Polarized Near-Threshold J/Ψ Opportunities at JLab

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Overview

Introduction

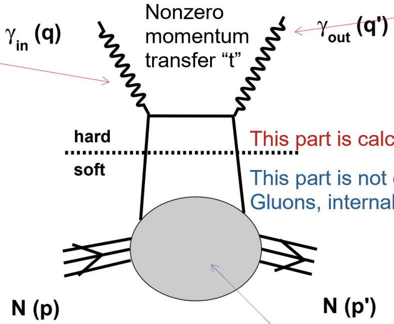
Jefferson Lab

- The focus and motivation for this study is the potential extraction of Generalized Parton Distributions (GPDs) allowed through the analysis of the production of vector mesons [1].
- In addition to the following justifications for the study of J/Ψ, it is currently the heaviest meson produceable at JLab during the 12 GeV era.

Generic handbag diagram for hard exclusive reaction involving photons

real or virtual photon strikes a quark

Momentum released from the quark via emission of virtual or real photon, or meson



This part is calculable; “hard”

This part is not calculable; “soft”: quark exchange, Gluons, internal motion, shadowing, spin...

Matrix element = GPD, Generalized Parton Distribution

Contain correlation between quark’s longitudinal momentum & transverse position

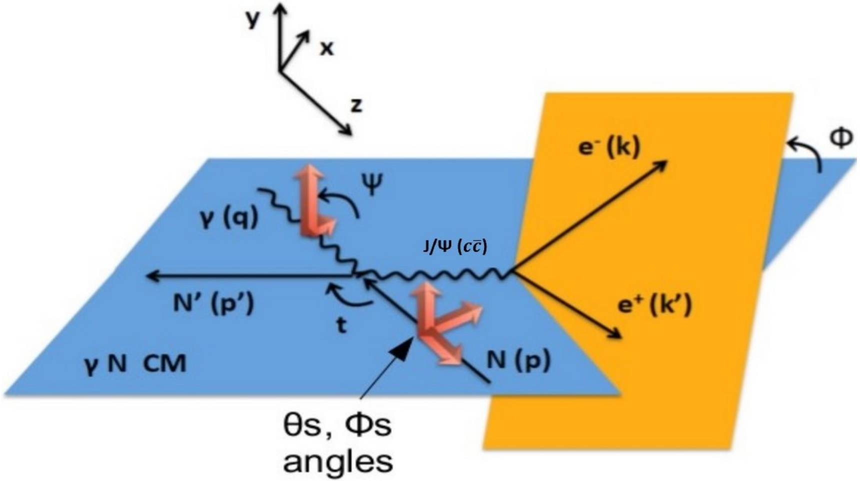


Figure: Angle map for J/Ψ photoproduction. (Courtesy of Dr. Marie Boër).

Study of J/Ψ

- Interesting GPDs [1] can be accessed by examining different hard exclusive reactions. Meson production happens to be a great choice for simplicity sake due to the set masses.
- "Penta-quark" Bound States and the Color Van Der Waals Force [2].
- Production of quarkonia states and heavy particles.
- Practicality.

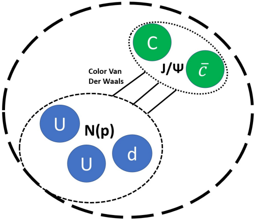


Figure: "Penta-quark" bound state cartoon.

Near Threshold

- Near Threshold, production is more likely to occur exclusively (leaving the target intact) [3].
- This exclusive reaction may allow for the access of GPDs.
- J/Ψ "pentaquark" bound states have only been seen in the lower reaches of J/Ψ production thresholds [2].
- Transfer momentum dependence has been proven for two-gluon exchange production models for vector mesons [4].
- Brodsky proposed that charm productions has evidence of having multi-gluonic dependence near its production threshold as higher order terms are not suppressed as well [5].

Significance

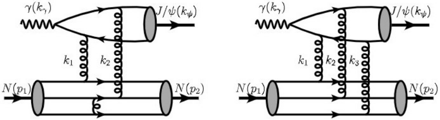


Figure: 2-gluon (left) and 3-gluon (right) production diagrams for J/Ψ [6].

- The 3-gluon production scheme was recently rejected by acknowledging Brodsky's lack of accounting for C-parity conservation that makes the 3-gluon term vanish [6].
- If Brodsky were correct, an asymmetry would likely arise between the two of these models due to 2 gluonic exchange being an asymmetrical process meaning that a bias could be seen if tested for.
- Experimental confirmation of the 3-gluon vanishing (further supporting for C-parity conservation) can then only be tested via a reaction with a polarized target.

Specifics of GPDs for J/Ψ Photoproduction

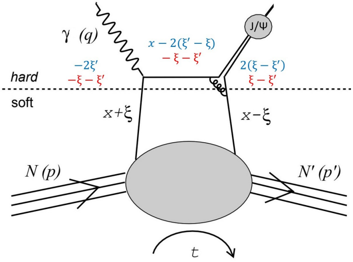
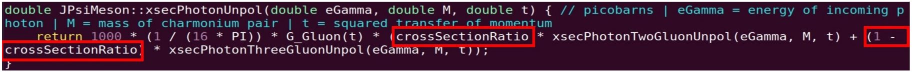


Figure: J/Ψ photoproduction reaction with the ξ interpretations added.

$\xi = \frac{Q^2+Q'^2}{2s+Q^2-Q'^2-2m_p^2+t} = \frac{2Q'^2}{2s-2m_p^2+1}$; $\xi' = \frac{Q^2-Q'^2+\frac{t}{2}}{2s+Q^2-Q'^2-2m_p^2+t} = \frac{\frac{t}{2}}{2s-2m_p^2+t}$

Notation used found in Guidal, Vanderhaegen [7] as described in [1], expressed in [8] as η and ξ respectively.

DeepSim



```
double JPsiMeson::xsecPhotonUnpol(double eGamma, double M, double t) { // picobarns | eGamma = energy of incoming p
hoton | M = mass of charmonium pair | t = squared transfer of momentum
    return 1000 * (1 / (16 * PI)) * G_Gluon(t) * (crossSectionRatio * xsecPhotonTwoGluonUnpol(eGamma, M, t) + (1 -
crossSectionRatio) * xsecPhotonThreeGluonUnpol(eGamma, M, t));
}
```

Figure: DEEPSim Screenshot emphasizing the mixing ratio.

Experiments like HERA had the advantage of large acceptances for detecting J/Ψ production [9] that JLab does not currently have so knowing the acceptance range for J/Ψ production is very pertinent to any simulation.

TCSAna

Originally built to study the TCS region. Options have been added for plotting of the GPD and production mechanism relevant kinematics for J/Ψ events. This effectives expands the range of analysis to cover the most of the accessible regions at JLab.

```
// jpsi = mu+ + mu-
// rho = pi+ + pi-
ALV_virtual_lab[0] = (ALV_minus_lab[0]+ALV_plus_lab[0]);
ALV_virtual_lab[1] = (ALV_minus_lab[1]+ALV_plus_lab[1]);
ALV_virtual_lab[2] = (ALV_minus_lab[2]+ALV_plus_lab[2]);
ALV_virtual_lab[3] = (ALV_minus_lab[3]+ALV_plus_lab[3]);

// jpsi angles in the lab frame
phi_virtual_lab = atan2(ALV_virtual_lab[2],ALV_virtual_lab[1]);
if (phi_virtual_lab<0) phi_virtual_lab+=2.*PI;
P_virtual_lab = sqrt(pow(ALV_virtual_lab[1],2)+pow(ALV_virtual_lab[2],2)+pow(ALV_virtual_lab[3],2))

theta_virtual_lab = acos(ALV_virtual_lab[3]/P_virtual_lab);
PT_virtual_lab = sqrt(pow(ALV_virtual_lab[1],2)+pow(ALV_virtual_lab[2],2));

//Calculate the mass based off of the detector readings
mass_meson = sqrt( pow(ALV_virtual_lab[0], 2) - pow(P_virtual_lab,2));
//Calculate the mass directly from Q'^2 which should ideally equal the mass of the messon
//This is used as a check on the above calculated method
mass_meson_2 = sqrt(Qp2);

// some kinematics that was not in the tree
float ss = pow(M_proton, 2.) + 2. * M_proton * Egamma;
float xi = Qp2/(2.*(ss-pow(M_proton,2)) + tt - Qp2);
float xip = (tt/2)/(2.*(ss-pow(M_proton,2)) + tt);
```

Figure: TCSAna Screnshot showing kinematic calculations.

Current Results

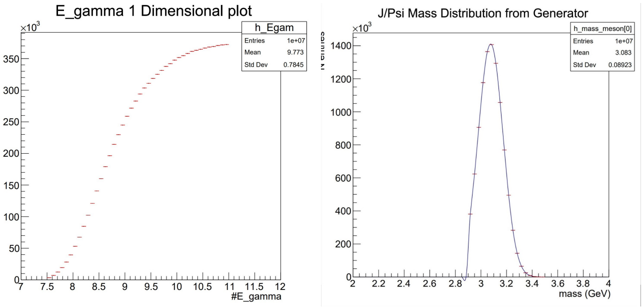


Figure: Left: E_γ vs. Occurrences defining the Threshold Region; Right: Mass Distribution of J/Ψ generated with roughly 10% resolution.

*NOTE: All data shown is from and exclusively 2-gluon production mechanism unpolarized target run of J/Ψ photoproduction events unless otherwise specified.

Results Extended

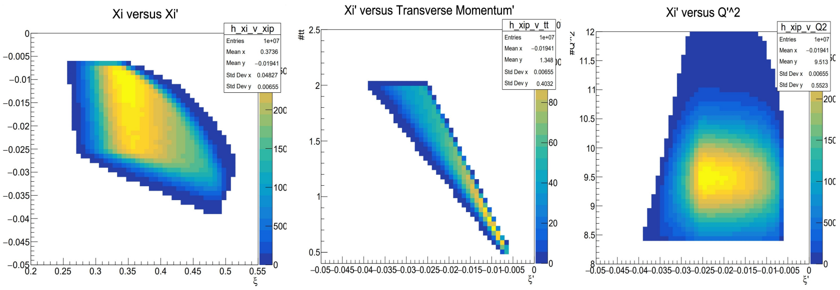


Figure: Left: ξ vs ξ' showing near constant ξ';Center: ξ' vs t showing the momentum slice accessed; ξ' vs. Q'^2 to show energy slice accessed

The Need for Target Polarization

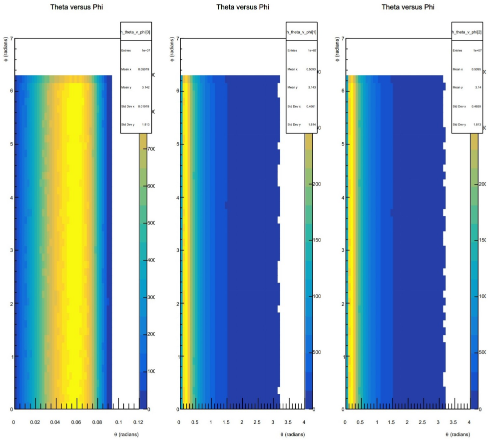


Figure: Θ versus Φ from an exclusively 2 gluon production scheme across the threshold region.

The Need for Target Polarization

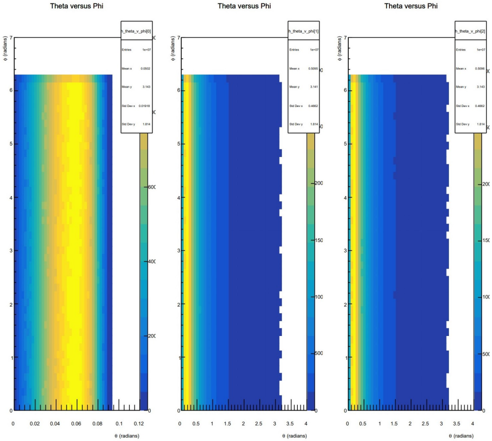


Figure: Θ versus Φ from an constant 50-50 mix of a 2 and 3 gluon production scheme across the threshold region.

The Need for Target Polarization

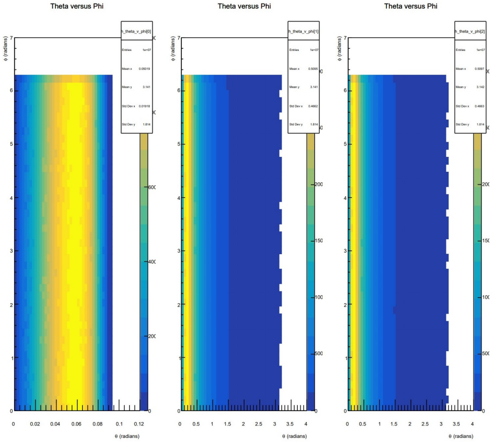


Figure: Θ versus Φ from an exclusively 3 gluon production scheme across the threshold region.

- Unpolarized target data cannot quantify 2 vs. 3 gluon production dominance near threshold and reflects the type of data that should be generated with polar
- With a transversely polarized target we could experimentally demonstrate the lack of asymmetry present dependent on the rates of C-parity conservation violating production process.
- For GPD extraction in this reaction we need more robust modelling of polarized cross sections to build into DEEPSim for adequate evaluation of whether it should be ruled out or is just challenging.
- **Theory development is needed!!!**

Comparisons with DVCS, TCS, and DDVCS

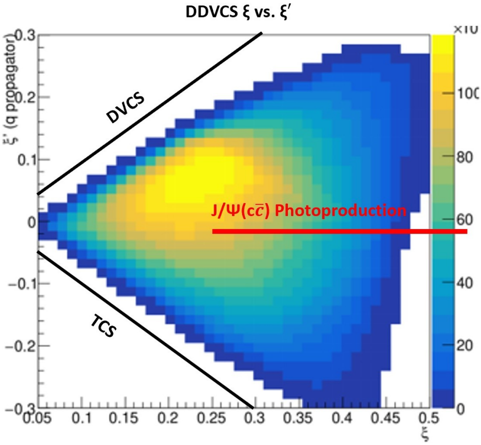


Figure: DDVCS ξ vs. ξ' with J/Ψ Photoproduction, DVCS, and TCS cartoon overlay shown.

Help Wanted

Summary

- Can we interpret near threshold J/Ψ in terms of GPDs?
- This may complement "penta-quark" bound state studies in the threshold production region of J/Ψ.
- One of the first steps for building out an understanding of this region is to more robustly describe polarized cross sections at these energies. A polarized target is required for an adequate test of C-party conservation.
- If we have a muon detector, electroproduction could be later expanded into to sweep across a greater region of potential GPDs (without concern of a selection bias), but the production should be understood first.

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