Inclusive Photo-Production Backgrounds in an Electron-Ion Collider

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I discuss a simple approximation to the photoproduction rate in ep and eA collisions.

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I. QUASI-REAL VIRTUAL PHOTON FLUX

The electromagnetic field of a high energy electron can be resolved into a virtual photon flux. For a heavy ion, this is usually described in the Weizsäcker Williams approximation. For near 0° electron scattering, the flux can be derived from the ordinary leptonic tensor, while keeping all first order terms in m_e^2. Roughly speaking, the *virtual* photon flux is [1]:

$$\frac{d\phi_\gamma}{dk_\gamma} \approx \frac{t_V}{k_\gamma}, \qquad \text{with} \quad t_V \approx 0.02 \tag{1}$$

The numerical value of t_V is obtained as a numerical factor times α_{QED}, and it depends rather slowly on incident electron energy. Using this approximation, the total photo-production rate from quasi-real *ep* scattering is:

$$\mathcal{R} = \mathcal{L} \int_{\mathrm{Th}}^{k_e} dk_\gamma \frac{t_V}{k_\gamma} \sigma(\gamma p \to X) = \mathcal{L} \int_{\mathrm{Th}}^{s_e} ds_\gamma \frac{t_V}{s_\gamma - M^2} \sigma(s_\gamma) \tag{2}$$

with

$$s_e = 2k_e \left(E + P\cos\theta_{\mathrm{Crossing}}\right) + M^2 \qquad \text{and} \quad s_\gamma = 2k_\gamma \left(E + P\cos\theta_{\mathrm{Crossing}}\right). \tag{3}$$

For *ep* collisions, the threshold is the pion production threshold. For *eD* collisions, the threshold is reduced to the deuteron binding energy. For medium to heavy nuclei, the important low energy contribution will come from the Giant Dipole Resonance (GDR).

II. PHOTO-PRODUCTION CROSS SECTION

Above the resonance region, the photo-nucleon cross section $\sigma_\gamma \approx 100\,\mu\mathrm{b}$ 1. At high energy, the cross section has a slow rise from the Pomeron intercept. Although the cross section is larger at lower energies, particularly at the Δ-resonance. I will use just a constant $\sigma = 100\,\mu\mathrm{b}$ to get an order-of-magnitude estimate of rates.

For a Luminosity $\mathcal{L} = 10^{33}/\mathrm{cm}^2/\mathrm{sec} = 10^3/\mu\mathrm{b/sec}$ in a $5 \otimes 100(\mathrm{GeV/c})^2$ collider:

$$\begin{aligned}\mathcal{R}\left(10^{33}\right) &= \frac{10^3}{\mu\mathrm{b\,sec}} (100\,\mu\mathrm{b})\,(0.02) \int_{(M+m_\pi)^2}^{s_e} \frac{ds_\gamma}{s_\gamma - M^2} \\ &= \left(2\cdot 10^3/\mathrm{sec}\right) \ln\left[\frac{s_e - M^2}{2Mm_\pi + m_\pi^2}\right] \approx \left(2\cdot 10^3/\mathrm{sec}\right) \ln\left[\frac{2000}{0.27}\right] \approx 2\cdot 10^4/\mathrm{sec}\end{aligned} \tag{4}$$

This rate does not include beam-gas interactions, but only includes the beam-beam collisions.

Because of the dominance of low energy photons, one can consider that excitations in the resonance region will likely only populate the forward detectors. For example, a pion of perpendicular momentum $\leq 300 MeV/c$ with longitudinal momentum $(m_\pi/M)P = 14$ GeV/c is emitted at an angle of 20 mrad. Increases the threshold to $s_\gamma = 4\,\mathrm{GeV}^2$, the rate in the central detector (including endcaps) can be estimated as

$$\mathcal{R}_{\mathrm{Central}}\left(10^{33}\right) \approx \frac{2\cdot 10^3}{\mathrm{sec}} \ln\left[\frac{2000}{4.0 - M^2}\right] \approx 10^4/\mathrm{sec} \tag{5}$$

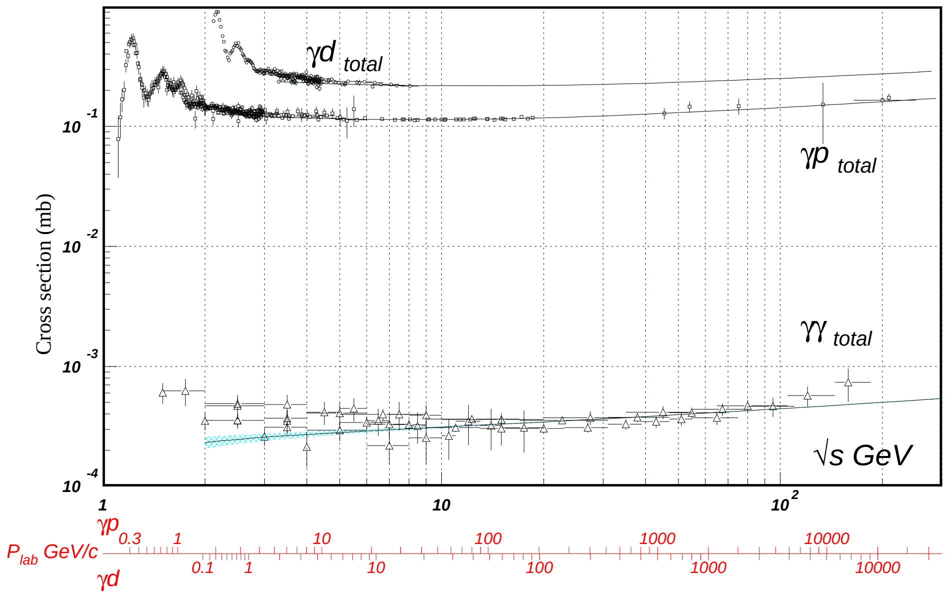

FIG. 1. Total photo-absorption cross sections on protons, deuterons, and photons, compiled by Particle Data Group [2].

III. NUCLEI

Low energy photo-absorption on nuclear beams will produce forward neutrons and other light fragments. This will be dominated by the Giant Dipole Resonance. The GDR cross section can be estimated from the Thomas-Reiche-Kuhn sum rule:

$$\int \sigma d\omega = \frac{2\pi(\hbar c)^2 \alpha_{\rm QED}}{M_p c^2}\,\frac{NZ}{A} \approx 60\frac{NZ}{A}\,\text{GeV}\,\mu\text{b} \tag{6}$$

A comprehensive survey of photo-absorption cross sections on nuclei and the Giant Dipole Resonance is presented in [3]. In particular, the energy of the GDR can be approximated as

$$E_{\rm GDR} \approx (80\,\text{MeV})\,A^{-1/3} \tag{7}$$

We can then estimate the bremsstrahlung weighted integral over the GDR as

$$\int \frac{d\omega}{\omega}\sigma(\omega) \approx \frac{1}{E_{\rm GDR}}\int d\omega\sigma \approx \frac{60\,\text{GeV}\,\mu\text{b}}{0.080\,\text{GeV}}A^{1/3}\frac{NZ}{A} = (750\,\mu\text{b})\,\frac{NZ}{A^{2/3}} \tag{8}$$

For the ion luminosity, we assume the total ion current is independent of Z, therefore the number of ions scales as $1/Z$. Furthermore, assume the normalized emittances and β-functions are independent of Z and A. Then for ions of total momentum ZP_0, the rms size of the focus scales as A/Z and the *per nucleus* Luminosity scales as $1/A$. Therefore, relative to an *ep* luminosity of 10^{33}, the low energy ${}^{Z}A(\gamma, n)X$ rate will scale approximately as

$$\mathcal{R}_A \approx \frac{10^3}{A\,\mu\text{b}\,\text{sec}}(0.02)\,(750\,\mu\text{b})\,\frac{NZ}{A^{2/3}} = \frac{1.5\cdot 10^4}{\text{sec}}\frac{NZ}{A^2}\,A^{1/3} \tag{9}$$

In fact, this estimate can be improved, as [3] gives the inverse (or Bremsstrahlung) weighted sum rule:

$$\sigma_{-1} = \int \frac{\sigma}{\omega} d\omega = \frac{4\pi}{3} \alpha \frac{NZ}{A-1} \left\langle r^2 \right\rangle \tag{10}$$

where the mean square charge radius scales as:

$$\left\langle r^2 \right\rangle \approx r_0^2 A^{2/3} \sim (1\,\mathrm{fm})^2 A^{2/3}. \tag{11}$$

This leads to a scaling of the photo-neutron rate as $A^{2/3}$ rather than $A^{1/3}$.

The review of Berman and Fultz [3] details both the (γ, n) and multi-n cross sections. However single neutron production usually dominates. Thus the rates calculated here can be considered equal to the neutron rates in the Zero Degree Calorimeter (ZDC).

[1] C. E. Hyde, W. Bertozzi and J. M. Finn, "Electron Scattering At 0-degrees: A Photon Tagging Technique," In *Newport News 1985, Proceedings, Continuous Electron Beam Accelerator Facility* 532-551.

[2] J. Beringer *et al.* [Particle Data Group Collaboration], Phys. Rev. D **86**, 010001 (2012).

[3] B. L. Berman and S. C. Fultz, Rev. Mod. Phys. **47**, 713 (1975).