J/Psi Production

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[1] JLab

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Outline

1. Physics Motivations
   - Introduction
   - Photoproduction Mechanisms
   - ψN Cross Section
2. Program for 12 GeV
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Outline

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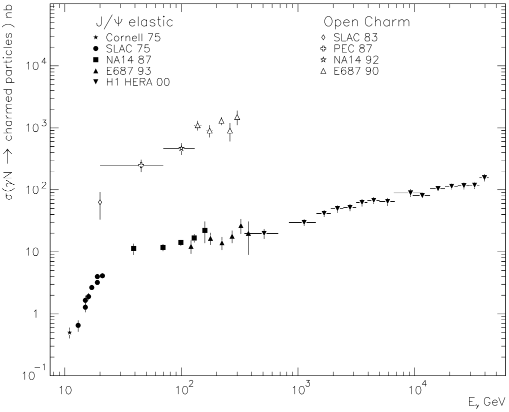
Charm at 12 GeV

J/ψ: 32 announced on Nov, 1974

CEBAF at 12 GeV crosses the charm γN threshold:

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

Existing Data on Charm Photoproduction



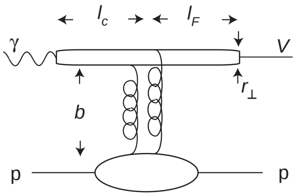
γp $\rightarrow J/\psi(1S)$p   E$_\gamma$ > 11 GeV

γp $\rightarrow c\bar{c}$+X   E$_\gamma$ > 20 GeV

*Only a part of the experimental results are presented

What is special about J/ψ photoproduction?..

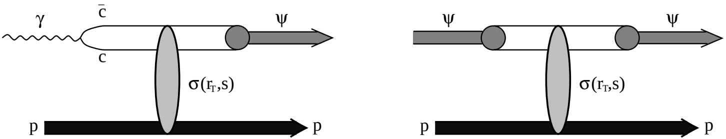
- No $c\bar{c}$ in nucleons: $c\bar{c}$ production only via gluons from the target
- Small size
- Important features of charm photoproduction:



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

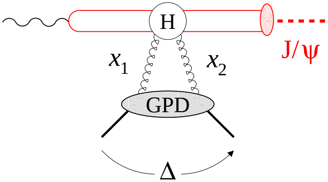
- $c\bar{c}$ is a small size probe of the gluon field of the target
- VDM: $\ell_{coh} > 1$ fm ($E_\gamma > 25$ GeV)
- Coherent on heavy nucleus: $\ell_{coh} > 4$ fm ($E_\gamma > 100$ GeV)
- $E_\gamma \sim 10$ GeV $\ell_{coh} \ll d_{nucleus}$, $\ell_F < d_{nucleus}$ no shadowing effects, $c\bar{c}$=J/ψ propagation through nuclear material

ψ Photoproduction and ψ-N interaction



- Similarity between the two processes
- Check the model on photoproduction

Exclusive J/ψ production in *ep*: High vs. low *W*



$W \gg M^2_{c\bar{c}}$ - HERA, FNAL

- Momentum transfer $|\Delta_\perp| < 1$ GeV/c, $\Delta_\parallel$ - small
- Gluon GPD $x_1 \sim x_2 \ll 1$
- "Transverse gluon imaging"

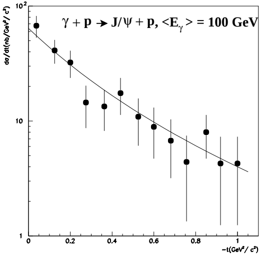
$W \sim M^2_{c\bar{c}}$ - JLab

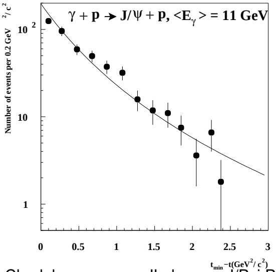
- Large $\Delta_\parallel$, large $|t_{min}|$
- Gluon GPD $x_1 \neq x_2 \sim 1$ ("skewness")
- Probes transition form factor of gluon dipole moment at high t

- Unique probe of small-size gluon configuration in proton
- Dipole moment $\sim r_{c\bar{c}}$
- "Color transparency"

t-Dependence: dipole approximation

L.Frankfurt, M.Strikman, Phys.Rev.D66:031502 (2002), M.Str., C.Weiss hep-ph/0408345





$x \ll 1 \quad \frac{d\sigma_{\gamma P \to J/\psi p}}{dt} \propto \frac{H_g(x,t)^2}{H_g(x,0)^2}$

$\Rightarrow$ FT $\Rightarrow$ spacial distribution

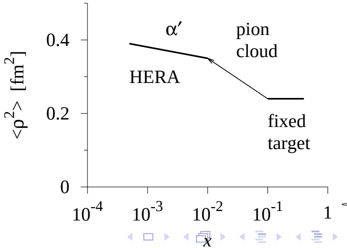
Argued: dipole approximation:

$H_g(x,t) \propto (1 - t/m_g^2)^{-2}$

$m_g^2 \approx 1.1$ GeV/c^2 at x$\sim$0.1

$\langle \rho^2 \rangle = 8/m_g^2 \approx 0.28$ fm^2

$\frac{d\sigma_{\gamma P \to J/\psi p}}{dt} \propto (1 - t/1.0GeV^2)^{-4}$



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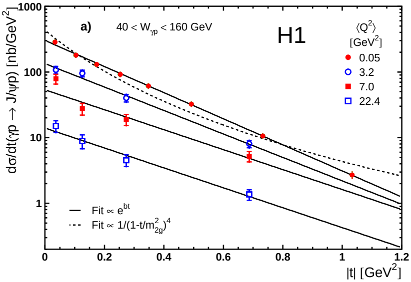

HERA: exponential provides a better fit

$x \ll 1 \quad \frac{d\sigma_{\gamma P \to J/\psi p}}{dt} \propto \frac{H_g(x,t)^2}{H_g(x,0)^2}$

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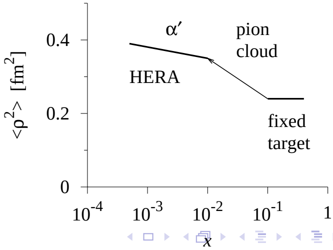
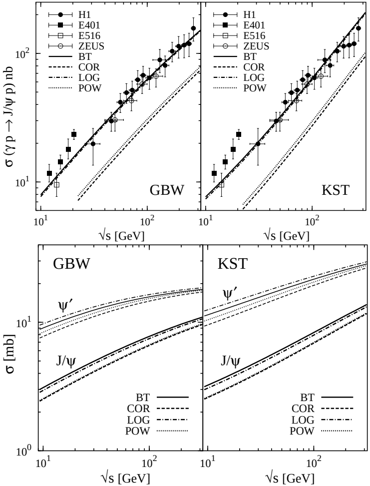


Calculation of $\sigma(\psi N)_{tot}$ and ψ Photoproduction

B.Kopeliovich, J.Raufeisen LA-UR-03-3079, hep-ph/0305094 Hufner,Kopeliovich

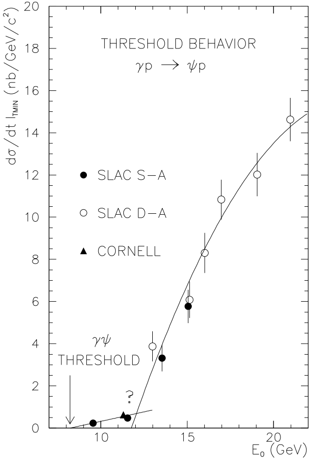
- VDM extended to a multi-channel case (account for J/ψ $\psi\prime$ mixing)
- dipole interaction
- accurate setting of the wave functions etc
- no tune to J/ψ data

- Photoproduction: good agreement at high energies
- $\sigma(\psi N)$ - extrapolation to low energies?



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

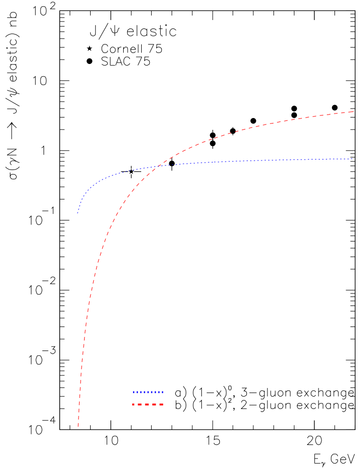
Should probe the particle distributions at high x.
Several constituents from the target should take part.
No detailed calculation exists so far.
Qualitative arguments on $\sigma(E_\gamma)$
(S.Brodsky, E.Ch., P.Hoyer, J.-M. Laget PL B498, 23 2001):

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

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

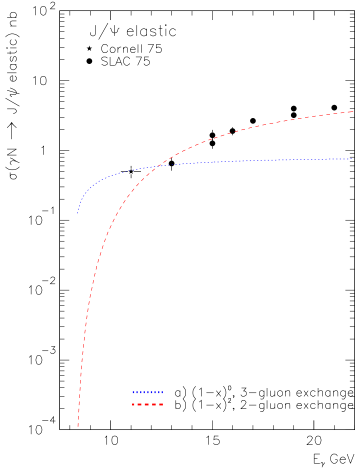
- Applicable at $x \sim 1 \Rightarrow E_\gamma < 12 - 15 GeV$
- The factors $\mathcal{N}$ - fit to the data

Production near threshold



- "2-gluon" fit to high E points
- "3-gluon" fit to 2 low energy points

Production near threshold



- "2-gluon" fit to high E points
- "3-gluon" fit to 2 low energy points

Subthreshold experiment E-03-008

No J/ψ observed
Large cross section at threshold ruled out

Are the old data correct?

ψN Interactions

ψN interactions: attention from theorists
Practical interest: J/ψ deficit = signature for QGP

Features:

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

At low energy:

- attractive potential (Van der Waals) (Luke,Manohar,Savage,1992)
  $E_{binding} \sim 8\ MeV$
- $\sigma(\psi N)_{tot} \sim 7$ mb (Brodsky,Miller,1997), falling with energy

How to compare these predictions with experiment?

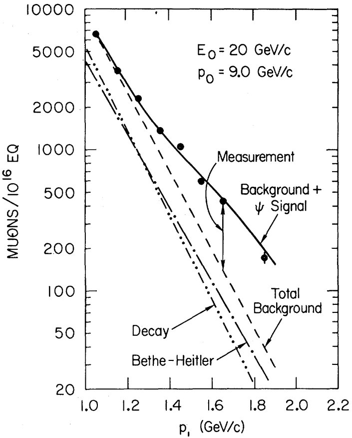
ψN measurements and interpretations

Experimental situation: was confusing. Now improving.
Methods:

- From photoproduction, using VDM, optical theorem and assumptions on Re(A)/Im(A) (~ 0)
  - 20 GeV: $d\sigma(J/\psi N \rightarrow J/\psi N)/dt \mid_{t=0} \sim 25\ \mu b$
  - 20-200 GeV: $\sigma(J/\psi N)_{tot} \sim 1$ mb $\Rightarrow$ 2.8 - 4.1 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 γA: $\sigma(J/\psi N)_{abs} \approx 3.5 \pm 0.8 \pm 0.6$ mb
  - 80-150 GeV pA: $\sigma(J/\psi N)_{abs} \approx 7$ mb $\Rightarrow$ 3.6 mb
  - 400-450 GeV pA: $\sigma(J/\psi N)_{abs} \approx$ 4.3$\pm$0.3 mb

SLAC results on $\gamma A \to \psi + X$

Single spectrometer measurements (From: R.Andersen et al PRL 38, 263 (1977))



- 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

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

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

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

Program for JLab at 11 GeV

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

Advantages (to SLAC):

- lower energy - smaller effects from ℓ_{coh}, ℓ_F
- low background for J/ψ
- reconstructed kinematics of J/ψ
- separation of coherent and incoherent production
- several targets used

Disadvantages comparing to the SLAC experiment:

- ○ lower energy - stronger effect from Fermi motion

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

Goals:

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

(3) Look for more exotic effects:

- "Hidden color" $\gamma D \to J/\psi pn$
- Bound state: peak in σ/V at x=1 (threshold)

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

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

Hall C setup:

- LH,LD 15 cm, with a 6%RL radiator
- Heavy targets of 7.7%RL ($\approx$ 6% radiator + LH target)
- For $J/\psi(1S)$ production $\sigma_A \approx A \cdot \sigma_N$
- Beam 11 GeV, 50 μA
- HMS 21°, 4.3 GeV/c, SHMS 15°, 6.1 GeV/c $\Rightarrow E_\gamma > 10.5$ GeV, $|t| < 1.2$ (GeV/c)^2, acceptance $1.2 \cdot 10^{-4}$
- Assume $\frac{d\sigma}{dt}(E_\gamma = 10.5 - 11) = 0.6 \cdot e^{1.1 \cdot t}$ nb/GeV^2 (Cornell)
- Combined efficiency 50%
- Coherent production excluded by kinematics and J/ψ angle

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

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

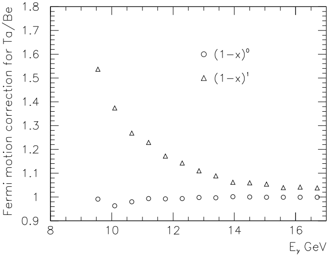
Extraction of $\sigma_{\psi N}$

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

SLAC model: semi-classical eikonal approximation of nuclear rescattering

Assumed: statistical error for each target 3%

$\sigma_{\psi N}$ mb		A 9	12	27	63	108	207	$\sigma(\sigma_{\psi N})$ mb
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. (kinematically suppressed?)

Conclusion

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

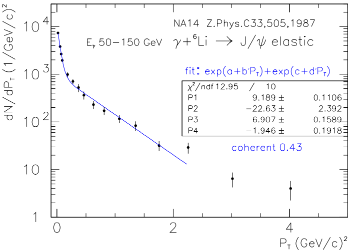
(1) Measurements of ψ-Nucleon cross-section. The expected errors are about 10% statistical and 15% systematic. This measurements are aiming to test if there is a considerable gluonic potential between colorless states. This cross-section has also been of a considerable interest for heavy ion physics.

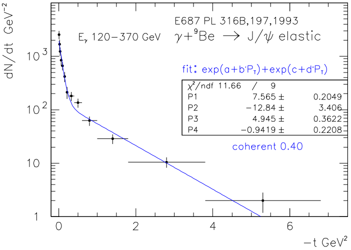
(2) Measurements of $\frac{d\sigma}{dt}(E_\gamma)$ of $\mathrm{J}/\psi(1\mathrm{S})$ is needed in order to fulfill (1). It is also of independent interest, probing compact, coherent states of valence quarks.

Experimental possibilities:

- The part (1) SHMS+HMS in 2 months
- The part (2) - longer time (several options)

$J/\psi(1S)$ Photoproduction on Nuclei





Vertex detectors:

- NA14: ^6Li 50-150 GeV
- E687: ^9Be 120-370 GeV

- A large coherent production: ≈40%
- “Coherent” slopes: NA14 and E687 are inconsistent
- NA14 and E687 - good t resolution, recoil undetected
- full cross-section A-dependence $\approx A^1$
- $L_{coh} > 2$ fm $E_\gamma > 50$ GeV

Generalized VDM

L.Frankfurt,M.Strikman...hep-ph/0304301

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

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

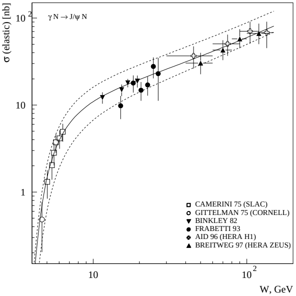
Calculation of $\sigma(\psi N)_{tot}$ (rigorous in heavy quark limit):

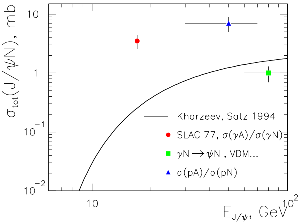
- short-distance QCD (similar to DIS)
- using gluon PDF of the nucleon

Is m_c large enough?
Test:
$\psi N \Rightarrow \gamma p \rightarrow \psi p$, 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





SLAC results on $\gamma p \rightarrow \psi p$ at 13-21 GeV

Double spectrometer measurements

(From: U.Camerini et al PRL 35, 483 (1975))

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 $\psi(3770)$

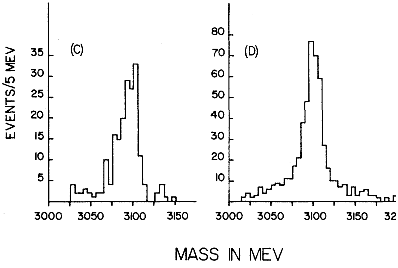
at 13 GeV:

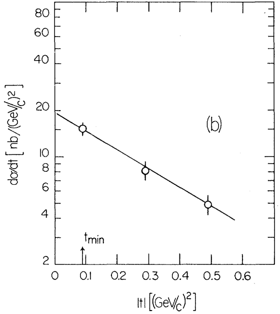
$\frac{d\sigma}{dt} \mid tmin = 3.8 \pm 0.8$ nb/GeV^2

at 20 GeV:

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

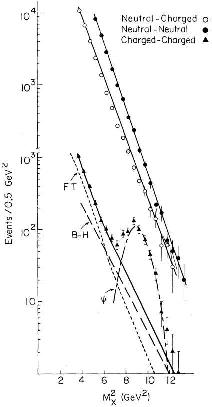
From VDM: $d\sigma(\psi N \rightarrow \psi N)/dt \mid_{t=0} \approx 25\mu$b

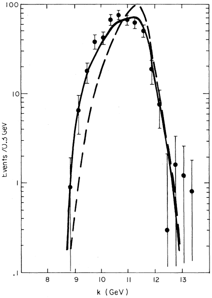




Cornell Results at 11.8 GeV

- $J/\psi \rightarrow e^+e^-$ detected with lead-glass calorimeters ($\frac{\sigma E}{E} = \frac{0.16}{\sqrt{E}}$)
- $\langle\gamma$-flux$\rangle$ $1{\cdot}10^9$/s for $8.5 < E_\gamma < 11.8$ GeV, duty cycle=7%, Be 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$^2 \cdot e^{1.13 \pm 0.18 \cdot t}$

No dependence of cross-section on E_γ observed!

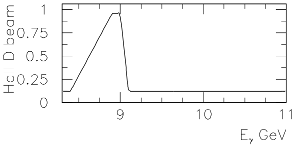
JLab spectrometers

hall	beam μA	setup	$\Delta\Omega$ ster	θ_{min} deg	P_{max} GeV	$\pm\frac{\Delta P}{P}$ %	$\frac{\sigma P}{P}$ %	$\sigma\theta_{in}$ mrad	$\sigma\theta_{out}$ mrad
Hall A	100	HRS	0.006	12.5	4.0	-5./+5.	0.02	0.6	1.0
		HRS	0.006	12.5	3.2	-5./+5.	0.02	0.6	1.0
		MAD	0.030	35.0	8.0	-15./+30.	0.1	1.0	1.0
			0.006	12.0	8.0	-15./+30.	0.1	1.0	1.0
Hall C	100	HMS	0.008	10.5	7.3	-10./+10.	0.1	0.8	1.0
		SOS	0.009	-	1.8	40.0	0.1	1.0	1.0
		SHMS	0.004	10.0	11.0	-15./+25.	0.2	3.0	1.5
Hall B	0.03	CLAS	$\sim 2\pi$	-	-	0.5			
Hall D	γ		$\sim 4\pi$	-	-	$<$1.			

Luminosity and Acceptance

Possible photon flux:

- Halls A,C: 50μA at 6% RL radiator: $6 \cdot 10^{12}\gamma$/s 8.5-11 GeV on 10 cm LH
- A,C ECAL: 2μA at 6% RL radiator: $3 \cdot 10^{11}\gamma$/s 8.5-11 GeV on 4 cm LH
- Halls B: no tagging forseen
- Halls B: $\mathcal{L} < 10^{35}$ cm^{-2}s^{-1}: $1.2 \cdot 10^{9}\gamma$/s 8.5-11 GeV on 10 cm LH
- 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



- "Standard" 12 GeV equipment: acceptance A/B/C/D/ECAL
  $0.2 \cdot 10^{-3}$ / 0.2 / $0.1 \cdot 10^{-3}$ / 0.4 / 0.2