Possible Experiments on Charm at JLab

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reaction	E_γ threshold
γp $\to J/\psi(1S)$p	8.2 GeV
γp $\to \psi(3770)$p	11.0 GeV
γp $\to \Lambda_c^+ \overline{D}^0$	8.7 GeV
γp $\to D^0 \overline{D}^0$ p	11.1 GeV

These reactions are within the reach at 12 GeV. At 7-8 GeV one may consider subthreshold production on nuclei, using Fermi motion.

Detecting charm is difficult:

- Low cross-section: $\approx$1nb.
- Low branching ratios, for ex. $J/\psi(1S) \to e^+e^-$ 6%.

Illustration:

the yield $J/\psi(1S) \to e^+e^-$ to $\phi(1020) \to K^+K^- \sim 10^{-4}$.

Nevertheless: charm detection at low energies is *possible*.

Charm Identification

Effective mass reconstruction:

- Small (or zero) particle width.
- Large free energy $\Rightarrow$ low background.

2-body decays provide the lowest background:

particle	mass	decay	BR	P_{CM}
	MeV/c^2			MeV/c^2
$J/\psi(1S)$	3100	e^+e^-	6.0%	1548
		$\mu^+\mu^-$	6.0%	1545
$\psi(3770)$	3690	e^+e^-	0.8%	1843
		$\mu^+\mu^-$	0.8%	1840
$\overline{D}^0$	1865	$K^+\pi^-$	4.0%	861
$\chi_{c1}(1P)$	3510	$J/\psi(1S)\gamma$	27.0%	389

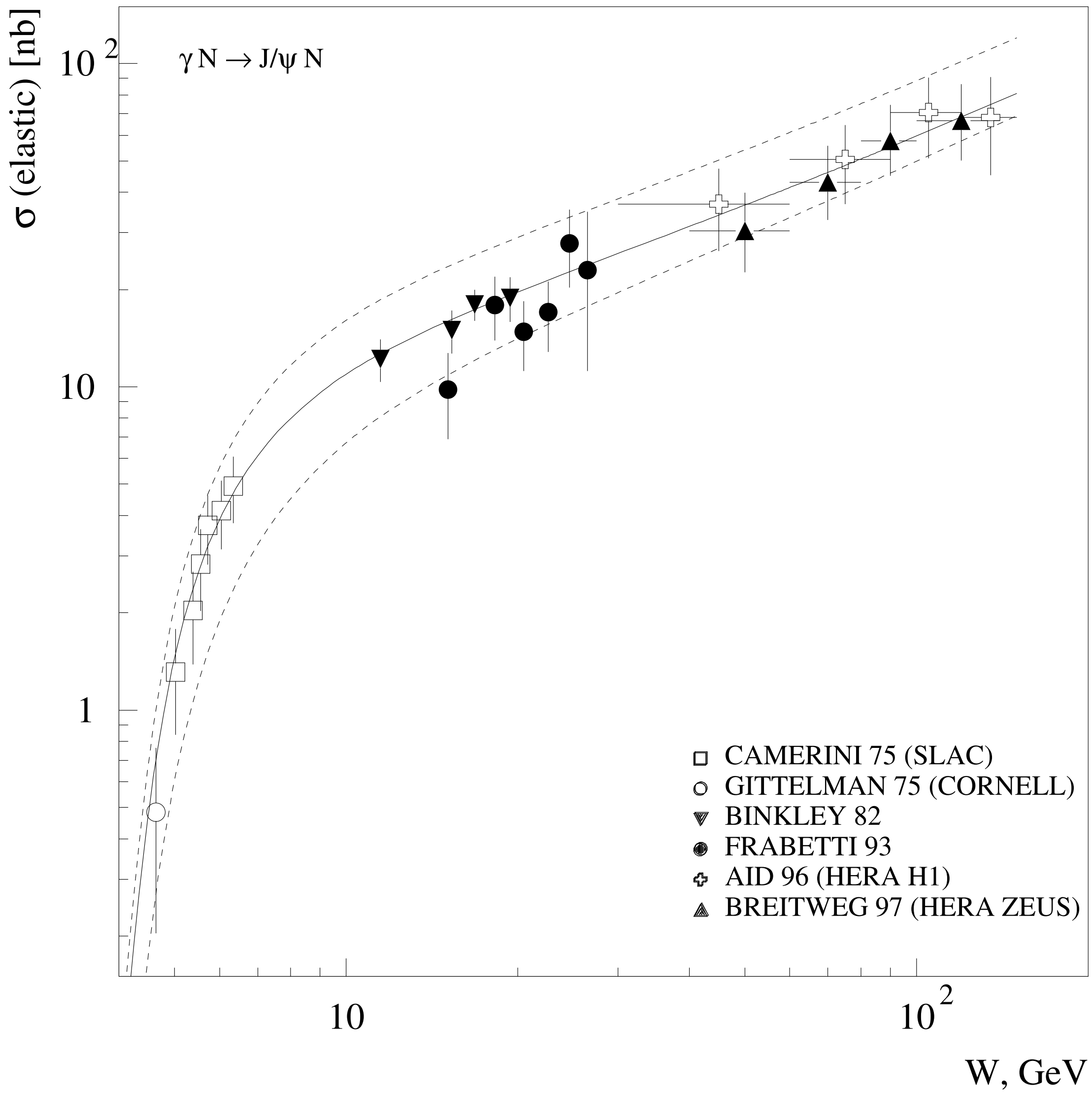
Open charm production may provide other signatures:

- Decay path 0.01 - 1 cm
- Decays of the associated particle

Existing Data on Charm Photoproduction

$\gamma p \to J/\psi(1S) p$ was measured at $E_\gamma > 11$ GeV:

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



Open charm was measured at $E_\gamma > 20$ GeV.

Low Energy Charm Photoproduction

γp $\rightarrow J/\psi(1S)$p at low energies was detected:

- SLAC, at 19 GeV on ^{1}H and 13-21 GeV on ^{2}H.
  - 5% radiator and 30 cm target.
  - Standard spectrometers (20 and 8 GeV) used.
  - $J/\psi(1S) \rightarrow e^+e^-$, $\mu^+\mu^-$ detected.
  - Signals: 1200 $J/\psi(1S)$ and 13 $\psi(3770)$.
  - Results: in γp: $\frac{d\sigma}{dt} \mid_{tmin} = 10.8 \pm 1.1$ nb/GeV^2.
- SLAC, at E_0=19 GeV on Be and Ta.
  - Single 20 GeV spectrometer detecting μ^- at high P_T.
  - High statistics and high background.
  - Results: $\sigma(Be)/\sigma(Ta) = 1.21 \pm 0.7 \Rightarrow$
    $\sigma_{\psi N}$ $=3.5 \pm 0.8$ mb.
- Cornell, at E_0=11.8 GeV on Be.
  - $J/\psi(1S) \rightarrow e^+e^-$ detected with lead-glass calorimeters.
  - Average photon flux $1{\cdot}10^9$/s for 8.5<$E_\gamma < 11.8$ GeV, duty cycle=7%, Be target 3.9g/cm^2
  - Signal/background $\sim$470/70
  - Results: $\frac{d\sigma}{dt} = A \cdot \exp Bt$, where
    A$=0.9 \pm 0.1$ nb/GeV^2, B$=1.13 \pm 0.18$ GeV^2.

Possible Experiments on Charm Production at JLab

What can be done at JLab?

reaction	measured	impact
$\gamma p \to J/\psi(1S)p$ $\psi \to e^+e^-, \mu^+\mu^-$	$\frac{d\sigma}{dt}$ (E_γ)	Production mechanisms Models: gluon PDF Models: $\sigma_{\psi N}$
$\gamma A \to J/\psi(1S)X$ $\psi \to e^+e^-, \mu^+\mu^-$	$\frac{d\sigma}{dt}$ (A)	Models: $\sigma_{\psi N}$
$\gamma A \to \psi(3770)X$ $\psi \to e^+e^-, \mu^+\mu^-$	$\frac{d\sigma}{dt}$ (A)	Models: $\sigma_{\psi N}/\sigma_{\psi' N}$
$\gamma p \to \Lambda_c^+ \overline{D}^0$ $\overline{D}^0 \to K^+\pi^-$	$\frac{d\sigma}{dt}$ (E_γ)	Production mechanisms
$\gamma A \to \chi_{c1}(1P)X$ $\chi_{c1}(1P) \to J/\psi(1S)\gamma$ $\psi \to e^+e^-, \mu^+\mu^-$	$\frac{d\sigma}{dt}$	Production mechanisms
....		

Improvements with respect to the old experiments:

- Higher statistics $\times 100$
- Better systematics

Possible Experiments on Charm Production at JLab

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
		LAS*	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	0.01		$\sim 2\pi$	-	-			

$(*)$ Proposed for structure functions measurements

Possible photon flux is given for:

- Electron beam E_0=11 GeV, useful range E_γ >8.5 GeV
- Halls A,C: 50μA at 6% RL radiator: 0.012 γ/e
- Halls B,D: in $0.2 < \frac{E_\gamma}{E_0} < 0.95$: $< 10^7/10^8$ tagged/untagged photons

hall	tagged flux/s	untagged flux/s
A,C	-	$3.7 \cdot 10^{12}$
B,D	$1.6 \cdot 10^6$	$1.6 \cdot 10^7$

Possible Experiments on Charm Production at JLab

Simulation

γp $\rightarrow J/\psi(1S)$p

- 2-body reaction, $t = (p_\psi - p_\gamma)^2$, $\frac{d\sigma}{dt}$~$e^{1.0\cdot t}$
- Decay e^+e^- $\sim (1 + cos\theta^*)$

γp $\rightarrow \Lambda_c^+ \overline{D}^0$

- 2-body reaction, $t = (p_D - p_\gamma)^2$, $\frac{d\sigma}{dt}$~$e^{1.0\cdot t}$
- Decay $\overline{D}^0 \rightarrow K^+\pi^-$ is isotropic

Other conditions:

- The cross-section is 0.5nb, does not depend on E_γ
- Targets A>1: Fermi motion
- Tracking is simplified - no secondary interactions
- Acceptance and mass resolution are calculated.
- Efficiency of 0.5 (trigger, dead time etc)

Possible Experiments on Charm Production at JLab

Standard spectrometers

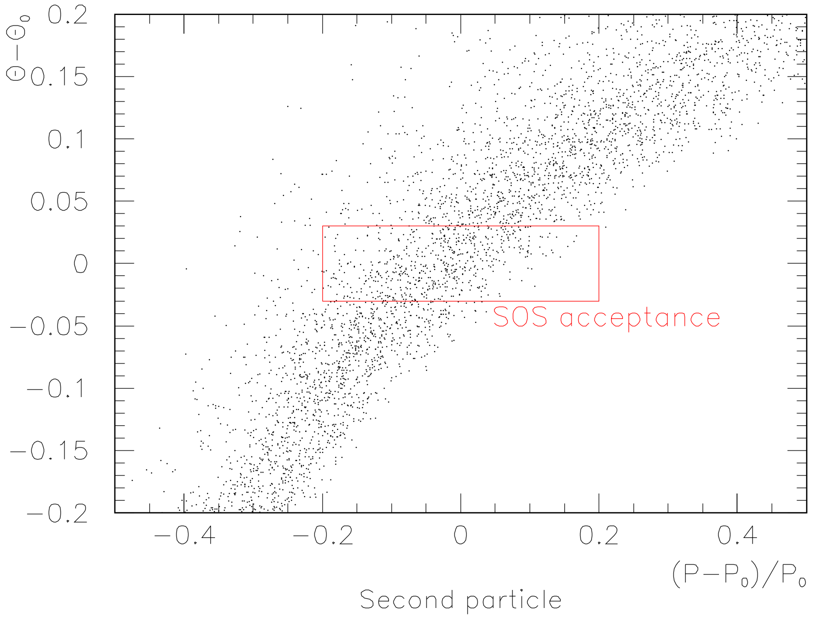
meaning	Hall B/D	HRS+HRS	HRS+LAS	HMS+SOS	HMS+SHMS
flux untagged	$1.6 \cdot 10^7$	$3.7 \cdot 10^{12}$	$3.7 \cdot 10^{12}$	$3.7 \cdot 10^{12}$	$3.7 \cdot 10^{12}$
flux tagged	$1.6 \cdot 10^6$	-	-	-	-
target LH	10 cm	10 cm	10 cm	4 cm	10 cm
$\mathrm{J}/\psi(1\mathrm{S})$					
End point GeV	-	-	11.	10.	11.
decay angle CM	-	-	100^o	52^o	90^o
Acceptance %	~ 30	-	0.034	0.016	0.009
$\sigma M/M$	$\sim 1\%$	-	0.24%	0.2%	0.2%
events/day untagged	2.6	-	680	85	180
$\overline{\mathrm{D}}^0$					
End point GeV	-	11.	11.	10.5	11.
decay angle CM	-	90^o	90^o	70^o	90^o
Acceptance %	~ 30	0.003	0.026	0.001	0.006
$\sigma M/M$	$\sim 1\%$	0.17%	0.2%	0.2%	0.2%
events/day untagged	1.7	40	350	45	80

LAS – spectrometer proposed for structure functions measurements

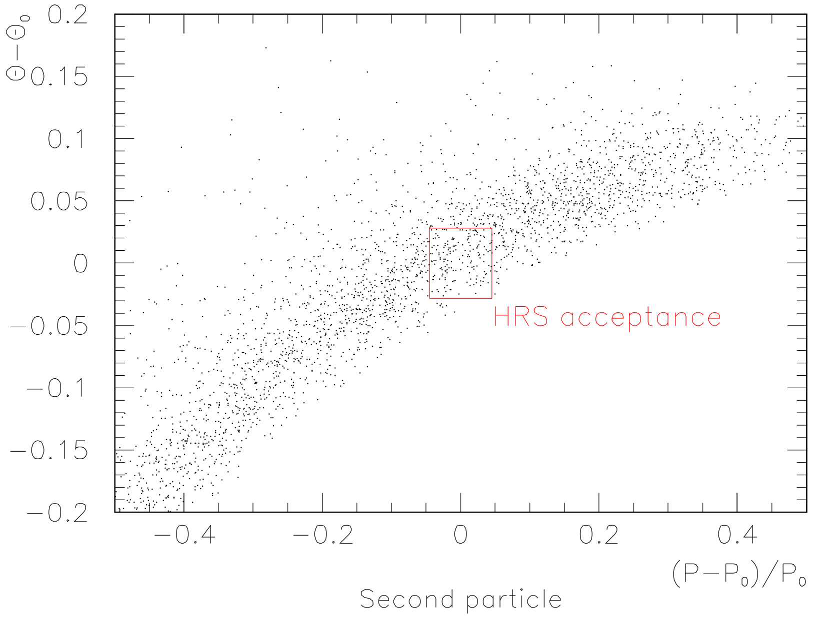
HRS,HMS acceptance

One spectrometer is hit:

γp $\rightarrow J/\psi(1S)$p



γp $\rightarrow \Lambda_c^+ \overline{D}^0$



Electromagnetic calorimeter

Electromagnetic calorimeter may be a good option for $\psi \rightarrow e^+e^-$:

- large acceptance
- relatively high background:
  - sucessfully used at Cornell (duty cycle 0.07, BG/sig$\sim$ 0.15)
  - Hall A real Compton scattering: OK

Assumed parameters:

- 2 arms of lead glass, 1×1 m^2
- 3 m from the target, $\pm 19^o$ ($< E_e >= 4.1$ GeV)
- $\sigma(E)/E = 0.02 + 0.06/\sqrt{E}$, $\sigma x \sim 0.5$ cm
- 5μA, 6% radiator, 10 cm LH target (RCS experience)

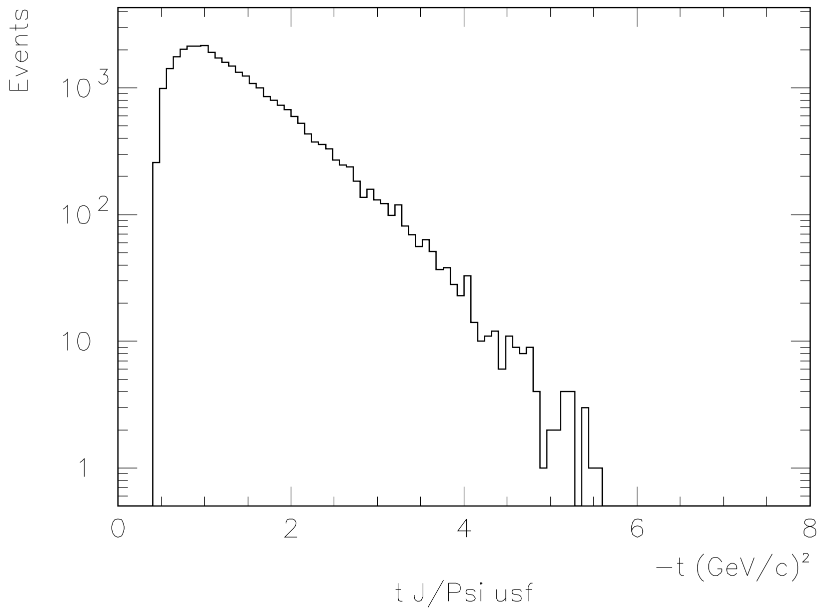
process	accept	$\sigma M/M$	events/day
γp $\rightarrow$J/ψ(1S)p	0.033	3.5%	6000

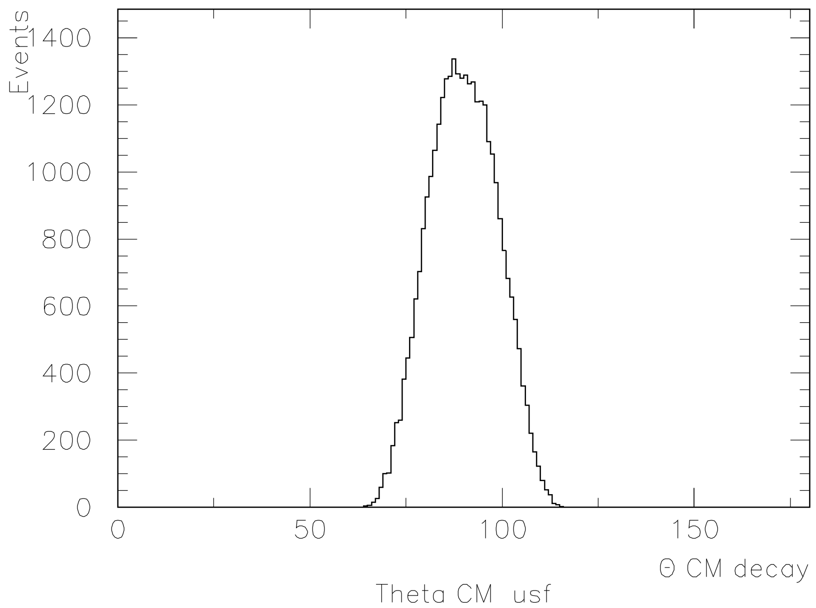
$\sigma M/M$ is dominated by the energy resolution.
Luminocity $\sim\ \times 5.8$ of Cornell during the spill

Possible Experiments on Charm Production at JLab

Kinematical range

$J/\psi(1S)p$ detected with EM calorimeter





Electromagnetic calorimeter development

Promissing results:

- very high statistics
- mass resoulution about 3 time better than at Cornell
- estimated background $<$15%.
- Background/signal from accidental coincidences: $< \times 6$ of Cornell (did not play a role there).

Important issues:

- good rejection of neutrals (neutrals$\sim$charged$\times$10)
- radiation hardness
- Consider PbW crystals $\Rightarrow$ better mass resolution
- Consider GEM detectors in front of the calorimeter: measure the angles, reduce the accidentals
- trigger rate

A calorimeter is being built for RCS:

- $\sim 1\times$1 m^2 array of $4\times$4 cm^2 lead glass
- segmented veto counters

A 2-nd calorimeter has to be built.

Summary of the options

$J/\psi(1S)p$ study:

- Hall A HRS: too high momenta.
- Hall C HMS+SOS - very limiting, HMS+SHMS - OK
- Hall B/D very low statistics
- Hall A/C calorimeter: good.

process	setup	$\sigma M/M$	BG/sig	events/day
$\gamma p \to J/\psi(1S)p$				
$\to e^+e^-$	(A), ECAL	3.5%	0.15	6000
$\to e^+e^-, \mu^+\mu^-$	A, HRS+LAS	0.2%	<0.02	1360
$\to e^+e^-, \mu^+\mu^-$	C, S/HMS	0.2%	<0.02	360
$\to e^+e^-, \mu^+\mu^-$	B/D no tag	1.0%	0.05	4
$\gamma p \to \Lambda_c^+ \overline{D}^0$				
$\to K^+\pi^-$	A, 2HRS	0.2%	0.10	40
$\to K^+\pi^-$	A, HRS+LAS	0.2%	0.10	350
$\to K^+\pi^-$	C, S/HMS	0.2%	0.10	80
$\to K^+\pi^-$	B/D no tag	1.0%	0.10	2

LAS – spectrometer proposed for structure functions measurements