TCS with CLAS12 at Jefferson Lab

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CLAS Collaboration meeting
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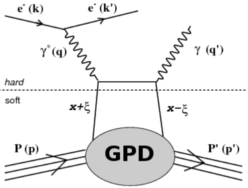
Overview of this talk

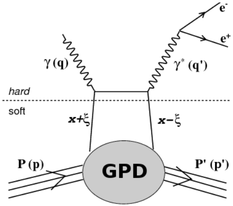
- Current state of the analysis
- New approach to extract TCS cross section
- Proton efficiency in the central detector

Timelike Compton Scattering

DVCS $(\gamma^* p \to \gamma p)$



TCS $(\gamma p \to \gamma^* p)$



Compton Form Factors

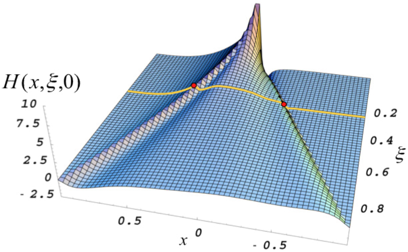
$$\mathcal{H} = \sum_q e_q^2 \left\{ \mathcal{P} \int_{-1}^{1} dx H^q(x,\xi,t) \left[\frac{1}{\xi - x} - \frac{1}{\xi + x} \right] + i\pi \left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t) \right] \right\}$$

Imaginary part

- Measured in DVCS asymmetries

Real part

- Accessible in DVCS cross section
- Accessible in TCS in cross section angular modulation



Data analysis

$$ep \rightarrow (e)\gamma p' \rightarrow (e)\gamma^* p' \rightarrow (e)e^+e^-p'$$

Final state

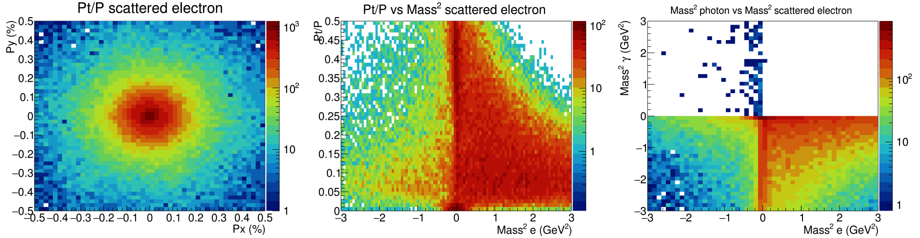
- Use the CLAS12 EB
- Events with e^+e^-pX selected

Incoming photon

- Make sure the photon is quasi-real
- Cuts on $Xp \rightarrow e^+e^-p$ missing mass

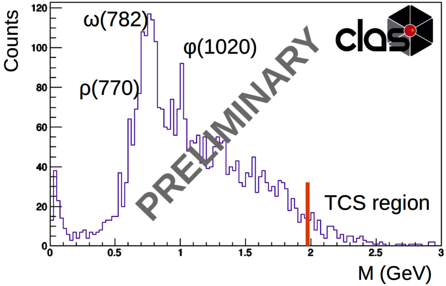
Scattered electron

- Additional cuts on scattered electron
- Look at $ep \rightarrow e^+e^-pX$ system

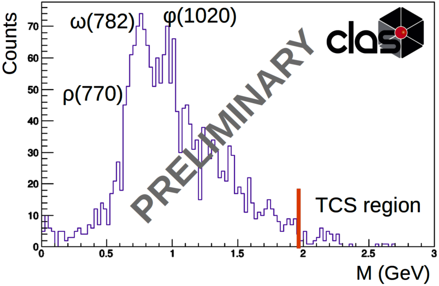


Lepton-pair spectrum shown at DNP 2018

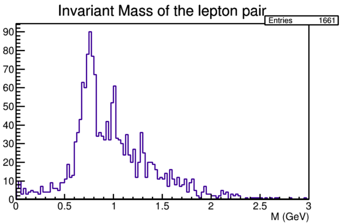
e⁻ inbending

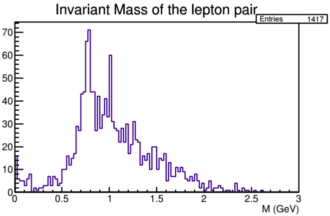


e⁻ outbending



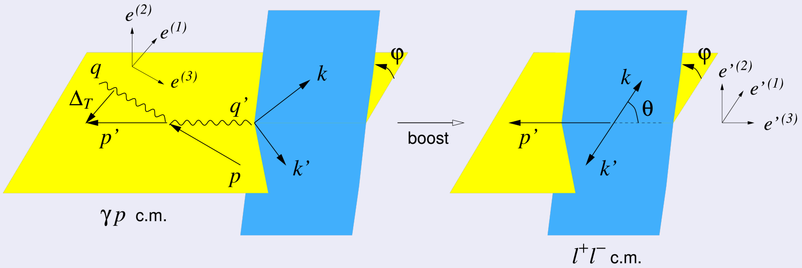
Data cooked in March





Part I
New Algorithm to extract TCS observables

$\gamma p \rightarrow e^+e^-p$ kinematics



$$Q'^2 = (k + k')^2 \qquad t = (p' - p)^2$$

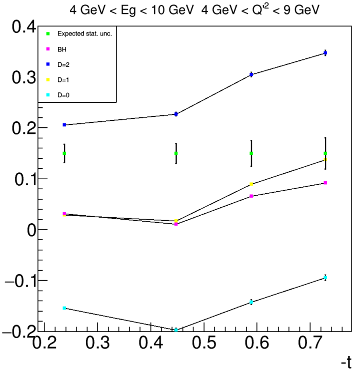
$$L = \frac{(Q'^2 - t)^2 - b^2}{4} \qquad L_0 = \frac{Q'^4 sin^2\theta}{4} \qquad b = 2(k - k')(p - p')$$

$$\tau = \frac{Q'^2}{2p\cdot q} \qquad s = (p + q)^2 \qquad t_0 = -\frac{4\xi^2 M^2}{(1-\xi^2)}$$

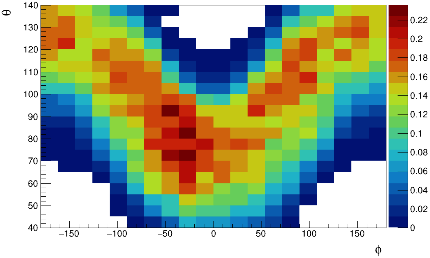
R ratio calculation

Experimental cross section ratio

$$R' = \frac{\sum_{\phi} cos(\phi) Y_{\phi}}{\sum_{\phi} Y_{\phi}} \qquad Y_{\phi} = \sum_{\theta} \frac{L}{L_0} N_{\theta}^{\phi} \frac{1}{A_{\theta}^{\phi}}$$



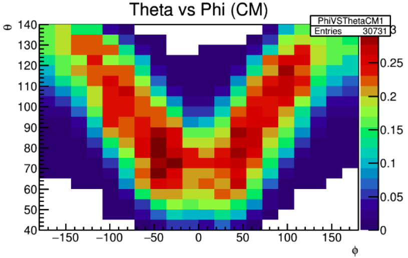
Expected results from CLAS12

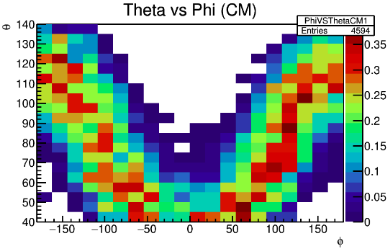


Acceptance in the θ/ϕ plane
$(0.5\ GeV^2 < -t < 0.7\ GeV^2)$

Problems with this observable

- Acceptance limits change the final value of the ratio
- Acceptance in both torus field is different $\rightarrow$ difficulties of combining them





$\rightarrow$ R. Paremuzyan developed a method that would cancel this acceptance limits dependance

Theta dependance of the interference term is trivial :

$$\frac{dS_{Tot}}{dQ'^2dtd\phi} = \int_{\pi/4}^{3\pi/4} d\theta \frac{d\sigma}{dQ'^2dtd(cos(\theta))d\phi} \cdot \frac{L}{L_0} = S_{\mathrm{BH}} + S_{Int} = S_{BH} + A \cdot ReM^{--} \cdot cos(\phi)$$

$$A = \int_{\pi/4}^{3\pi/4} d\theta \cdot a = -\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{M}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\int_{\pi/4}^{3\pi/4}(1+cos^2(\theta))d\theta$$

$$\longrightarrow \quad {}_A^B S_{Int} = {}_a^b\, S_{Int} \frac{\int_A^B (1+cos^2(\theta))d\theta}{\int_a^b (1+cos^2(\theta))d\theta}$$

Where A and B do not depend on Φ

Experimentally INT weighted cross section θ(a-b) is calculated by

$$\left.\frac{dS_{EXP}^{int}}{dQ'^2dtd\phi}\right|_a^b = \frac{1}{\mathcal{L}}\frac{1}{Acc}\frac{1}{\Delta Q'^2\Delta t\Delta\phi} \cdot \sum_{i=1}^{n_{exp}} \frac{L(\theta,\phi)}{L_0(\theta)} - \left.\frac{dS_{BH}}{dQ'^2dtd\phi}\right|_a^b$$

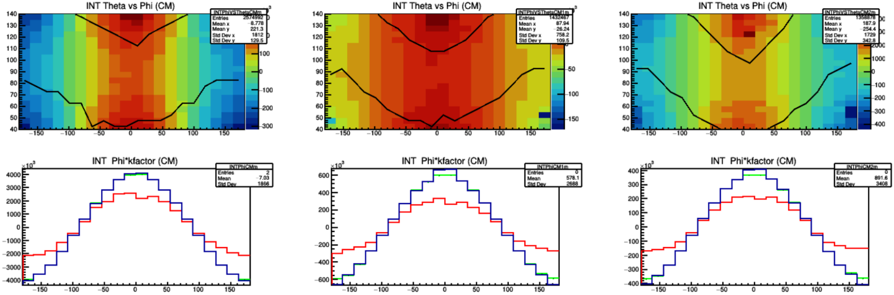
From data

Calculable with MC

Implementation (1)

- Events generated with R. Paremuzyan generator
- Weighted with BH/TCS*(L/L0) interference term only
- Acceptance limits estimated using full chain simulation

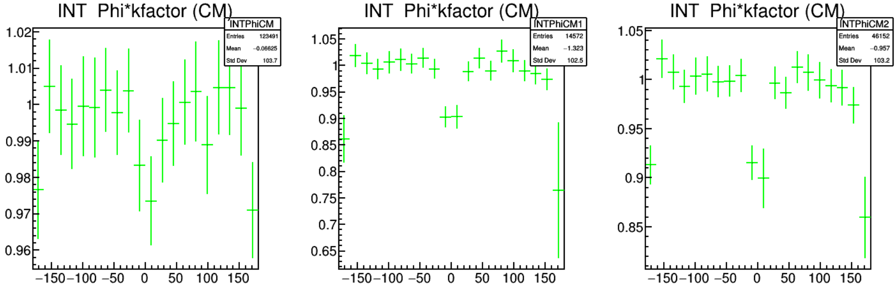
BH/INT*(L/L0) weighted events (acceptance limits in black)



Integrated number of events in acceptance limit within $40deg < \theta < 140deg$ extrapolated.

Implementation (2)

Ratio Extrapolated/generated

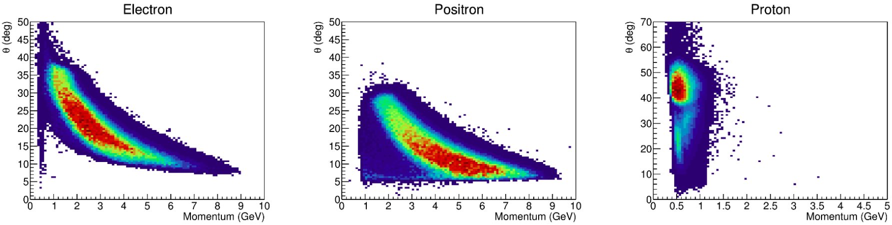


- Need to develop a strategy to subtract the BH contribution

Part II
Proton efficiency in the CD

Proton efficiency in the central detector

Reconstructed kinematics from simulation (BH + Interference BH/TCS)
($-t < 0.8\ GeV^2$ and $Q'^2 > 3\ GeV^2$)
$\rightarrow$ Most protons are in the central detector



Study of proton efficiency in the CD from data and MC
$\rightarrow$ Look at $ep \rightarrow e(p)\pi^+\pi^-$ and $ep \rightarrow ep\pi^+\pi^-$

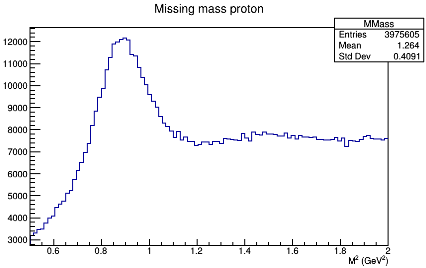
$$Efficiency = \frac{ep \rightarrow ep\pi^+\pi^-}{ep \rightarrow e(p)\pi^+\pi^-}$$

Event selection

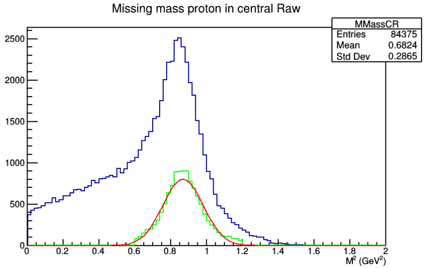
Use electron skim files for run 5532, 5533, 5534 (negative outbending)
Applied cuts :

- Electron, Pions in FD, Pions momentum >1 GeV, Pions chi2 within -4 and 4
- Missing proton within 40 deg. and 65 deg.
- Missing mass proton within 0.6 GeV and 1.2 GeV

Missing proton



all events

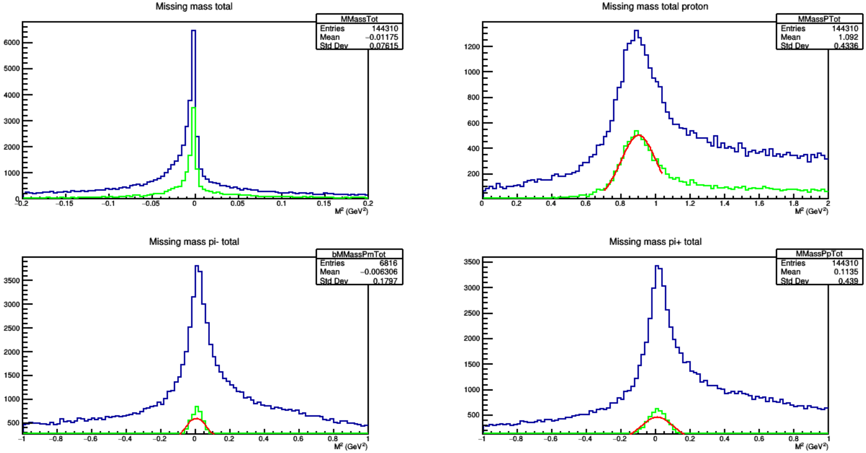


$45\ deg. < \theta < 60\ deg.$

all cuts

Detected proton

Requires detected proton in the CD



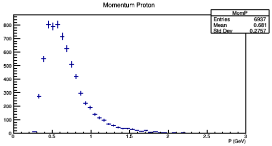
$45\ deg. < \theta < 60\ deg.$

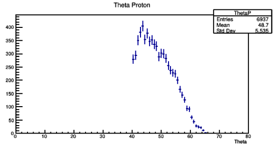
all cuts

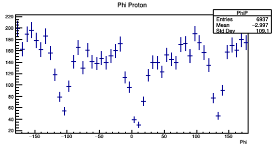
Efficiencies

Integrated efficiencies

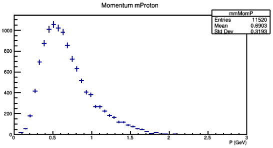
Events with detected proton

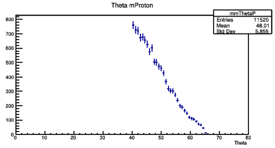


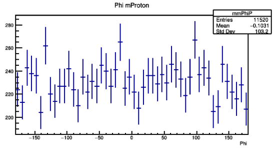




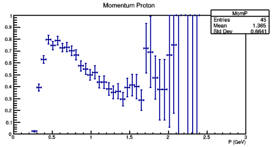
Events with missing proton

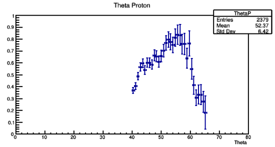


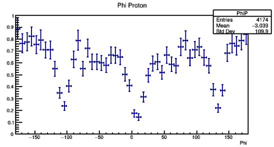




Efficiency





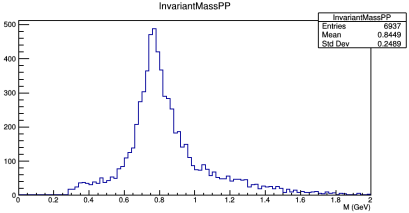


Momentum Theta Phi

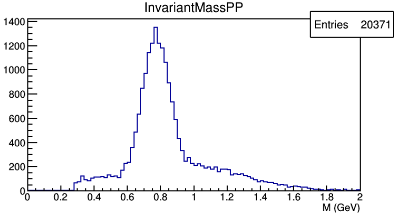
Simulation

- Using genev generator used in CLAS analysis, ρ^0 channel used

Reconstructed invariant mass $\pi^+\pi^-$

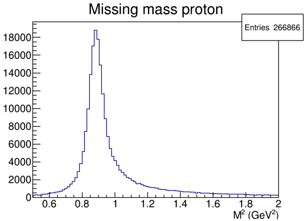


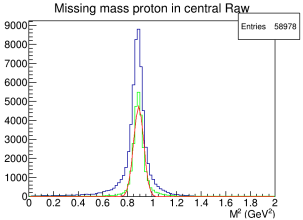
Data



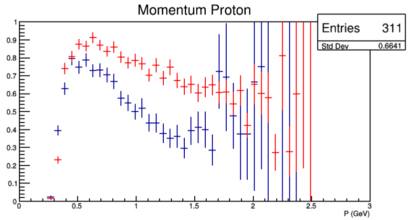
Simulation

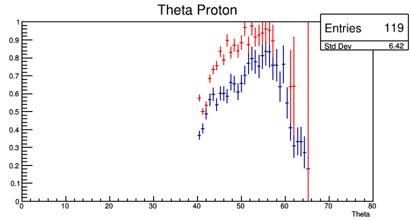
- GEMC 4.3.0, coatjava 5b76 (not the latest, but the same as for the data)
- Apply same cuts as data (this requires more study)

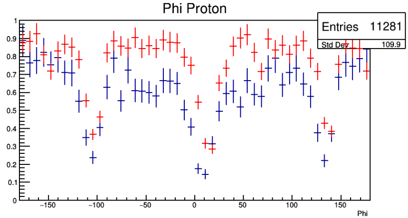




Efficiencies comparison



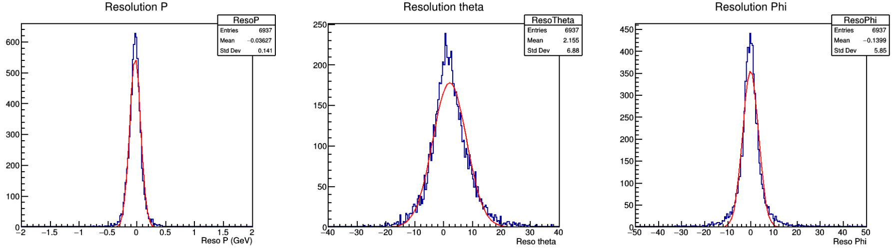




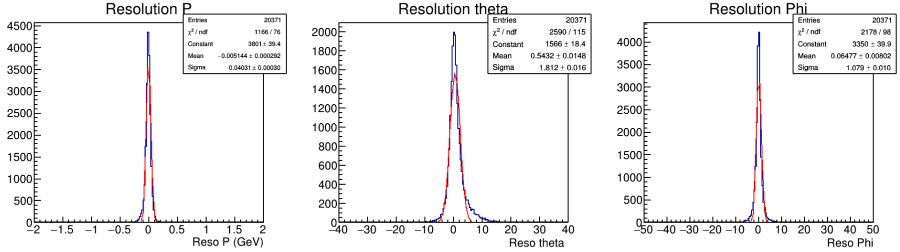
MC efficiency Data efficiency

Resolutions

Data

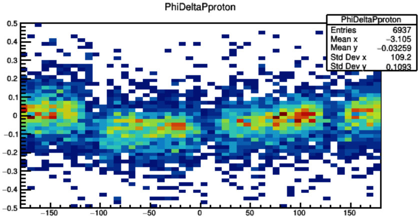


Simulation

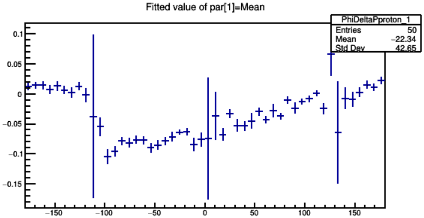


Outlook on proton CD efficiency

- Efficiency of the CD for proton has been estimated for data and simulation.
- Need to study systematics (proton missing mass cut in particular)
- Efficiency correction for the simulation will be produced
- Possibility of using the same data to correct proton momentum after alignment and energy loss correction.



$\Delta\ P\ vs\ \Phi$

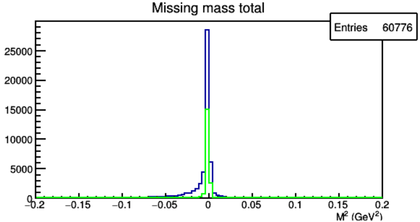


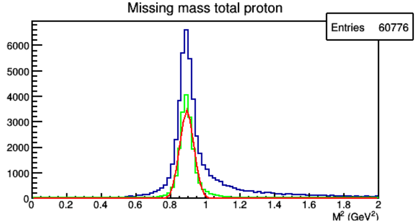
Mean of gaussian fit of each slice

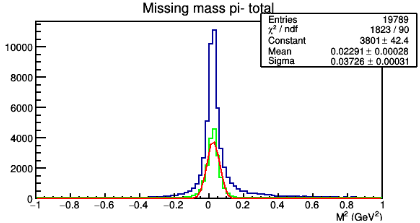
Thank you !

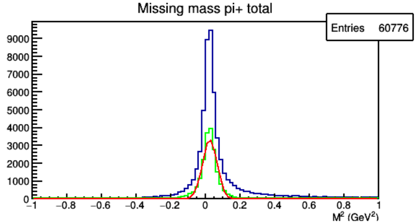
Back up

Simulation exclusivity plots

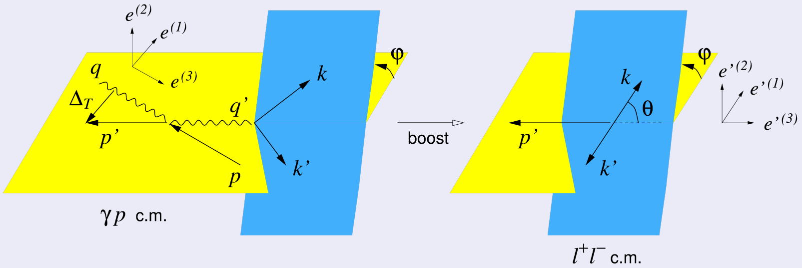








$\gamma p \rightarrow e^+e^-p$ kinematics



$$Q'^2 = (k + k')^2 \qquad t = (p' - p)^2$$

$$L = \frac{(Q'^2-t)^2-b^2}{4} \qquad L_0 = \frac{Q'^4 sin^2\theta}{4} \qquad b = 2(k - k')(p - p')$$

$$\tau = \frac{Q'^2}{2p{\cdot}q} \qquad s = (p + q)^2 \qquad t_0 = -\frac{4\xi^2 M^2}{(1-\xi^2)}$$

$\gamma p \to e^+e^-p$ Cross section and CFFs

Interference cross section

$$\frac{d^4\sigma_{INT}}{dQ'^2dtd\Omega} = -\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{m_p}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}\left[\cos(\phi)\frac{1+\cos^2(\theta)}{\sin(\theta)}\, Re\ \tilde{M}^{--} + \ldots\right]$$

$$\to \tilde{M}^{--} = \frac{2\sqrt{t_0-t}}{M}\frac{1-\xi}{1+\xi}\left[F_1\mathcal{H} - \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}\right]$$

BH cross section

$$\frac{d^4\sigma_{BH}}{dQ'^2dtd\Omega} \approx -\frac{\alpha_{em}^3}{2\pi s^2}\frac{1}{-t}\frac{1+\cos^2(\theta)}{\sin^2(\theta)}\left[(F_1^2 - \frac{t}{4M^2}F_2^2)\frac{2}{\tau^2}\frac{\Delta_T^2}{-t} + (F_1+F_2)^2\right]$$

Weighted cross section ratio

$$R(\sqrt{s}, Q'^2, t) = \frac{\int_0^{2\pi} d\phi\ \cos(\phi)\ \frac{dS}{dQ'^2dtd\phi}}{\int_0^{2\pi} d\phi \frac{dS}{dQ'^2dtd\phi}} \qquad \frac{dS}{dQ'^2dtd\phi} = \int_{\pi/4}^{3\pi/4} d\theta \frac{L}{L_0}\frac{d\sigma}{dQ'^2dtd\phi d\theta}$$