J/ψ at JLab 12 GeV

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Outline

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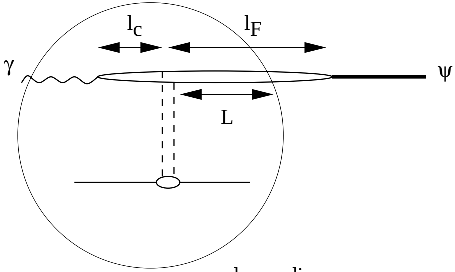
J/ψ photoproduction at 12 GeV

Charmed particles have been studied extensively since 1974

What is special about J/ψ photoproduction at 12 GeV?
Can we use J/ψ as a probe for the nucleon/nucleus?

- Photoproduction of close to threshold (gluon GPD at high x)
- Double-spin asymmetry (polarized gluon GPD at high x)
- Interaction of $\mathrm{J}/\psi(1\mathrm{S})$ - a “long living” particle - with matter

J/ψ photoproduction at 10 GeV: Scales



$$r_\perp \sim \frac{1}{\alpha_s \cdot m_c} = 0.3\ fm$$

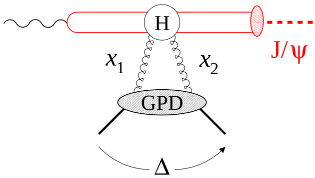
At $E_\gamma = 10$ GeV:

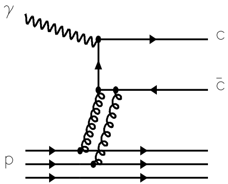
$$\ell_{coh} = \frac{2E_\gamma}{4m_c^2 + Q^2} \approx 0.4\ fm$$

$$\ell_F \cong \frac{2E_\gamma}{m^2_{\psi'} - m^2_{J/\psi}} \sim 1\ fm$$

- No coherent production on heavy nucleus: $\ell_{coh} \ll R_A$
- No shadowing effects: $\ell_{coh}, \ell_F < R_A$
- VMD not applicable: $\ell_{coh} < 1$ fm

J/ψ photoproduction at 10 GeV: Dynamical models

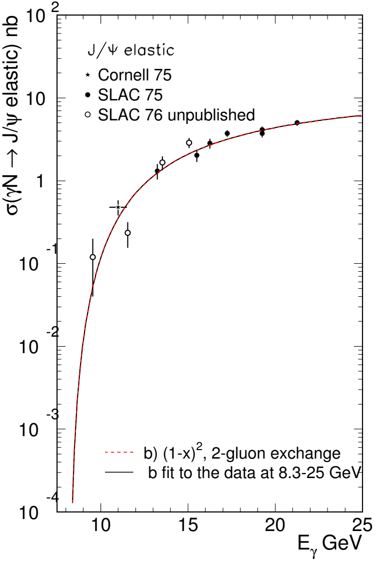




- Partonic soft mechanism Frankfurt..2002..
  - Well tested at high energies
  - 2-gluon formfactor: $\frac{d\sigma_{\gamma P \to J/\psi p}}{dt} \propto (1 - t/1.0 GeV^2)^{-4}$
  - 10 GeV: gluons $x_1 \neq x_2 \sim 1$ $|t_{min}| > 0.4$ GeV/c
- Hard scattering mechanism Brodsky.., 2001
  - 10 GeV: Quark counting rules
  - 2-gluon exchange $\propto (1 - x)^2$
  - 3-gluon exchange $\propto (1 - x)^0$

Unique probe of small-size gluon configurations in proton

J/ψ photoproduction at 10 GeV: Dynamical models

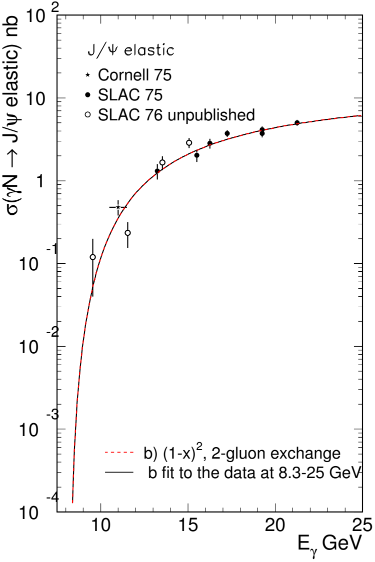


Both models fit the data at 11-25 GeV:

- Frankfurt 2003
- Brodsky 2001: 2-gluon exchange (red curve)

- Brodsky 2001: 3-gluon exchange alone does not fit the data

J/ψ photoproduction at 10 GeV: Dynamical models



Both models fit the data at 11-25 GeV:

- Frankfurt 2003
- Brodsky 2001: 2-gluon exchange (red curve)

Subthreshold experiment E-03-008

No J/ψ observed
Spectral functions $\otimes$ σ not large

ψN Interaction: Physics

- Small size color dipole $r_\perp \sim \frac{1}{\alpha_s \cdot m_c} = 0.3$ fm
  interaction $\propto$ color dipole moment $\propto r_{c\bar{c}}$ (small)
  $\Leftrightarrow$ color transparency,
  $\sigma_{\rm tot}^{\psi N} \ll \sigma_{\rm tot}^{\pi N} \approx 30$ mb

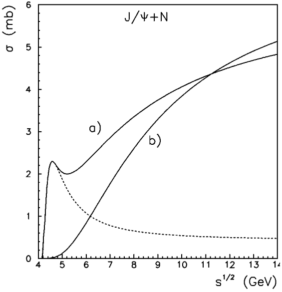
- Low energy: attractive potential (Luke,Manohar,Savage,1992)
  similar to Van der Waals, $E_{binding} \sim 8\ MeV$

- Absorption: breakup to $D\overline{D}$, $\psi + N \rightarrow \Lambda_c^+ \overline{D}$

ψN Interaction: $\sigma^{\psi N}$ Theoretical Calculations

Various models: VMD, exchange meson currents, etc.

authors	model	$\sqrt{s}$, GeV	$\sigma^{\psi N}$, mb
Brodsky,Miller,1997	Van-der-Waals potential	small	7
Kopeliovich...,1994	GVMD, wave functions	10–400	3–10
Gerland..., 1998	VMD, data for VM	>7	3.6
Sibirtsev..., 2001	boson exchange	>4	2.2
	Lattice		



Sibirtsev et al, 2001

- a) FF calculations, ψ+N→$\Lambda_c^+\overline{D}$ $D\overline{D}$
- b) short distance QCD

ψN Interaction: Experimental Access

1. Calculated from photoproduction on nucleons using VMD/GVMD

   γN $>$20 GeV $\sigma^{\psi N}_{\rm tot} \sim$ 2.8 - 4.1 mb model dependent

2. Nuclear absorption: from A-dependence, Glauber model

   γA 20 GeV $\sigma^{\psi N}_{\rm abs} = 3.5 \pm 0.9$ mb clean interpretation poor accuracy

   pA $>$100 GeV $\sigma^{\psi N}_{\rm abs} = 4.2 \pm 0.4$ mb not ψN: $\ell_{coh}, \ell_F \gg R_A$ contamination $\chi_c, \psi\prime$

We use arguments from Farrar et al.,1990, Kharzeev et al, 2007

Experiment in Hall C

PR12-07-106 for Hall C: conditionally approved by PAC32.
Objectives:

1. Accurate measurement of J/ψ-nucleon cross-section at $\sqrt{s} = 5$ GeV
   - Test theoretical ideas (color dipole model, Van-der-Waals force)
   - Benchmark for future calculations
   - Interest for heavy ion physics.
2. Measurement of J/ψ photoproduction cross section $\frac{d\sigma}{dt}(E_\gamma)$ at $E_\gamma \sim 8.8 - 11$ GeV
   - Input for (1).
   - Probes large-x gluon GPD / small-size gluon configurations in proton.

Experiment: Rates on Nuclear Targets

- Acceptance $\epsilon \approx 0.03\%$
- Internal Bremsstrahlung 1.6%
- No nuclear absorption is assumed for the moment

	^{1}H	^{2}H	Be	C	Al	Cu	Ag	Au
A	1	2	9	12	27	63.5	108	197
Z	1	1	4	6	13	29	47	79
T/T_{RL}	0.022	0.027	0.10	0.10	0.10	0.10	0.10	0.10
J/ψ per h	170	340	560	370	208	112	78	55
Time*, h	24	12	7	11	19	36	51	72

* – in order to detect 4000 events per target

- 200 hours on nuclear targets

Experiment: Expected Results on $\sigma^{\psi N}$

Total error per target ∼3%

- beam flux $\sim 1\%$
- target thickness $< 1.5\%$
- Fermi correction $< 1.\%$
- statistics $\sim 1.5\%$
- acceptance: nearly cancels
- other $\sim 0.5\%$

Glauber model used to extract $\sigma^{\psi N}$

Expected transparencies $T_N(A) = \sigma_A / A\sigma_N$

	$\sigma^{\psi N}$ mb	A: 9	12	27	63	108	197	$\delta(\sigma^{\psi N})$ mb
T	1.0	0.982	0.980	0.974	0.963	0.952	0.931	0.29
	3.5	0.938	0.931	0.908	0.870	0.833	0.760	0.25
	7.0	0.876	0.863	0.816	0.740	0.665	0.519	0.18

$\sigma^{\psi N} \approx (3.5) \pm 0.12 \pm 0.20$ mb at $\sqrt{s} \sim 5$ GeV

SLAC: 0.80 ± 0.60

Hall D Potential for Heavy Quark Physics

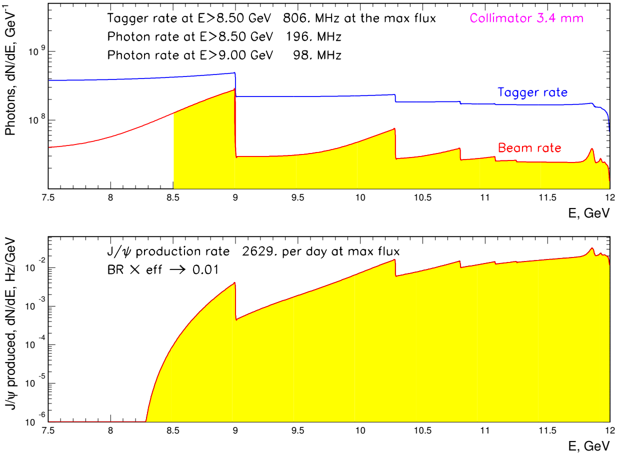
Obvious advantages to Hall C

1. Large uniform acceptance for all particles, including the recoil: potentially a good measurement of $\frac{d\sigma}{d\Omega}(E, t, \cos\theta)$
2. Separation "elastic"/"inelastic" $\gamma p \to \psi p$ vs $\gamma p \to \psi N\pi$
3. Tagged photon beam of the highest flux usable
4. Possibility to run in parallel with the main program
5. Fast DAQ - no need for a special trigger

Disadvantages to Hall C

1. Lower beam photon flux
2. Worse mass/energy resolution
3. Linear polarization is useless at 8.4-9 GeV

Hall D J/ψ rate, standard collimation



Low beam: 800 events is 1 year, for free

Tagger rate:
0.4 GeV: 100 MHz
bucket: 0.2/2 ns

Tagger $<$11.6 GeV

High beam rate
J/ψ rate: $\sim$50 / day
Low beam rate
J/ψ rate: $\sim$5 / day

Double Spin Asymmetry

Longituninally polarized beam, target:

$A_{LL} \sim \frac{\tilde{H}(x,\xi,t)}{H(x,\xi,t)}$

$\tilde{H}(x, \xi \to 0, t \to 0) \to x\Delta g(x)$

Pre-LOI by M.Osipenko et al for Hall B

1. Luminocity 10^{35} cm^{-2}s^{-1}: 100 nA, 3 cm target
2. Polarized target: ammonia $<$ 100 nA, dilution ~ 0.2
3. Asymmetry $\sim 0.05 \Rightarrow >$1 M events needed
4. Large acceptence (? - need a number)
5. About 10^6 events in 6 months
6. Muon detector needed

SoLID (Hall A) may run at 10^{37} cm^{-2}s^{-1}

mEIC Outlook

Unpolarized production measured at HERA at $x \sim 0.0001$
mEIC potential:

- $x \sim 0.01$
- Better accuracy

Polarized production: 12 GeV? ($x \sim 0.4$)
mEIC potential:

- $x \sim 0.01$
- No dilution: FOM $\times 25$
- Luminocity 10^{34} - OK
- Better accuracy

Summary for J/ψ Physics

1. Measurements at 12 GeV:
   - $\frac{d\sigma}{d\Omega}(E, t, cos\theta)$ for $9.5 < E_{beam} < 11.4$ GeV
   - The cross section for ψN
   - ? Double-spin asymmetries
2. Potential mEIC:
   - $\frac{d\sigma}{d\Omega}(E, t, cos\theta)$ for $x \sim 0.01$
   - Double-spin asymmetries

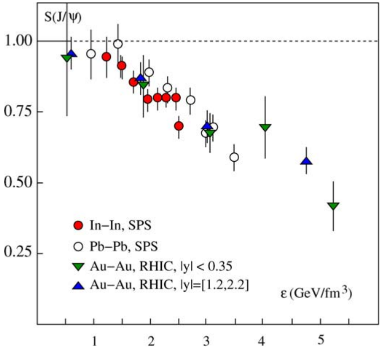
ψN Interaction: Signature for QGP

J/ψ suppression in *AA* collisions $\Rightarrow$ signature for QGP

Range: $\sqrt{s} \sim 5 - 400$ GeV

deficiency found, using

experiment	$\sigma_{abs}^{\psi N}$
SPS	4.18 mb
RHIC	$\sim$ 3. mb

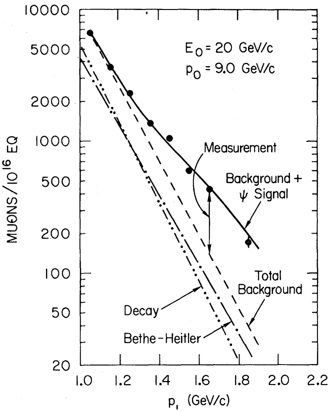


Interpretation: not resolved yet
mixture ψ, χ_c...; regeneration at RHIC

- JLab experiment - measure $\sigma_{abs}^{\psi N}$ at lower energy $\sqrt{s} \sim 5$ GeV, in different conditions

ψN Interaction: Experiment at SLAC 1977

- The cleanest method used so far: $\ell_{coh}, \ell_F < R_A$
- Large experimental uncertainties



- 20 GeV e^- on Be and Ta targets
- Detecting only μ^-, through iron
- The background was calculated (decays, Bethe-Heitler)
- Nuclear coherence not measured

$$\sigma(Be)/\sigma(Ta) = 1.21 \pm 0.7$$

$$\Rightarrow \sigma_{\psi N} = 3.5 \pm 0.8 \pm 0.6 \text{ mb}$$

Authors: syst. errors might be larger

- JLab: we can do a much more accurate experiment!

Experiment: Setup

- Use decays to $e^+e^-(6\%), \mu^+\mu^-(6\%)$ to identify J/ψ mass

Standard Hall C equipment

- High rate at various targets
- Low background: $< 2\%$, scaled from Cornell, SLAC
- Reconstruction of E_γ, identification of γ+p$\rightarrow$J/ψ+p

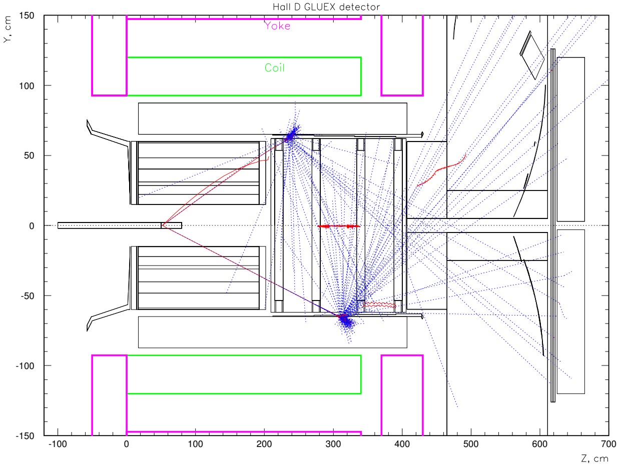
Hall C Spectrometers

- HMS: e^-, μ^- at $\theta > 20^\circ$
- SHMS: e^+, μ^+ at $\theta < 20^\circ$
- $e^+, e-$ Gas Cher., Shower
- $\mu^+, \mu-$ Gas Cher.

Beam and target

- Bremsstrahlung by 50 μA beam
- 6 targets $A = 9 - 197$, 10% r.l. thick
- Each target: 3 plates $\sim$ 5 cm apart
- 20 cm LH_2 with a 7% radiator
- 20 cm LD_2 with a 7% radiator

Hall D: detecting γ+p$\rightarrow$p+J/$\psi\rightarrow e^+e^-$



Acceptance:

$e^\pm$ 75/25 BCAL/FCAL

p 88/12 BCAL/TOF

Accept.: $\varepsilon \sim$70%

Losses: $\varepsilon \sim$70%

Identification:

e^+e^- - calorimeter

$\mu^+\mu^-$ - ?

p 70%, TOF π^+ $\times$0.01

p kin. fit π^+ $\times$0.01

Hall D: detecting J/ψ, resolutions

- Track momentum, angular resolutions - from reconstruction
- Track fit assumes the beam $\sigma_X = \sigma_Y = 1$ mm
- Tagger energy resolution 60 MeV / $\sqrt{12}$ = 17 MeV

Event fit	Variable		
	M_ψ GeV/c^2 e^+,e^-	E_{beam} GeV e^+,e^-,p	M_{recoil} GeV/c^2 e^+,e^-,tagger
none	0.045	0.190	0.100
Using E_{tagger}	0.022	-	-
Using M_ψ	-	0.080	0.032

- M_ψ window (no fit) $5\sigma \sim 0.230$ GeV/c^2: BG$\sim$7%
- Tagger window $5\sigma \sim 1$ GeV (no fit), 0.4 GeV (M_ψ fit)