Rutherford Scattering

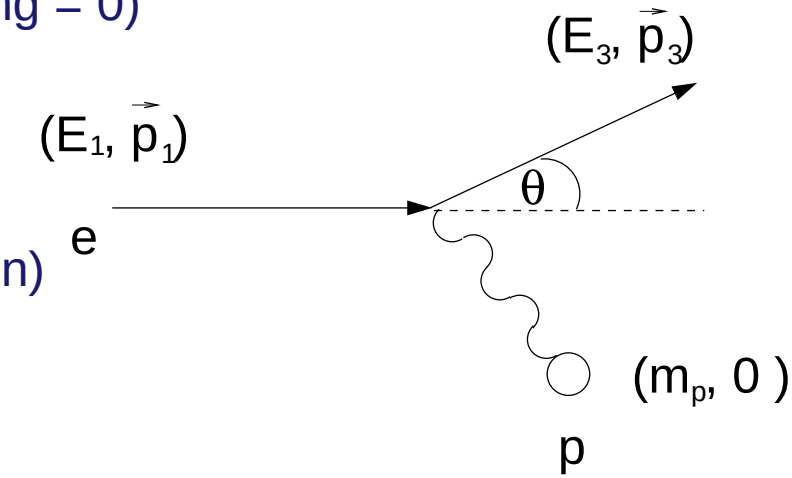
- $E_{kin,e} \ll m_e \ll m_p$

  $\rightarrow$ recoil ignored (p_p before and after scattering = 0)

  $\rightarrow$ implies magnetic IA (spin-flip) is ignored

  $\rightarrow s = E^2_{CMS} = m^2_p$

  $\rightarrow$ non-relativistic limit (no helicity conservation)



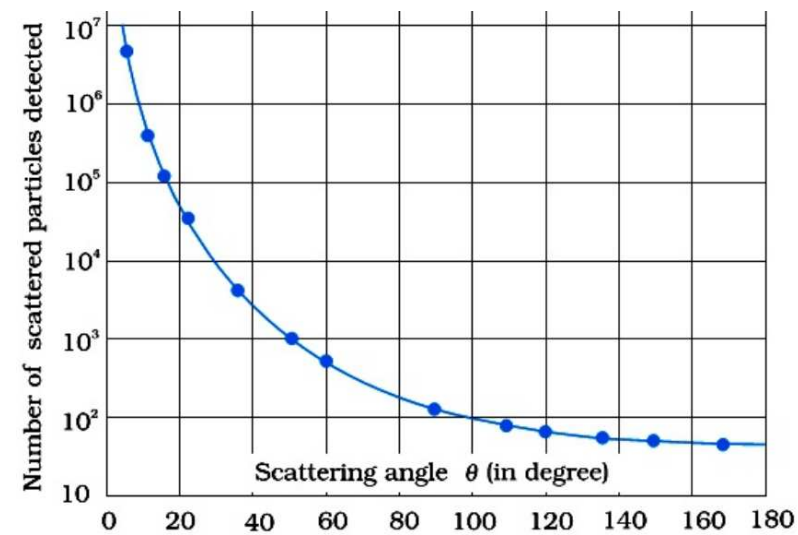
- $\lambda >> r_{target}$

  λ: de Broglie wave length of incoming electron

  r_{target}: size of target particle (proton)

- point-like scattering particles, spin=1/2

  $\rightarrow$ Dirac spinors describe the process



$$\left(\frac{d\sigma}{d\Omega}\right)_{Ruth} = \frac{\alpha^2}{16E^2_{kin}} \frac{1}{\sin^4 \theta/2}$$

$$|q| = 2|\vec{p}| \sin \theta/2$$

Mott Scattering

- $m_e << E_e << m_p$

  $\rightarrow$ recoil still neglected (no spin flip of proton)

  relativistic limit for description of electron

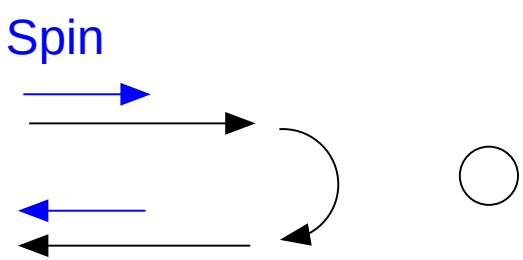
  $\rightarrow$ helicity $\equiv$ chirality

  $\rightarrow$ helicity conservation

$$\left(\frac{d\sigma}{d\Omega}\right)_{Mott} = \left(\frac{d\sigma}{d\Omega}\right)_{Ruth} \cos^2 \theta/2$$

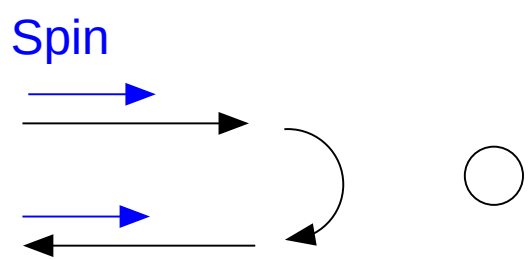
backward scattering is suppressed

(simultaneous conservation of angular momentum and helicity not possible)



Helizitaet erhalten

Drehimpuls nicht erhalten



Helizitaet nicht erhalten

Drehimpuls erhalten

Extended Charge Distribution

$$\left(\frac{d\sigma}{d\Omega}\right)_{extended} = \left(\frac{d\sigma}{d\Omega}\right)_{point} |F(\vec{q}^2)|^2$$

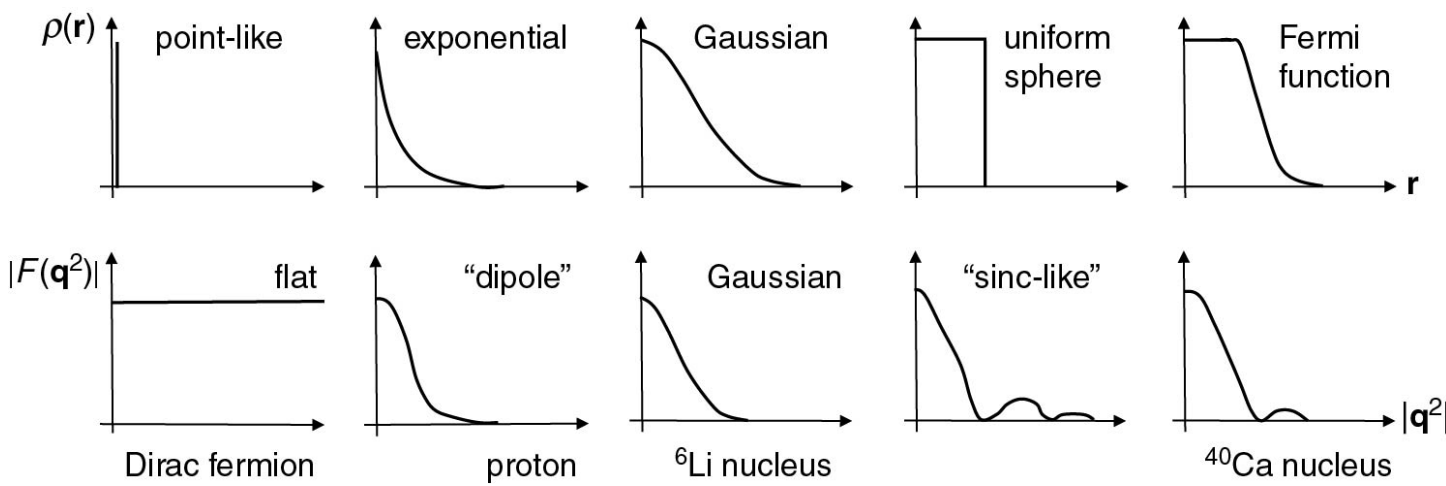
$\vec{q} = (\vec{p} - \vec{p}')$ 3-momentum transfer

Form-factor is fourier transformed charge distribution of proton

This interpretation was derived und the assumption of no recoil of proton

$\rightarrow m_p >> m_e, p_p = 0$ before and after scattering

$\rightarrow E_1 = E_3 \rightarrow q^2 = -\vec{q}^2$



Dirac Scattering

$$\left(\frac{d\sigma}{d\Omega}\right)_{Dirac} = \left(\frac{d\sigma}{d\Omega}\right)_{Ruth} \frac{E_3}{E_1}(\cos^2\theta/2 + \frac{Q^2}{2m_p^2c^2}\sin^2\theta/2)$$

$Q^2 = -q^2$ (4-momentum transfer)

el. IA: Mott scattering for high relativistic particles

mag. IA: depend on Q^2 introduced by considering recoil

(m_p is not much larger than Q^2)

$$\left(\frac{d\sigma}{d\Omega}\right)_{Dirac} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \frac{E_3}{E_1}(1 + 2\tau\tan^2\theta/2)$$

$\tau = \frac{Q^2}{4m_p^2}$

Rosenbluth Formular

$$\left(\frac{d\sigma}{d\Omega}\right) =$$

$$\frac{\alpha^2}{4E_1^2 \sin^4(\theta/2)} \frac{E_3}{E_1} \left(\frac{G_E^2(Q^2)+\tau G_M^2(Q^2)}{1+\tau} \cos^2\theta/2 + 2\tau G_M^2(Q^2) \sin^2\theta/2 \right)$$

$$= \left(\frac{d\sigma}{d\Omega}\right)_0 \left(\frac{G_E^2(Q^2)+\tau G_M^2(Q^2)}{1+\tau} + 2\tau G_M^2(Q^2) \tan^2\theta/2 \right)$$

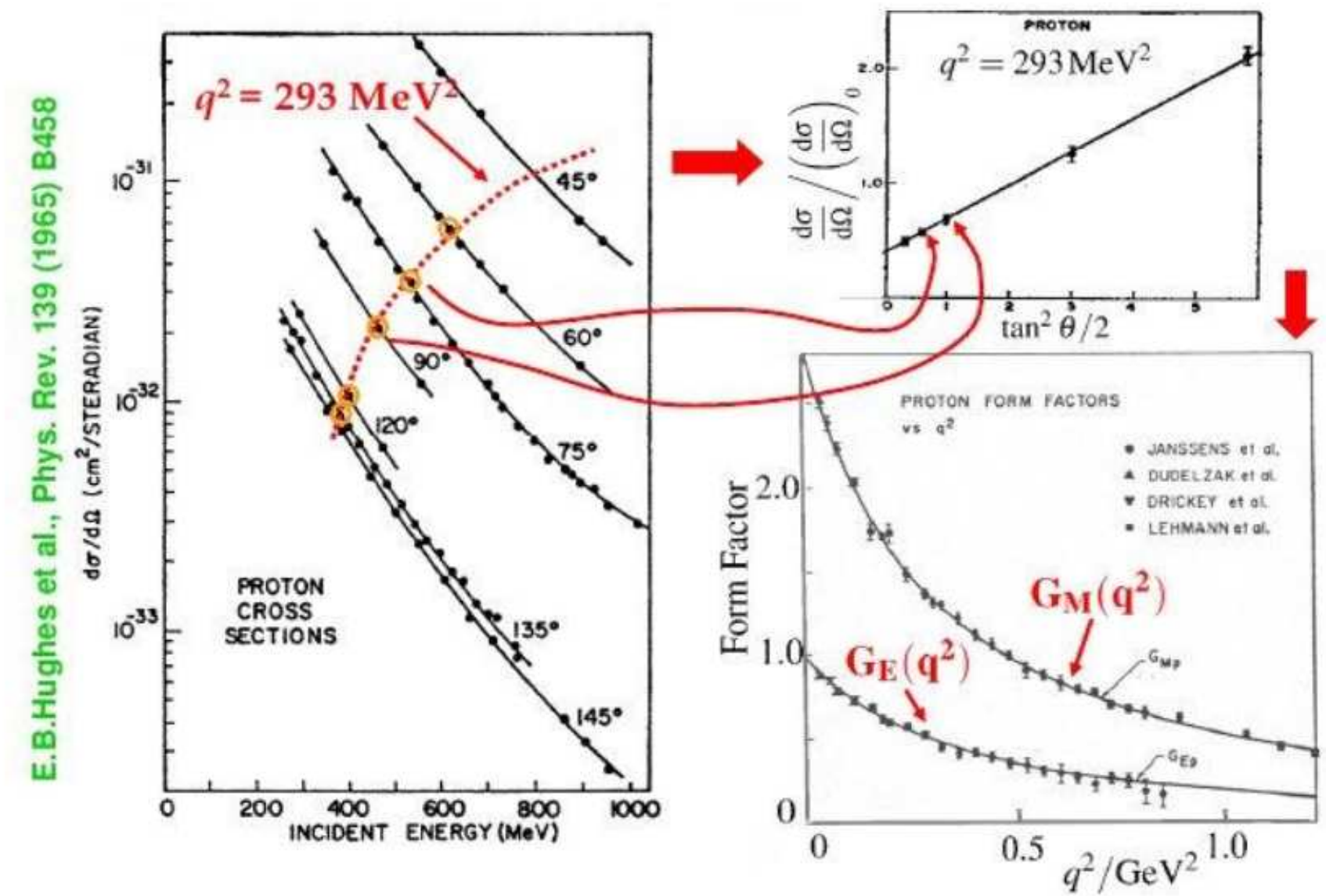
$$\tau = \frac{Q^2}{4m_p^2}$$

$$\left(\frac{d\sigma}{d\Omega}\right) / \left(\frac{d\sigma}{d\Omega}\right)_0 = \frac{G_E^2(Q^2)+\tau G_M^2(Q^2)}{1+\tau} + 2\tau G_M^2(Q^2) \tan^2\theta/2$$

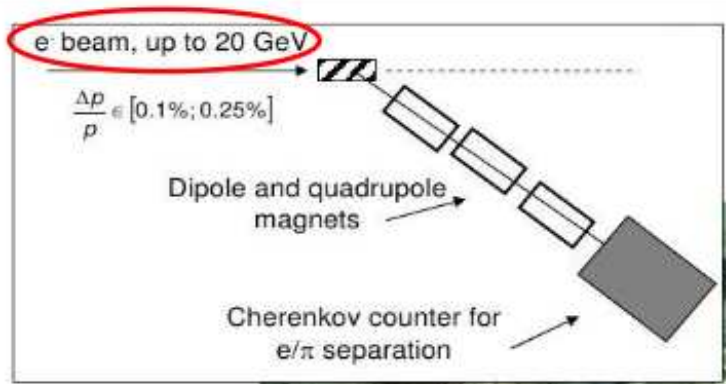
$\rightarrow$ Measure $\left(\frac{d\sigma}{d\Omega}\right) / \left(\frac{d\sigma}{d\Omega}\right)_0$ for fixed Q^2 at different $\tan^2\theta/2$ values!

Slope and absizze determine G_M and G_E at this Q^2 value.

Measurement of el. and mag. Formfactors

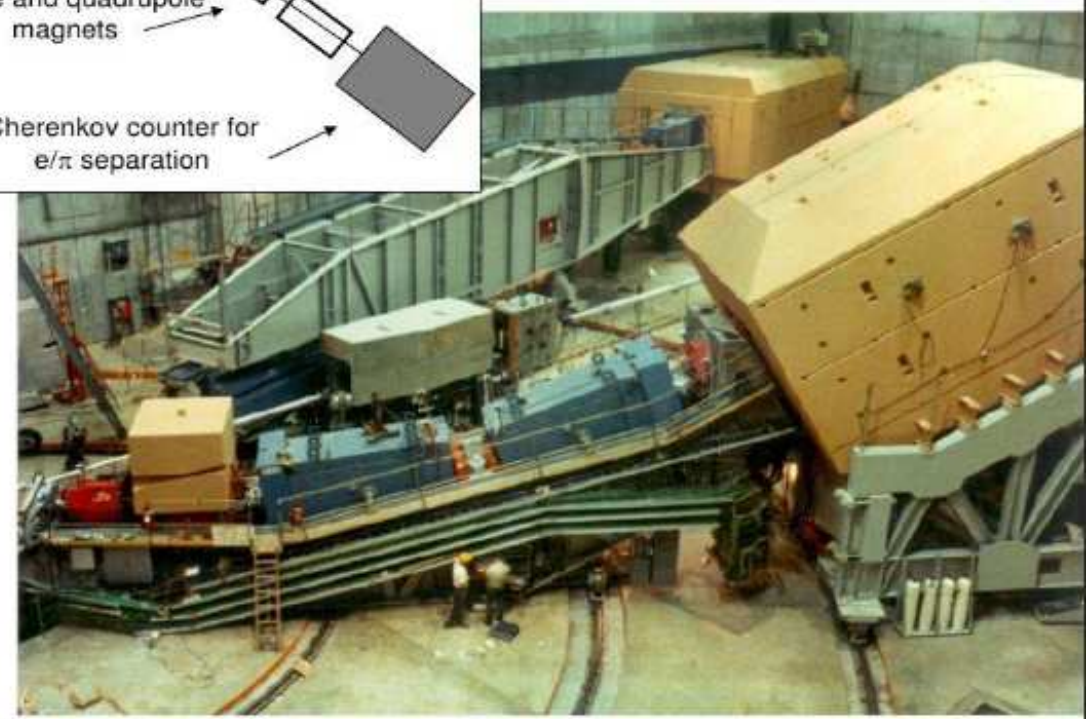


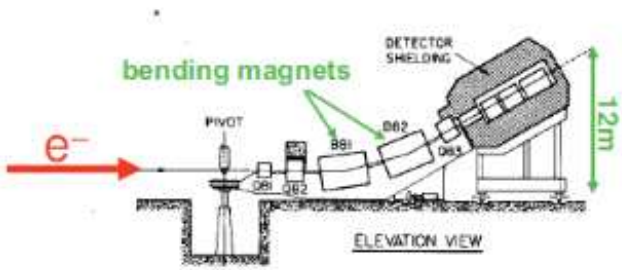
SLAC Experiment

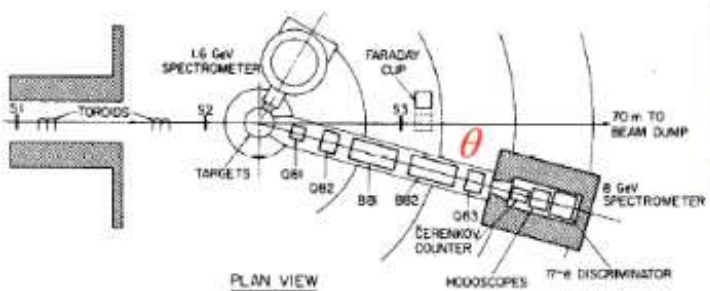


Spectrometer at fixed θ

$\frac{\Delta p}{p} \sim 0.1\%$ $\Delta\theta \sim 0.7$mrad



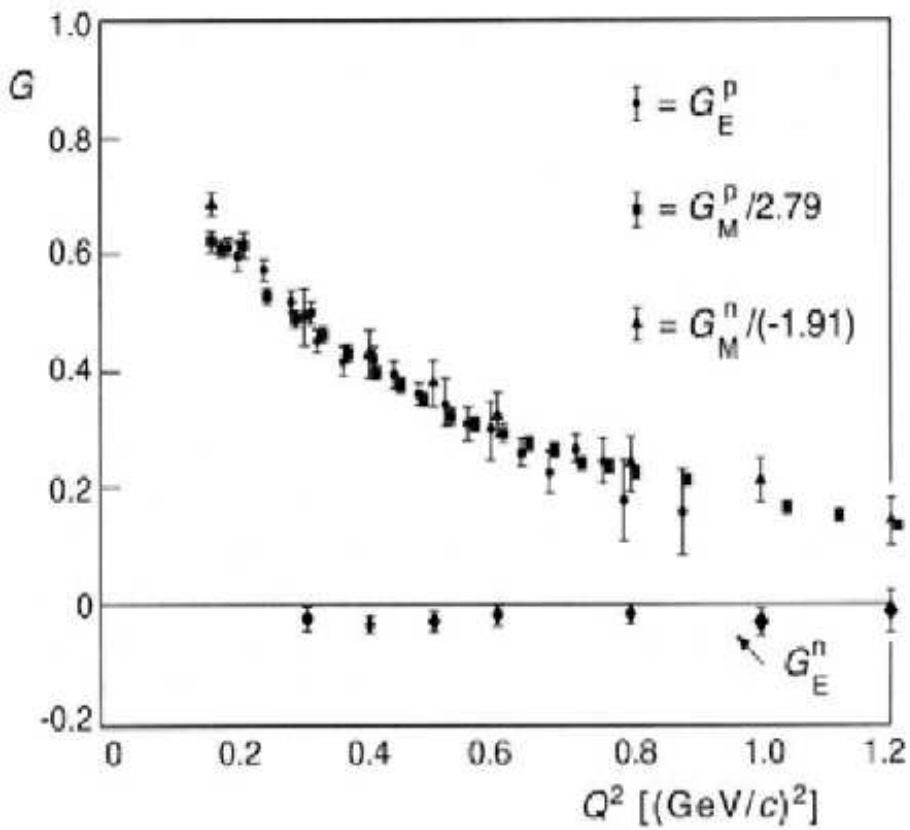




P.N.Kirk et al., Phys Rev D8 (1973) 63

Measurement of el. and mag. Formfactors

$$G_E^p(Q^2) = \frac{G_M^p}{2.79} = \frac{G_M^n}{-1.91} = G^{Dipole}(Q^2)$$



Charge and magnetic moment have give the same size for the proton. Both quantities are equally distributed in the proton.

$$G(Q^2) = \frac{1}{(1+Q^2/0.71\ GeV^2)^2}$$

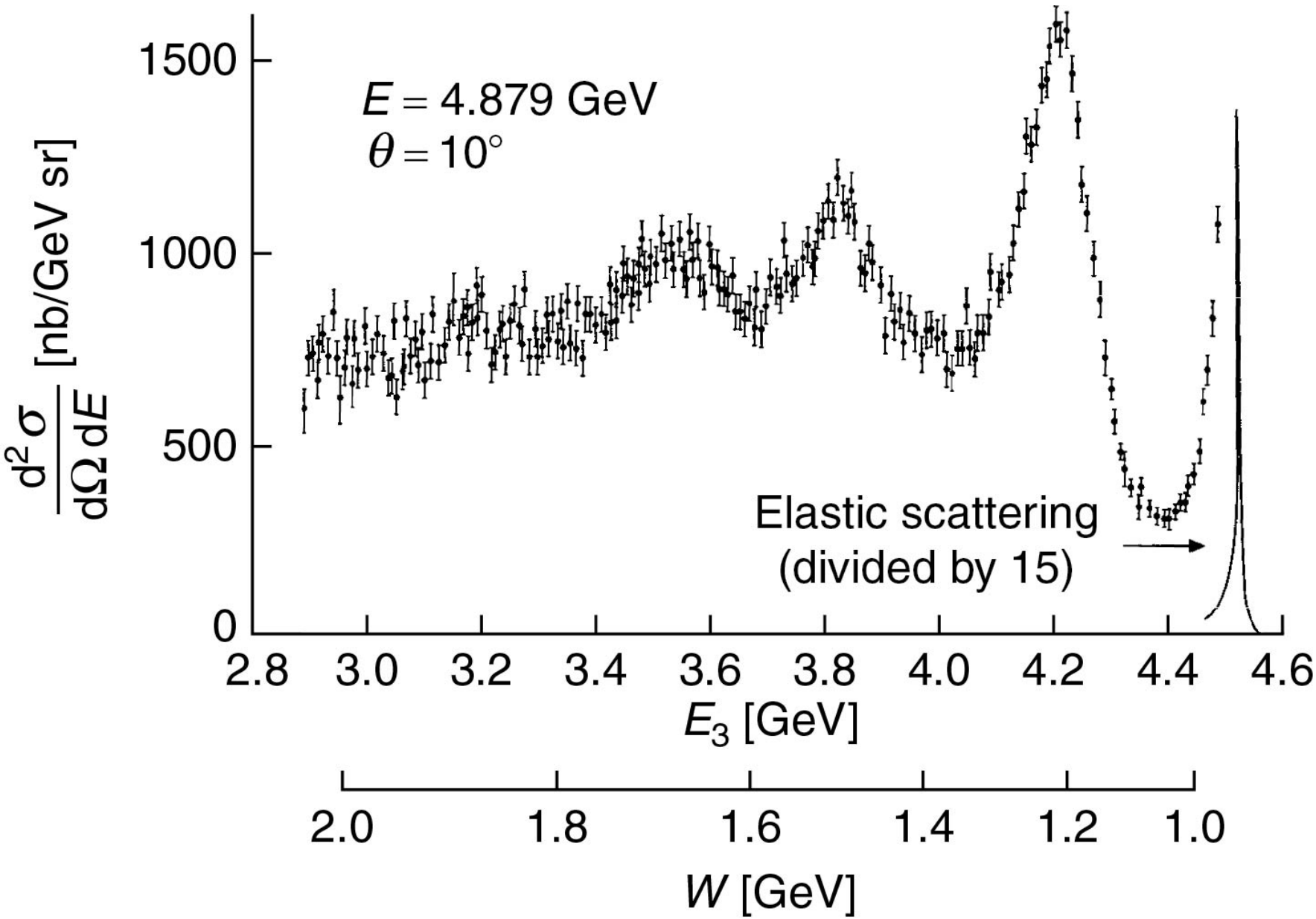
$$\langle r^2 \rangle = -6 \frac{dF(Q^2)}{dQ^2}\Big|_{Q^2=0}$$

$$\sqrt{< r^2 > Dipole} = 0.81\ fm$$

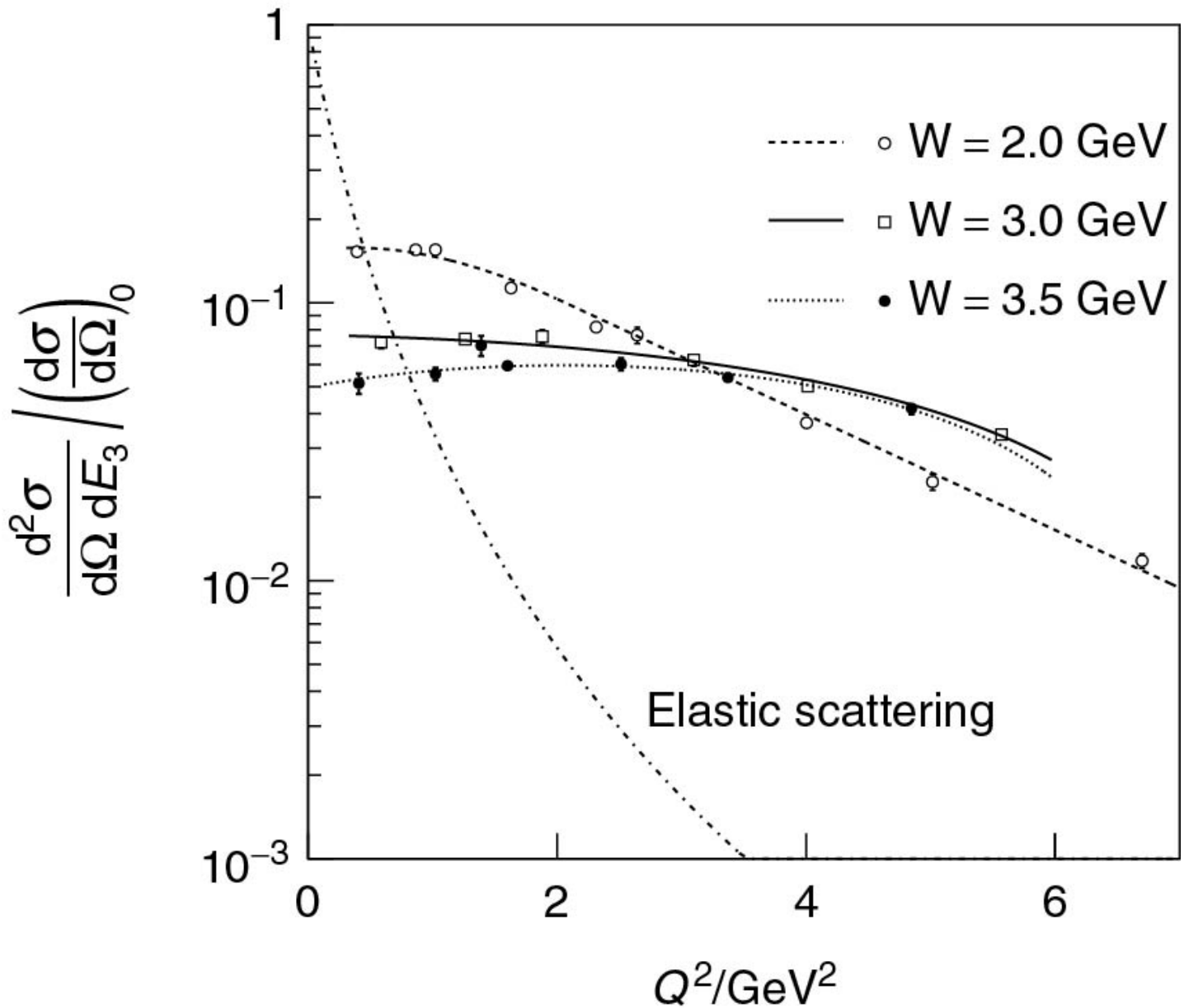
Charge/magnetic moment distribution

$\rho(r) = \rho(0)\ e^{-ar}$ $\quad a = 4.27\ fm^{-1}$

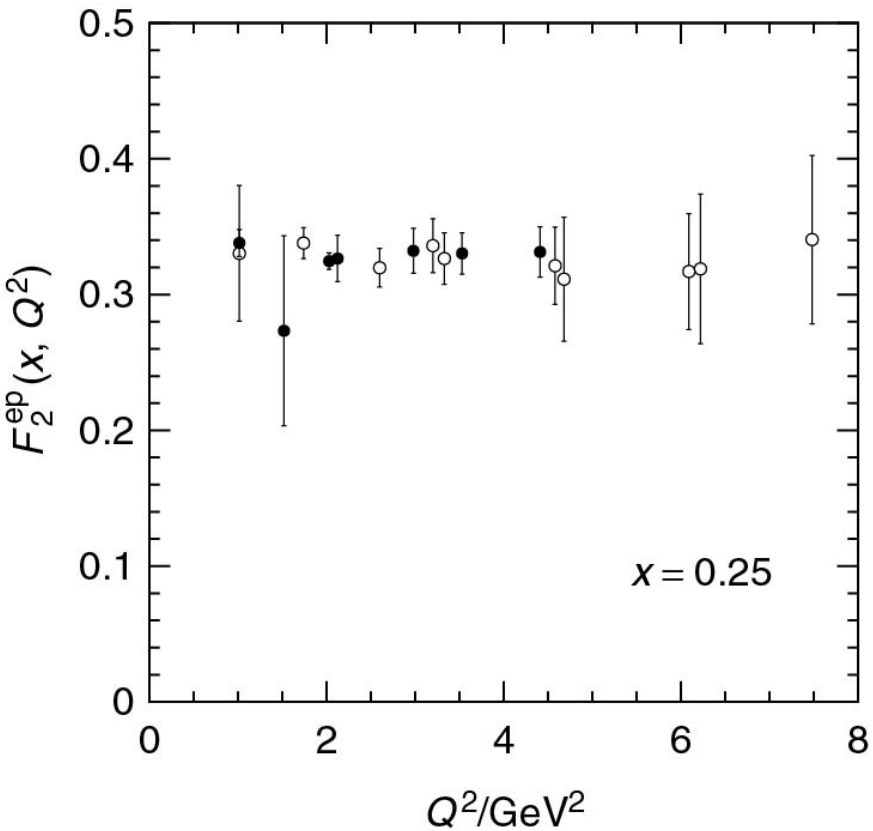
Inelastic scattering

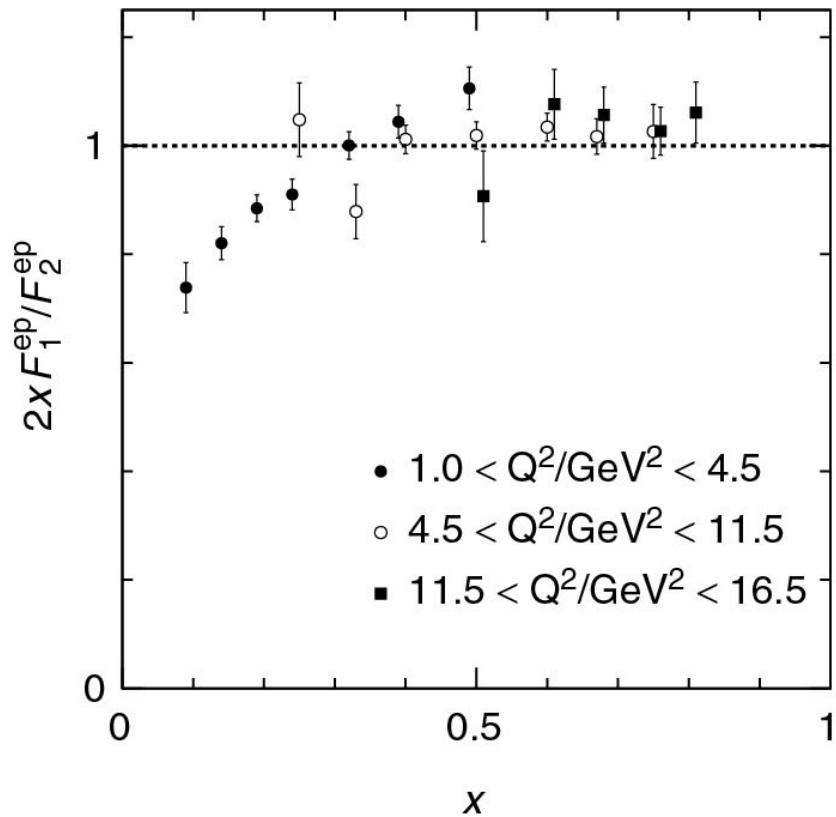


Inelastic scattering



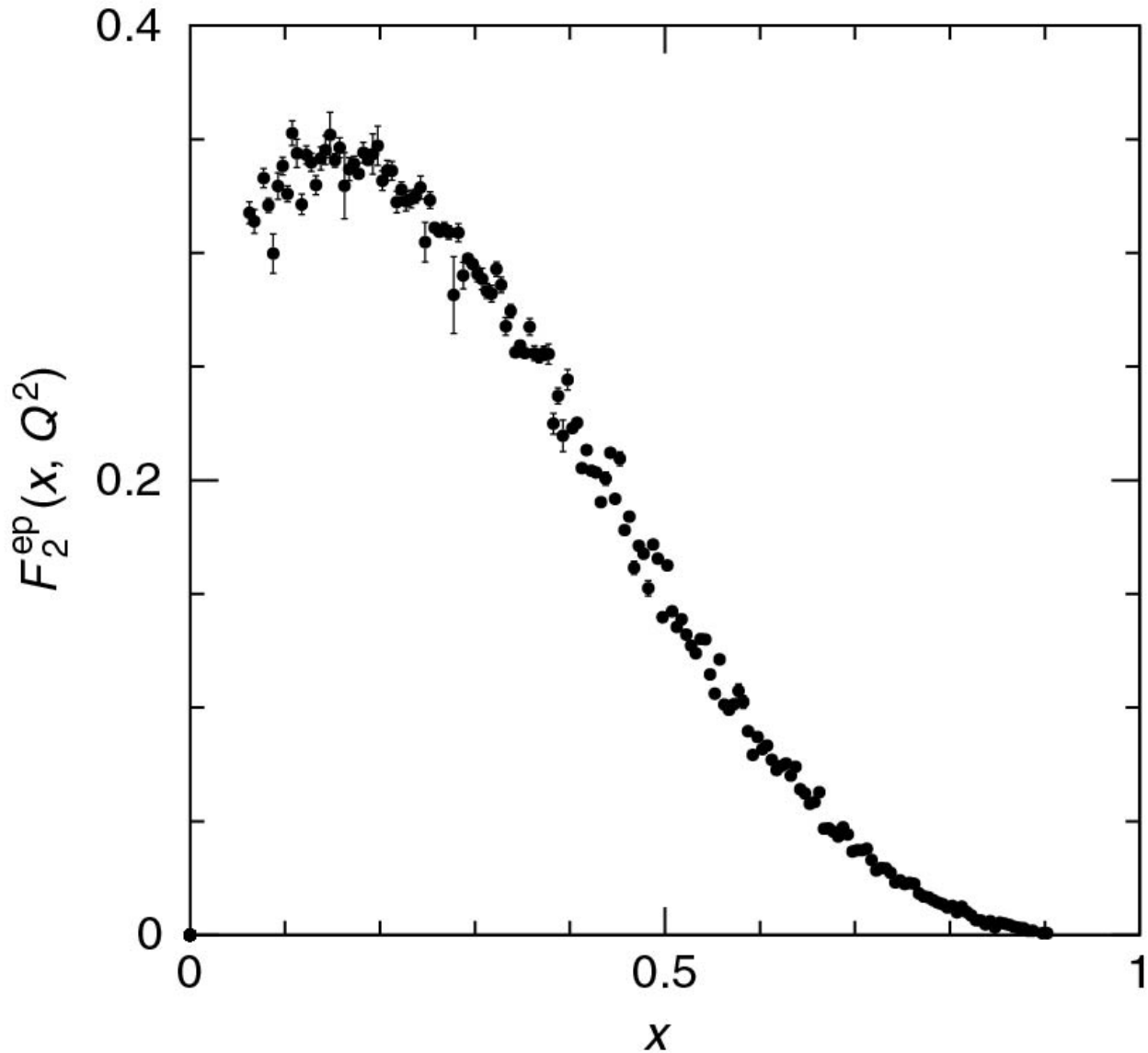
Inelastic scattering



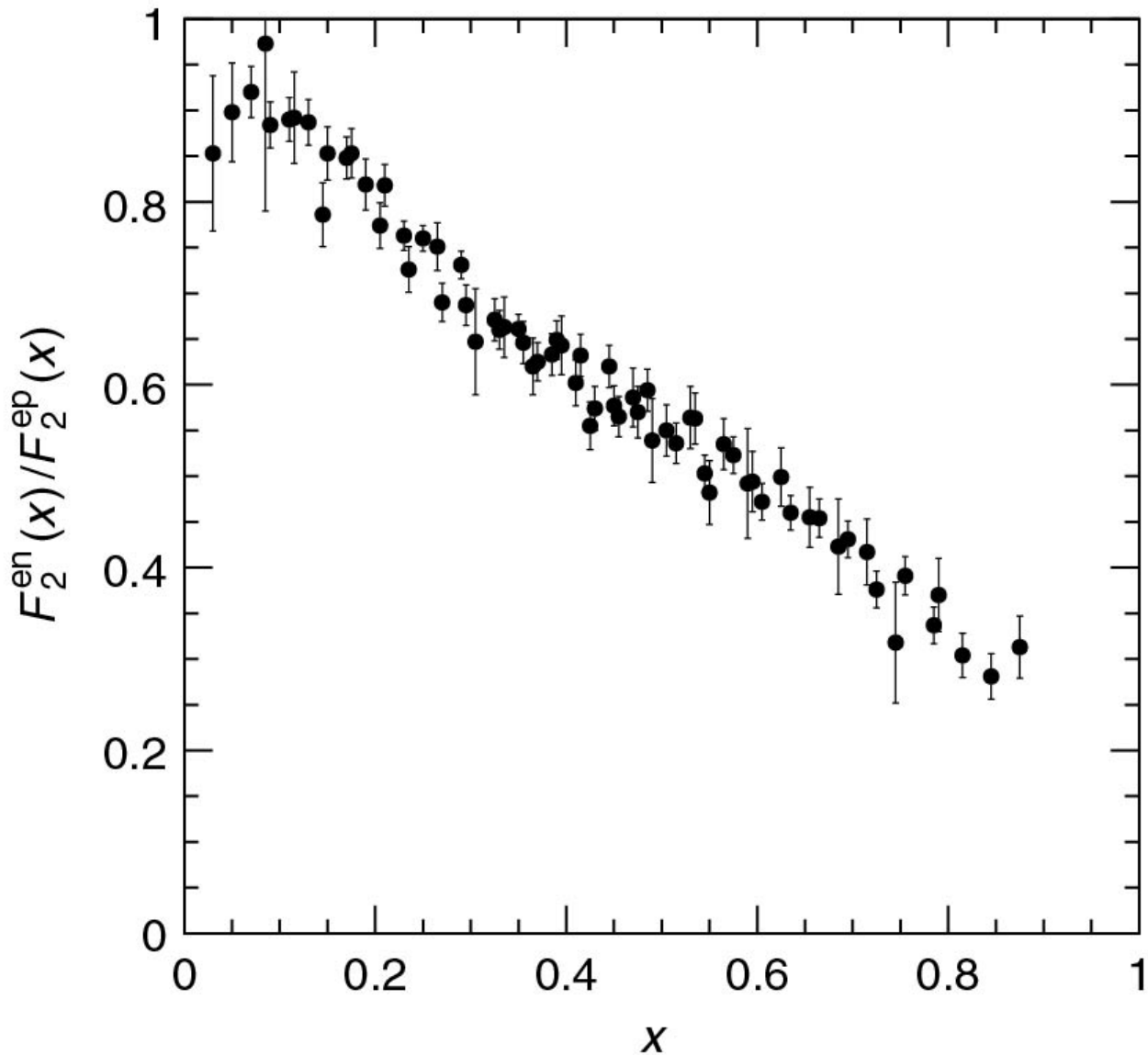


The proton consists of Dirac (point-like Spin 1/2) particles!

Measurement of stucture function

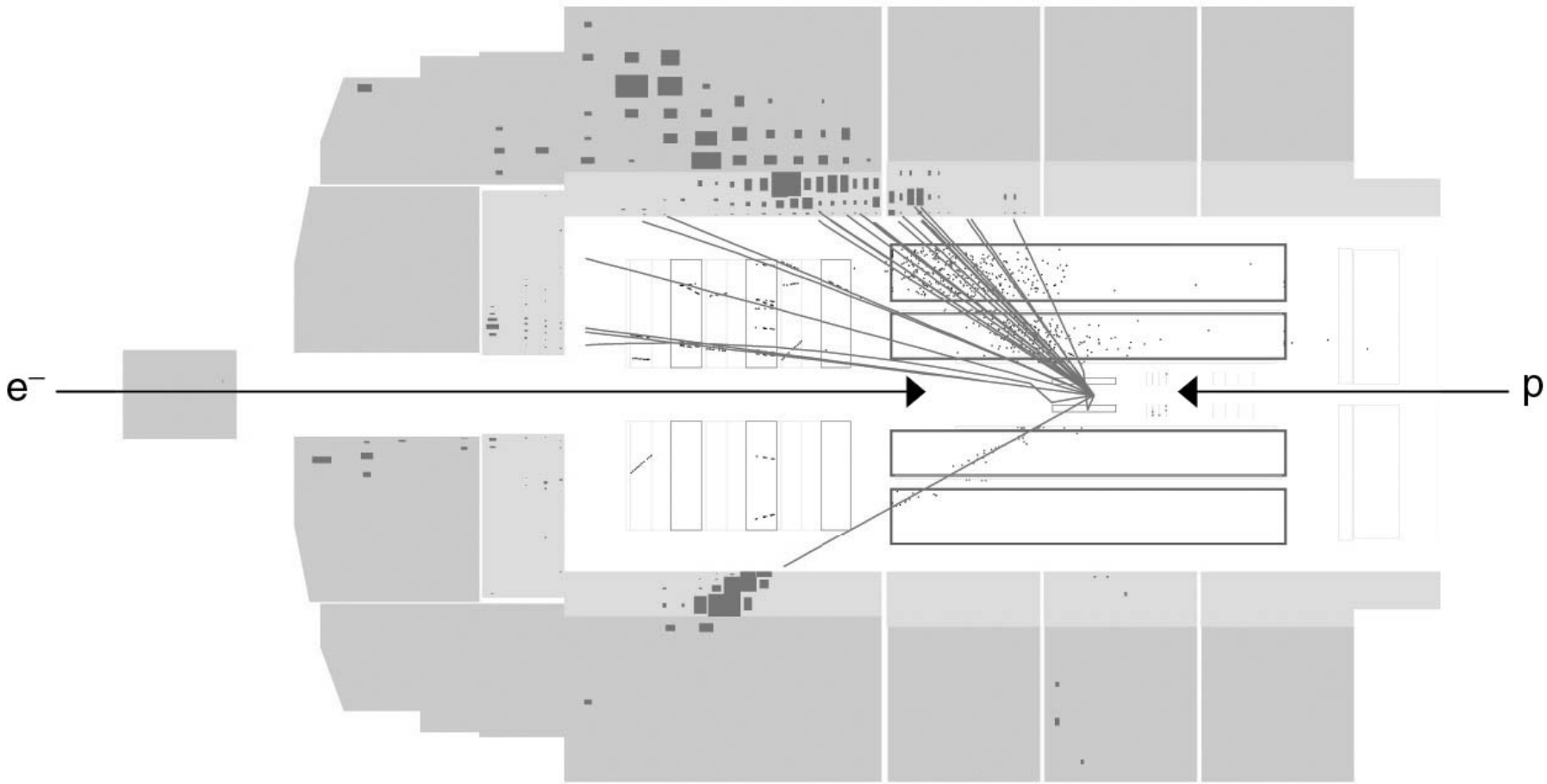


Ratio of Form Factors



H1 at HERA

Two detectors measureing structure functions located at HERA/DESY (1991-2007): ZEUS & H1



$E_e = 27.5GeV$, $E_p = 820$ or $920GeV$

Structure functions