Charm at threshold and ψ-N cross-section

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- LOI to PAC13 by P.E. Bosted, J.A. Dunne, R. Ent, J.H. Mitchell for measurement of $\sigma_{\psi N}$ with subthreshold photoproduction. Too high background.
- Charm at Threshold: a new LOI (see http://www.jlab.org/ gen/charm/meetings.html) Measurement of $\sigma_{\psi N}$ - a part of that LOI

In this talk:

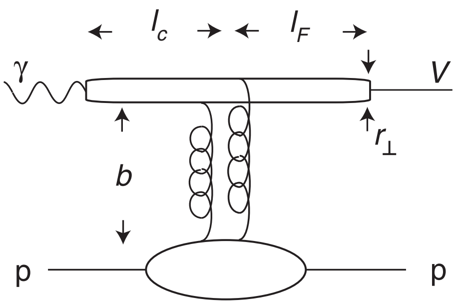
- General features of charm photoproduction
- $\sigma_{\psi N}$ - theoretical and practical interest
- Capabilities of the facilities at JLAB to detect charm
- Proposed measurement of $\sigma_{\psi N}$

Charm at threshold and ψ-N cross-section

CEBAF at 12 GeV crosses the charm γN threshold
(8.2 GeV for $\mathrm{J}/\psi(1\mathrm{S})$)
$\Rightarrow$ a new probe to study the nucleon/nucleus

Important features of charm photoproduction:

- Small size



$$m_c \approx 1.5\ GeV > \Lambda_{QCD}$$
$$r_\perp \sim \frac{1}{m_c} = 0.13\ fm$$
At $E_\gamma \sim 10$ GeV:
$$\ell_{coh} = \frac{2E_\gamma}{4m_c^2+Q^2} \approx 0.4\ fm$$
$$\ell_F \cong \frac{2}{m_{\psi'}-m_{J/\psi}} \left[\frac{E_{J/\psi}}{2m_c}\right] \sim 1-2\ fm$$
$$b \sim 1/\sqrt{-t} \sim 0.2\ fm$$

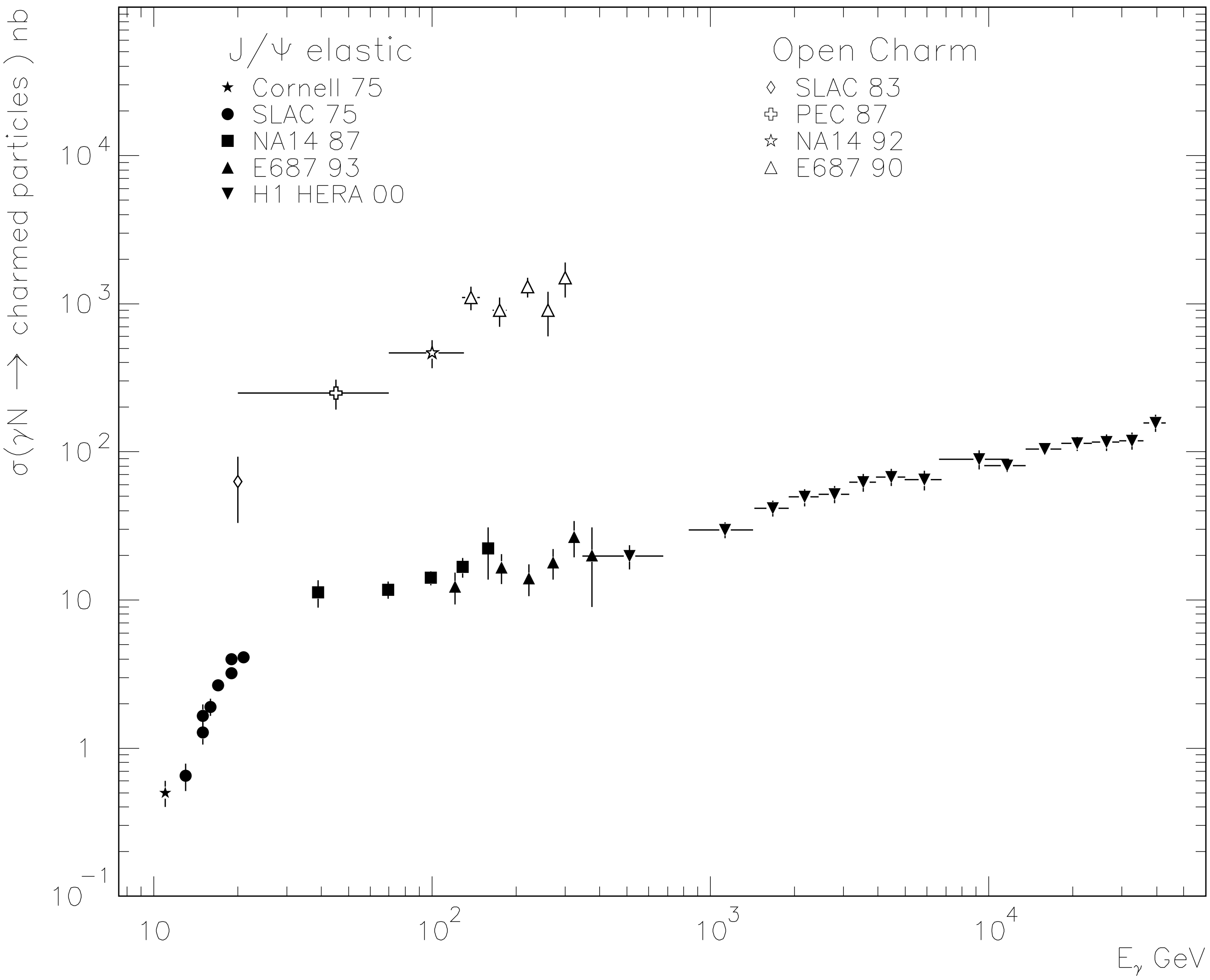
- No $c\bar{c}$ in nucleons
  - $c\bar{c}$ production only via gluons from the target

$c\bar{c}$ is a small size probe of the gluon field of the target

Existing Data on Charm Photoproduction

γp $\rightarrow$J/ψ(1S)p was measured at $E_\gamma > 11$ GeV

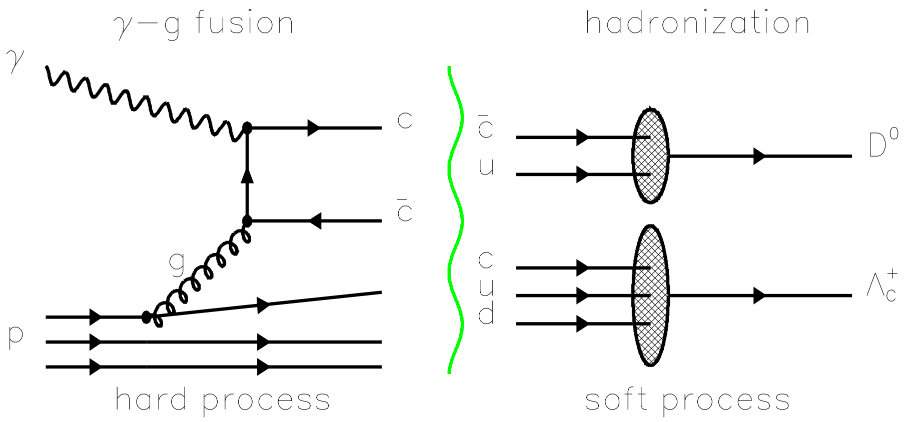
γp $\rightarrow c\bar{c}$+X was measured at $E_\gamma > 20$ GeV



*Only a part of the experimental results are presented

Theory: Open Charm Photoproduction

Factorization



Calculated in LO and NLO

Main parameters:

– m_C: 1.2-1.8GeV

– renormalization scale

– gluon PDF

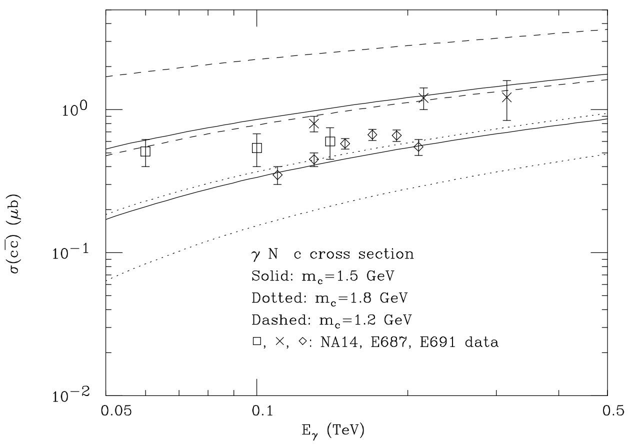
Full inclusive charm:

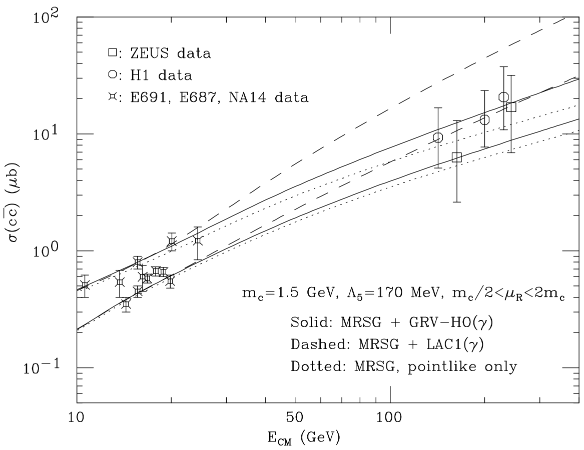
– hadronization ignored

Exclusive production:

– use fragmentation functions from e^+e^-

– final state interaction

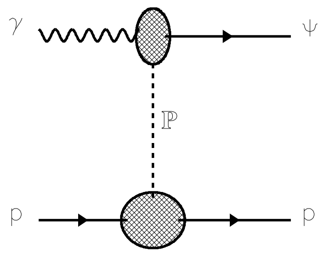




S.Frixione,M.Mangano,P.Nason,G.Ridolfi, CERN-TH/97-16

Theory: Charmonium Photoproduction

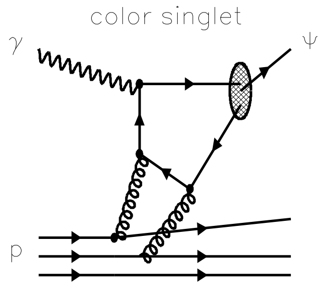
$c\bar{c}$ must combine into a colorless state.



Pomeron Exchange

– Underestimates the rise $\sigma(E_\gamma)$

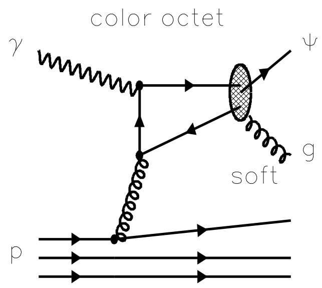
– 2 pomerons - "soft" and "hard"



Color Singlet

– everything is calculable

– Underestimates the Tevatron data by $\times 50$



Color Octet

– The soft part: phenomenology

– Tevatron calibration $\Rightarrow$ too high $\sigma_{\gamma p \to \psi X}$ at z∼1

– Problems with polarization

High energy: probes the gluon PDF at low x.

In order to verify the models:

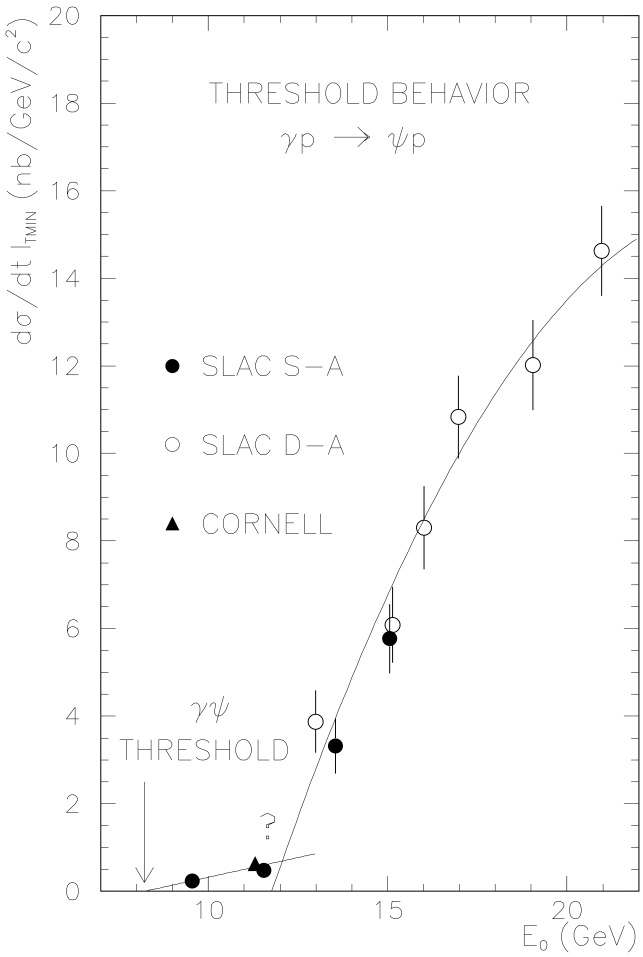
– Cross-sections

– Polarization

Measuring Singlet/Octet is important in order to extract ΔG in Ψ production at RHIC

Experiment: Low Energy Photoproduction

Cornell and SLAC:



SLAC:

Double Arm: published

Single arm: unpublished

large errors <12 GeV

σ: SLAC≈ Cornell

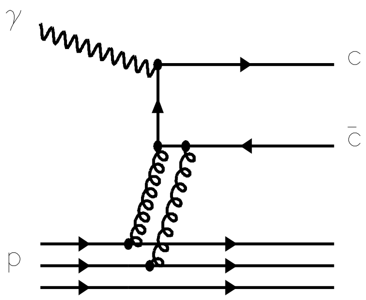
$$\frac{d\sigma}{dt} = A \cdot \exp Bt$$

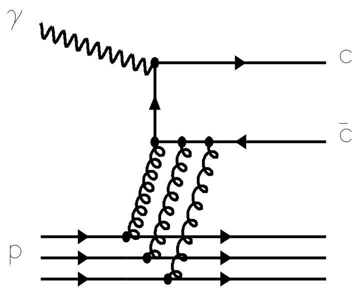
E_γ GeV	11.	19
B $(GeV)^{-2}$	1.13±0.18	2.9±0.3

Indication: a slow decrease of cross-section towards the threshold

Production near threshold

Should probe the particle distributions at high x.
Several constituents from the target should take part.
No detailed calculation exists so far.
Qualitative arguments on $\sigma(E_\gamma)$ (S.Brodsky, J.-M. Laget):

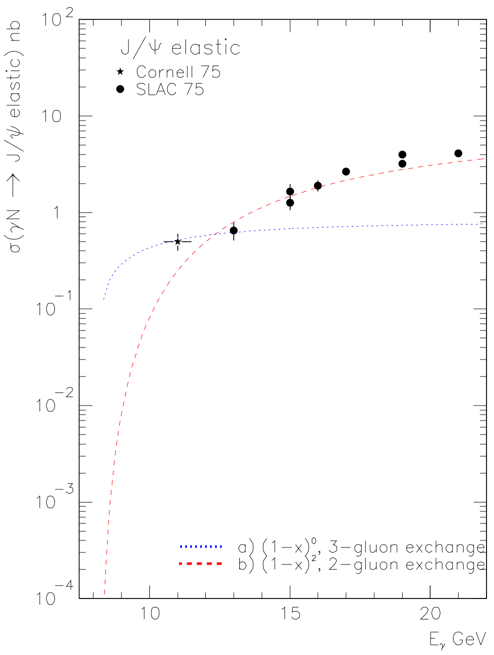




$$\frac{d\sigma}{dt} =$$

$$\mathcal{N}_{2g} v \frac{(1-x)^2}{R^2 \mathcal{M}^2} F_1(\tfrac{t}{4})(s-m_p^2)^2 \qquad \mathcal{N}_{3g} v \frac{(1-x)^0}{R^4 \mathcal{M}^4} F_1(\tfrac{t}{9})(s-m_p^2)^2$$

where: $x = \frac{s_{thresh}-m_p^2}{s-m_p^2}$, $\mathcal{M} = 2\ m_c$, $R \approx 1/m_c$



– applicable at $x \sim 1 \Rightarrow$ $E_\gamma < 12 - 15 GeV$

– fit to 2 low energy points

– Calling for rigorous calculations (GPD?)

ψN interactions

ψN interactions: attention from theorists

Practical interest: QGP

Features:

- small color dipole interacting with nuclear matter
- breakup by excitation to $\mathrm{D}\overline{\mathrm{D}}$ $\Delta E \sim 0.6\ GeV$
- possible loss due to ψ+N$\rightarrow\Lambda_c^+\overline{\mathrm{D}}$ at $P_\psi > 1.8\ GeV/c$

At low energy:

- attractive potential (Van der Waals) (Luke,Manohar,Savage,1992)
- $\sigma(\psi\mathrm{N})_{tot} \sim 7$ mb (Bordsky,Miller,1997), falling with energy

ΨN interactions

Experimental situation: confusing. Methods:

- From photoproduction, using VDM, optical theorem and assumptions on Re(A)/Im(A) (~ 0)
  - 20 GeV: $d\sigma(J/\psi\mathrm{N}\rightarrow J/\psi\mathrm{N})/dt\mid_{t=0} \;\sim\; 25\ \mu\mathrm{b}$
  - 20-200 GeV: $\sigma(\mathrm{J}/\psi\mathrm{N})_{tot} \sim 1$ mb
- From A-dependence of photo and hadro-production, using Glauber model and considering color transparency effects at $\ell_{coh}, \ell_F > R_{target}$
  - 20 GeV γp: $\sigma(\mathrm{J}/\psi\mathrm{N})_{abs} \approx 3.5 \pm 0.8 \pm 0.6$ mb
  - 80-150 GeV hp: $\sigma(\mathrm{J}/\psi\mathrm{N})_{abs} \approx 7$ mb

Later corrections to the interpretations of the results:

- VDM: extended to a milti-channel case Hufner,Kopeliovich: $\sigma(\mathrm{J}/\psi\mathrm{N})_{tot} \sim 1$ mb $\Rightarrow$ 2.8 - 4.1 mb
- A-dependence: color transparency effects taken into account
  - 20 GeV γp: considered reliable
  - 80-150 GeV hp: $\sigma(\mathrm{J}/\psi\mathrm{N})_{abs} \sim 7$ mb $\Rightarrow$ 3.6 mb

Calculation of $\sigma(\psi\mathrm{N})_{tot}$ and ψ Photoproduction

(From: D.Kharzeev et al Eur.Phys.J. C 9,459 (1999))

Calculation of $\sigma(\psi\mathrm{N})_{tot}$ (rigorous in heavy quark limit):

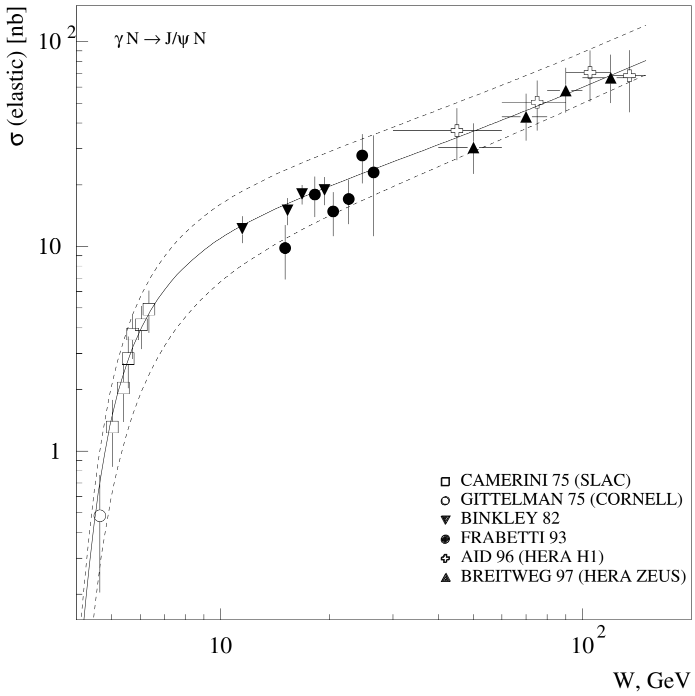
- short-distance QCD (similar to DIS)
- using gluon PDF of the nucleon

Is m_c large enough?

Test:

ψN $\Rightarrow$ γp$\rightarrow$ ψp, using:

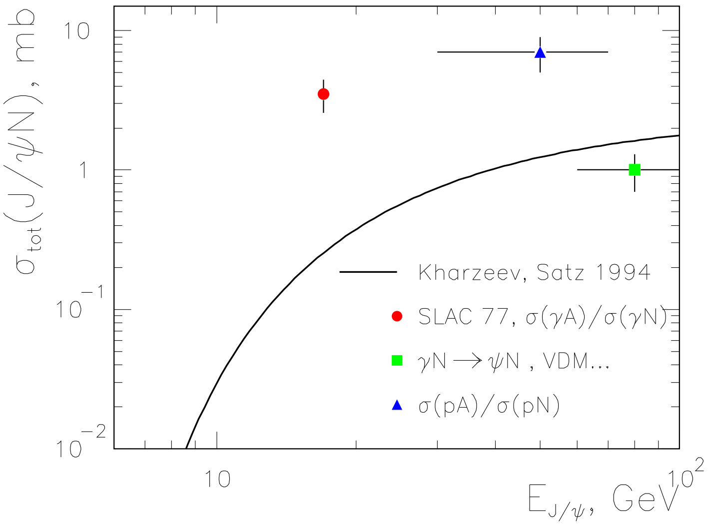
- VDM: E_γ >25 GeV
- optical theorem
- dispersion relations



Discrepancy at 17 GeV $\times$10

Fast drop at E<20 GeV

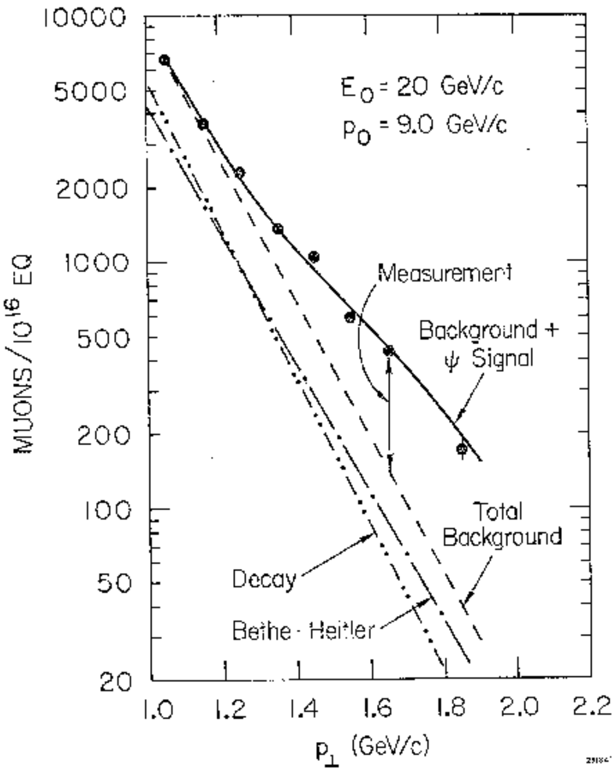
At E$\sim$10 GeV - decisive



Charm at JLAB at 12GeV

SLAC results on γA$\rightarrow$ ψ+X

Single spectrometer measurements.



20 GeV e^- on Be and Ta targets

20 GeV spectrometer, μ^-, μ-filter

High statistics on a high background

The background was calculated:

- decays
- Bethe-Heitler

Cross-section per nucleon: $\sigma(Be)/\sigma(Ta) = 1.21 \pm 0.7 \Rightarrow$

$\sigma_{\psi N}$ $=3.5 \pm 0.8$ mb.

Attempts to measure the cross-section down to 9 GeV: unpublished

Program for JLab at 11 GeV

(1) Measure $\sigma(\mathrm{J}/\psi\mathrm{N})_{abs}$ using
A-dependence of $\sigma(\gamma\mathrm{A}\rightarrow\mathrm{J}/\psi\mathrm{X})$

Advantages comparing to the SLAC experiment:

- low background for $\mathrm{J}/\psi(1\mathrm{S})$
- reconstructed kinematics of $\mathrm{J}/\psi(1\mathrm{S})$
- separation of coherent and incoherent production
- lower energy - smaller effects from ℓ_{coh},ℓ_F
- several targets used

Disadvantages comparing to the SLAC experiment:

- ◦ lower energy - stronger effect from Fermi motion

(2) Measure $\frac{d\sigma}{dt}(E)$ for $\gamma\mathrm{p}\rightarrow\mathrm{J}/\psi\mathrm{p}$

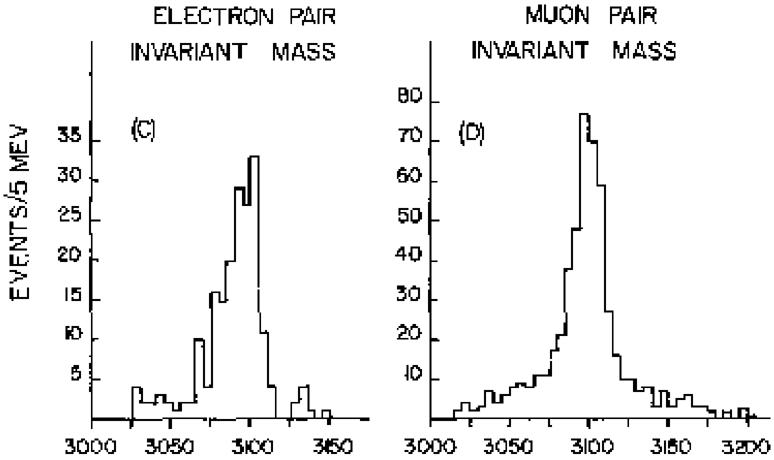
Goal:

- Provide Fermi-motion correction for (1)
- Measurement in a new energy range (3-gluon exchange?)

Charm at JLAB at 12GeV

SLAC results on γp$\rightarrow$ ψp at 13-21 GeV

Double spectrometer measurements.

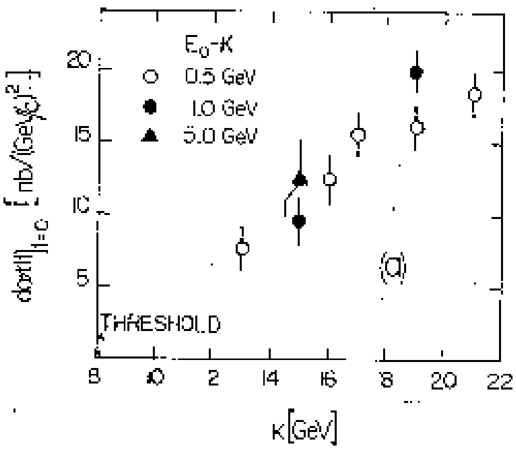


5% RL, 30 cm ^{1}H, ^{2}H

20, 8 GeV spectrometers

$J/\psi(1S) \rightarrow e^+e^-, \mu^+\mu^-$

1200 $J/\psi(1S)$ and 13 $\psi(3770)$

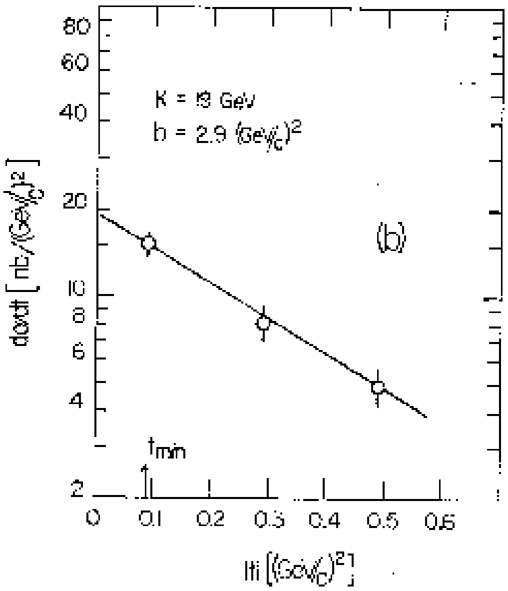


at 13 GeV:

$\frac{d\sigma}{dt} \mid_{tmin} = 3.8 \pm 0.8$ nb/GeV^2

at 20 GeV:

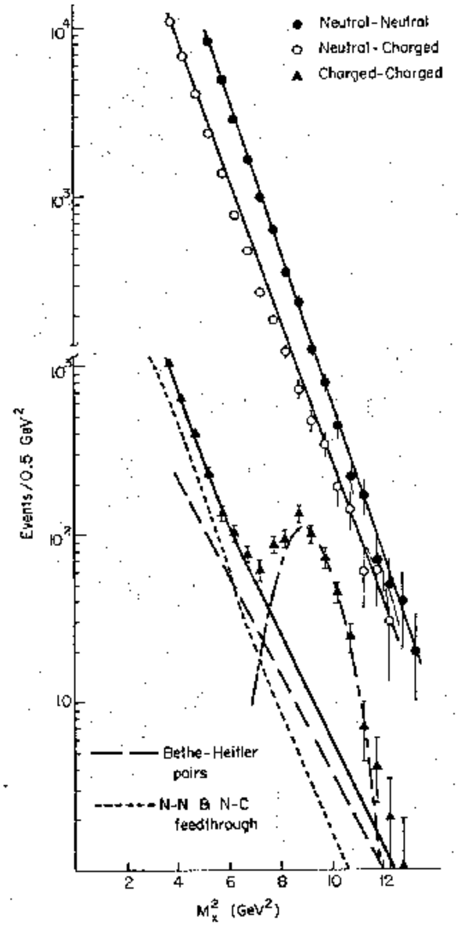
σ: $\psi(3100)/\psi(3770) \sim 6.8 \pm 2.4$

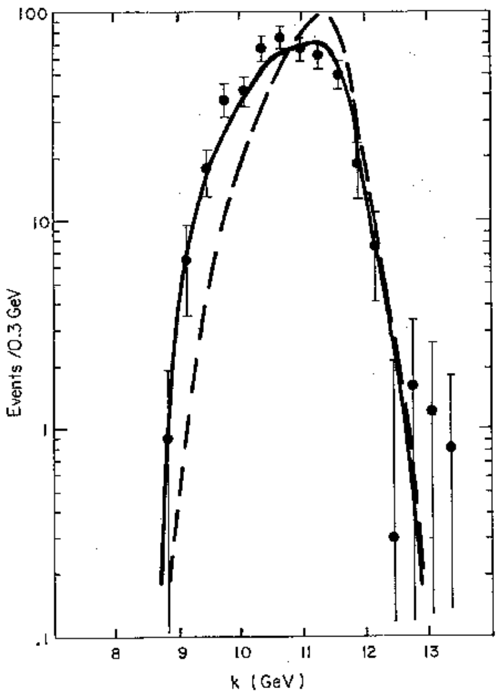


From VDM: $d\sigma(\psi N \rightarrow \psi N)/dt \mid_{t=0} \approx 25\mu$b

Cornell Results at 11.8 GeV

- $J/\psi(1S) \rightarrow e^+e^-$ detected with lead-glass calorimeters ($\sigma E/E = 0.16/\sqrt{E}$)
- Average photon flux $1 \cdot 10^9$/s for $8.5 < E_\gamma < 11.8$ GeV, duty cycle=7%, Be target 2.9g/cm^2
- Background: neutrals $\times 10$ charged, charged - BH
- Signal/background $\sim$470/70
- Results: $\frac{d\sigma}{dt} = 0.9 \pm 0.1\ nb/GeV^2 \cdot e^{1.13 \pm 0.18\ GeV^2 \cdot t}$





No dependence of cross-section on E_γ observed!

JLab standard spectrometers

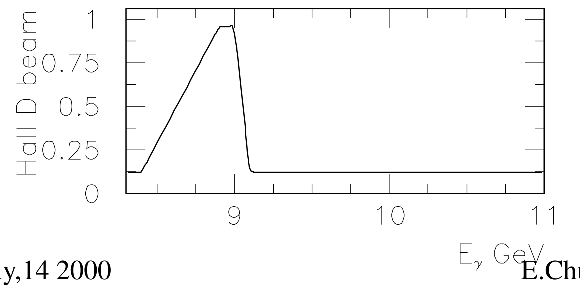
hall	beam μA	setup	$\Delta\Omega$ ster	P_{max} GeV	$\frac{\Delta P}{P}$ %	$\frac{\sigma P}{P}$ %	$\sigma\theta_{in}$ mrad	$\sigma\theta_{out}$ mrad
Hall A	100	HRS	0.006	4.0	9	0.01	0.6	2.0
		HRS	0.006	3.2	9	0.01	0.6	2.0
		MAD*	0.030	6.0	15	0.3	1.0	2.0
Hall C	100	HMS	0.006	7.5	18	0.1	0.8	0.8
		SOS	0.009	1.8	40	0.1	1.0	1.0
		SHMS	0.003	12.	18	0.1	1.0	1.0
Hall B	0.01	CLAS	$\sim 2\pi$	-	-	0.5		
Hall D	γ		$\sim 4\pi$	-	-	<1.		

$(*)$ Proposed for structure functions measurements

Possible photon flux:

- Halls A,C: $25\mu A$ at 6% RL radiator: $1.3 \cdot 10^{12}\gamma$/s/GeV on 15 cm LH
- Halls B: in $0.2 < \frac{E_\gamma}{E_0} < 0.95$: $< 10^7/10^8$ tagged/untagged
- Halls D, tagged:

  $\sim 2 \cdot 10^7/s$ in $8.4 < E_\gamma < 9.1$GeV coherent
  $\sim 2 \cdot 10^7/s$ in $8.4 < E_\gamma < 11.$GeV incoherent



Charm at JLAB at 12GeV

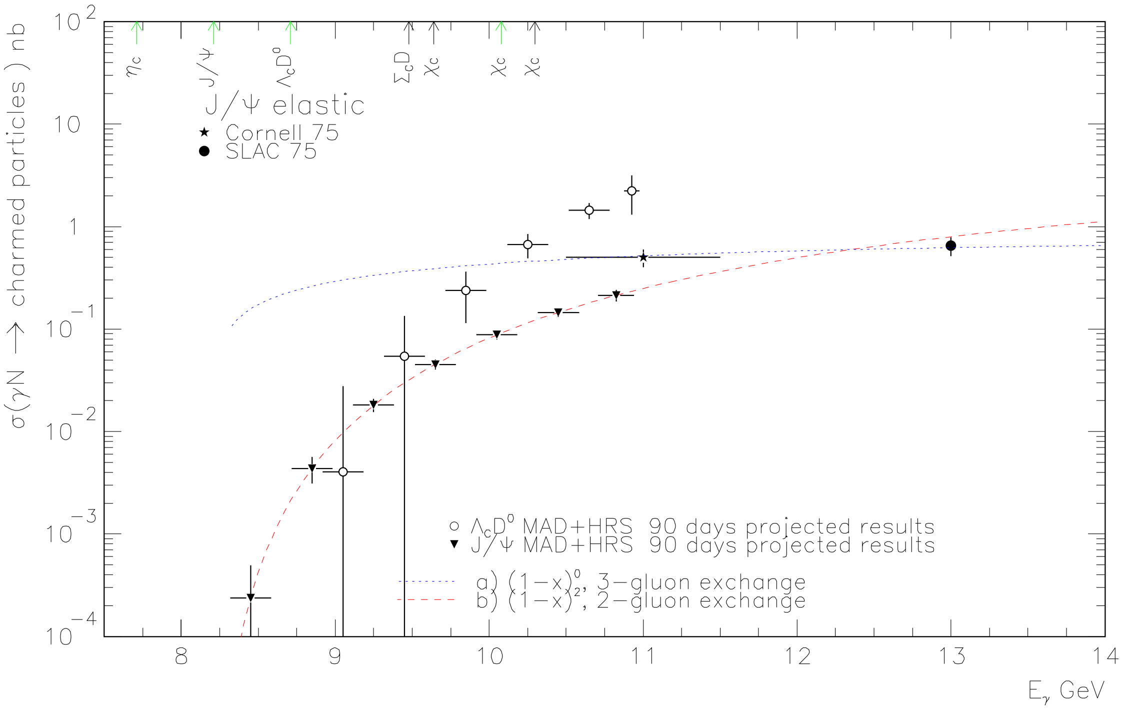
Standard spectrometers

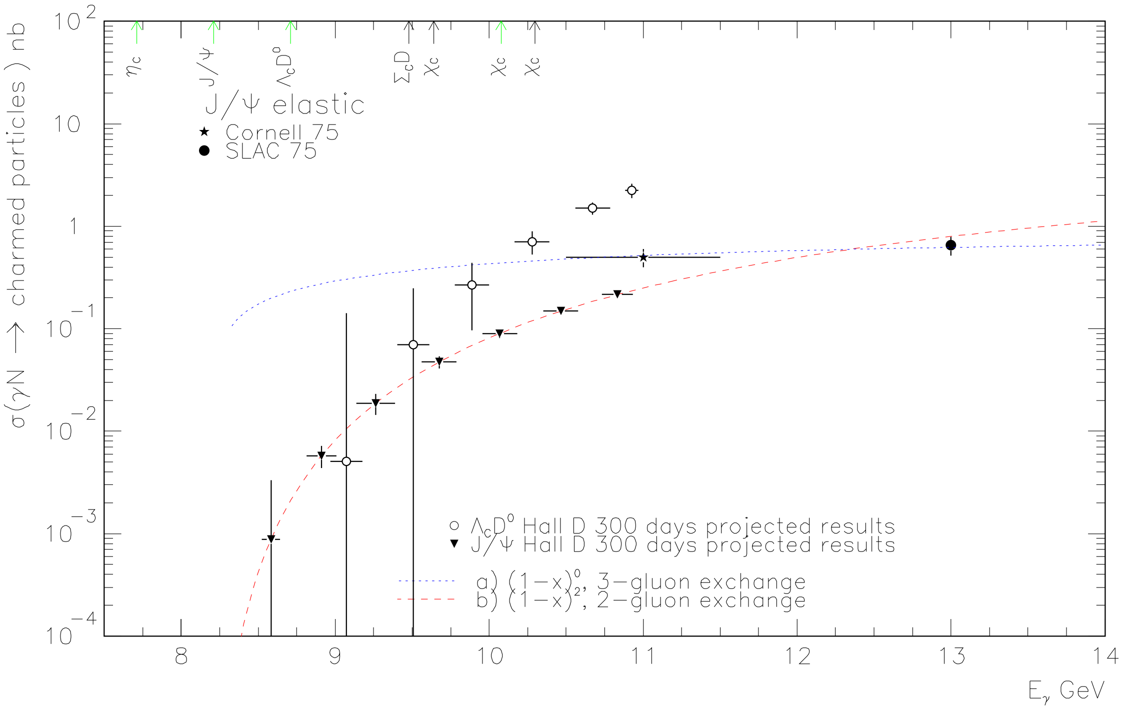
meaning		Hall D	HRS HRS	HRS MAD	HMS SOS	HMS SHMS
tagged γ		yes				
target LH		30 cm	15 cm	15 cm	4 cm	15 cm
$J/\psi(1S) \rightarrow e^+e^-, \mu^+\mu^-$						
$E_\gamma range$ GeV		8.3-11.	8.3-11.	8.3-11.	8.3-9.5	8.3-11.
decay angle CM		-	-	100°	51°	90°
Acceptance %		~ 40	-	0.027	0.026	0.009
$\sigma M/M$		$\sim 1\%$	-	0.24%	0.2%	0.2%
$(1-x)^2$	events/90days	260	-	2400	100	800
	days required*	640	-	190	-	560
$(1-x)^0$	events/90days	2100	-	28000	4100	9500
	days required*	40	-	45	-	130
$\overline{D}^0 \rightarrow K^+\pi^-$						
$E_\gamma$range GeV		8.7-9.3	8.7-11.	8.7-11.	8.7-10.	8.7-11.
decay angle CM		-	90°	100°	66°	80°
Acceptance %		~ 40	0.003	0.022	0.026	0.008
$\sigma M/M$		$\sim 1\%$	0.17%	0.2%	0.2%	0.2%
$(1-x)^2$	events/90days	540	400	2900	120	1100
$(1-x)^0$	events/90days	3400	13000	29000	4600	10000

$*$ – Condition: the <error> at $E_\gamma - E_{thresh} > 0.4GeV$ is $< 10\%$

Charm at JLAB at 12GeV

Expected Results





$\mathrm{J}/\psi(1\mathrm{S})$ on nuclear targets

- Hall D does not plan to use nuclear targets for the first stage.
- Hall A,C (say, MAD+HRS) can use nuclear targets for A-dependence measurements. No need to detect the recoil.

$\sigma_{\Psi N}$ can be derived from the A-dependence of the cross-section

R. Anderson, PRL38,263(1977)

J. Dunne, E. Ent, J.H. Mitchell and P.E. Bosted, LOI (1997)

J. Dunne, JLAB at 6-12 GeV Workshop (1998)

using nuclear models (Glauber model).

Assume for MAD+HRS:

- LH,LD 15 cm, with a 6%RL radiator
- Heavy targets of 7.7%RL ($\approx$ 6% radiator + LH target)
- For $\mathrm{J}/\psi(1\mathrm{S})$ production $\sigma_A \approx A \cdot \sigma_N$
- End point of 11 GeV

target		^{1}H	^{2}H	Be	C	Al	Cu	Pb
$\mathrm{J}/\psi(1\mathrm{S})$ /day	$(1-x)^2$	160	320	550	360	210	110	60
	$(1-x)^0$	×5.4						

1000 events per target: $\sim$ 50 days run

Extraction of $\sigma_{\psi N}$

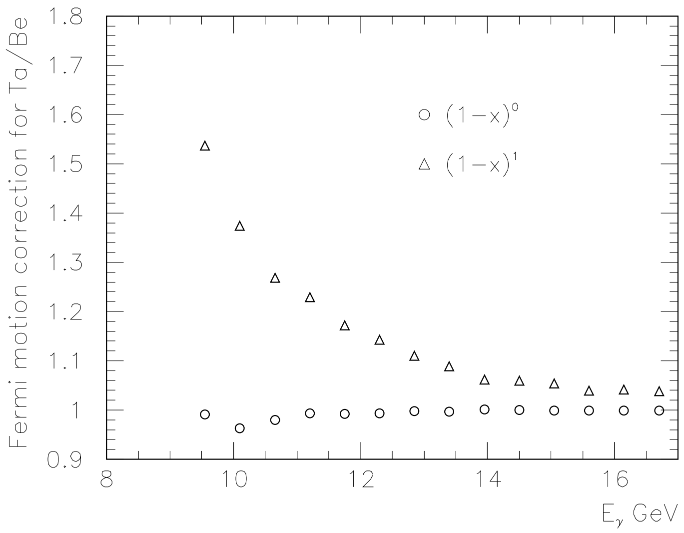
- Nuclear transparency: $T = \sigma_{\gamma A}/(A \cdot \sigma_{\gamma N})$

Same model as at SLAC: semi-classical eikonal approximation of nuclear re-scattering

Assumed: statistical error for each target 3%

$\sigma_{\psi N}$ mb		A						$\sigma(\sigma_{\psi N})$ mb
		9	12	27	63	108	207	
T	1.0	0.982	0.980	0.974	0.963	0.952	0.929	0.28
	3.5	0.938	0.931	0.908	0.870	0.833	0.751	0.24
	7.0	0.876	0.863	0.816	0.740	0.665	0.502	0.17

- Fermi-motion correction.



Conclusion

At 12 GeV JLab is capable of using $c\bar{c}$ as a probe of nuclear matter
Several measurements are proposed:

(1) Measurements of ψ-Nucleon cross-section. The expected errors are about 10% statistical and 15% systematic. This measurements are aiming to test if there is a considerable gluonic potential between colorless states. This cross-section has also been of a considerable interest for heavy ion physics.

(2) Measurements of $\frac{d\sigma}{dt}(E_\gamma)$ of $J/\psi(1S)$ is needed in order to fulfill (1). It is also of independent interest, probing compact, coherent states of valence quarks.

Experimental possibilities:

- The part (1) MAD+HRS in 2 months
- The part (2) MAD+HRS in 3 months
- The part (2) on $J/\psi(1S)$ - Hall D in 2 years.