J/ψ Photoproduction at 12 GeV

E.Chudakov[1]

[1] JLab

Small Size Configurations at high-t,
Workshop at Jlab, March 2011

Outline

Outline

Outline

1. Introduction
   - Experimental opportunities
   - ψN Interaction
2. Program at JLab
   - Experiment in Hall C
   - Hall D Potential
   - Hall B Potential
3. Summary

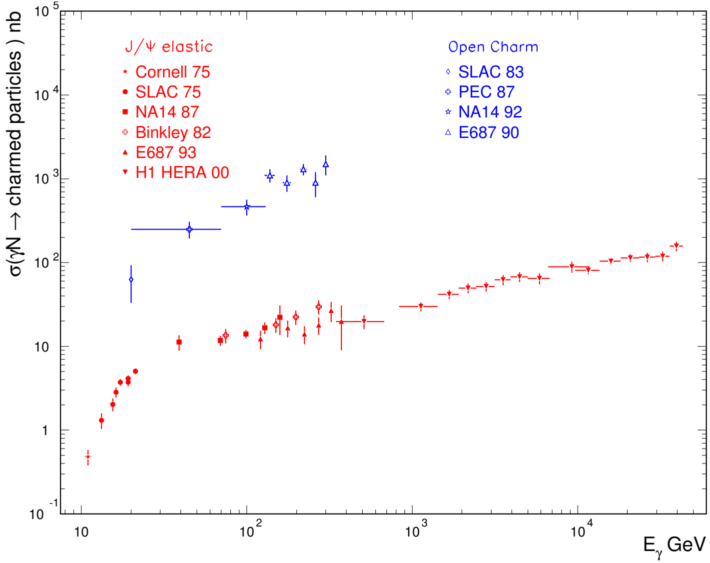
Charm photoproduction at 12 GeV

Charmed particles have been studied extensively since 1974
Can be used as a tool to study the hadronic structure

- Photoproduction cross section $\sigma_{charm} \sim 10^{-5} - 10^{-4}\sigma_{total}$
- Useful decays $BR < 0.06$
- Signal extraction: 2-body decay, small σ_M, leptons, vertex det.

	reaction	E_γ GeV threshold	useful decay mode	BR	cross section E_γ, GeV	σ nb
	$\gamma p \rightarrow \eta_c(1S)p$	7.7 GeV	$\eta_c(1S) \rightarrow p\bar{p}$	0.12%	-	-
⋆	$\gamma p \rightarrow J/\psi(1S)p$	8.2 GeV	$J/\psi(1S) \rightarrow e^-e^+/\mu^-\mu^+$	6.0%	11.	0.5±0.2
⋆	$\gamma p \rightarrow \Lambda_c^+ \bar{D}^0$	8.7 GeV	$\bar{D}^0 \rightarrow K^+\pi^-$	4.0%	20.	$\sim$ 63.±30.
	$\gamma p \rightarrow \Lambda_c^+ D^*(2010)^0$	9.4 GeV	$D^*(2010)^0 \rightarrow \bar{D}^0 X$	100.0%	20.	$\sim$ 63.±30.
	$\gamma p \rightarrow \chi_{c0}(1P)p$	9.6 GeV	$\chi_{c1}(1P) \rightarrow K^+K^-$	0.71%		
	$\gamma p \rightarrow \chi_{c2}(1P)p$	10.3 GeV	$\chi_{c1}(1P) \rightarrow J/\psi(1S)\gamma$	13.0%	90.	$<$ 27% J/ψ
	$\gamma p \rightarrow \psi(3770)p$	11.0 GeV	$\psi(3770) \rightarrow e^-e^+/\mu^-\mu^+$	0.8%	21.	1.1±0.4
	$\gamma p \rightarrow D\bar{D}p$	11.1 GeV			20.	$\sim$ 63.±30.

Photoproduction measurements



Potential experimental opportunities at 12 GeV JLab

A vertex detector for $\Lambda_c^+, \overline{D}$ can hardly be used.

Best chances:

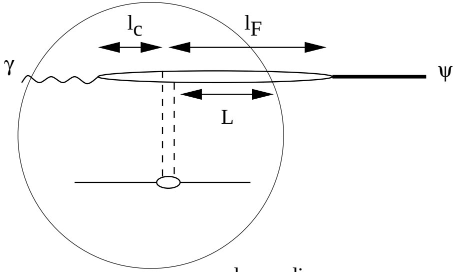
- $\gamma p \to p\, J/\psi(1S) \to e^- e^+/\mu^- \mu^+$, proved at Cornell 11 GeV
- $\gamma p \to \Lambda_c^+ \overline{D}^0 \to K^+ \pi^-$ $M_{miss} \sim M_{\Lambda_c^+}$ - seems possible
- $\gamma p \to p\, \eta_c(1S) \to p\bar{p} < 0.01$ of $J/\psi(1S)$ - harder

Physics with J/ψ

- Photoproduction of $J/\psi(1S)$ close to threshold (GPD)
- Interaction of $J/\psi(1S)$ - a “long living” particle - with matter
- Double-spin longitudinal $J/\psi(1S)$ (GPD, for CLAS)

Can we use $J/\psi(1S)$ as a probe for the nucleon/nucleus?

J/ψ photoproduction at 10 GeV: Scales



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

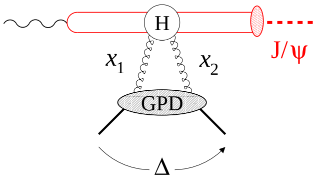
At $E_\gamma = 10$ GeV:

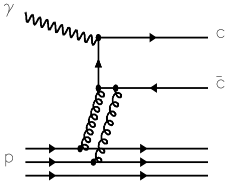
$$\ell_{coh} = \frac{2E_\gamma}{4m_c^2 + Q^2} \approx 0.4\ fm$$

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

- 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

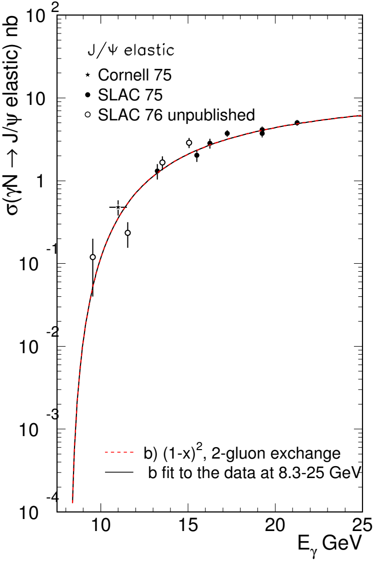




- **Partonic soft mechanism** Frankfurt..2002..
  - Well tested at high energies
  - 10 GeV: gluons $x_1 \neq x_2 \sim 1$ $|t_{min}| > 0.4$ GeV/c
  - 2-gluon formfactor: $\frac{d\sigma_{\gamma P \to J/\psi p}}{dt} \propto (1 - t/1.0 GeV^2)^{-4}$
- **Hard scattering mechanism** Brodsky.., 2001
  - 10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

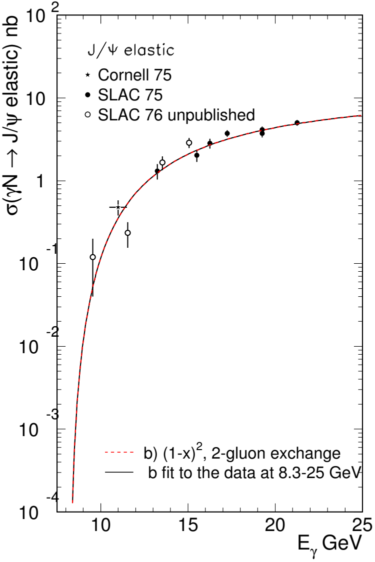


Both models fit the data at 11-25 GeV:

- 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

Photoproduction on nucleons

1. Measure $\frac{d\sigma}{dt}(E)$ for γ+p$\rightarrow$J/ψ+p
close to threshold, at $E_\gamma \sim$ 8.5 – 11 GeV
Low energy $\Rightarrow$ sensitive to high-x gluons in the nucleon

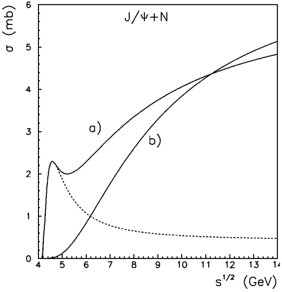
ψN Interaction: Physics

- 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 $\mathrm{D\overline{D}}$, ψ+N$\rightarrow\Lambda_c^+\overline{\mathrm{D}}$

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$\rightarrow\Lambda_c^+\overline{\mathrm{D}}$ $\mathrm{D}\overline{\mathrm{D}}$
- b) short distance QCD

ψN Interaction: Experimental Access

1. Calculated from photoproduction on nucleons using VMD/GVMD

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

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

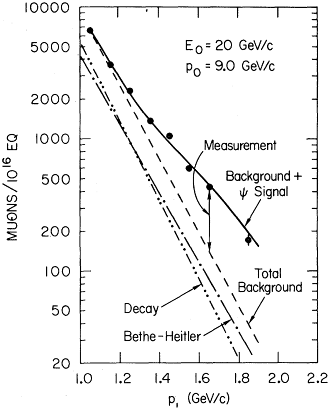
   γA 20 GeV $\sigma_{\rm abs}^{\psi N} = 3.5 \pm 0.9$ mb clean interpretation poor accuracy

   pA $>$100 GeV $\sigma_{\rm abs}^{\psi N} = 4.2 \pm 0.4$ 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

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!

Photoproduction on Nuclei

1. Measure the A-dependence of $\sigma(\gamma + A \rightarrow J/\psi + X)$, extract $\sigma^{\psi N}_{\rm abs}$ at $\sqrt{s} \sim$ 5 GeV
   Much improved accuracy and a cleaner interpretation.

Experiment in Hall C

PR12-07-106 for Hall C, conditionally approved (questions concerning the the physics/motivation). Dropped by the jeopardy rules.

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: 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$\to$J/ψ+p

Hall C Spectrometers

- HMS: e^-, μ^- at $\theta > 20°$
- SHMS: e^+, μ^+ at $\theta < 20°$
- $e^+, e-$ 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

Experiment: Rates on Nuclear Targets

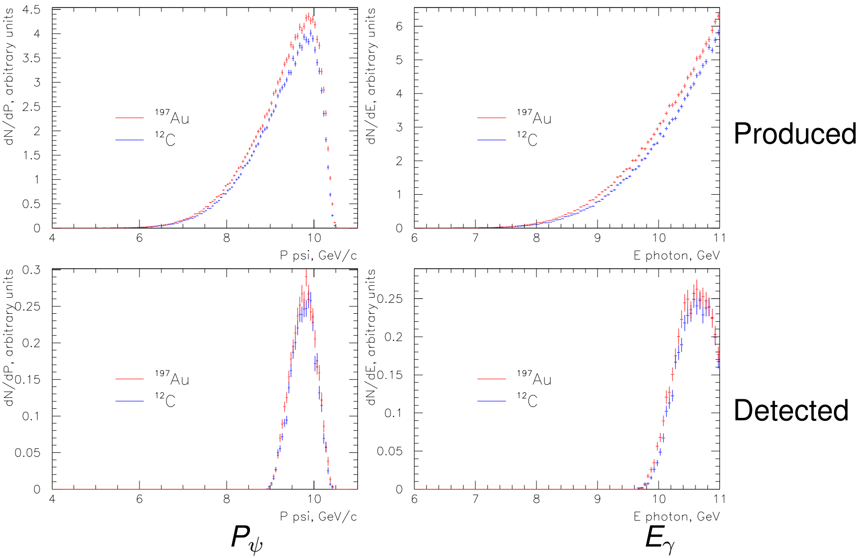
- Acceptance $\epsilon \approx 0.03\%$
- Internal Bremsstrahlung 1.6%
- No nuclear absorption is assumed for the moment

	^{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

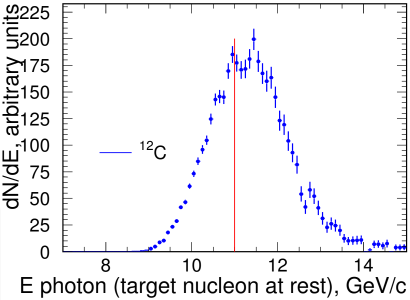
- 200 hours on nuclear targets

Hall C: acceptance



Fermi motion Correction and Hydrogen Measurements

Fermi motion $\otimes\ \sigma_{\gamma N \to \psi X}(E_\gamma)$:
$Au/C \approx 1.10$ sensitive to $\sigma(E_\gamma)$
Need to measure $\sigma(E_\gamma)$



Plan for $\sigma_{\gamma p \to \psi p}(E_\gamma)$ measurement

3 endpoints at 8.8, 10.2, 11.0 GeV
"Elastic" $\gamma p \to \psi p$ dominates
Use reconstructed photon energy $\mathcal{E}_\gamma$
$\mathcal{E}_\gamma > E_{e^-} - 0.3$ GeV: pure "elastic"
Constraints from SLAC $E_\gamma > 15$ GeV
Simulation shows: $\delta(Au/C) < 0.01$

Measurements on LH_2

$< E_\gamma >$ GeV	$\sigma_\psi(E)$ error
8.7	15%
10.0	3%
10.8	3%

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

Total error per target $\sim$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

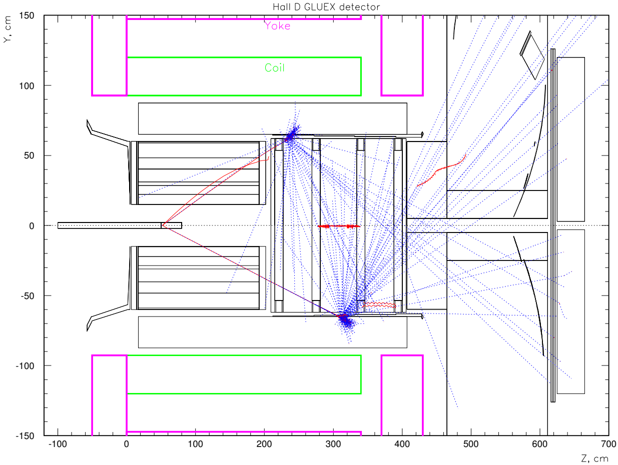
Obvious advantages to Hall C

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: detecting γ+p→p+J/ψ→e^+e^-



Acceptance:

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

p 88/12 BCAL/TOF

Accept.: $\varepsilon \sim$70%

Losses: $\varepsilon \sim$70%

Identification:

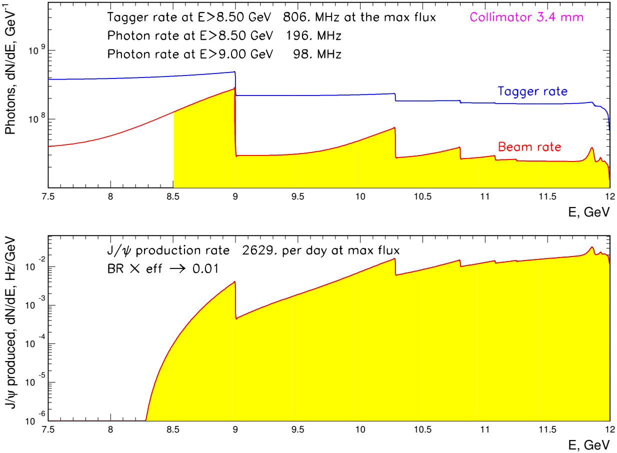
e^+e^- - calorimeter

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

p 70%, TOF π^+ $\times$0.01

p kin. fit π^+ $\times$0.01

Hall D 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}

Summary for J/ψ Physics

1. Potential 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 (Hall B)
2. Organization
   - Program well developed for Hall C
   - The $\frac{d\sigma}{d\Omega}(E, t, cos\theta)$ can be measured in Hall D parazitically - needs to be elaborated
   - Hall B?