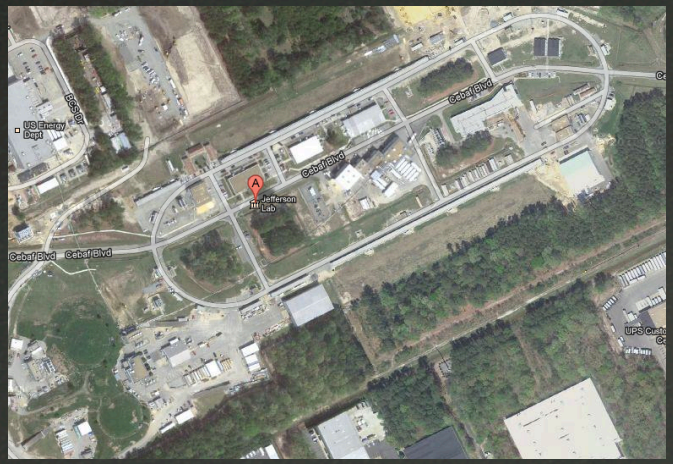
06/22/2012 : HUGS

DVCS

Deeply Virtual Compton Scattering

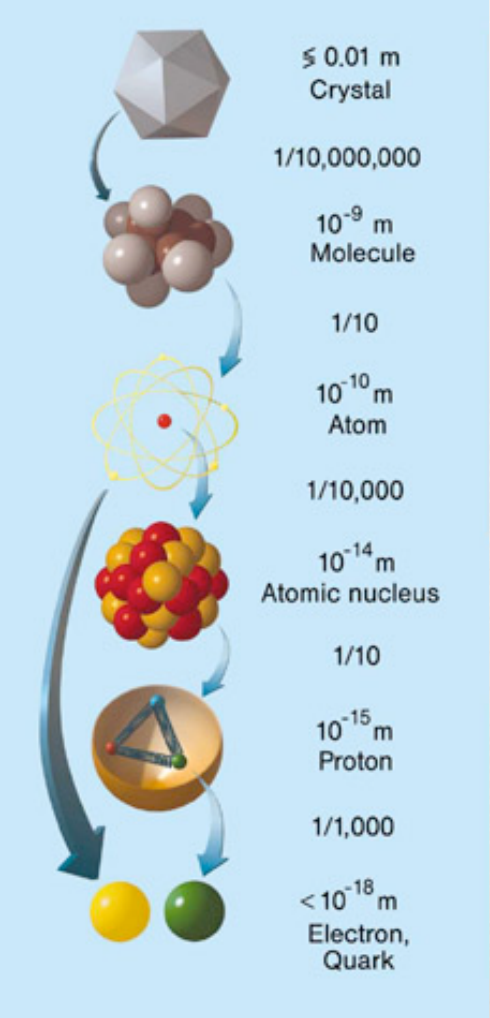


Hashir Rashad
ODU

Outline

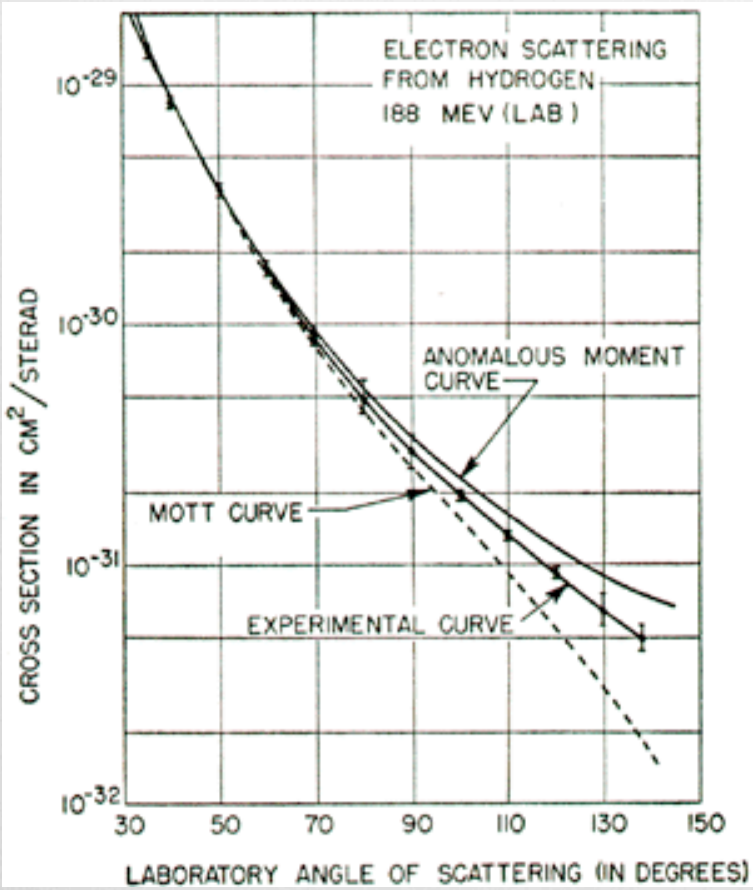
- History
- DVCS – an overview
- ep→ep γ process
- BH Cross section calculation
- Monte-Carlo Event Generator

Brief History on Understanding Nucleons



- 1910 Rutherford scattering (Gold foil)- Electrons orbiting Nucleus
- 1919 Rutherford scattering (Nitrogen Gas)- Discovery of Protons and Hint for Neutron
- 1932 Chadwick - Neutron
- Robert Hofstadter - Started around 1953 in an accelerator at Stanford University

Elastic Electron Scattering



- Cross-Section:

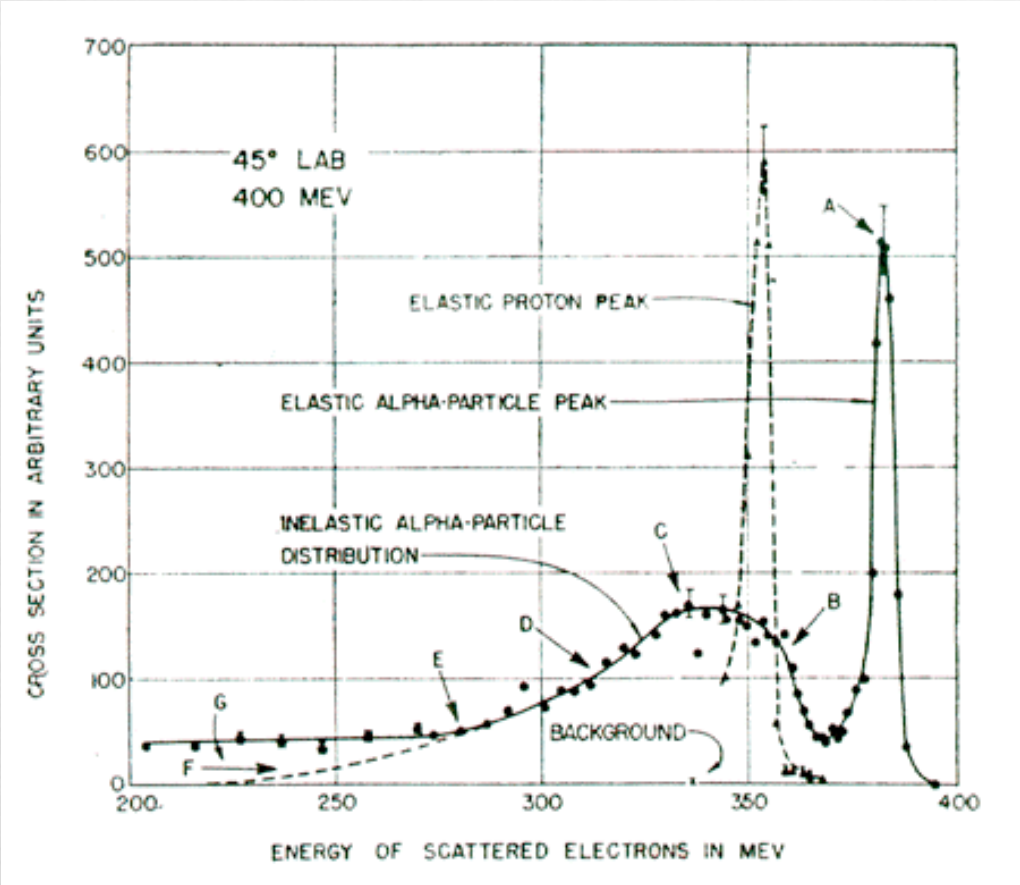
$$\left(\frac{d\sigma}{d\Omega}\right)=\left(\frac{d\sigma}{d\Omega}\right)_{mott}\left(\frac{G_E^2(Q^2)+\tau G_M^2(Q^2)}{1+\tau}+2\tau G_M^2(Q^2)\tan^2\left(\frac{\theta}{2}\right)\right)$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{mott}=\frac{\alpha^2}{4E^2\sin^4\left(\frac{\theta}{2}\right)}\left(\frac{E'}{E}\right)\cos^2\left(\frac{\theta}{2}\right)$$

- Form Factors => spatial distribution

SLAC 1954 – Robert Hofstadter

Probing Nucleus (α) …



- Energetic electron's can see the nucleons inside a nucleus
- Can more energetic electrons see something inside a nucleon too?

SLAC 1954 – Robert Hofstadter

Inclusive Deep Inelastic Scattering (DIS)

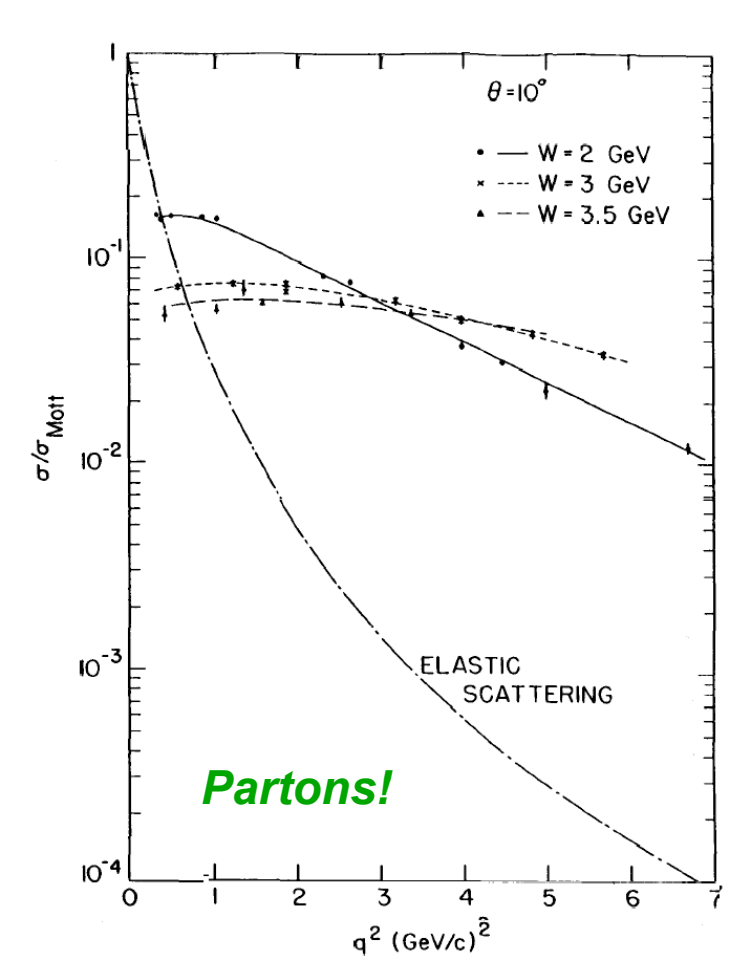
- Differential Cross-Section:

$$\frac{d^2\sigma}{d\Omega dE'} = \left(\frac{d\sigma}{d\Omega}\right)_{mott}\left[W_2(Q^2,\nu) + 2W_1(Q^2,\nu)\tan^2\left(\frac{\theta}{2}\right)\right]$$

- Dimensionless Structure functions

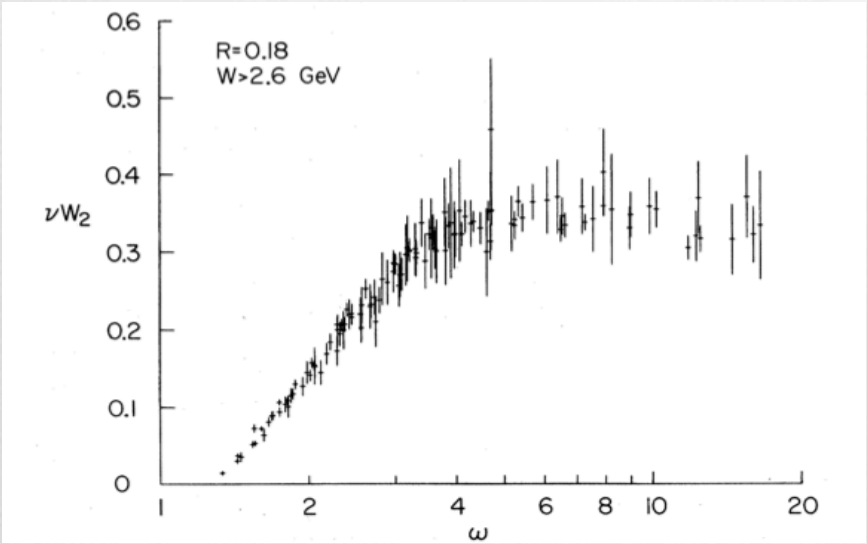
$$F_1(x,Q^2) = Mc^2 W_1(Q^2,\nu)$$

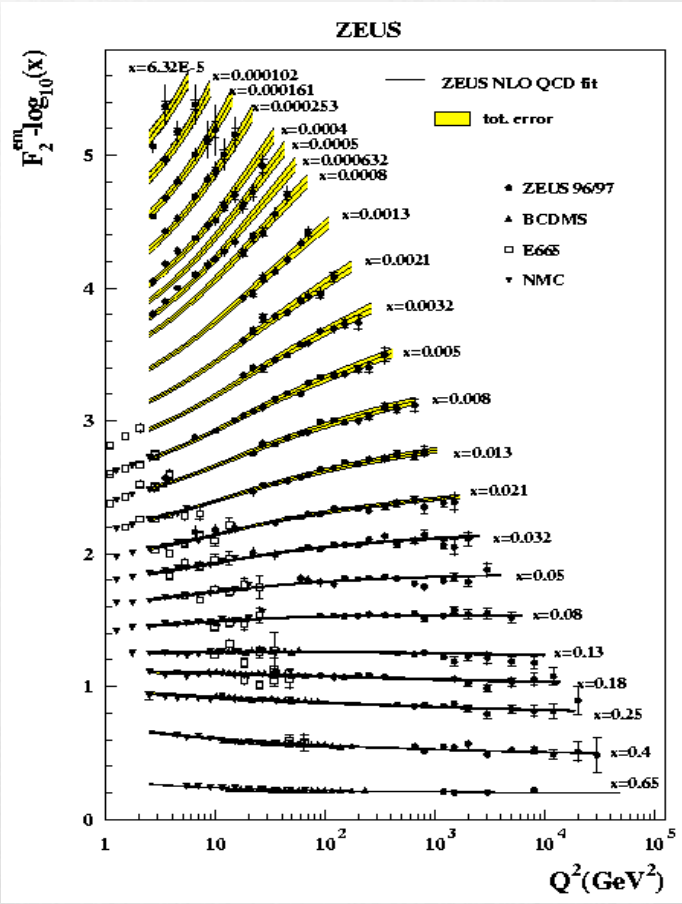
$$F_2(x,Q^2) = \nu W_2(Q^2,\nu)$$



SLAC-MIT (1969)

Scaling and Scaling Violation

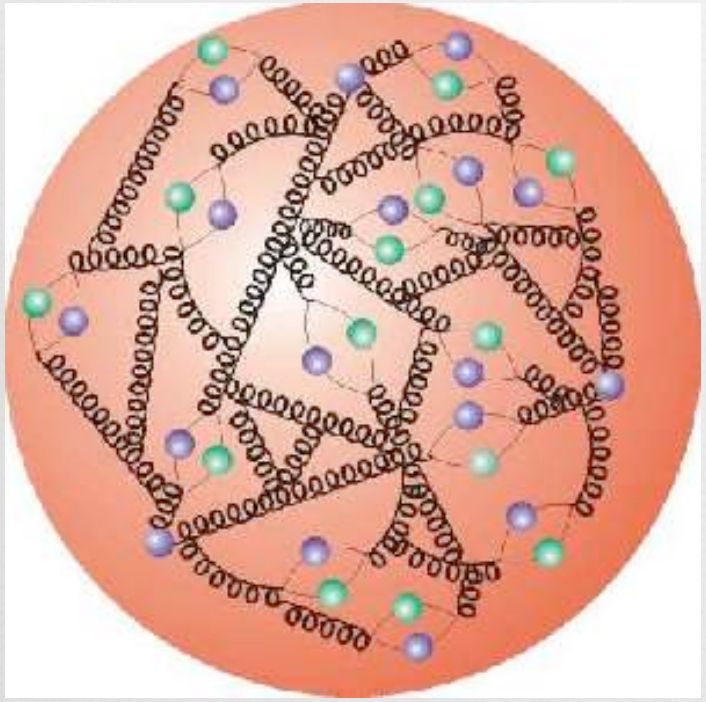




$$F_2 = x\Sigma_q e_q^2 \ (q(x)+\bar{q}(x))$$

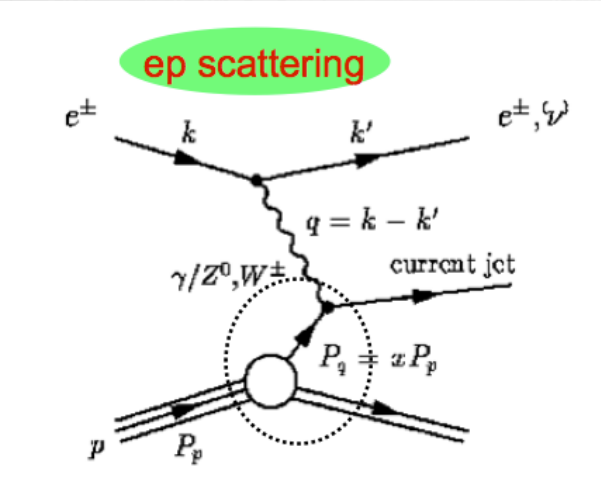
$$x = -\frac{Q^2}{2P.Q} = \chi_b$$

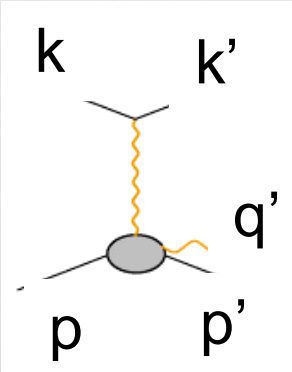
QPM and Beyond



- Quarks and Gluons
- Gluons radiates Quark—Anti-Quark pairs
- 3 more quarks than anti-quarks (Nucleons)

Kinematics of DIS and DVCS





Four-Momentum transfer squared

$$Q^2=-q^2=(k-k')^2=2kk'(1-\cos(\theta e))$$

Energy transferred from the lepton to proton

$$2M\nu= W^2c^2+Q^2-M^2c^2$$

Fractional Energy transfer

$$y=\frac{\nu}{k}$$

Bjorken Scaling Variable

$$\chi_b=-\frac{Q^2}{2P.Q}=\frac{Q^2}{2M\nu}$$

Four momentum transfer squared at proton vertex

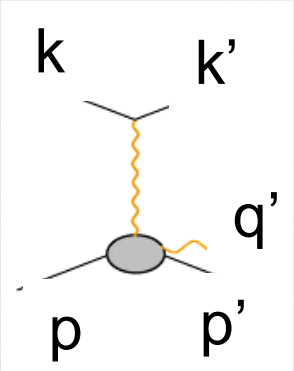
$$t=(p'-p)^2$$

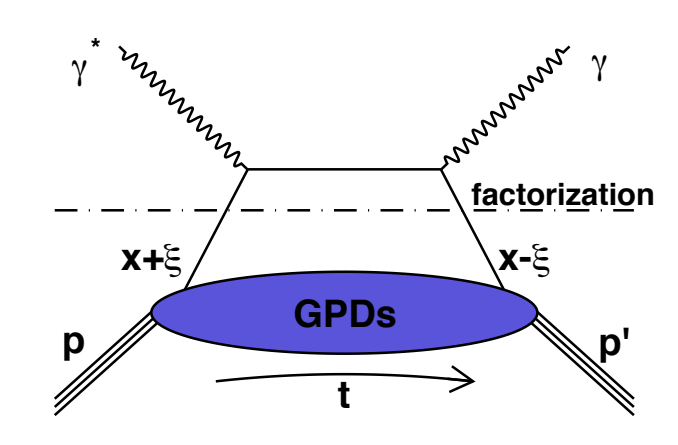
Generalized Bjorken variable

$$\xi \sim \frac{\chi_b}{2\chi_b}$$

DVCS - Overview

$ep \rightarrow ep\,\gamma$





- Underling process is a virtual photon scattering off of a quark which produces a real photon

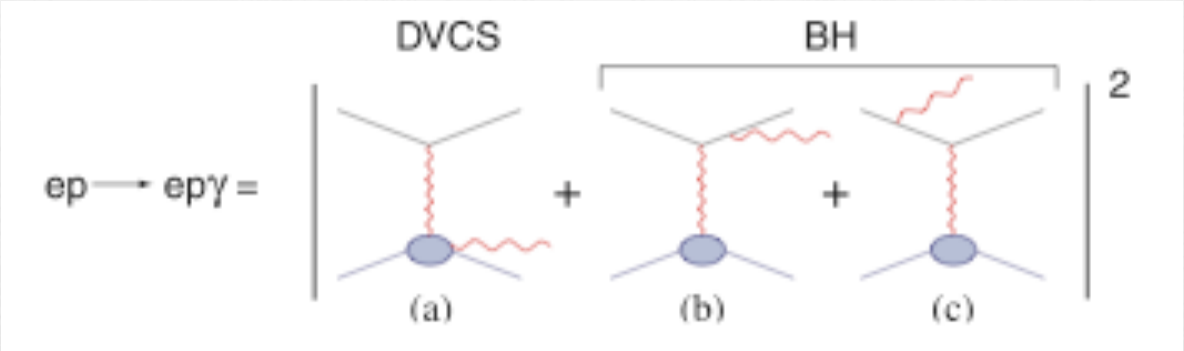
Generalized Parton Distributions (GPDs)

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle P'|\bar{\psi}(-\lambda n/2)\gamma^\mu \psi(\lambda n/2)|P\rangle = H(x,\xi,\Delta^2)\bar{U}(P')\gamma^\mu U(P)$$
$$+E(x,\xi\Delta^2)\bar{U}(P')\frac{i\sigma^{\mu\nu}\Delta_\nu}{2M}U(P) + \dots ,$$
$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle P'|\bar{\psi}(-\lambda n/2)\gamma^\mu \gamma_5 \psi(\lambda n/2)|P\rangle = \tilde{H}(x,\xi,\Delta^2)\bar{U}(P')\gamma^\mu \gamma_5 U(P)$$
$$+\tilde{E}(x,\xi,\Delta^2)\bar{U}(P')\frac{\gamma_5 \Delta^\mu}{2M}U(P) + \dots ,$$

$$\int_{-1}^{1} dx H(x,\xi,\Delta^2) = F_1(\Delta^2) ,$$
$$\int_{-1}^{1} dx E(x,\xi,\Delta^2) = F_2(\Delta^2) ,$$
$$\int_{-1}^{1} dx \tilde{H}(x,\xi,\Delta^2) = G_A(\Delta^2) ,$$
$$\int_{-1}^{1} dx \tilde{E}(x,\xi,\Delta^2) = G_P(\Delta^2) .$$

- *…. generalized parton distributions (GPDs), which are hybrids of the usual form factors and parton distributions, but in addition include correlations between states of different longitudinal and transverse momenta. – JLab page*

DVCS Process



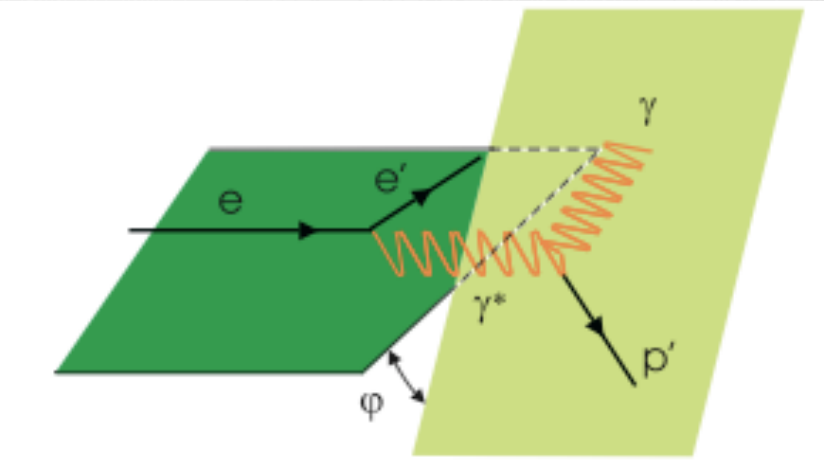
- The actual ep→ep γ process is a combination of DVCS and Bethe-Heitler.

$$\frac{d\sigma}{dx_{\mathrm{B}}dyd|\Delta^2|d\phi d\varphi} = \frac{\alpha^3 x_{\mathrm{B}} y}{16\,\pi^2\,\mathcal{Q}^2\sqrt{1+\epsilon^2}}\left|\frac{\mathcal{T}}{e^3}\right|^2 . \qquad \epsilon \equiv 2x_{\mathrm{B}}\frac{M}{\mathcal{Q}} .$$

BH Cross-section

$$\mathcal{T}^2 = |\mathcal{T}_{\rm BH}|^2 + |\mathcal{T}_{\rm DVCS}|^2 + \mathcal{I}\,,$$

$$\mathcal{I} = \mathcal{T}_{\rm DVCS}\mathcal{T}^*_{\rm BH} + \mathcal{T}^*_{\rm DVCS}\mathcal{T}_{\rm BH}\,,$$



$$|\mathcal{T}_{\rm BH}|^2 = \frac{e^6}{x_{\rm B}^2 y^2 (1+\epsilon^2)^2 \Delta^2\, \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ c_0^{\rm BH} + \sum_{n=1}^{2} c_n^{\rm BH}\, \cos(n\phi) + s_1^{\rm BH}\, \sin(\phi) \right\}$$

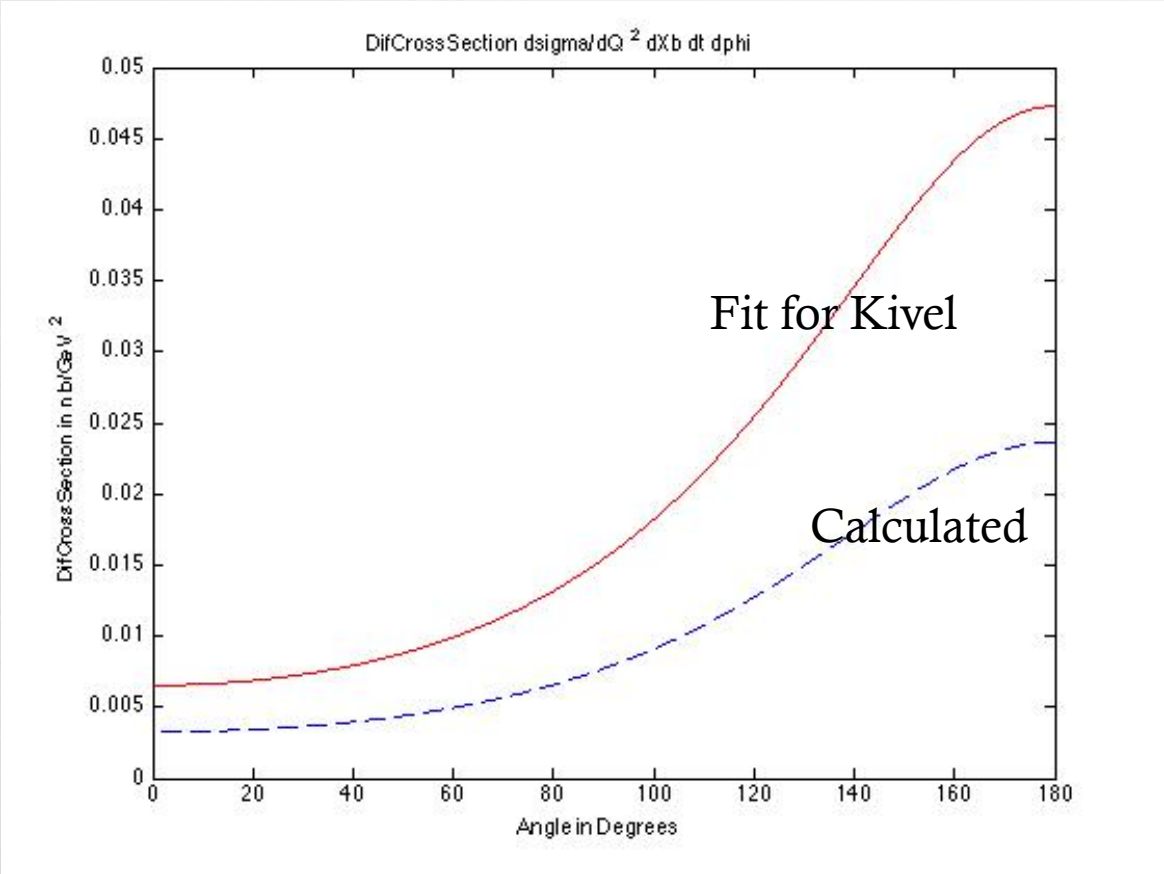
$$\mathcal{P}_1 = -\frac{1}{y(1+\epsilon^2)} \left\{ J + 2K\cos(\phi) \right\}\,, \qquad \mathcal{P}_2 = \frac{1}{y(1+\epsilon^2)} \left\{ 1 + J + \frac{\Delta^2}{\mathcal{Q}^2} + 2K\cos(\phi) \right\},$$

Contains a typo

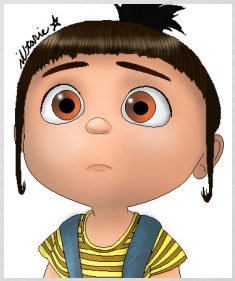
$$c_{2,\rm unp}^{\rm BH} = 8 x_{\rm B}^2 K^2 \left\{ \frac{4M^2}{\Delta^2} \left(F_1^2 - \frac{\Delta^2}{4M^2} F_2^2 \right) + 2\left(F_1 + F_2\right)^2 \right\}$$

Belitsky, Mueller, Kirchner

Warm-up calculation of BH Cross-Section

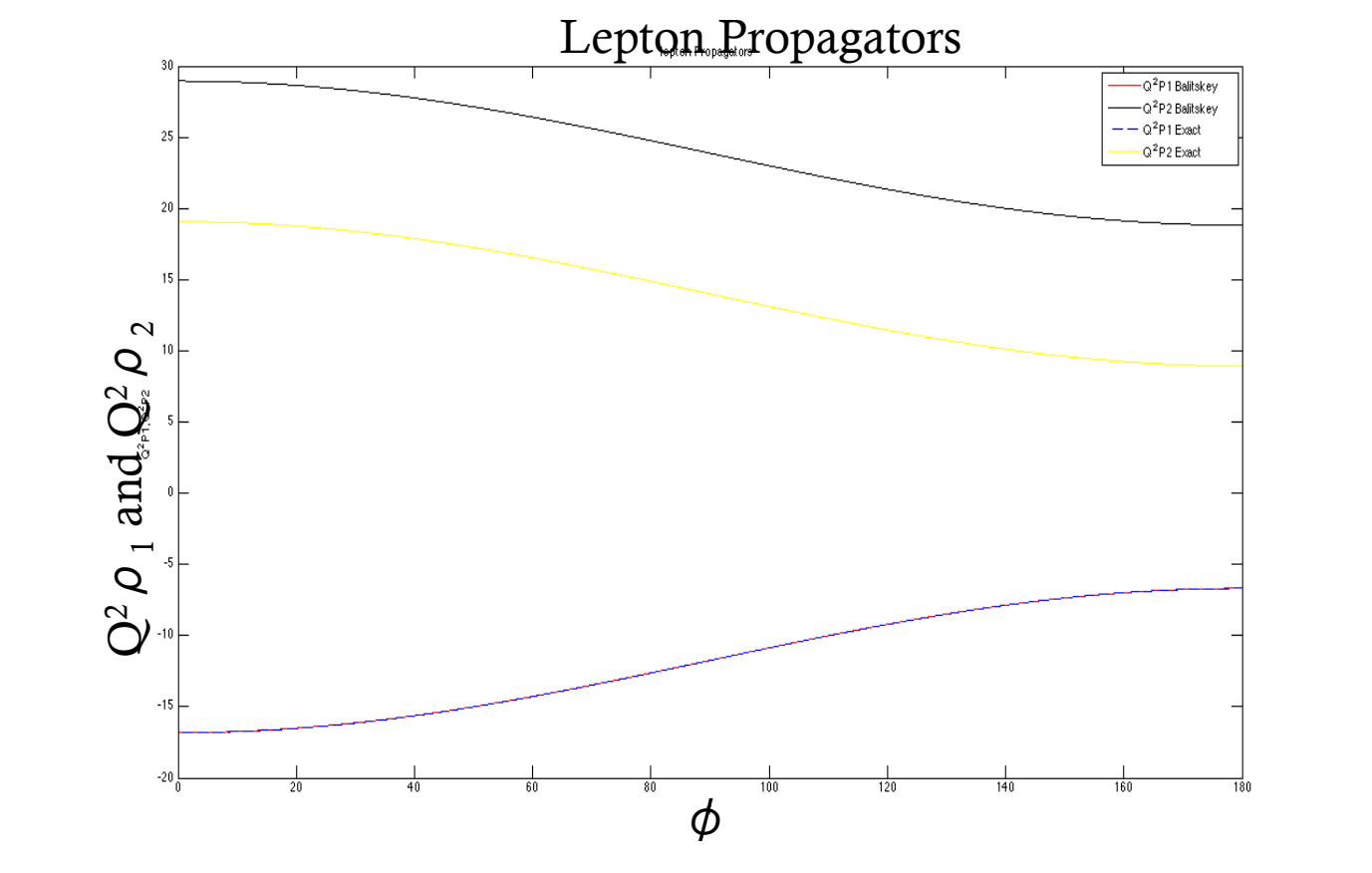


- Didn't Work!



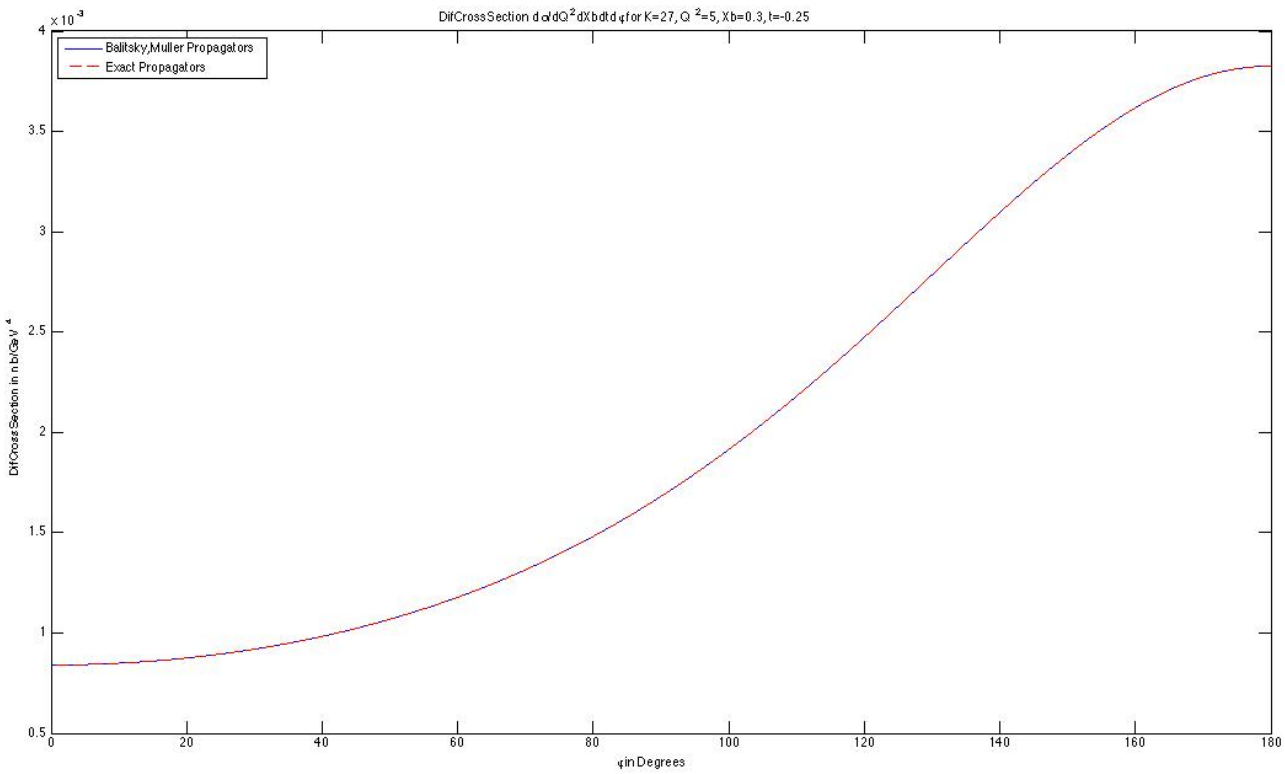
Exact Calculation of Propagators

$Q^2\varrho_1=(k-q')^2 \qquad Q^2\varrho_2=(k'+q')^2$

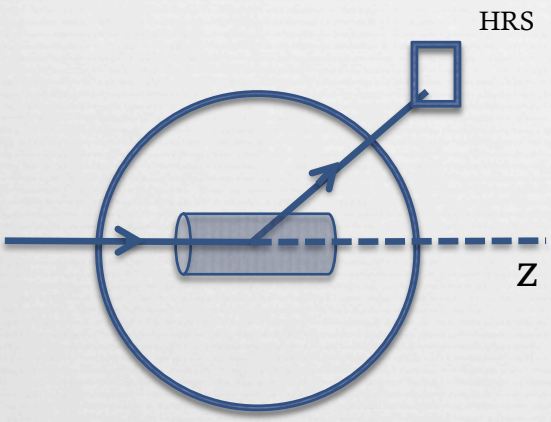


- ρ_2 was the culprit

BH Cross-section with adjusted propagators



Monte-Carlo Event Generator

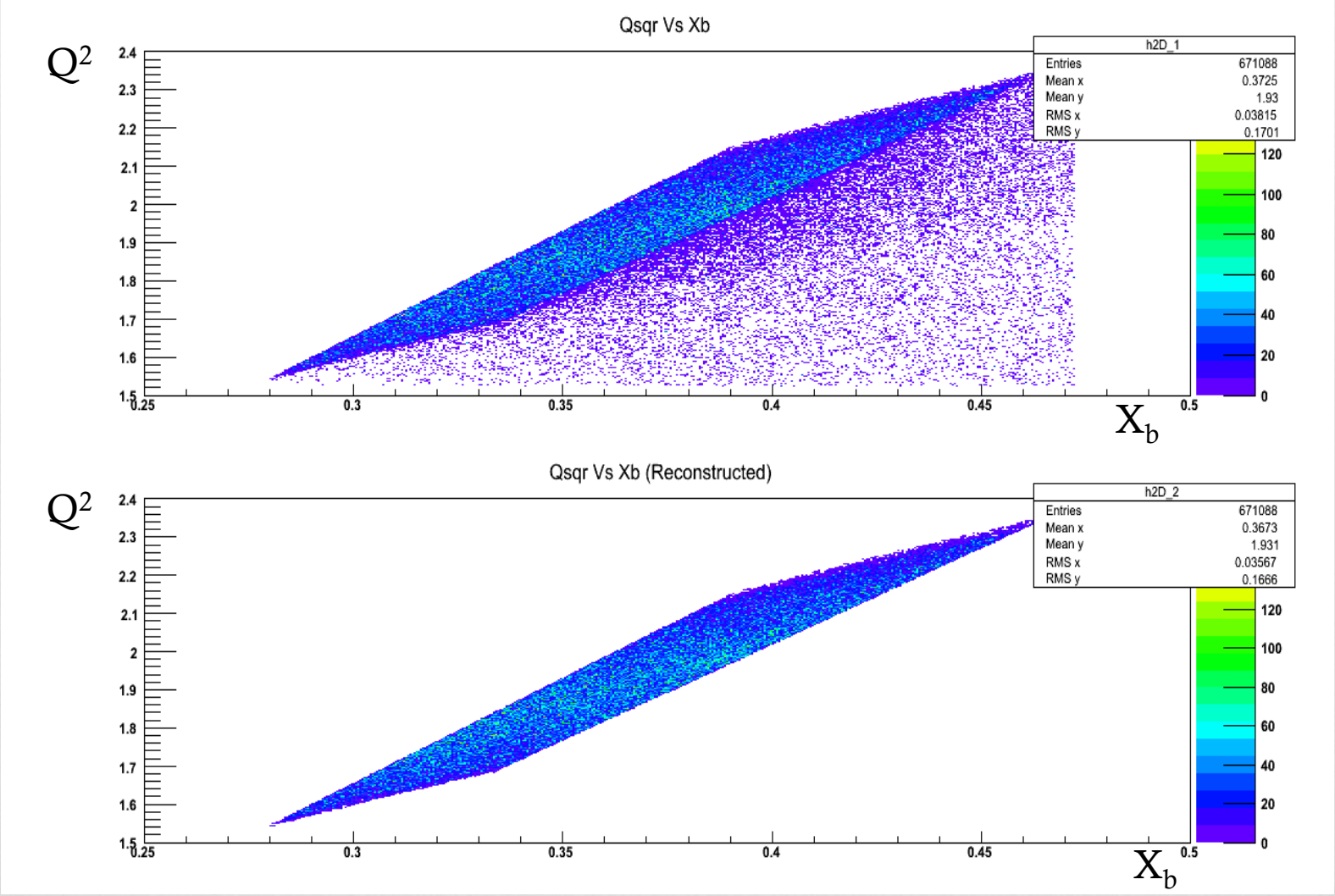


Momentum Acceptance
$\Delta k = 4.5\%$

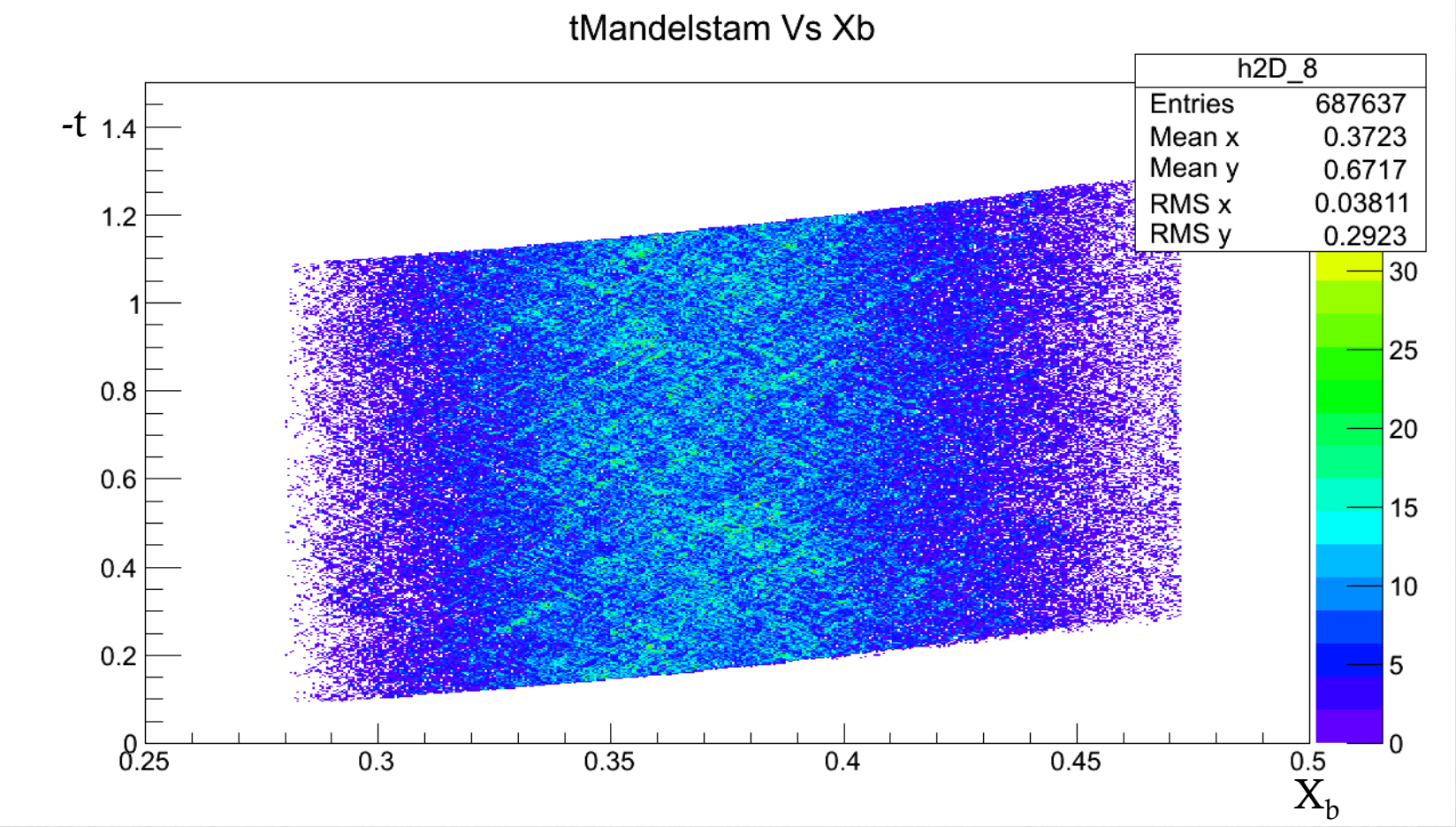
Angular acceptance
$\Delta \theta_H = 30$ mr
$\Delta \theta_V = 60$ mr

- Five fold differential space for final state of ep→ep γ
- Includes radiative corrections
- To be used as an input for GEANT4 simulation

$Q^2 - X_b$ Space


Qsqr Vs Xb
h2D_1
Entries 671088
Mean x 0.3725
Mean y 1.93
RMS x 0.03815
RMS y 0.1701
Q2
Xb
Qsqr Vs Xb (Reconstructed)
h2D_2
Entries 671088
Mean x 0.3673
Mean y 1.931
RMS x 0.03567
RMS y 0.1666
Q2
Xb

-t – X_b space


tMandelstam Vs Xb
h2D_8
Entries 687637
Mean x 0.3723
Mean y 0.6717
RMS x 0.03811
RMS y 0.2923
-t
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.25
0.3
0.35
0.4
0.45
0.5
X_b
30
25
20
15
10
5
0

References

- Nuclear and Particle Physics, B.R Martin
- Particles and Nuclei, Povh.Rith.Scholz.Zetsche
- High Energy Inelastic e-p Scattering at 6^0 and 10^0, Friedman,Kendall,Taylor
- Correspondence Arguments for High-Energy Collisions, Bjorken, Kogut
- Introduction to Deep Inelastic Scattering, Stephen Magill, 2009 CTEQ SUmmer School
- Theory of deeply virtual Compton scattering on the nucleon, A.V. Belitsky, D. Mueller, A. Kirchner
- Recent Results in DIS from Jlab, Dave Gaskell
- Inside the Proton - Investigating the structure of Proton through DIS(http://www.physics.ox.ac.uk/documents/PUS/dis/SLAC.htm)
- Global analysis of proton elastic form factor data with two-photon exchange corrections, J. Arrington, W. Melnitchouk , J. A. Tjon

Thank You

- Questions?????