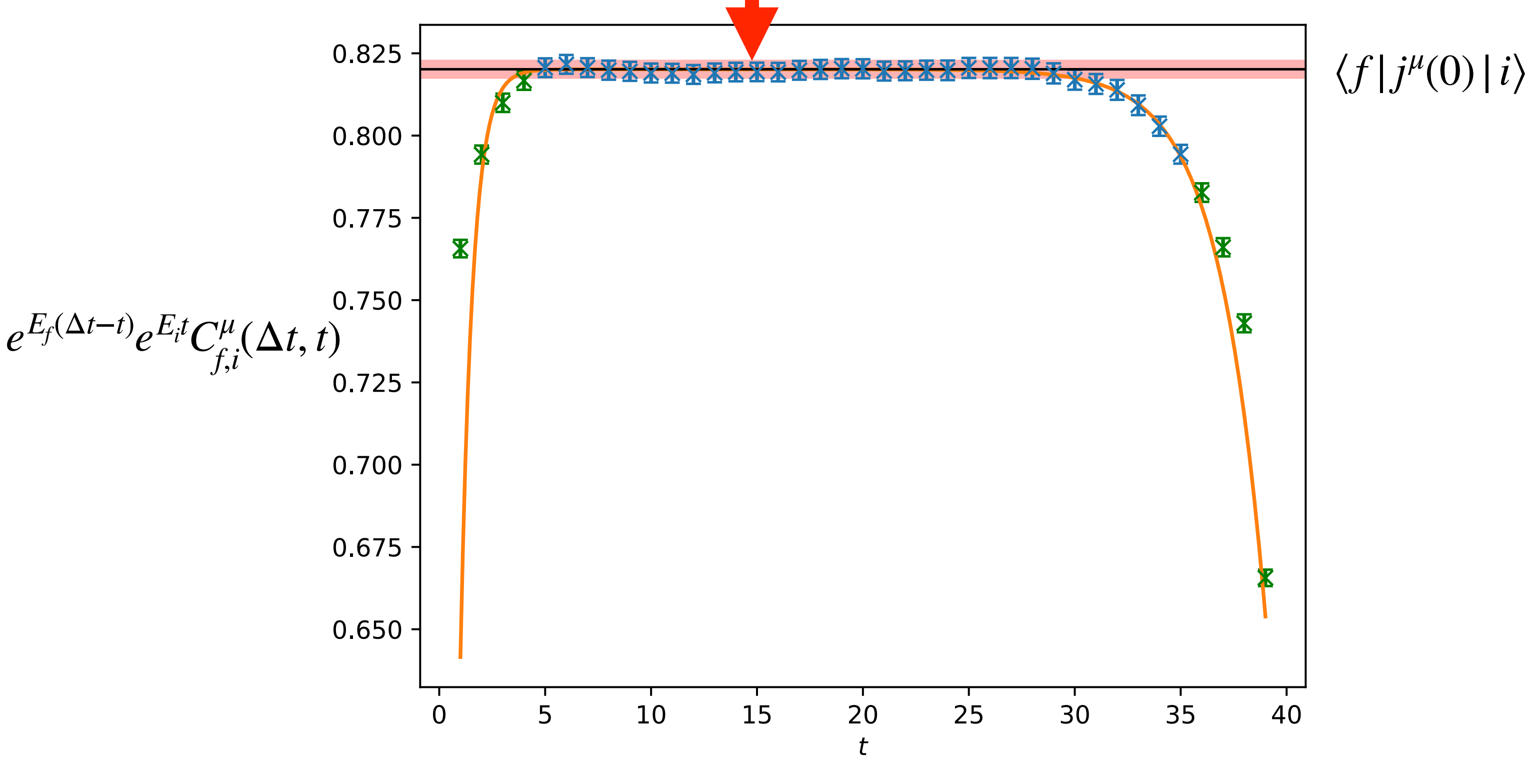
Using large basis of <u>single</u> fermion bilinear operators

$$\langle n_i|j^\mu|n_f\rangle = \sum_j K_j^\mu[\lambda_i, \lambda_f, p_i, p_f]\, F_j(Q^2)$$

$$j^\mu(0) \sim \bar{c}\gamma^\mu c$$

Extracting Matrix Elements

$$e^{E_f(\Delta t - t)}\, e^{E_i t}\, C^{\mu}_{fi}(\Delta t, t) = \langle f \,|\, j^{\mu}(0) \,|\, i \rangle + \varepsilon_f\, e^{-\delta E_f (\Delta t - t)} + \varepsilon_i\, e^{-\delta E_i t} + \mathcal{O}(\varepsilon^2)$$



Z_V Determination

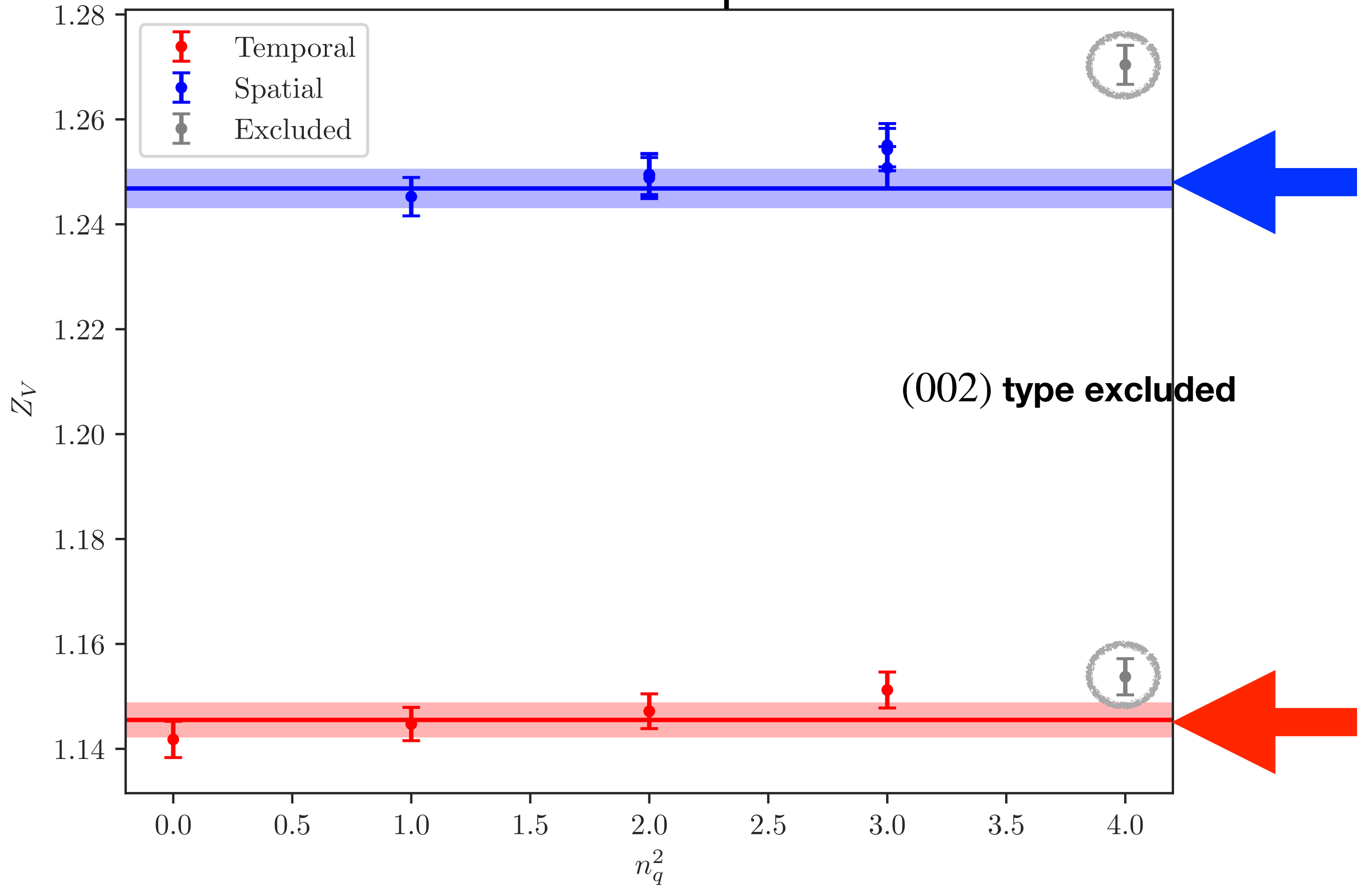
$$j_0 = Z_V^t(\bar{c}\gamma_0 c + \frac{1}{4}\frac{\nu_s}{\xi}(1-\xi)a_s\partial_j(\bar{c}\sigma_{0j}c))$$

$$j_k = Z_V^s(\bar{c}\gamma_k c + \frac{1}{4}(1-\xi)a_t\partial_0(\bar{c}\sigma_{0k}c))$$

$$Z_V = \frac{F_{\eta_c}^{cont.}(0)}{F_{\eta_c}^{lat.}(0)} = \frac{1}{F_{\eta_c}^{lat.}(0)}$$

$$Z_V^t = 1.145(3)$$

$$Z_V^s = 1.247(4)$$



(002) **type excluded**

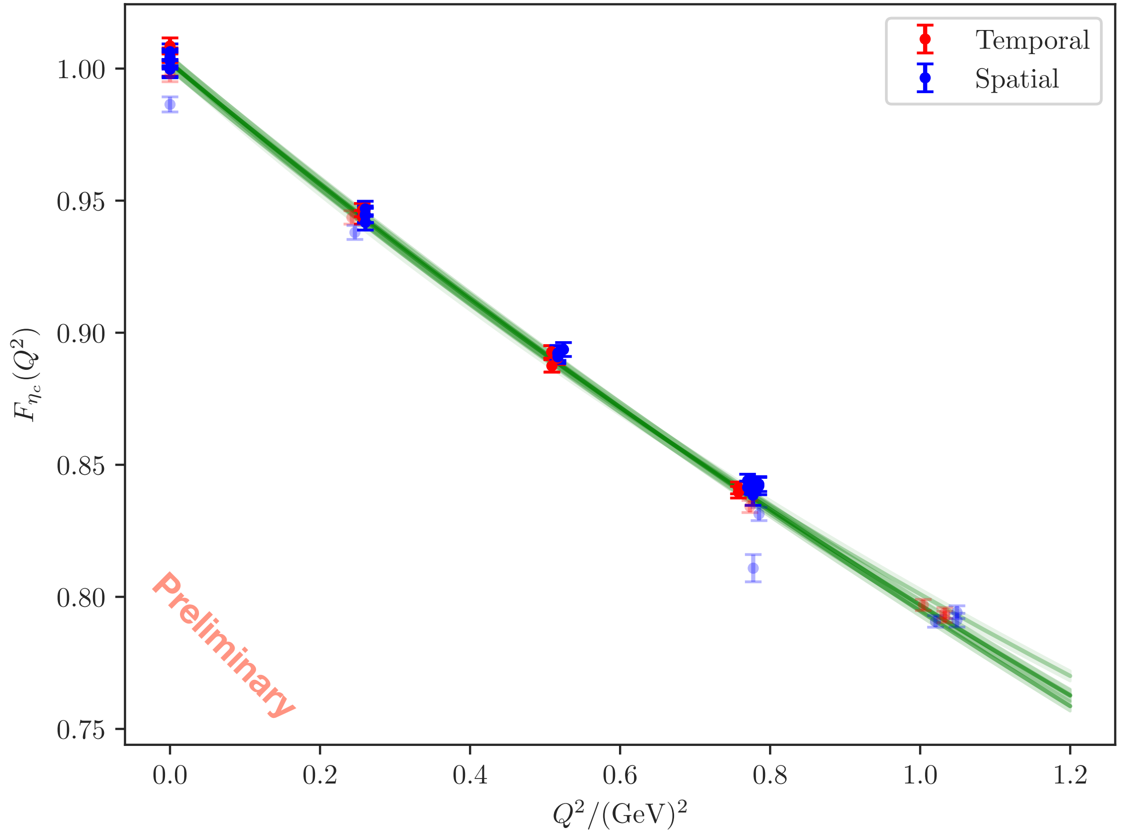
η_c Form Factor

$$\langle \eta_c(p') \,|\, j^\mu \,|\, \eta_c(p) \rangle = (p + p')^\mu F(Q^2)$$

$$\left\langle r^2 \right\rangle^{\frac{1}{2}} \propto \frac{\mathrm{d}}{\mathrm{d}Q^2} F(Q^2) \bigg|_{Q^2=0}$$

Taking a spread over the <u>statistical uncertainties</u> of fit forms

$$\langle r^2 \rangle^{\frac{1}{2}} = 0.235(3)\,\mathrm{fm}$$

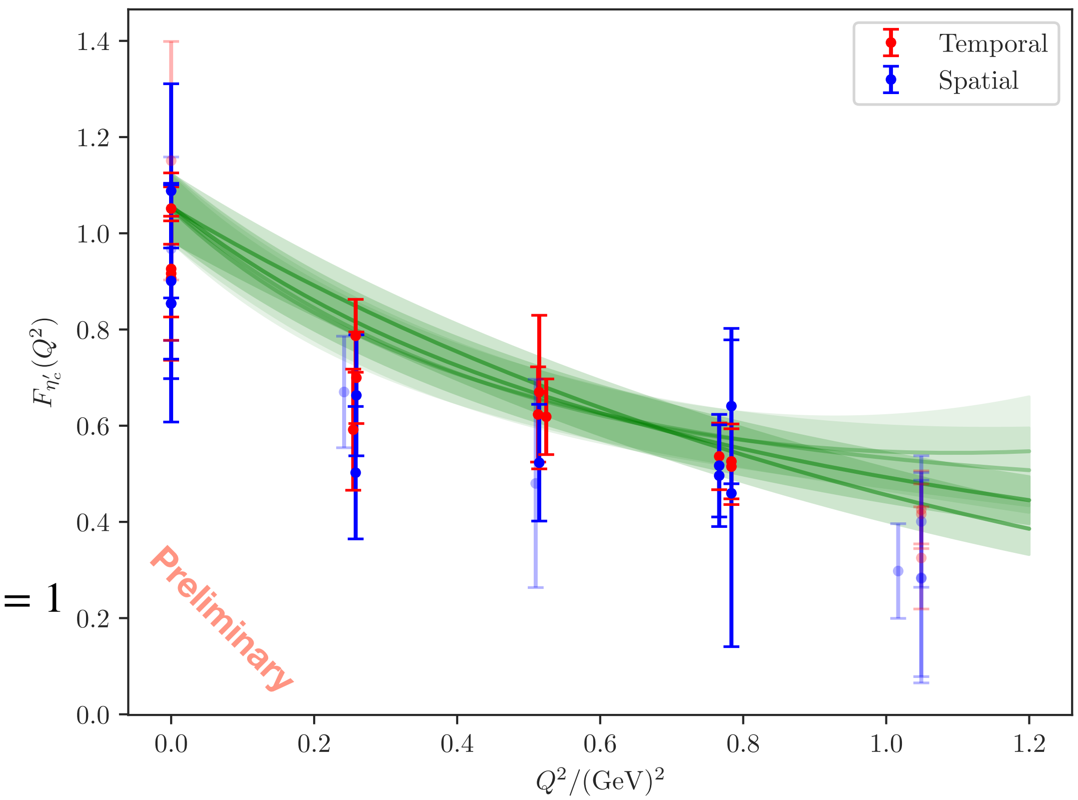


η_c' Form Factor

$$\langle \eta_c'(p') \,|\, j^\mu \,|\, \eta_c'(p) \rangle = (p + p')^\mu \, F_{\eta_c'}(Q^2)$$

$$\langle r^2 \rangle^{\frac{1}{2}} = 0.54(12)\,\text{fm}$$

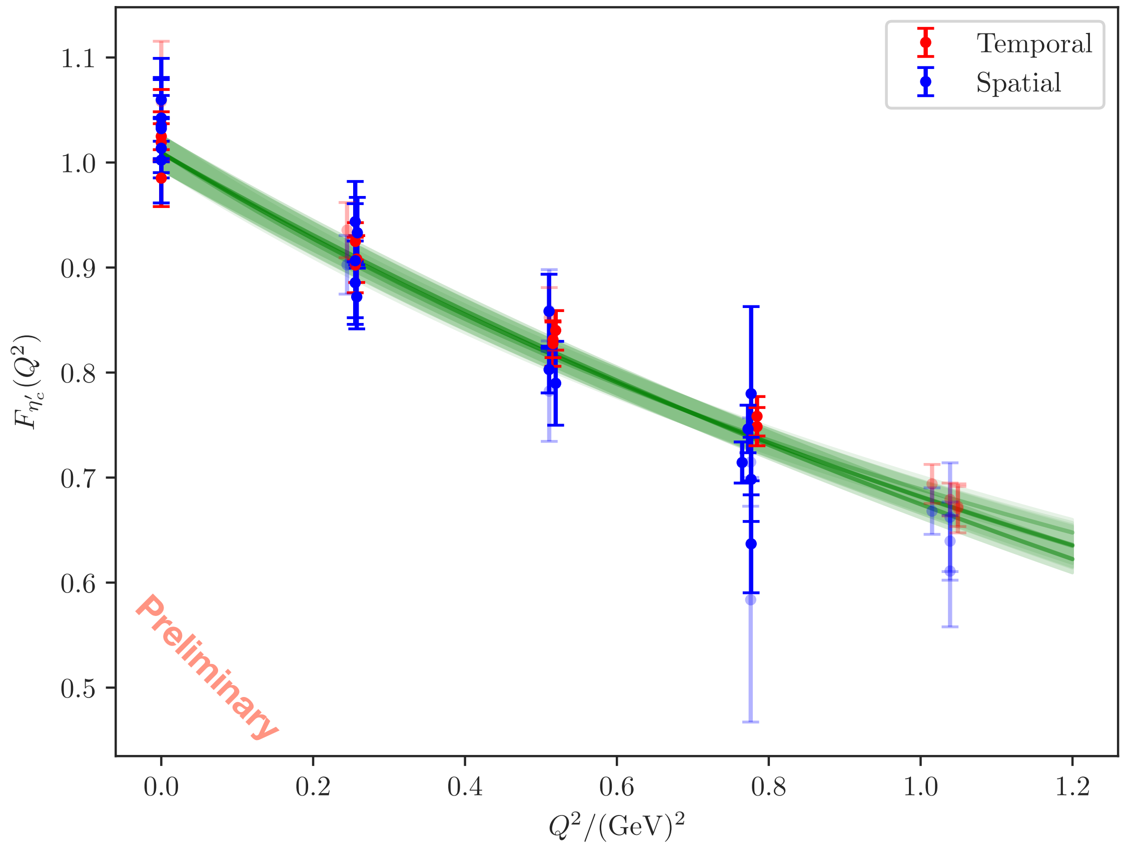
Non-trivial verification of the work to show that $F(Q^2 = 0) = 1$



χ_{c0} Form Factor

$$\langle \chi_{c0}(p') \,|\, j^\mu \,|\, \chi_{c0}(p) \rangle = (p + p')^\mu \, F_{\chi_{c0}}(Q^2)$$

$$\langle r^2 \rangle^{\frac{1}{2}} = 0.351(22)\,\mathrm{fm}$$



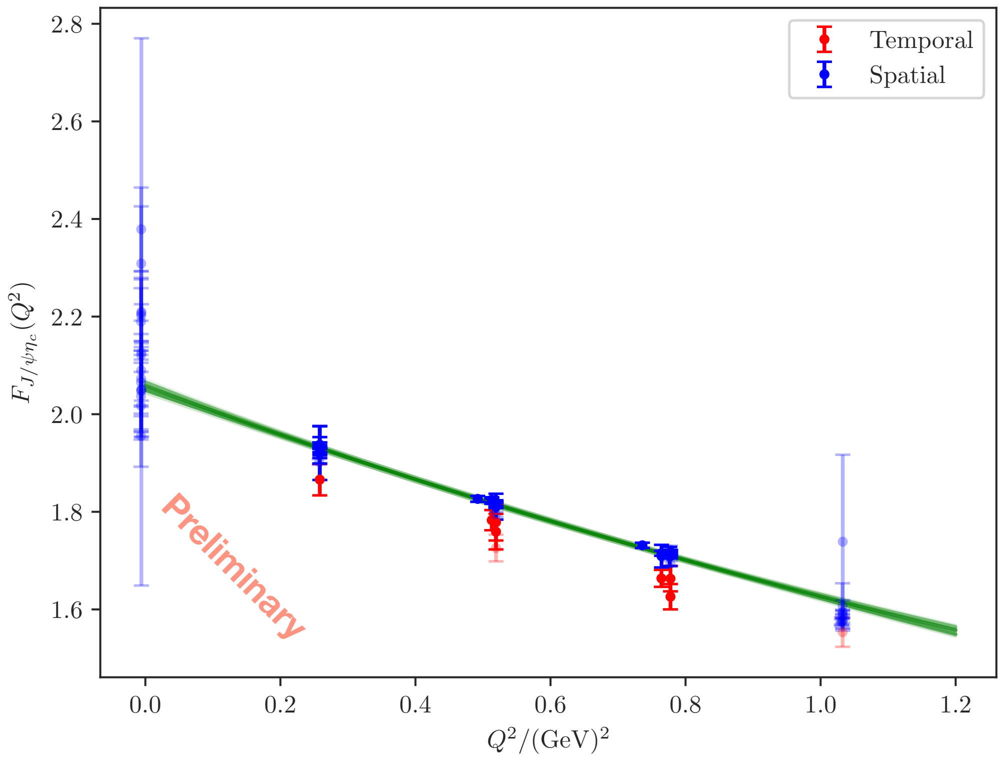
$J/\psi \to \eta_c \gamma$

$$\langle \eta_c(\vec{p}\,') | j^\mu(0) | J/\psi(\lambda, \vec{p}) \rangle = \epsilon^{\mu\nu\rho\sigma} p'_\nu p_\rho \epsilon_\sigma(\lambda, \vec{p}) \frac{2}{m_{J/\psi} + m_{\eta_c}} F_{J/\psi\eta_c}(Q^2)$$

Dependent on hyperfine splitting

$$\Gamma(J/\psi \to \eta_c \gamma) = \frac{64\alpha}{27} \frac{|\mathbf{q}|^3}{(m_{J/\psi} + m_{\eta_c})^2} |F(0)|^2$$

Study	$\lvert F(0) \rvert$	N_f
This work	1.95-2.05	2+1
1301.7203	1.90(7)(11)	2+1
1104.2655	2.01(2)	2
1206.1445	1.92(3)(2)	2
1906.03666	1.933(41)	0
0902.2241	1.89(3)	0
hep-ph/0601137	1.85(4)	0
PDG	1.57(18)	



Summary

- Demonstrated technology for low lying charmonia, showing aspects needed for exotics

- Further excited and exotics transitions in the pipeline