Study of J/ψ Photoproduction off Deuteron
PR12-11-003B

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Near Threshold J/ψ Production off Deuteron

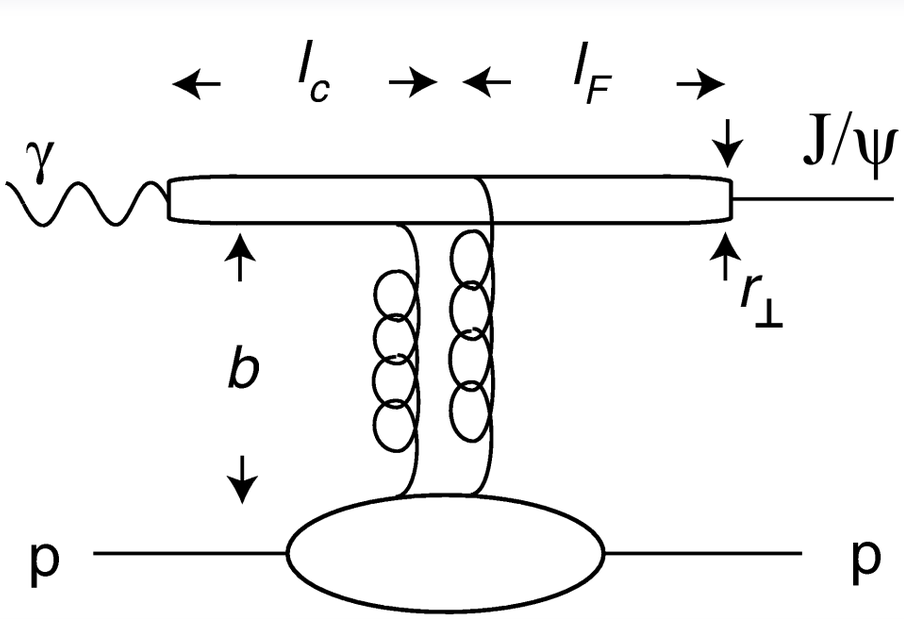
Objectives

To determine the cross section of:

- Final-State Interactions (J/ψN rescattering)
  - Estimate $\sigma_{J/\psi N}$
- Quasi-free photoproduction off neutron: $\gamma(n) \rightarrow J/\psi n$
  - Search for isospin partners of LHCb pentaquarks
  - Test bound-nucleon gluonic form factors
- Coherent photoproduction: $\gamma d \rightarrow J/\psi d$
  - Study gluonic form-factor of deuteron

Near Threshold J/ψ Production off Deuteron

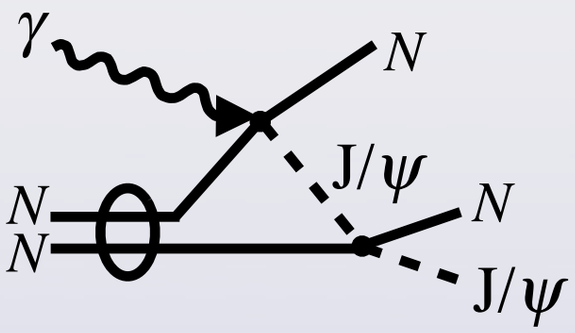
Why J/ψ?



S.J. Brodsky, E. Chudakov, P. Hoyer, J.M. Laget, Phys. Lett. B 498, 23 (2001).

- Small transverse size: $r_\perp \sim 1/m_c = 0.13$ fm
- $E_{thr} = 8.2$ GeV, $l_c \simeq 2E_\gamma^{lab}/4m_c^2 = 0.36$ fm
- At threshold, $|t_{min}| = 1.7$ (GeV/c)^2
- $b \sim 1/|t|^{1/2} = 0.2$ fm
- The $c\bar{c}$ couples to the gluon field in the target. Process dominated by multi-gluon exchange.
- Probes the short-range structure of the target.

Near-Threshold J/ψ Production off Deuteron



Incoherent Photoproduction: J/ψN FSI

- Direct access to J/ψN→J/ψN and the elementary J/ψN total cross section (l_F~1fm).

  $\sigma_{J/\psi N}$ < 1 mb (from J/ψ on N)

  $\sigma_{J/\psi N}$ ~ 3.5 mb (from A dependence of nuclear absorption).

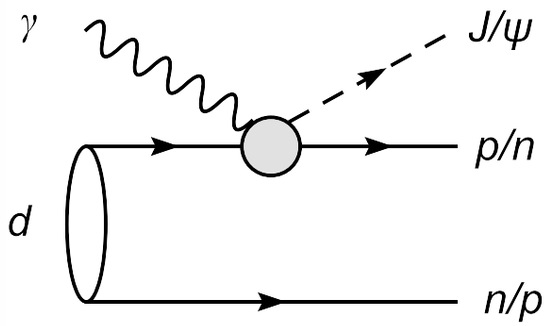
  $\sigma_{J/\psi N} \geq$ 17 mb (multiple expansion and low-energy theorems in QCD).

  $\sigma_{J/\psi N}$ ~ 7 mb (two-gluon exchange QCD calculation of interaction potential)

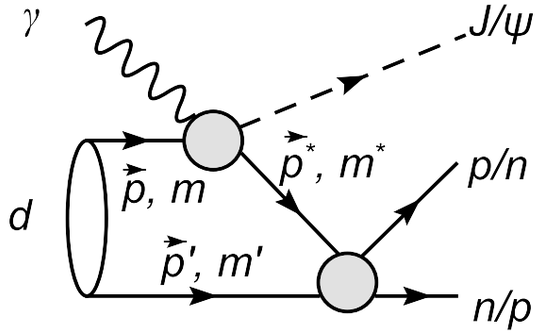
- $\sigma_{J/\psi N}$ is a relevant quantity to test different predictions for the QCD Van Der Waals interaction and J/ψ-nuclear bound states.

Near-Threshold J/ψ Production off Deuteron

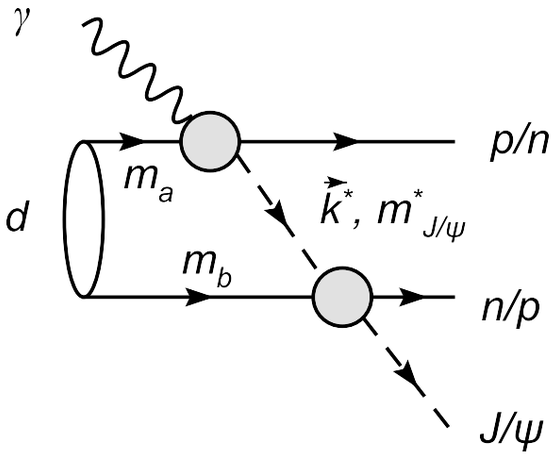
Incoherent Photoproduction: J/ψN FSI



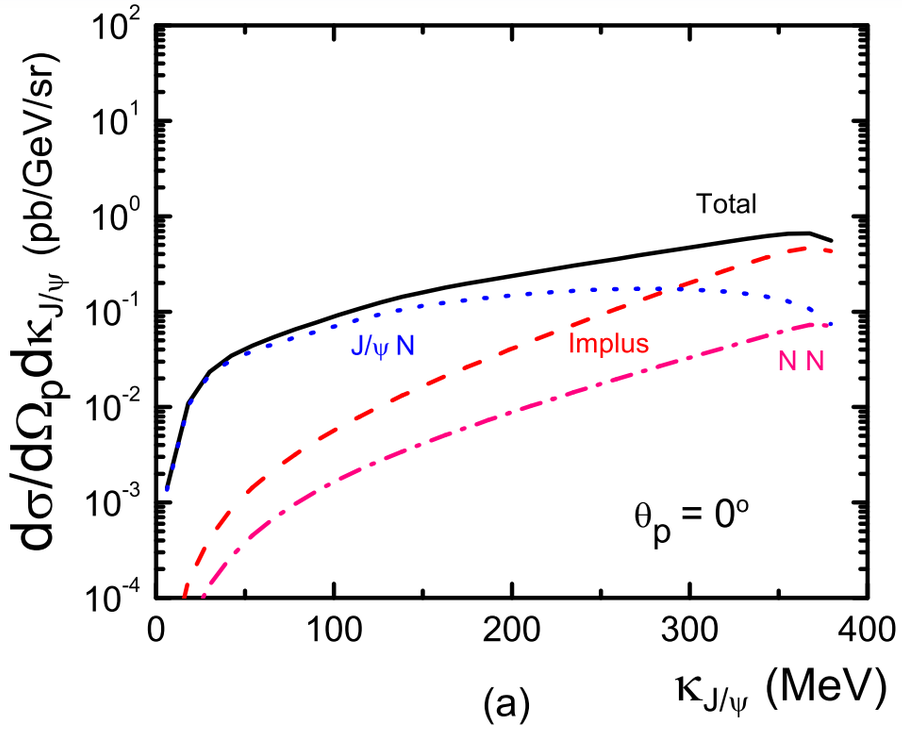
(a) Impulse



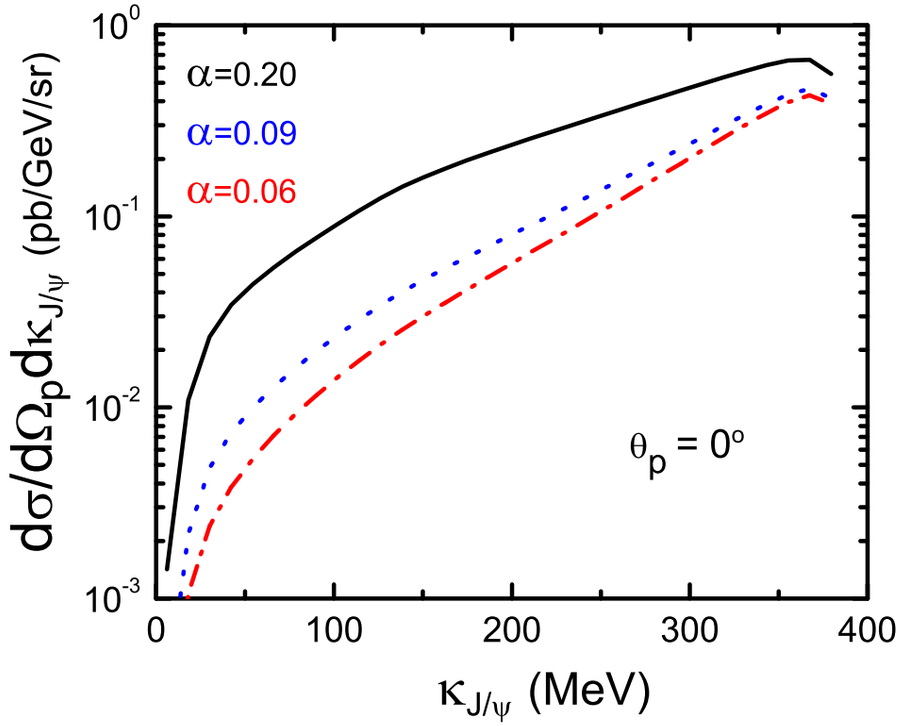
(b) NN Re-scattering



(c) J/ψ N Re-scattering



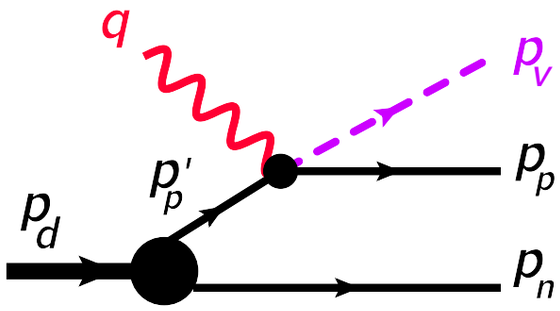
(a)

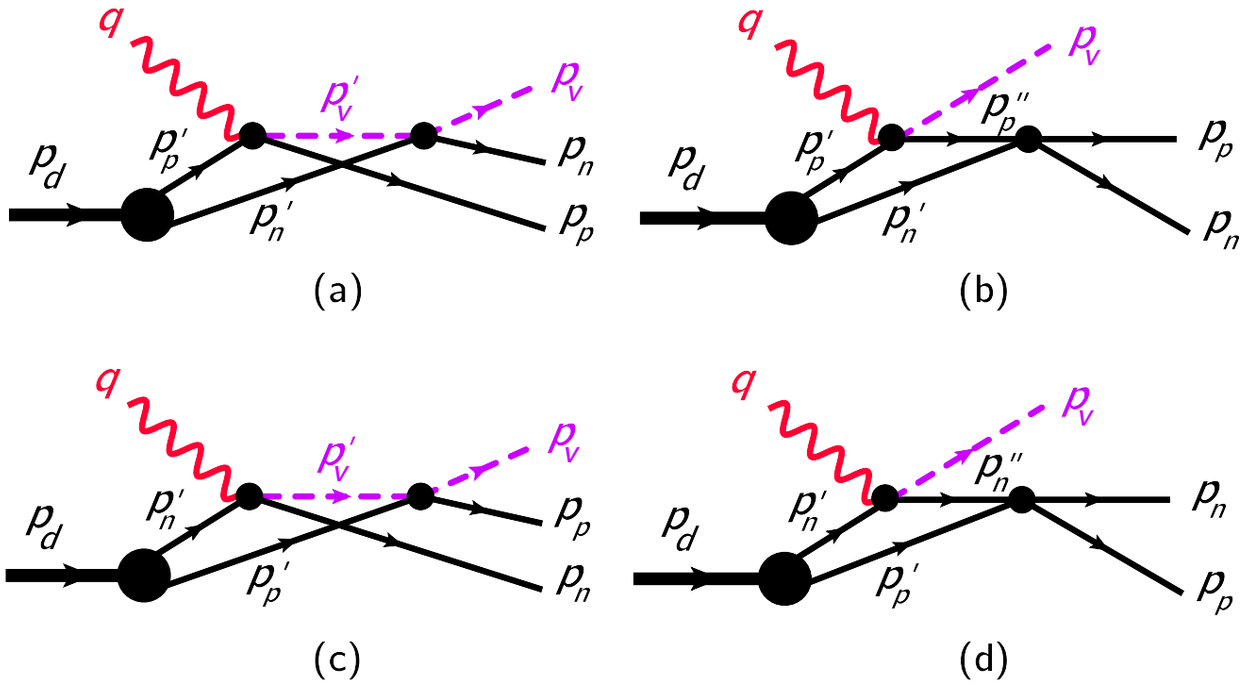


J.-J. Wu, T.-S. H. Lee, Phys. Rev. C **88,** 015205 (2013)

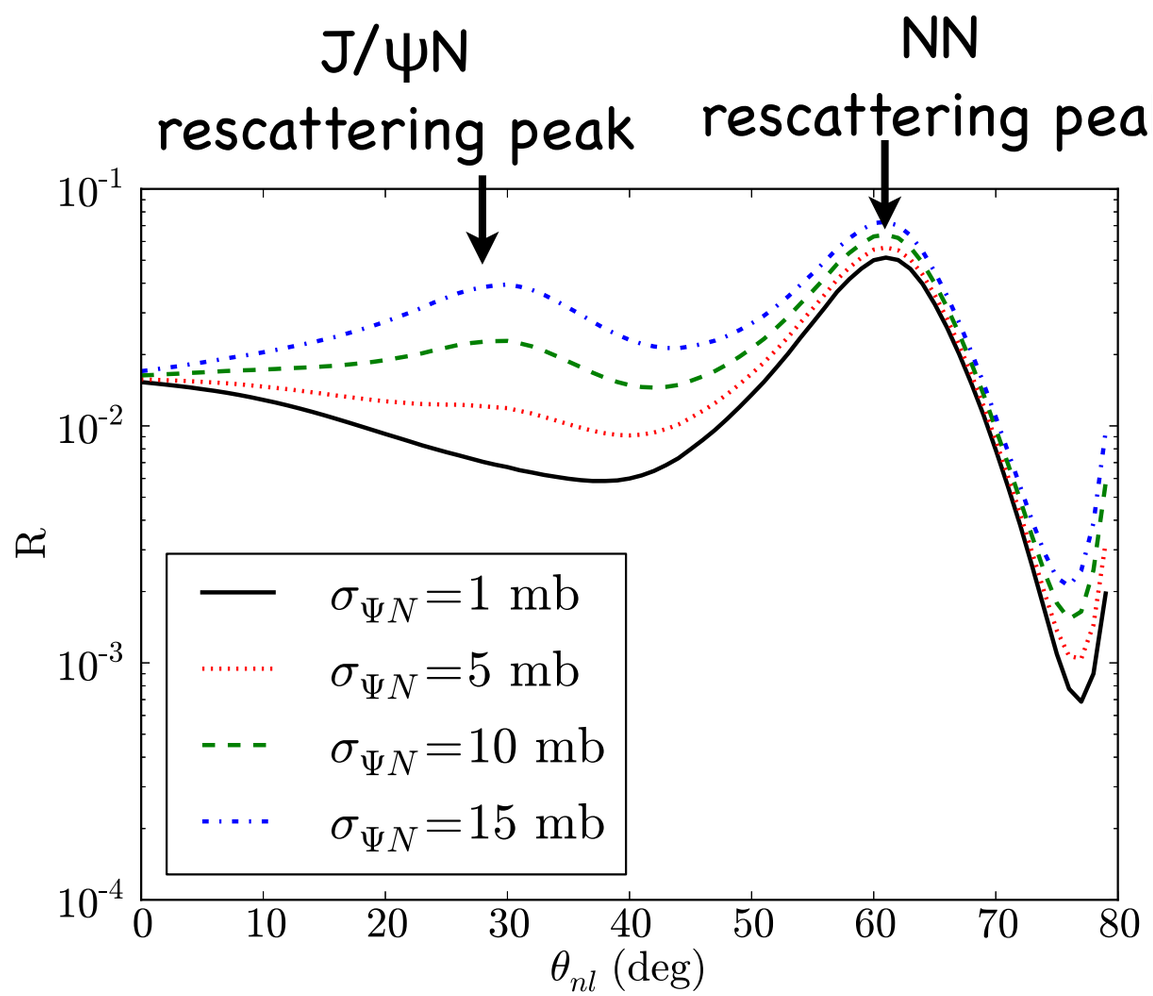
Near-Threshold J/ψ Production off Deuteron

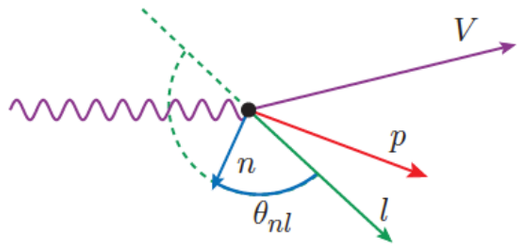
Incoherent Photoproduction: J/ψN FSI





$$R = \frac{\sigma(p_n = 600\ \text{MeV})}{\sigma(p_n = 200\ \text{MeV})}$$



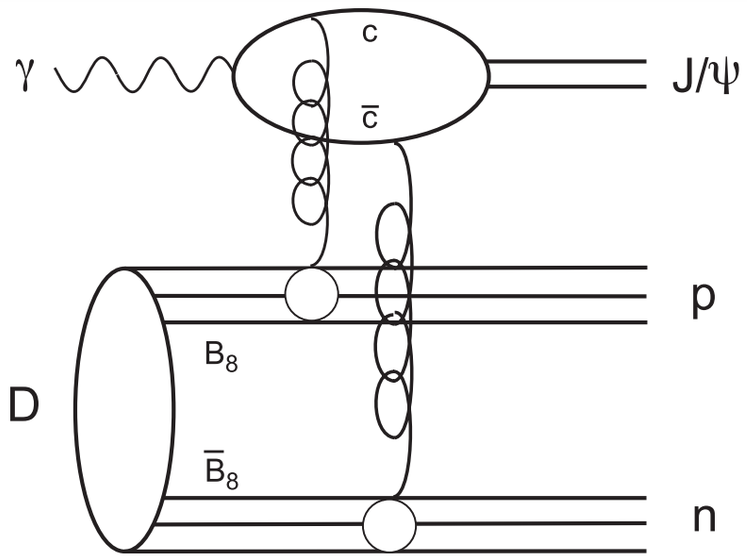


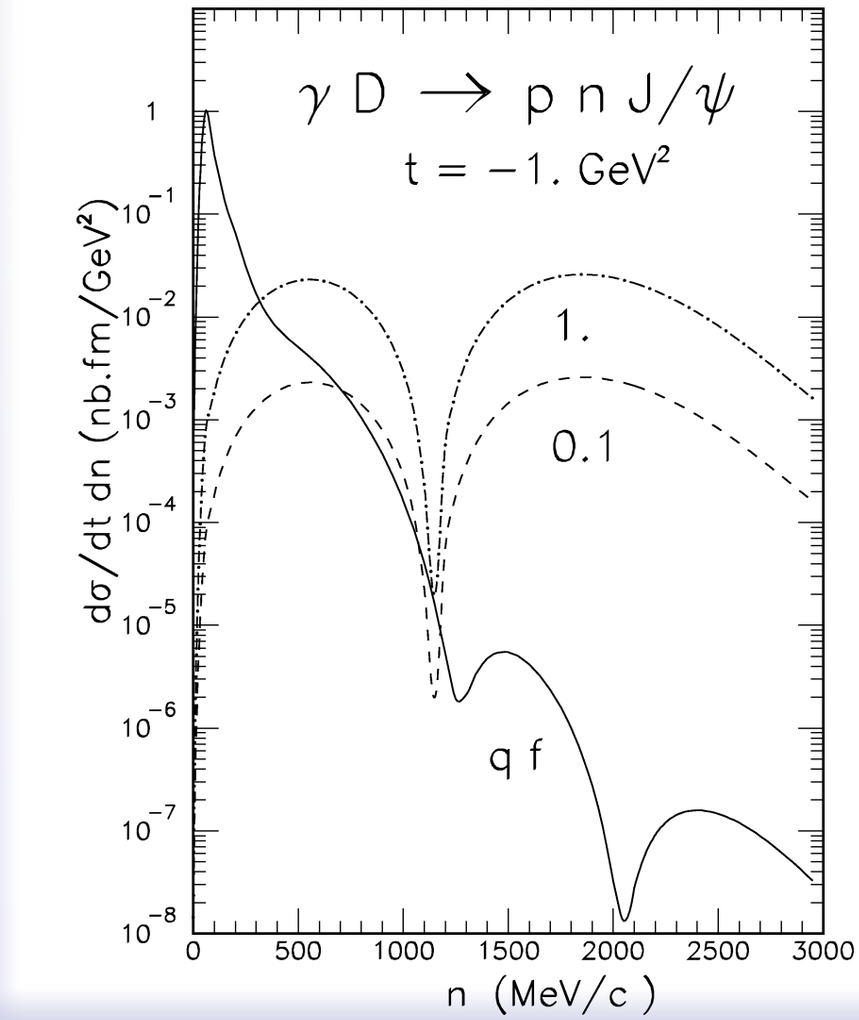
A. Freese, M. Sargsian, Phys. Rev. C **88**, 044604 (2013)

Near-Threshold J/ψ Production off Deuteron

Incoherent Photoproduction: J/ψN FSI

- **Sensitivity to hidden-color component of the deuteron wave function.**





Hidden-color component contribution dominates the cross section above neutron momenta of 500 MeV/c.

May dominate subthreshold photoproduction (on deuteron: E_{thr}=5.66 GeV).

$$\frac{d\sigma}{dt\, d|\vec{n}|} = \left.\frac{d\sigma}{dt}\right|_{\gamma p \to J/\psi p} 4\pi\vec{n}^2 \left[\varphi_{cc}\left(\frac{\vec{n}}{2}\right)\right]^2 \frac{F_1^4(t/4)}{F_1^2(t)}$$

J.-M. Laget, Nucl. Phys. A **581**, 397 (1995); M. Sargsian, private communication; S.J. Brodsky, E. Chudakov, P. Hoyer, J.M. Laget, Phys. Lett. B 498, 23 (2001).

Near-Threshold J/ψ Production off Deuteron

Quasi-Free Photoproduction off the Neutron

Search for a neutral hidden-charm pentaquark signal, P_c^0, (isospin partner of P_c^+).

Evaluate the ratio $\frac{\sigma_{\gamma(n)\to J/\psi n}}{\sigma_{\gamma(p)\to J/\psi p}}$ to probe the two-gluon exchange mechanism, which is flavor-blind.

Evaluate the ratio $\frac{\sigma_{\gamma(p)\to J/\psi n}}{\sigma_{\gamma p\to J/\psi p}}$ to probe for nuclear effects on the elementary amplitude or the bound nucleon.

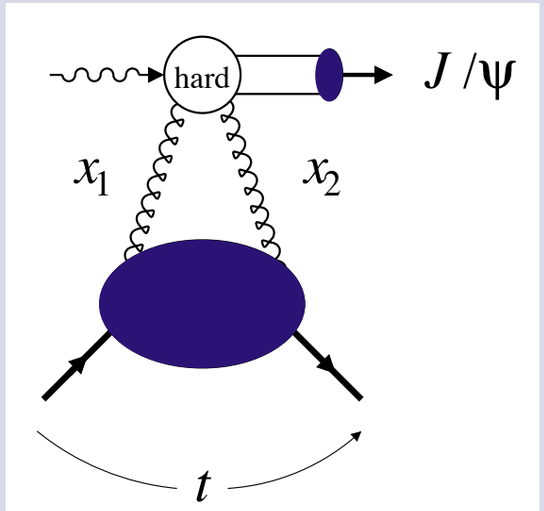
Near-Threshold J/ψ Production off Deuteron

Coherent Photoproduction

The t-dependence of the cross section can provide access to the deuteron gluonic structure (gluon form factor)

E_{thr}=5.66 GeV $\rightarrow |t_{min}|$=3.31 $(GeV/c)^2$

E=11 GeV $\rightarrow |t_{min}|$=0.26 $(GeV/c)^2$



$\varsigma = x_1 - x_2$

Large skewness

Hard scale set by the $c\bar{c}$ distance $r_\perp \sim 1/m_c$=0.13 fm. Probe is hard for all Q^2.

GPD Based Description, $|t| \leq 1$–2 GeV²

$$\frac{d\sigma}{dt} \sim |F_{gg}(x_1, x_2, t, \mu^2)|^2 = \frac{1}{(1 - t/m_{2g}^2)^4}$$

Universal F_{gg} expected, independent of μ^2; $m^2_{2g} \sim 1$ GeV²

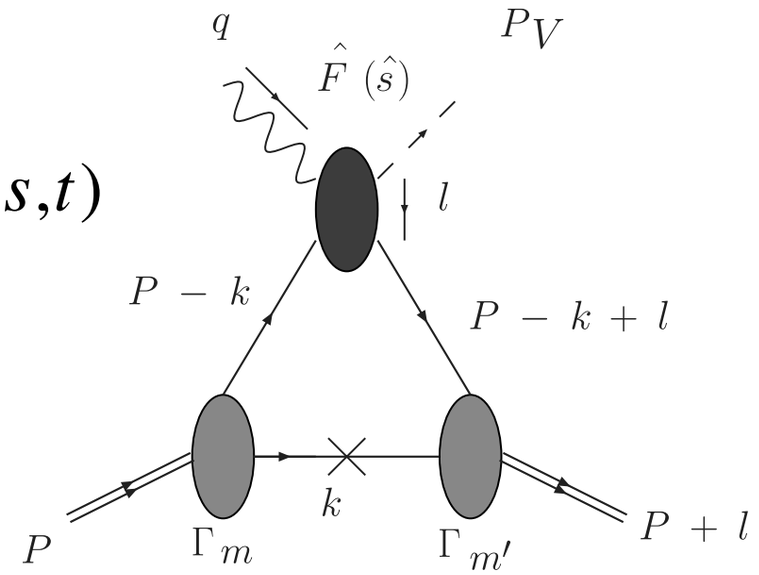
L. Frankfurt and M. Strikman, Phys. Rev. D 66, 031502(R) (2002).

Near-Threshold J/ψ Production off Deuteron

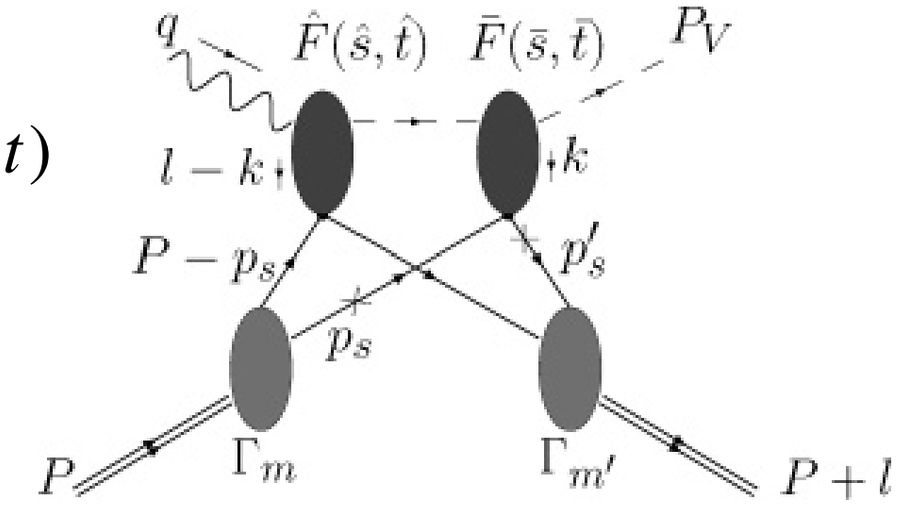
Coherent Photoproduction

Interpretation in terms of VMD and Glauber Theory:

$F^0_{m,m'}(s,t)$



$F^1_{m,m'}(s,t)$



$$\frac{d\sigma^{m,m'}}{dt} = \frac{1}{16\pi\Phi(s,0,m_N)}\left|F^0_{m,m'}(s,t)+F^1_{m,m'}(s,t)\right|^2$$

$$F^1_{m,m'} \sim -\int \frac{d^3\vec{p}_{s'}d^3\vec{p}_s}{(2\pi)^3}\Psi^*_{m'}\left(\frac{1}{2}-p_{s'}\right)\bar{F}(\bar{s},\bar{t})\hat{F}(\hat{s},\hat{t})\Psi_m(-p_s)$$

$$\bar{F}(\bar{s},\bar{t}) \sim \sigma_{J/\psi N}$$

Near-Threshold J/ψ Production off Deuteron

Coherent Photoproduction

The invariant cross section $\frac{d\sigma}{dt}_{\gamma d \to J/\Psi d}$ is important to:

- **Study nuclear gluon distributions**
- **Nuclear effects beyond the Born and multiple-scattering mechanisms**
- **Provide an independent estimate of $\sigma_{J/\psi N}$**

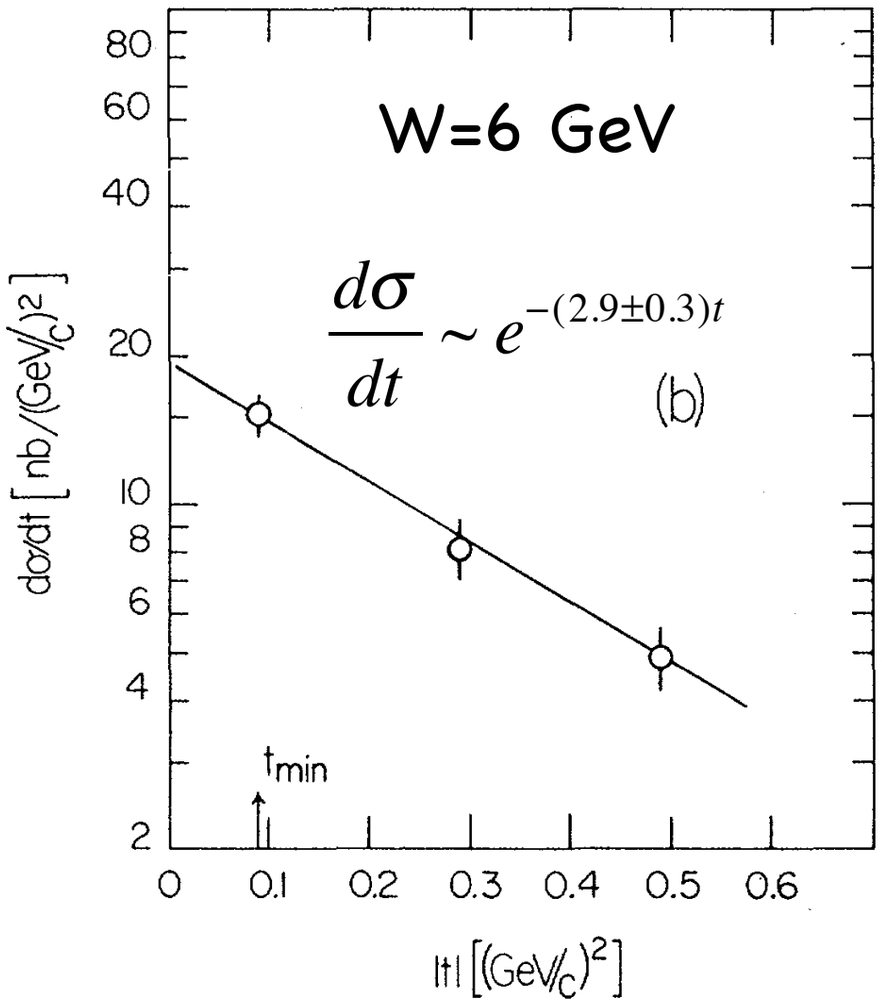
Near-Threshold J/ψ Deuteron Photoproduction Previous Measurements

SLAC, untagged real photon beam, e^+e^- and $\mu^+\mu^-$ detected

$\sigma_{tot}(J/\psi - N) \leq 0.8$ mb

TABLE I. Differential cross sections and kinematic conditions for the data points of this experiment. $t' \equiv t - t_{\min}$.

k (GeV)	E_0 (GeV)	$t_{\min}$ (GeV/c)^2	t' (GeV/c)^2	$d\sigma(t)/dt$ [nb/(GeV/c)^2]
		$\psi(3100)$ from deuterium target		
21.0	21.5	0.069	0.0	14.6 ± 1.2
19.0	20.0	0.088	0.0	15.0 ± 1.0
19.0	19.5	0.088	0.0	12.0 ± 1.1
17.0	17.5	0.116	0.0	10.8 ± 1.0
16.0	16.5	0.135	0.0	8.2 ± 1.1
15.0	20.0	0.160	0.0	7.7 ± 1.5
15.0	16.0	0.160	0.0	5.9 ± 1.0
13.0	13.5	0.236	0.0	3.8 ± 0.8
19.0	20.0	0.088	0.20	8.2 ± 1.1
19.0	20.0	0.088	0.40	4.9 ± 0.7

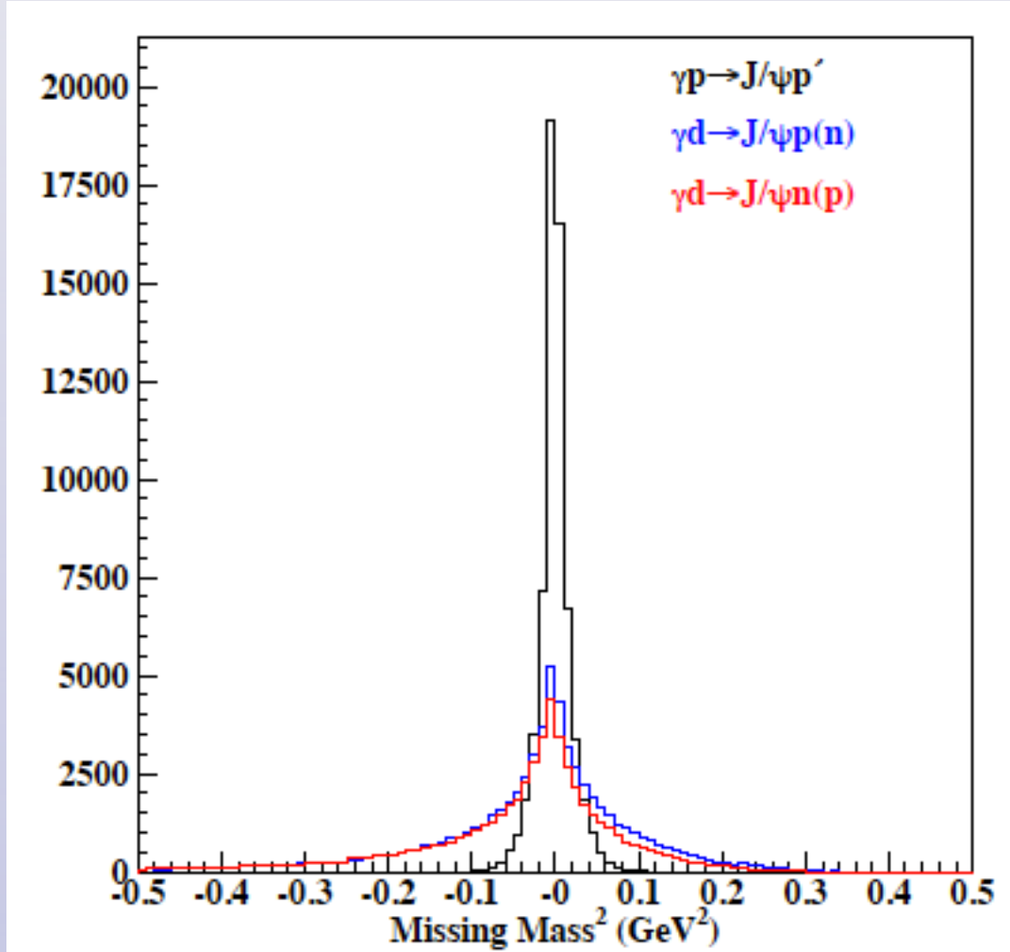


U. Camerini et al., Phys. Rev. Lett. **35**, 483 (1975)

Near-Threshold J/ψ Deuteron Photoproduction with CLAS12

Quasi-Free Quasi-Real Photoproduction off Bound Proton and Neutron

$$ed \to J/\psi N(e'N_s)$$



Detected: strike nucleon, J/psi decay products

Undetected: scattered electron, spectator nucleon

QF QR production identified kinematically by selection of events with small missing transverse momentum and small missing mass, assuming the target was at rest:

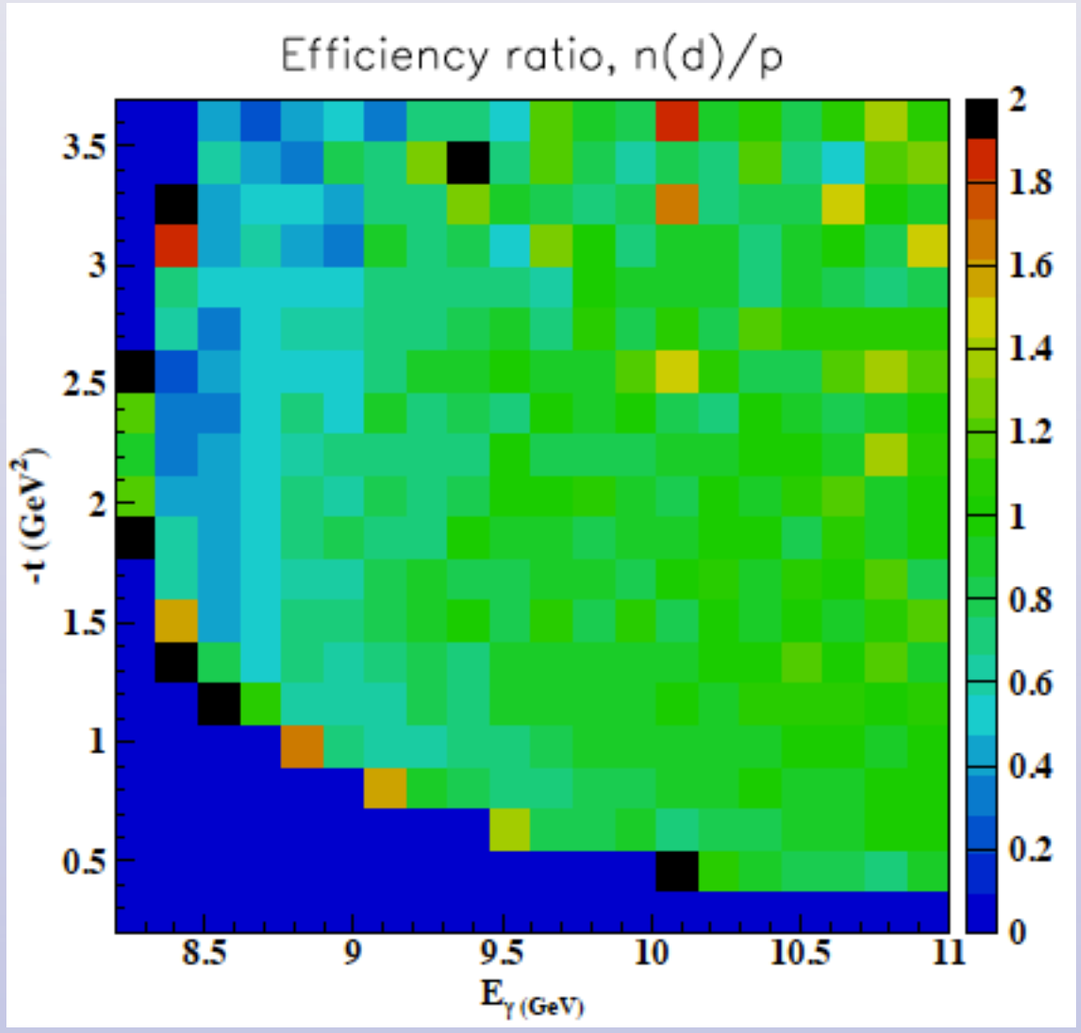
$$eN \to J/\psi NX,\ X \equiv e'$$

$E_\gamma = p_{N,z} + p_{J/\psi,z}$

Near-Threshold J/ψ Deuteron Photoproduction with CLAS12

Quasi-Free Photoproduction off Bound Proton and Neutron

$ed \to J/\psi N(e'N_s)$



Neutron detection efficiencies and kinematic distributions extracted by means of realistic deuteron wf and Fast MC simulation with realistic neutron detection efficiencies in FC.

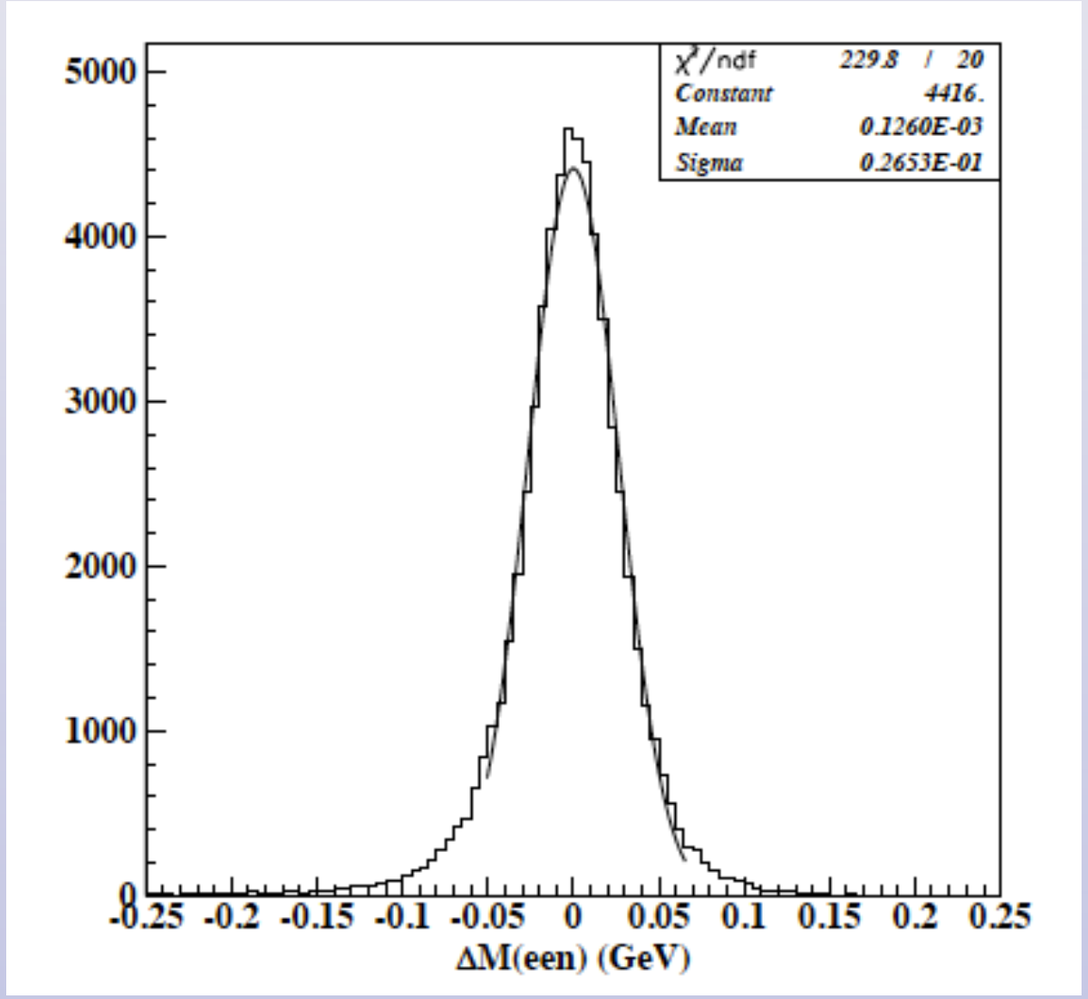
Bound nucleon kinematics and detection efficiencies comparable to those for production off free proton, expected counting rates then based on the estimates for free proton target.

Expected ~15 J/psi per day at full luminosity and e^+e^- decay measured only. Double rate if we detect the muon decay.

Near-Threshold J/ψ Deuteron Photoproduction with CLAS12

Quasi-Free Photoproduction off Bound Proton and Neutron

$$ed \rightarrow J/\psi N(e'N_s)$$



Sufficient IM(ne^+e^-) resolution for the pentaquark search.

Estimated number of pentaquarks per day (realistic tracking efficiency):

	Minimum - Maximum
$P_c(4380)$	31 - 975
$P_c(4450)$	45 - 1430

Near-Threshold J/ψ Deuteron Photoproduction with CLAS12

Quasi-Real Incoherent Photoproduction

$ed \rightarrow J/\psi\, pn(e')$

Detected: scattered nucleons, J/psi decay products

Undetected: scattered electron

CLAS Acceptance estimated with latest MC (4a.2.3) and reconstruction (5c.3.5): overall acceptance for rescattering: 5%.

Cross section estimates from model of A. Freese et al.

Expected total FSI yield: less than 10% of total QF yield, i.e. < 1 - 2 FSI events/day

In addition: $ed \rightarrow J/\psi Ne'(N)$, making use of the forward tagger.

Near-Threshold J/ψ Deuteron Photoproduction with CLAS12

Coherent Photoproduction

$ed \rightarrow J/\psi d(e')$

Detected: scattered deuteron, J/psi decay products

Undetected: scattered electron

No current cross section model estimates. Published data for φ photoproduction off proton and deuteron targets, $\frac{\sigma_{\gamma d \rightarrow \phi d}}{\sigma_{\gamma p \rightarrow \phi p}} = 1 - 4\%$.

Expected total coherent yield: ~ 1 event /2-3 PAC days. Expected t-coverage, 0.3 - 1 GeV/c^2.

Compatibility with Run Group B

Proposed measurements are compatible Run Group B Configuration

- Unpolarized LD2 target and 11-GeV electron beam, $L=10^{35}\ s^{-1}cm^{-2}$.
- Standard CLAS electron trigger.
- Charged-hadron detection in the Forward and Central Detectors.
- Neutron detection in the Forward Detector (will look for CND capabilities as well).
- Full torus field; electrons in-bending (75%), electrons out-bending (25%).
- Forward Tagger in operation.

Addition trigger: muon trigger (established in RGA).

Summary

Exclusive Near-Threshold J/ψ Photoproduction off Deuteron with CLAS provides an opportunity to study interesting physics

- direct access to the elementary J/ψN cross section.
- gluon structure of bound nucleons.
- search for isospin partners of the LHCB pentaquarks, P^0_c (4380) and P^0_c (4450).
- gluon structure of deuteron prior to EIC.

Very first experimental estimates of differential cross sections for these processes.

Supportive TAC review.

The End