INELASTIC ep SCATTERING

ROSENBLUTH is ELASTIC SCATTERING

→ PROTON REMAINS PROTON

HAVE ESTABLISHED PROTON HAS STRUCTURE

⇓ INELASTIC SCATTERING POSSIBLE

$ep \to ep$ ELASTIC

EXCITE PROTON STRUCTURE → $ep \to e\Delta^+$, $\Delta^+ \to p\pi^0$

$ep \to e n \pi^+$

} INELASTIC EXCLUSIVE

$ep \to X e$ INELASTIC INCLUSIVE

↑ X: HADRONIC SYSTEM INVARIANT MASS W

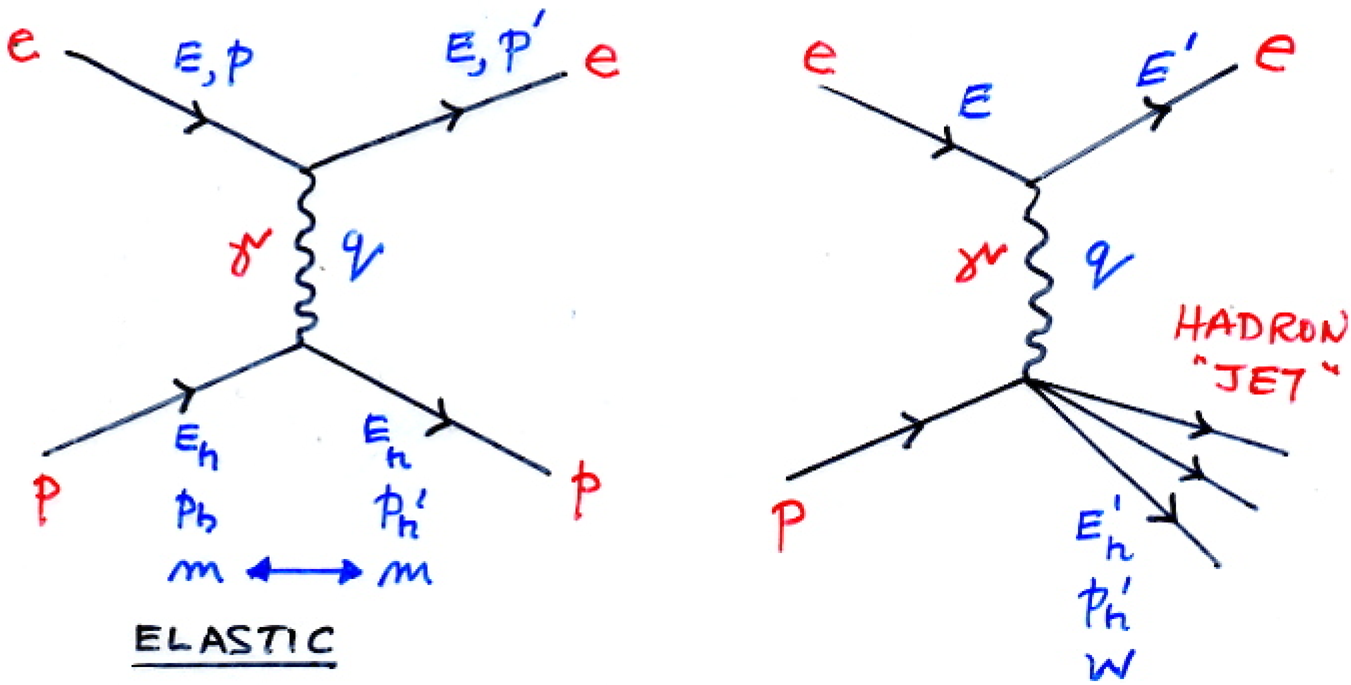
↑ BREAK PROTON UP

↑ INCLUSIVE: JUST MEASURE ELECTRON

INELASTIC ELECTRON SCATTERING

A POWERFUL TOOL TO LOOK AT STRUCTURE OF

NUCLEUS → NUCLEONS → QUARKS (PARTONS)



ELASTIC

TARGET NOT EXCITED / FRAGMENTED

INELASTIC

$$\nu = E - E' \quad \text{INELASTICITY}$$

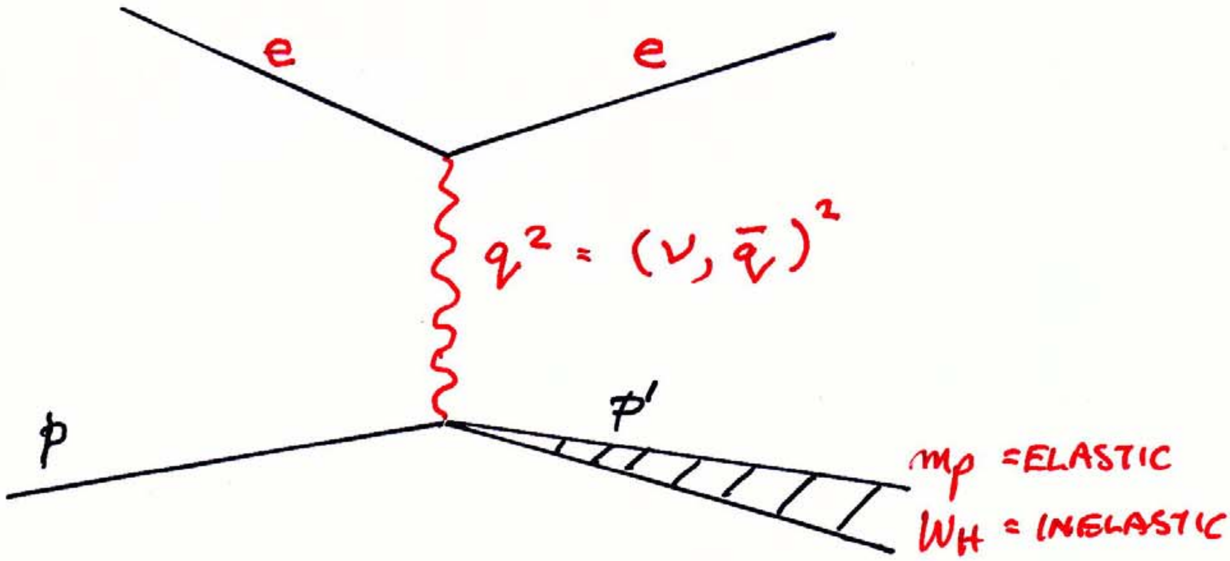
$$\nu = \frac{|q^2|}{2m_A}$$

$|q^2|$ ← 4-MOMENTUM XFER

m_A ← TARGET MASS (NUCLEUS)

$$q^2 = \frac{\nu^2}{c^2} - (\bar{p} - \bar{p}')^2 = \frac{\nu^2}{c^2} - \bar{p}_h'^2$$

ELASTIC & INELASTIC SCATTERING



W_H = INVARIANT MASS OF FINAL HADRONIC SYSTEM

m_p = MASS OF PROTON

GENERALLY $\quad q^2 = (p' - p)^2$

SINCE INVARIANT – EVALUATE IN LAB FRAME

$$q^2 = p'^2 + p^2 - 2p' \cdot p$$

$$= W_H^2 + m_p^2 - 2(\nu + m_p, \bar{p}')(m_p, 0)$$

$$q^2 = W_H^2 + m_p^2 - 2\nu m_p - 2m_p^2$$

$$q^2 = W_H^2 - m_p^2 - 2\nu m_p$$

$$W_H^2 = q^2 + m_p^2 + 2\nu m_p$$

INELASTIC
TWO VARIABLES $\bar{q}, \nu$ (4 MOMENTUM COMPONENTS)

GENERALLY HAVE

$$W_H^2 = q^2 + m_p^2 + 2\nu m_p$$

FOR ELASTIC SCATTERING $W_H^2 = m_p^2$

$$m_p^2 = q^2 + m_p^2 + 2\nu m_p$$

$$\therefore \quad q^2 = -2\nu m_p \quad (q^2 \text{ IS } -\text{VE})$$

ONLY ONE VARIABLE

LOOKING BACK AT DIAGRAM

$$q^2 = (\nu, \bar{q})(\nu, \bar{q}) = -2\nu m_p$$

$$\nu^2 - \bar{q}^2 = -2\nu m_p$$

3-MOMENTUM TRANSFER $\quad \bar{q}^2 = \nu^2 + 2\nu m_p$ ← ONLY 1 INDEP VARIABLE

IN THE LIMIT WHERE $\nu \gg m_p$

$$\bar{q}^2 \simeq \nu^2$$

THEN 4-MOMENTUM TRANSFER

$$q = (\nu, \bar{q}) \simeq (\nu, \nu)$$

$$q^2 \simeq \nu^2 - \nu^2 \simeq 0$$

ELASTIC SCATTERING HAS ONLY ONE VARIABLE

EXACTLY $\quad q = \left(\nu, \left(\nu^2 + 2\nu m_p\right)^{1/2}\right)$

ONE VARIABLE ν

SCATTERING CROSS SECTIONS

RUTHERFORD: NON RELATIVISTIC, SPINLESS POINT TARGET, BEAM

$z = 1$ FOR ELECTRONS

$$\frac{d\sigma}{d\Omega}_R = \frac{4m^2 (zZe^2)^2}{q^4}$$

MOTT: RELATIVISTIC SPIN $\frac{1}{2}$ ELECTRON SCATTERING OFF SPINLESS POINT TARGET

$$\frac{d\sigma}{d\Omega}_{MOTT} = \frac{4 E^2 (Ze^2)^2}{q^4} \left(1 - \beta^2 \sin^2\frac{\theta}{2}\right)$$

$\rightarrow 1$ AS $\beta \rightarrow 0$

FORM FACTOR: ELECTRON SCATTERING FROM EXTENDED TARGET

$$\frac{d\sigma}{d\Omega}_{EXTENDED} = |F(q^2)|^2 \left(\frac{d\sigma}{d\Omega}\right)_{MOTT}$$

ELASTIC SCATTERING:

$$\left(\frac{d\sigma}{d\Omega}\right)_{RO} = \left(\frac{d\sigma}{d\Omega}\right)_{MOTT} \left[\frac{G_E^2 + b G_M^2}{1+b} + 2b G_M^2 \tan^2\theta\right]$$

↳ COULD WRITE $\frac{d\sigma}{dq^2}$ → ONE SCATTERING VARIABLE

INELASTIC SCATTERING

$$\left(\frac{d^2\sigma}{dq^2 d\nu}\right)_{INEL} = \left(\frac{d^2\sigma}{dq^2 d\nu}\right)_{\text{"MOTT"}} \left[W_2(q^2,\nu) + 2W_1 \cdot b \cdot \tan^2\theta\right]$$

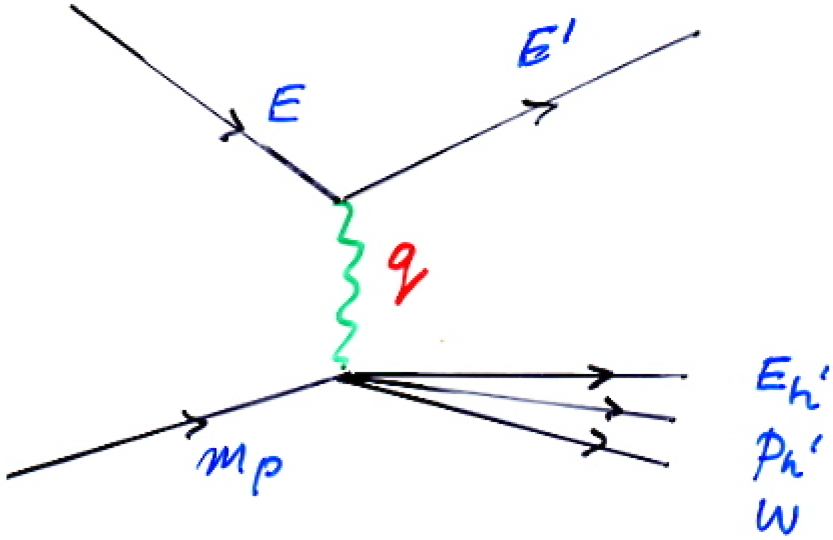
↳ $W_1(q^2,\nu)$

↳ TWO SCATTERING VARIABLES

OFTEN WRITTEN AS:

$$\frac{d^2\sigma}{dq^2 d\nu} = \frac{4\pi\alpha^2}{q^4}\frac{E'}{E m_p}\left[W_2(q^2,\nu)\cos^2\frac{\theta}{2} + 2W_1(q^2,\nu)\sin^2\frac{\theta}{2}\right]$$

INELASTIC SCATTERING:



- THE PROTON HAS ENERGY TRANSFERED TO IT.

q^2 HAS ENERGY ν 3 MOMENTUM $\bar{q}$

$$q^2 = \nu^2 - |\bar{q}|^2 \Leftarrow \text{VARY INDEPENDENTLY}$$

- NOW HAVE TWO VARIABLES IN SCATTERING KINEMATICS q^2, ν

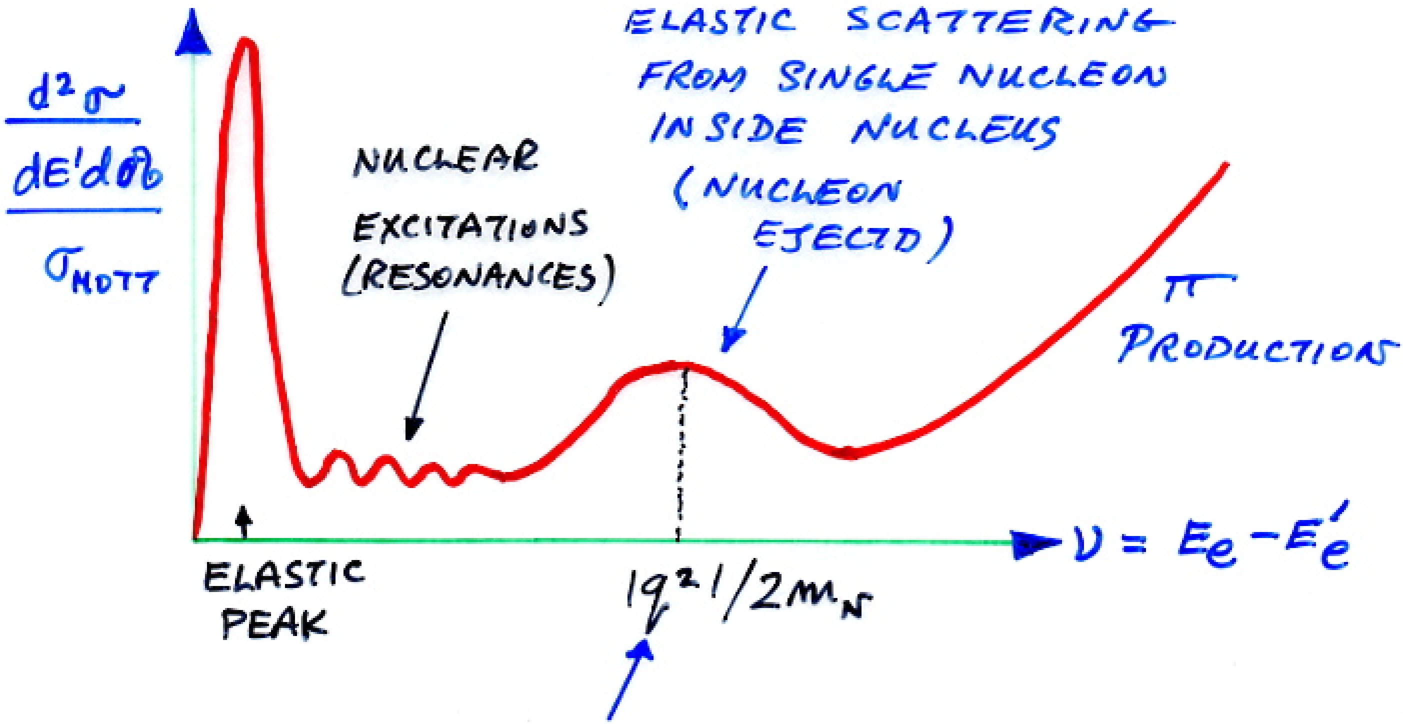
- FORM FACTORS DEPEND ON ↑ (q^2, ν)

  ↳ THEY ARE CALLED PROTON STRUCTURE FUNCTIONS

$$F(q^2) \longrightarrow W_1(q^2, \nu) \quad W_2(q^2, \nu)$$

ELASTIC → DEEP INELASTIC

ELECTRON SCATTERING FROM NUCLEUS



QUASI-ELASTIC SCATTERING

ENERGY TRANSFER IS TAKEN UP BY A SINGLE NUCLEON

$$\nu = \frac{|q^2|}{2m_N}$$ ← NUCLEON MASS

THE QUASI ELASTIC PEAK IS BROAD DUE TO FERMI MOTION INSIDE NUCLEUS

$$R \cdot p_{FERMI} \sim \hbar$$

$$p_{FERMI} \sim p_{NUCLEON} \sim \frac{\hbar}{R} \sim 100 \text{ MeV}/c$$

$$\nu = |q^2| / 2m_N$$

- SAY THE NUCLEON INSIDE THE NUCLEUS ABSORBS 4-MOMENTUM q^2 FROM VIRTUAL γ^V
- SAY INITIAL NUCLEON 4-MOMENTUM p_N

$$(p_N + q)^2 = m_N^2$$

$$p_N^2 + q^2 + 2p_N \cdot q = m_N^2$$

$p_N^2 = m_N^2$

$$|q^2| = 2p_N \cdot q$$

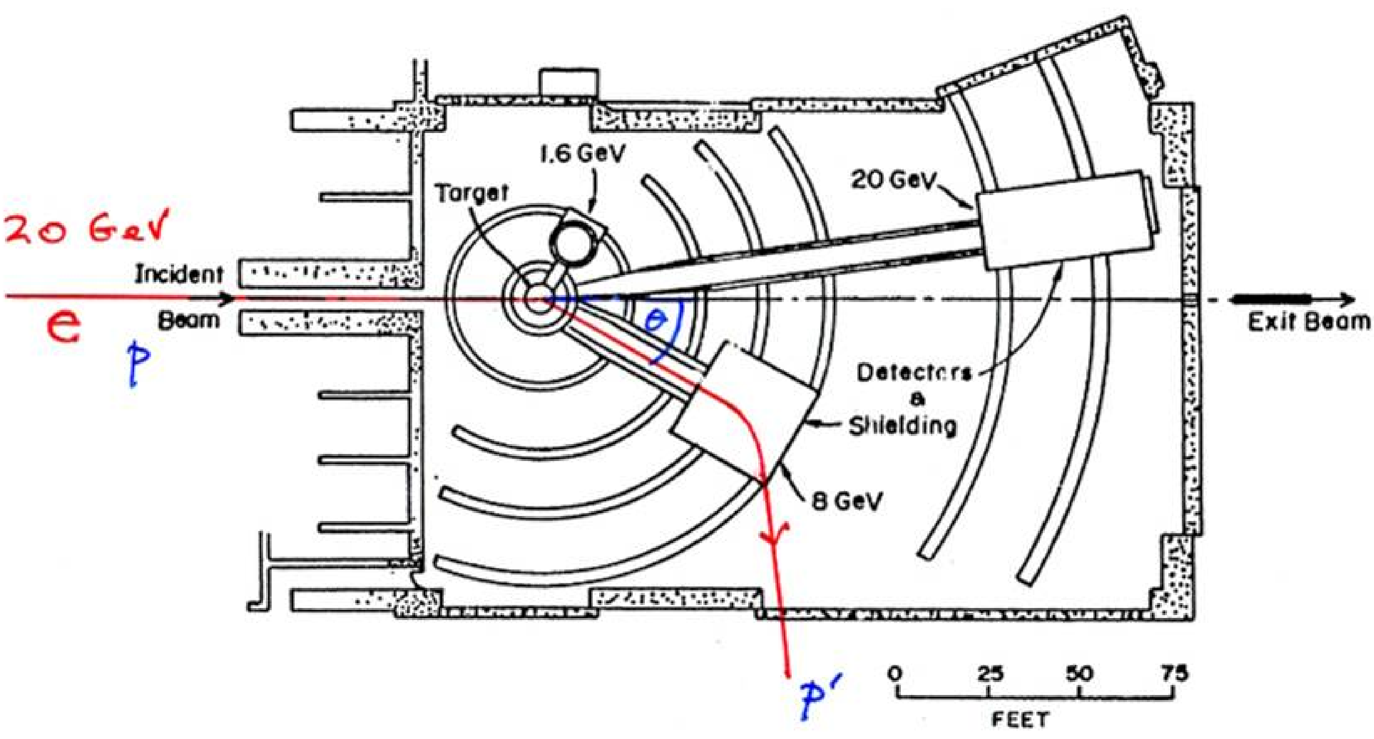
REST FRAME

$$= 2(m_N, 0)(\nu, \bar{q})$$

$$= 2m_N \nu$$

$$\nu = \frac{|q^2|}{2m_N}$$

SLAC SPECTROMETER



MEASURE SCATTERING ANGLE
AND FINAL STATE MOMENTUM OF ELECTRONS

5. DEEP INSIDE THE NUCLEON

During the 1960's a new particle accelerator was under construction that eventually resolved the quark quandary. Built under the direction of Wolfgang Panofsky with $114 million in AEC funds, the Stanford Linear Accelerator was 2 miles long and arrow-straight. Based on microwave technology invented at Stanford University during the late-1930's, this device pushed electrons from 0 to about 20 GeV in a *single* pass along its length. Most other accelerators of the day, like Berkeley's Bevatron and the Brookhaven AGS, imparted small doses of energy to the particles in every circuit as they sped around a circular path many thousands of times per second.

Stanford physicists had pioneered a very different acceleration method. Starting in the late 1940's, they built a series of longer and more pow-

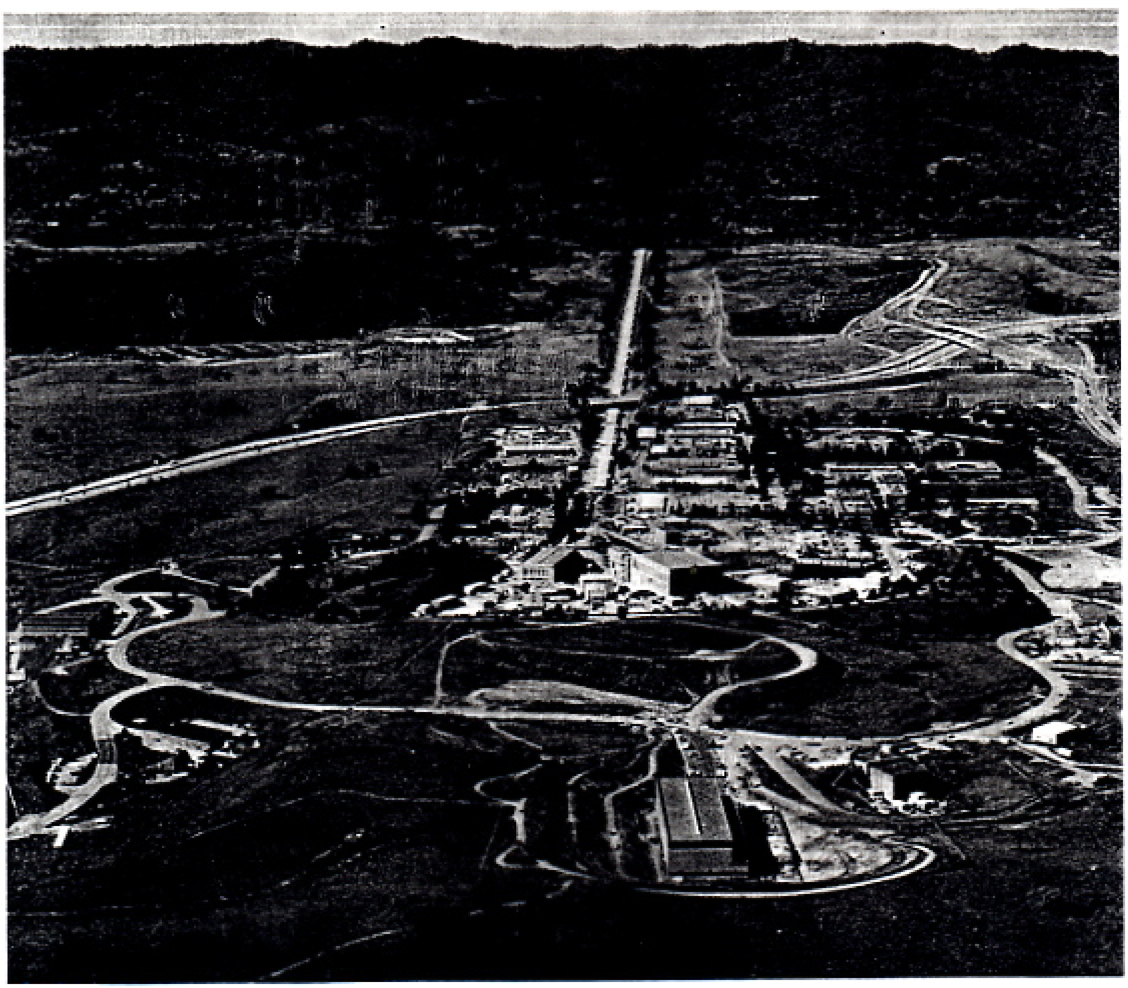
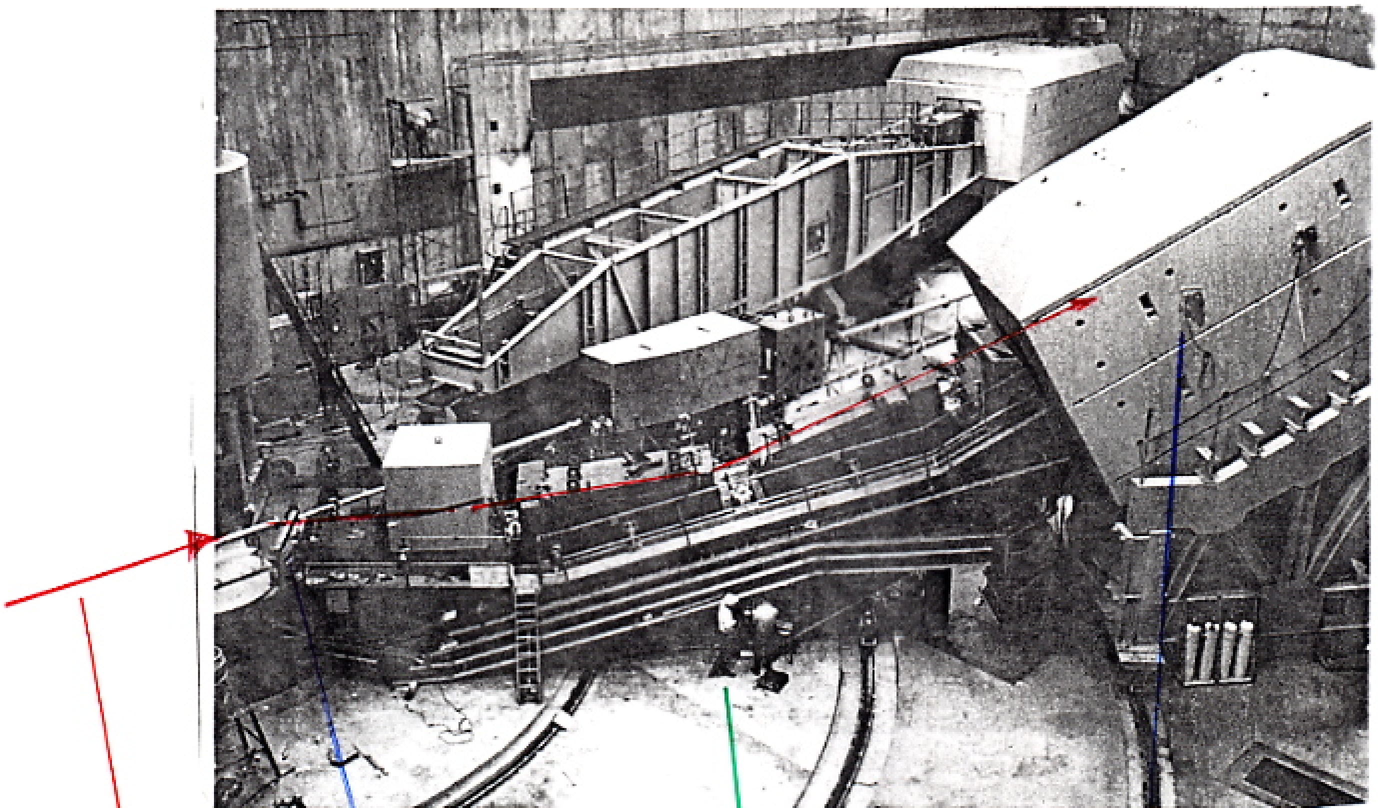


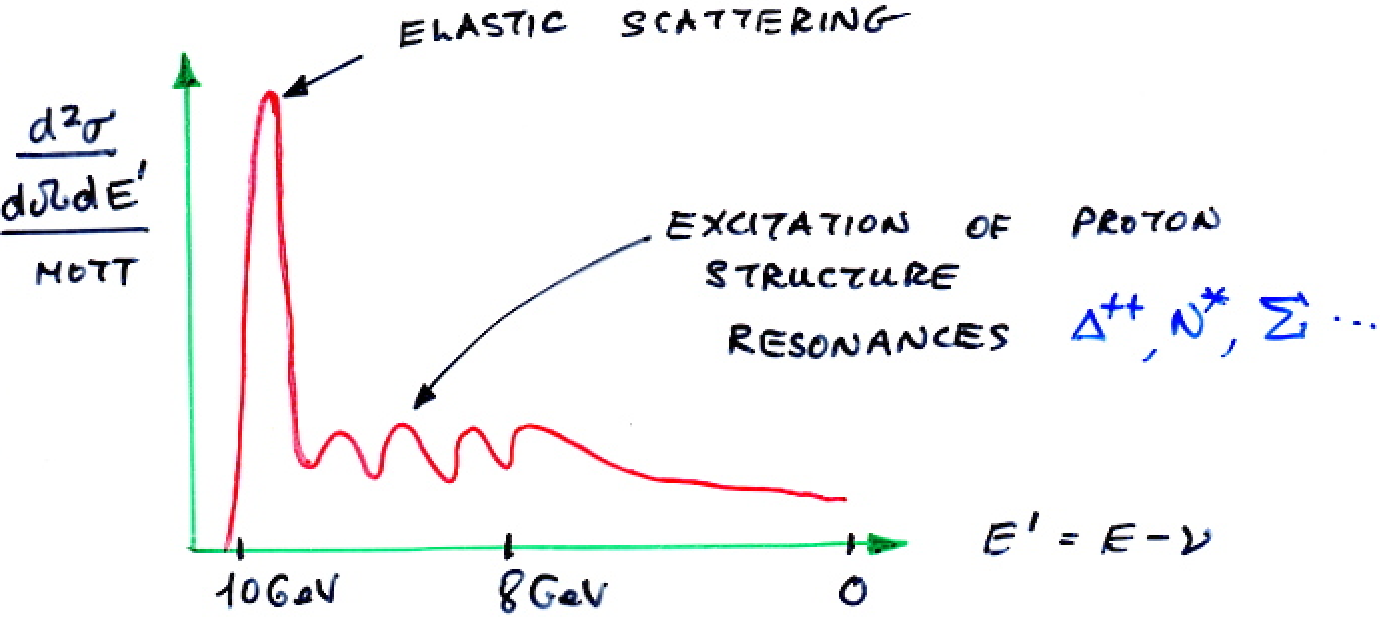
Figure 11. Aerial view of the Stanford Linear Accelerator Center.

SLAC SPECTROMETER



INELASTIC ELECTRON SCATTERING FROM PROTONS

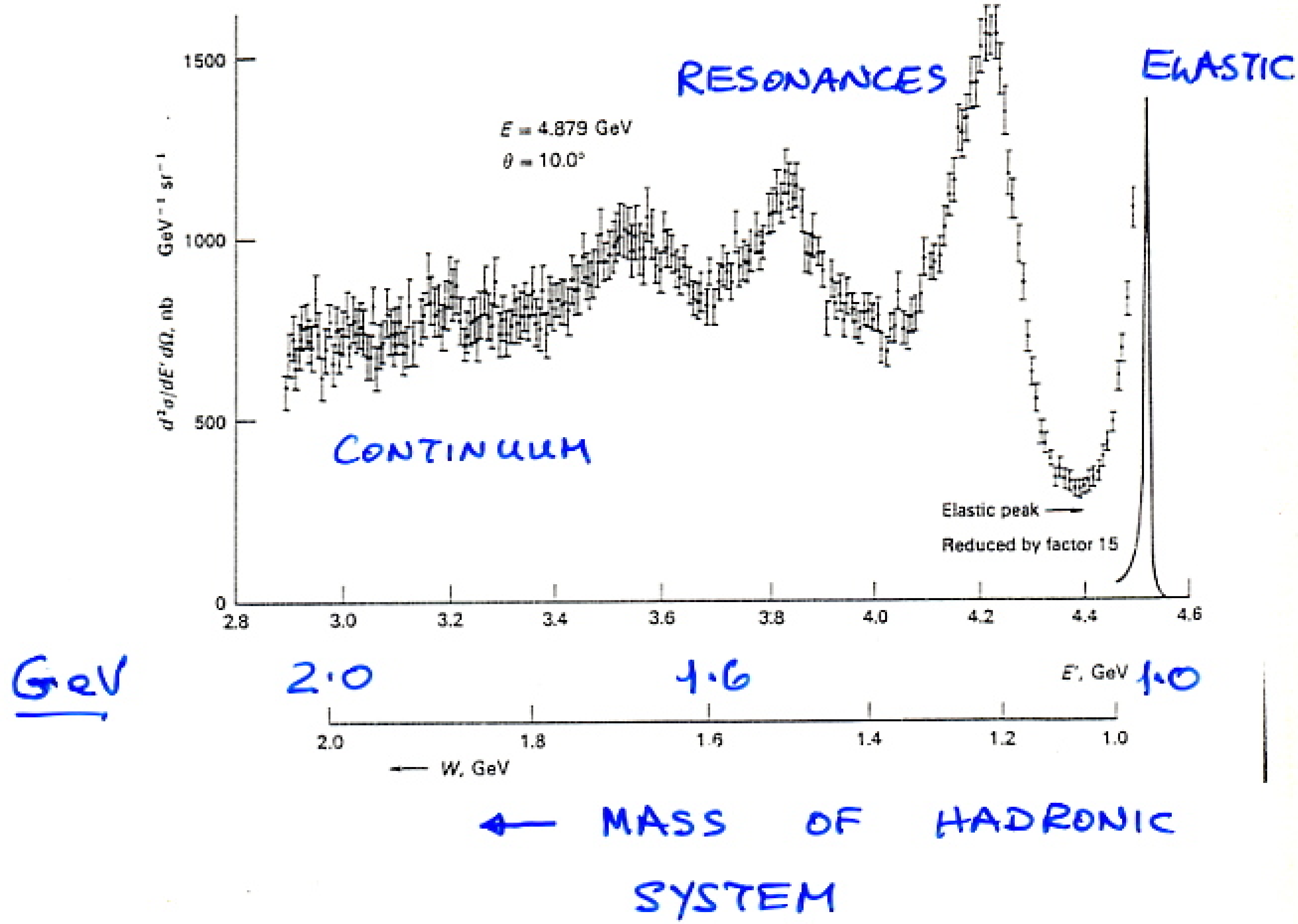
ELASTIC SCATTERING FROM PROTONS ALLOWS ONE TO INVESTIGATE THE SPATIAL EXTENT OF PROTONS JUST AS INELASTIC SCATTERING FROM NUCLEI SHOWS UP NUCLEAR STRUCTURE, INELASTIC SCATTERING FROM PROTONS SHOULD ALLOW ONE TO LEARN ABOUT STRUCTURES WITHIN THE PROTON



THIS LOOKS VERY SIMILAR TO THE CASE OF SCATTERING FROM NUCLEI

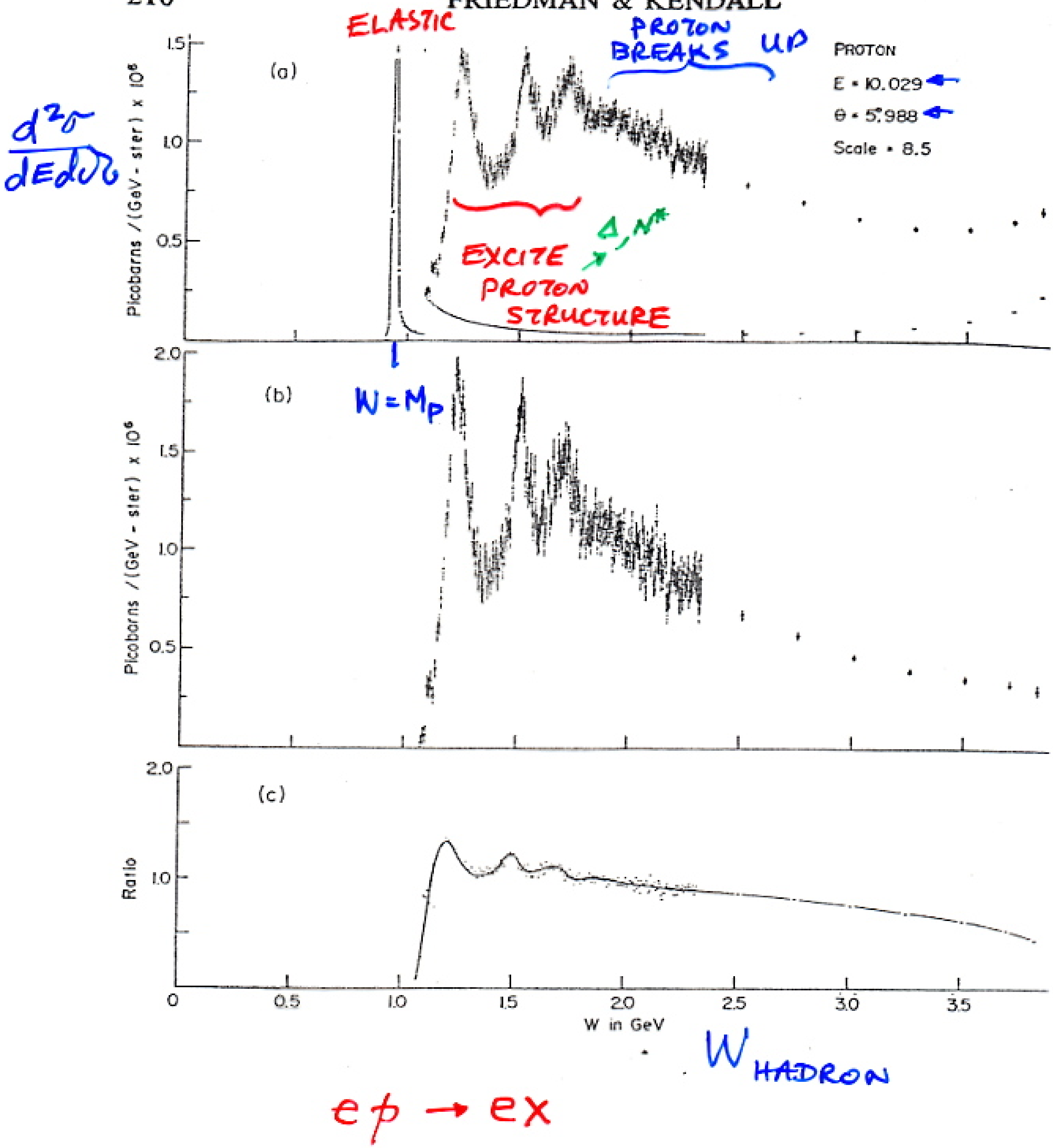
→ CONVINCING EVIDENCE THAT THE PROTON IS A COMPOSITE OBJECT

BUT. THERE IS NO ANALOG OF THE QUASI-ELASTIC PEAK. WHATEVER THE OBJECTS INSIDE THE PROTON THEY ARE NEVER KNOCKED OUT → CONFINED!



THIS IS ep SCATTERING AT DESY ELECTRON SYNCHROTRON ~ 1968

SLAC EXTENDED "MASS REACH" FOR HADRONIC SYSTEM.


ELASTIC
PROTON BREAKS UP
PROTON
E = 10.029
θ = 5.988
Scale = 8.5
(a)
Picobarns /(GeV - ster) x 10⁶
EXCITE PROTON STRUCTURE
Δ, N*
W = M_P
(b)
Picobarns /(GeV - ster) x 10⁶
(c)
Ratio
W in GeV
W HADRON
ep → ex