Hadron Elecro-Production with HallD Generator

Rakitha S. Beminiwattha

Department of Physics, Syracuse University

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Outline

From Last Meeting : Photo-Production Models Compared

- Total Photo-production cross sections from hall D
- Total Photo-production cross sections from PDG [1]
- Wiser Photo-production cross section summed for all the processes [2]

Hall D Photo-Production Generator

- Hall D generator uses various experimental data to generate photo-production cross sections for photon energies below $3\ \mathrm{GeV}$
- It uses modified version of PYTHIA to generate photo-production cross sections for photon energies above $3\ \mathrm{GeV}$
  - I have not looked at PYTHIA generator in details yet.

Following $\gamma + p^+$ reactions are considered for photon energies below $3\ \mathrm{GeV}$

1. $p^+ + \pi^0$
2. $n + \pi^+$
3. $p^+ + \pi^+ + \pi^-(non - res.)$
4. $p^+ + \rho^0$
5. $\Delta^{++} + \pi^-$
6. $p^+ + \pi^0 + \pi^0$
7. $n + \pi^+ + \pi^0$
8. $p^+ + \eta^0$
9. $p^+ + \pi^+ + \pi^- + \pi^0$
10. $n + \pi^+ + \pi^+ + \pi^-$

Compare Hall D vs. PDG

- Compared total cross sections from Hall D event generator and PDG photo-production cross sections on proton
- For γ momentum less than $3\ \mathrm{GeV}$ it uses combination of different models including SAID
- For γ momentum greater than $3\ \mathrm{GeV}$ it uses PYTHIA

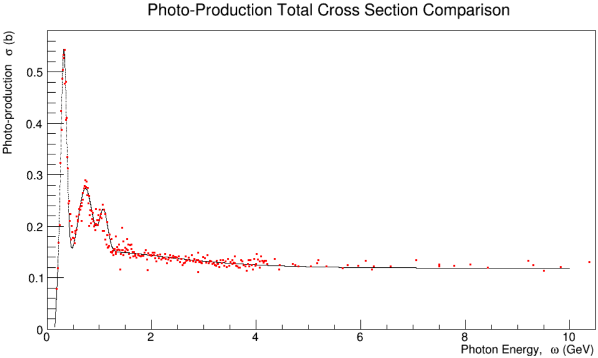


Figure: Black line : Hall D genertor, Red points : PDG

From Photo-Production to Electro-Production

- Electro-Production can takes place either from real bremsstrahlung photon radiated in the target or from virtual photon interaction approximated by Equivalent Photon Radiator (EPA) approximation
- Wiser generator estimate these two components to compute the electro-production cross-section
  - Bremsstrahlung contribution approximated according to MO and TSAI [3]
  - Virtual contribution approximated using the reference [4]
- I have implemented electro-production part to the hall D event generator
  - Bremsstrahlung contribution is implemented using equations available at PDG-2012 [5] and [6]
  - EPA contribution is implemented according to the reference [7]
- Next few slide will summarize the electro-production implementation

Electro-Production with Equivalent Photon Approximation

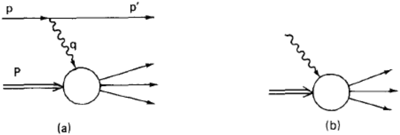


Figure: Electro-Production (a) and Photo-Absorption (b) equivalency [7]

The electro-production cross section for electron energy E using Equivalent Photon Approximation (EPA),

$$d\sigma = \sigma_\gamma(\omega) \cdot dn(\omega)$$

$$dn(\omega) = \int_{q^2_{min}}^{q^2_{max}} dn(\omega, q^2) \qquad = N_{EPA}(\omega)\frac{d\omega}{\omega}$$

where $\sigma_\gamma(\omega)$ is photo-production cross section at photon energy ω and,

$$N_{EPA}(\omega) = \frac{\alpha}{\pi}\left[\left(1 - \frac{\omega}{E} + \frac{\omega^2}{E^2}\right) ln\frac{q^2_{max}}{q^2_{min}} - \left(1 - \frac{\omega}{2E}\right)^2 ln\frac{(\omega^2+q^2_{max})}{(\omega^2+q^2_{min})} - \frac{m_e^2\omega^2}{E^2 q^2_{min}}\left(1 - \frac{q^2_{min}}{q^2_{max}}\right)\right]$$

Electro-Production with Radiated Real Photons

The Bremsstrahlung cross section for electron of energy E traveling inside a material [5]

$$\frac{d\sigma}{d\omega} = \frac{A}{X_0 N_A \omega}\left(\frac{4}{3} - \frac{4\omega}{3E} + \frac{4\omega^2}{3E^2}\right)$$

The electro-production cross section due to Bremsstrahlung photons,

$$d\sigma = \sigma_\gamma(\omega) \cdot N_{BREMS}(\omega)\frac{d\omega}{\omega}$$

$$N_{BREMS}(\omega) = \frac{d}{X_0}\left(\frac{4}{3} - \frac{4\omega}{3E} + \frac{4\omega^2}{3E^2}\right)$$

Where X_0 is the radiation length and $d = \rho \cdot t$ where ρ is target density and t is target thickness

EPA Photon Spectrum

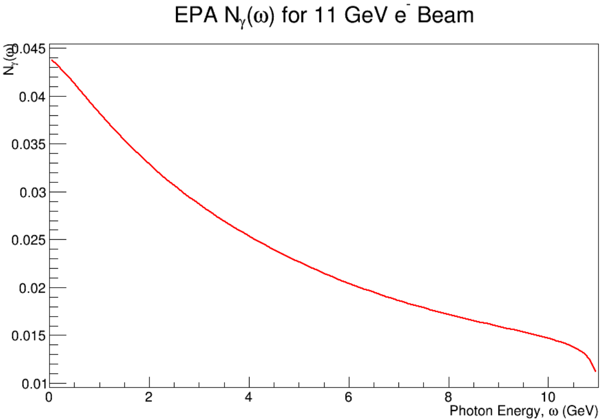


Figure: Photon Spectrum $N_{EPA}(\omega)$

Bremsstrahlung Photon Spectrum

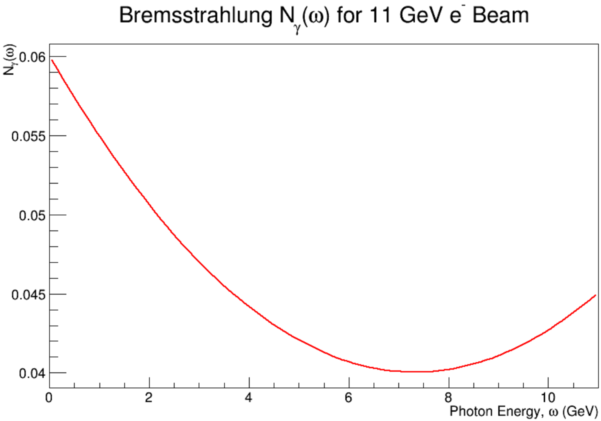


Figure: Photon Spectrum $N_{BREMS}(\omega)$

Complete Photon Spectrum

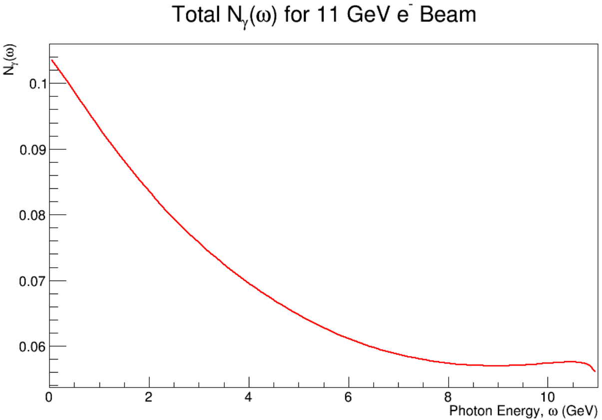


Figure: Photon Spectrum $N_{EPA}(\omega) + N_{BREMS}(\omega)$ for electron incident on a proton target

Electro-Production with Hall-D Generator

- Photon energy is sampled using electro-production cross section weighted distribution
- $11\ \mathrm{GeV}$ electron beam ($50\ \mu\mathrm{A}$) is incident into a $40\ \mathrm{cm}$ hydrogen target

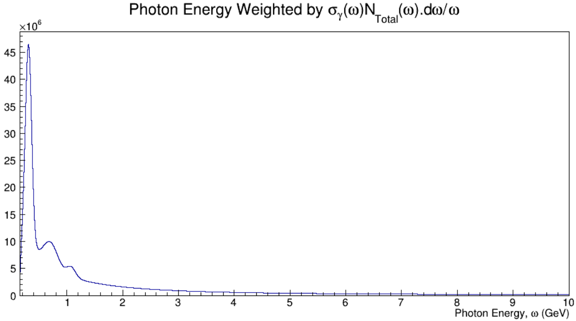


Figure: Hall D generator now samples the photon energy using electro-production cross section weighted distribution

Electro-Production : π^0

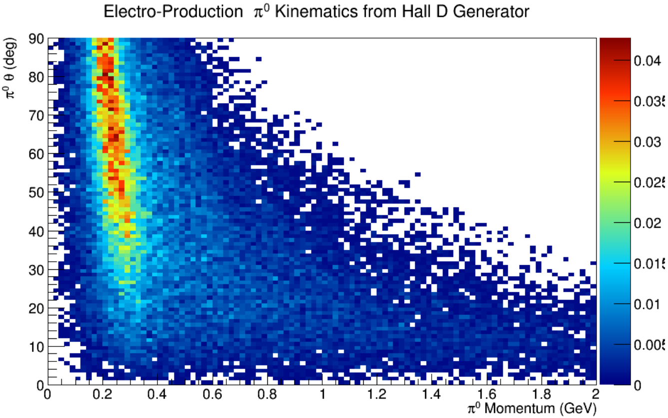


Figure: π^0 Only for $\theta < 90^0$ and $P < 2\ GeV$. Total cross-section is $\sim 30\ \mu\mathrm{b}$ for this limited kinematic phase-space

Pion Background from Different Methods

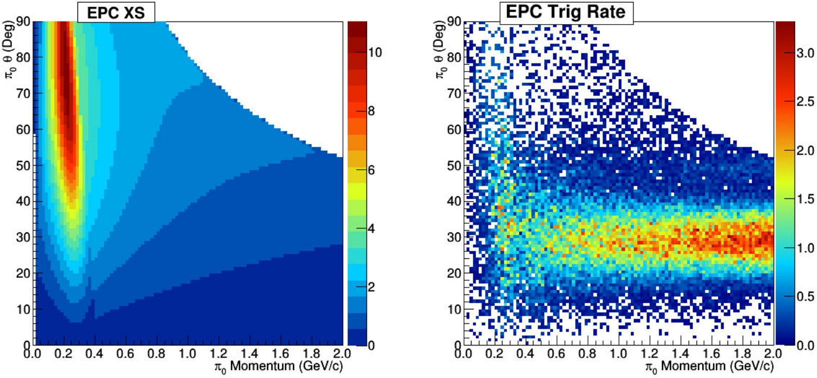


Figure: Using EPC code (see Michael Paolone's May 2015 collaboration meeting talk). Total cross section is $\sim 14\ \mu\mathrm{b}$

Pion Background from Different Methods

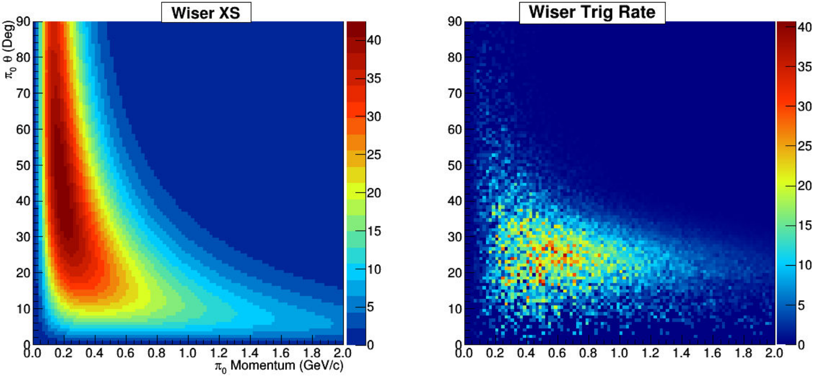
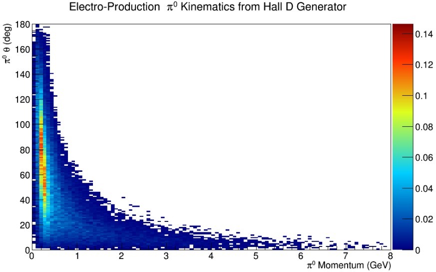


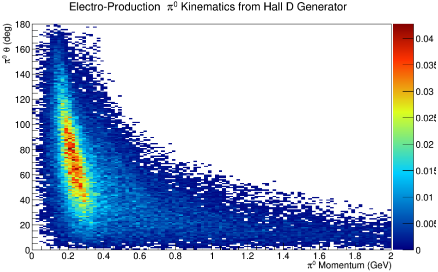
Figure: Using Std. Wiser Generator (see Michael Paolone's May 2015 collaboration meeting talk). Total cross section is $\sim 80\mu\mathrm{b}$

Summary

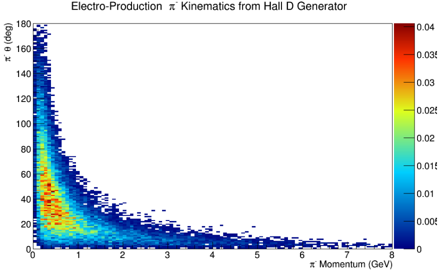
- Hall D generator is now configured with electro-production from proton target
- Needs to tweak $\frac{q^2_{max}}{q^2_{min}}$ better : Paul working on this
- Initial result match with the EPC code
- Cross section to a factor of 2 but not sure EPC results have real photon contribution
- Next immediate step : folding SoLID acceptance into these distribution and do a rate estimation
- Next long term step : implement a proper Geant4 generator based on the hall D generator

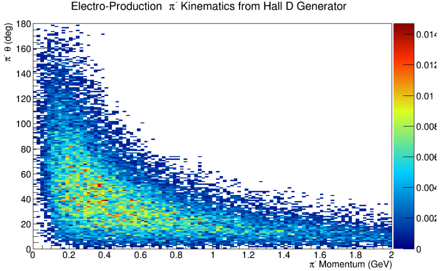
Electro-Production : π^0



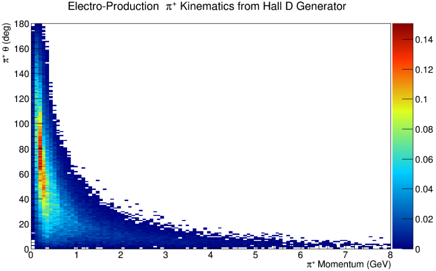


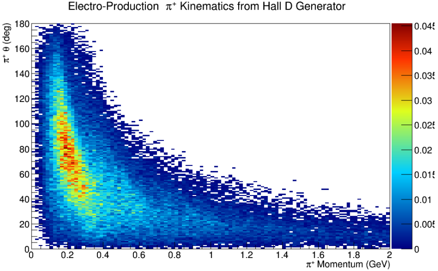
Electro-Production : π^-



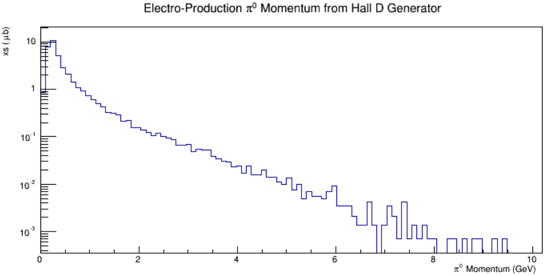


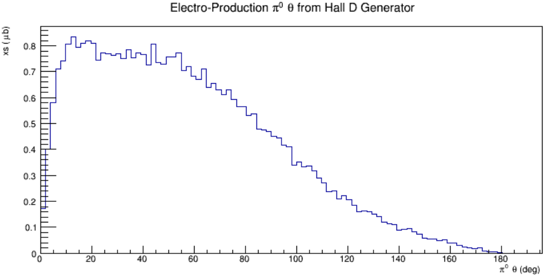
Electro-Production : π^+



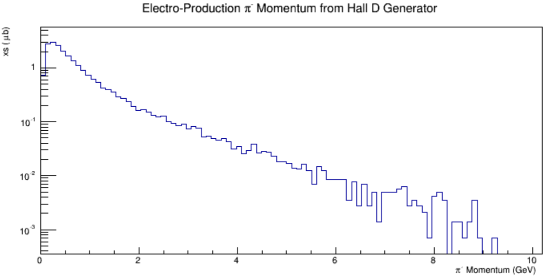


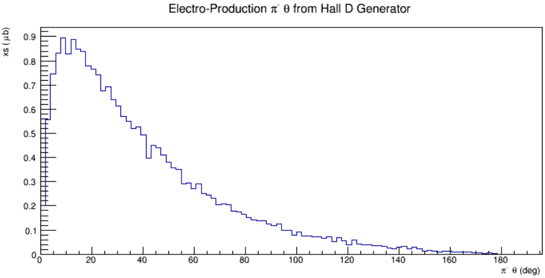
Electro-Production : π^0



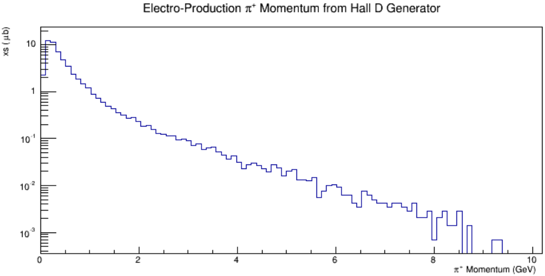


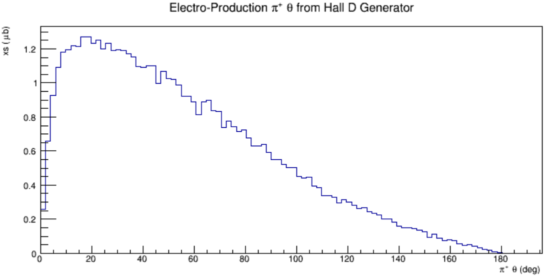
Electro-Production : π^-





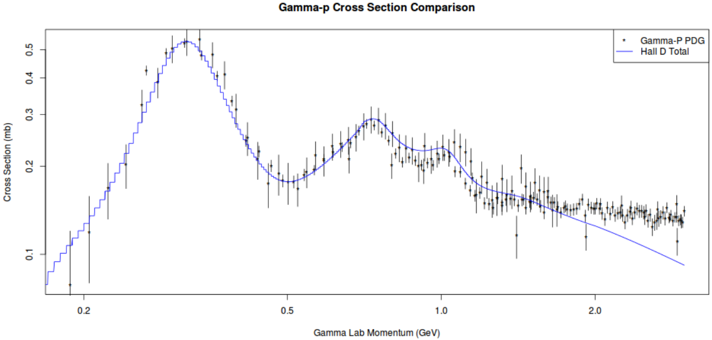
Electro-Production : π^+





Compare Hall D vs. PDG

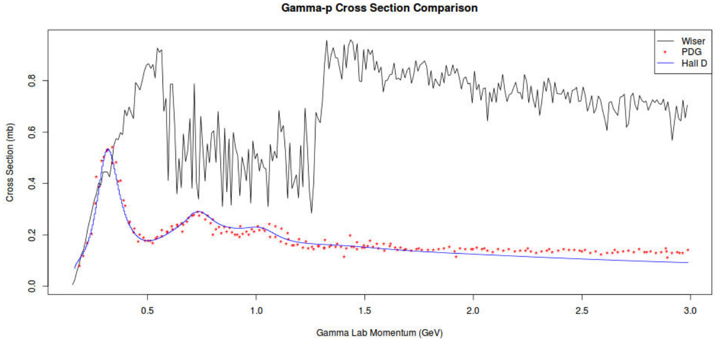
Compared total cross sections from Hall D low energy event generator and PDG photo-production cross sections on proton for γ momentum less than $3\ \mathrm{GeV}$



Wiser Photo-Production Cross Section

- Wiser cross section,$\sigma_\mathrm{i}(\mathrm{E}_\gamma)$ is computed for all the processes : $\pi^\pm$, $K^\pm$,P^+ and $\bar{P}^-$
- The cross section for π^0 is the average of $\pi^\pm$ cross sections
- Then all the cross sections are summed to compute the total wiser cross section
- See slide 27 for steps

Wiser Photo-Production Cross Section



Wiser Photo-Production Cross Section

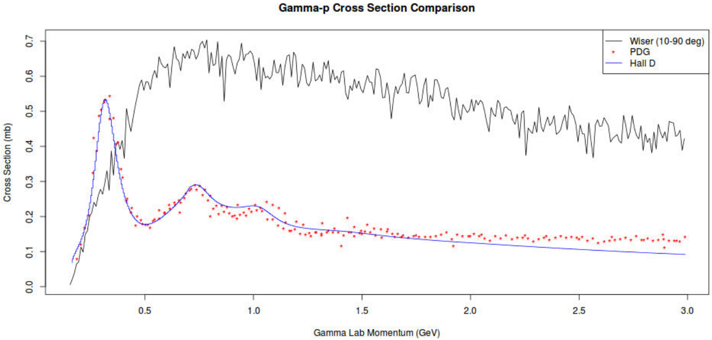


Figure: Wiser cross section only for 10 deg. to 90 deg.

Wiser Code Steps

- The main FORTRAN routine returns the differential cross section per monochromatic photon beam : $\mathrm{E}' \frac{\mathrm{d}^3\sigma}{\mathrm{dp}'^3}/\mathrm{E}_\gamma$
- Where $(\mathrm{E}', \mathrm{p}')$ is the hadron momentum and E_γ is the incident photon energy
- The total cross section for a monochromatic photon beam for i^{th} type interaction,

$$\sigma_\mathrm{i}(\mathrm{E}_\gamma) = \int_{\mathrm{phase-space}} \frac{\mathrm{d}\sigma_\mathrm{i}(\mathrm{E}_\gamma)}{\mathrm{dp}'\mathrm{d}\Omega} \mathrm{dp}'\mathrm{d}\Omega$$

- Where $\frac{\mathrm{d}\sigma_\mathrm{i}(\mathrm{E}_\gamma)}{\mathrm{dp}'\mathrm{d}\Omega} = \frac{\mathrm{p}'^2}{\mathrm{E}'} \cdot \left(\mathrm{E}' \frac{\mathrm{d}^3\sigma}{\mathrm{dp}'^3}/\mathrm{E}_\gamma\right) \cdot \mathrm{E}_\gamma$
- And subscript i is,

1. $\mathrm{i} = 0, 1 :\ \pi^\pm$
2. $\mathrm{i} = 2, 3 :\ K^\pm$
3. $\mathrm{i} = 4, 5 :\ P^+$ and $\bar{P}^-$

π^0 cross section is the average of $\pi^\pm$ cross sections

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