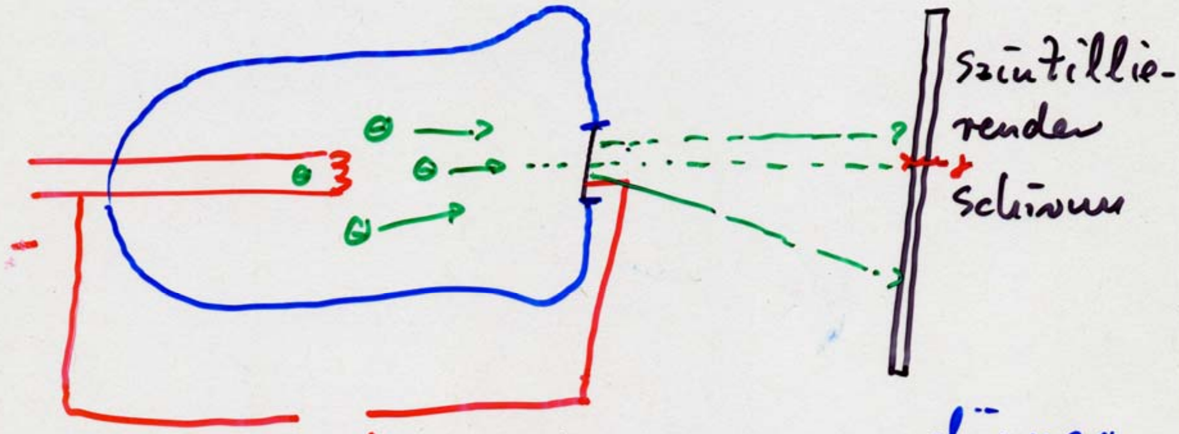
2.3.2 Bestimmung atomarer Strukturen

1) Versuch von Lenard (~ 1890)



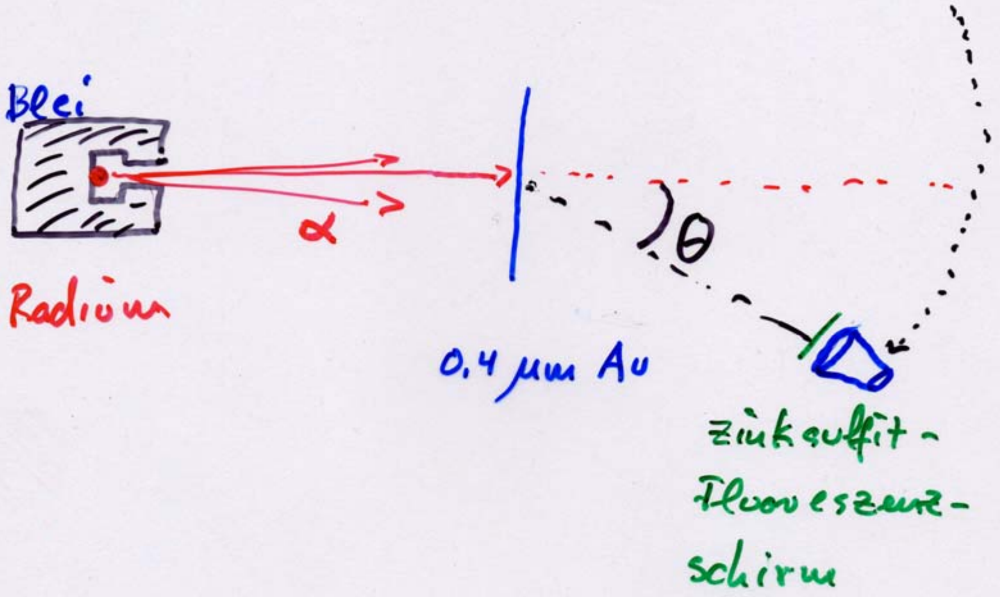
Streuung an dünner Alu - Folie

Beobachtung: e^- durchqueren 10^4 Atomlagen + Luft, werden nur selten gestreut!

Falls Atome feste Kügelchen: erwarte volle Absorption $\left(\lambda_{Luft} \sim 10^{-5} \, cm \right)$

Lenard: „Das Innere des Atoms ist so leer wie das Weltall"

2] Versuch von Rutherford (1911-1913)

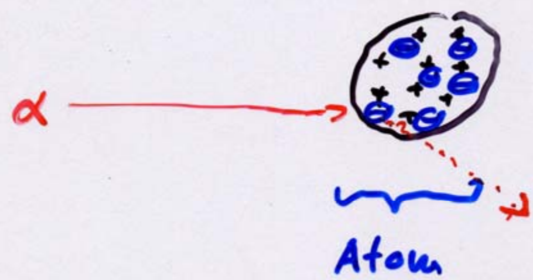


Streuung von α-Teilchen an Goldfolie [α: $^{4}_{2}He$ - Kerne]

Beobachtung: Die meisten α gingen wenig abgelenkt durch Folie, einige aber unter großen Winkeln

$P(90°) \sim 10^{-4}$

Erwartung nach Thomson:



i) Streuung von α an e^-:

Zentralen Stoß:

$$\Delta p = m_\alpha (v - v') = m_e v_e$$

$$\Delta E = \frac{m_\alpha}{2}(v^2 - v'^2) = \frac{m_e}{2} v_e^2$$

$$\Rightarrow v' = v \cdot \frac{m_\alpha - m_e}{m_\alpha + m_e}$$

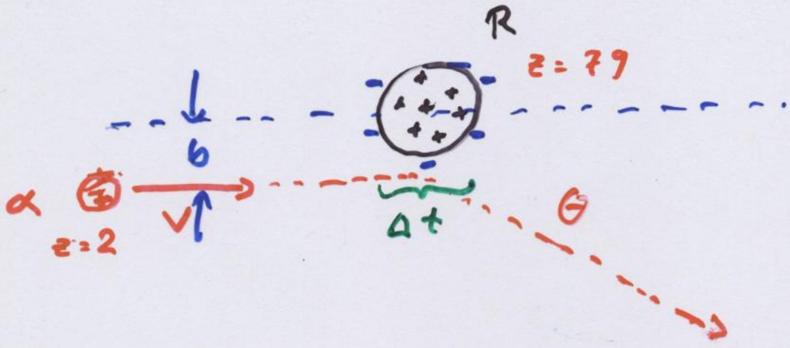
$$\Rightarrow \Delta v = v - v' = v \cdot \frac{2 m_e}{m_\alpha + m_e}$$

$$\Rightarrow \theta_{max} < \frac{\Delta p}{p} = \frac{\Delta v}{v} = \frac{2 m_e}{m_\alpha + m_e}$$

$$= 2{,}5 \cdot 10^{-4} \text{ rad}$$

$$\hat{=} 0{,}01°$$

ii) Streuung an geladener Kugel



Für $b > R$: $F_c = 0$ (Kugel neutral)

$b \le R$: $F_c \le \frac{1}{4\pi\varepsilon_0} \frac{2e \cdot 79e}{R^2}$

$\hookrightarrow \Delta p = F \cdot \Delta t \approx F \cdot \frac{2R}{v}$

$\approx \frac{1}{4\pi\varepsilon_0} \cdot \frac{2 \cdot 79 e^2}{R^2} \cdot \frac{2R}{v}$

$$\theta_{max} \le \frac{\Delta p}{p} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2 \cdot 79 e^2}{R^2} \cdot \frac{2R}{v} \cdot \frac{1}{m_\alpha v}$$

(R: $2{,}5 \cdot 10^{-10}$ m)

$= 1{,}8 \cdot 10^{-4}$ rad

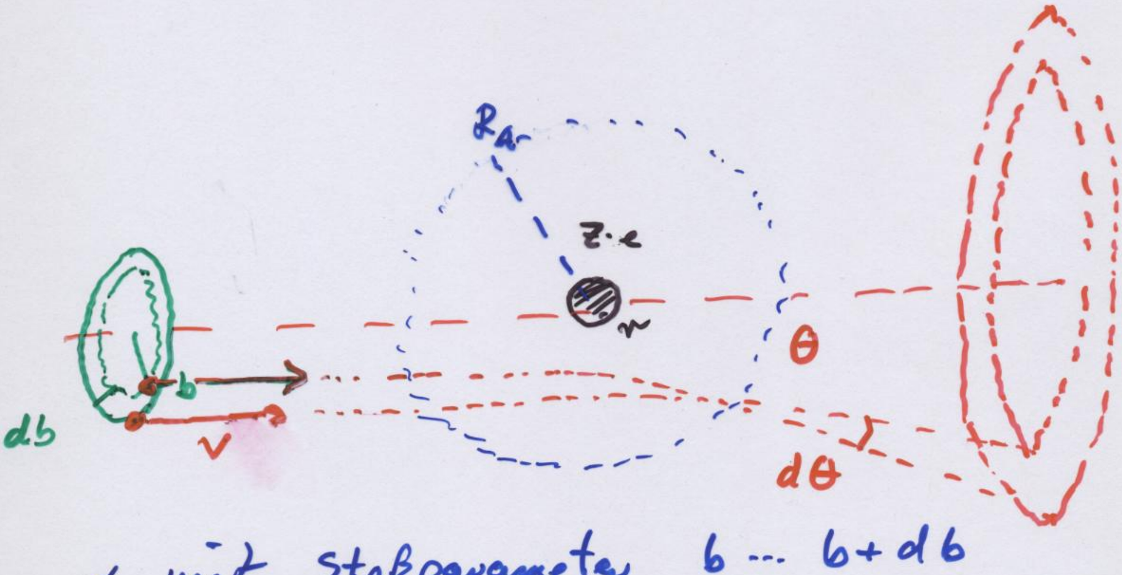
=> Thomsonsches Atommodell ist falsch!

Große θ bekommt man nun,
wenn $R \ll R_{Atom}$!

≙ Positive Ladung muß auf viel kleinerem Radius beschränkt sein.

Bsp: Radius für $\theta_{max} = 1 rad$:

$$\frac{R}{R_{Au}} = \frac{1,8 \cdot 10^{-4} \, rad}{1 \, rad} \Rightarrow R \approx 5 \cdot 10^{-14} m$$



α mit Stoßparameter b ... b+db
werden in Raumwinkelbereich dΩ gestreut

$$\frac{d\sigma}{d\Omega} = \left(\frac{z \cdot Z e^2}{4\pi\varepsilon_0}\right)^2 \cdot \frac{1}{16 \sin^4\frac{\theta}{2}} \cdot \frac{1}{E_\alpha^2} \sim \frac{1}{v^4}$$

Diskussion:

Energiebilanz: $E_\alpha = \frac{1}{2} m_\alpha v^2$

$$= \frac{1}{2} m_\alpha v(r)^2 + \frac{z Z e^2}{4\pi\varepsilon_0 r}$$

Für zentralen Stoß:

$$v(r_{min}) = 0$$

$$\Rightarrow E_\alpha = \frac{z Z e^2}{4\pi\varepsilon_0 r_{min}}$$

$$\Rightarrow r_{min} = \frac{z Z e^2}{4\pi\varepsilon_0 E_\alpha}$$

Bsp: 5 MeV α, $Z_{Au} = 79$, $z_{He} = 2$

$$r_{min} = 5 \cdot 10^{-14}\ \text{m}$$

$$> r_{Au}$$

5 MeV α stoßen nicht auf Kern, da $r_{min} > r_{Au}$

$$r_{Kern} = 1{,}3\ A^{\frac{1}{3}}\ \text{fm}$$

Phil. Mag. 21 (1911)

LXXIX. *The Scattering of α and β Particles by Matter and the Structure of the Atom.* By Professor E. RUTHERFORD, F.R.S., University of Manchester *.

§ 1. IT is well known that the α and β particles suffer deflexions from their rectilinear paths by encounters with atoms of matter. This scattering is far more marked for the β than for the α particle on account of the much smaller momentum and energy of the former particle. There seems to be no doubt that such swiftly moving particles pass through the atoms in their path, and that the deflexions observed are due to the strong electric field traversed within the atomic system. It has generally been supposed that the scattering of a pencil of α or β rays in passing through a thin plate of matter is the result of a multitude of small scatterings by the atoms of matter traversed. The observations, however, of Geiger and Marsden † on the scattering of α rays indicate that some of the α particles must suffer a deflexion of more than a right angle at a single encounter. They found, for example, that a small fraction of the incident α particles, about 1 in 20,000, were turned through an average angle of 90° in passing through a layer of gold-foil about ·00004 cm. thick, which was equivalent in stopping-power of the α particle to 1·6 millimetres of air. Geiger ‡ showed later that the most probable angle of deflexion for a pencil of α particles traversing a gold-foil of this thickness was about 0°·87. A simple calculation based on the theory of probability shows that the chance of an α particle being deflected through 90° is vanishingly small. In addition, it will be seen later that the distribution of the α particles for various angles of large deflexion does not follow the probability law to be expected if such large deflexions are made up of a large number of small deviations. It seems reasonable to suppose that the deflexion through a large angle is due to a single atomic encounter, for the chance of a second encounter of a kind to produce a large deflexion must in most cases be exceedingly small. A simple calculation shows that the atom must be a seat of an intense electric field in order to produce such a large deflexion at a single encounter.

Recently Sir J. J. Thomson § has put forward a theory to

* Communicated by the Author. A brief account of this paper was communicated to the Manchester Literary and Philosophical Society in February, 1911.

† Proc. Roy. Soc. lxxxii. p. 495 (1909).

‡ Proc. Roy. Soc. lxxxiii. p. 492 (1910).

§ Camb. Lit. & Phil. Soc. xv. pt. 5 (1910).

experimentally whether such a simple relation holds also for the lighter atoms. In cases where the mass of the deflecting atom (for example, hydrogen, helium, lithium) is not very different from that of the α particle, the general theory of single scattering will require modification, for it is necessary to take into account the movements of the atom itself (see § 4).

It is of interest to note that Nagaoka * has mathematically considered the properties of a "Saturnian" atom which he supposed to consist of a central attracting mass surrounded by rings of rotating electrons. He showed that such a system was stable if the attractive force was large. From the point of view considered in this paper, the chance of large deflexion would practically be unaltered, whether the atom is considered to be a disk or a sphere. It may be remarked that the approximate value found for the central charge of the atom of gold ($100\,e$) is about that to be expected if the atom of gold consisted of 49 atoms of helium, each carrying a charge $2\,e$. This may be only a coincidence, but it is certainly suggestive in view of the expulsion of helium atoms carrying two unit charges from radioactive matter.

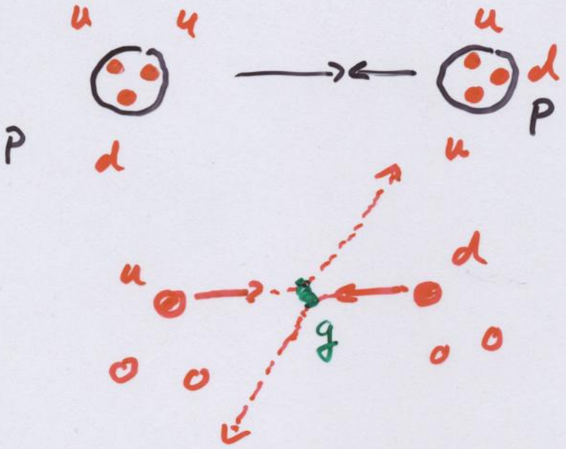
The deductions from the theory so far considered are independent of the sign of the central charge, and it has not so far been found possible to obtain definite evidence to determine whether it be positive or negative. It may be possible to settle the question of sign by consideration of the difference of the laws of absorption of the β particle to be expected on the two hypotheses, for the effect of radiation in reducing the velocity of the β particle should be far more marked with a positive than with a negative centre. If the central charge be positive, it is easily seen that a positively charged mass if released from the centre of a heavy atom, would acquire a great velocity in moving through the electric field. It may be possible in this way to account for the high velocity of expulsion of α particles without supposing that they are initially in rapid motion within the atom.

Further consideration of the application of this theory to these and other questions will be reserved for a later paper, when the main deductions of the theory have been tested experimentally. Experiments in this direction are already in progress by Geiger and Marsden.

University of Manchester,
April 1911.

* Nagaoka, Phil. Mag. vii. p. 445 (1904).

Anwendung: Die Größe von Quarks



Elastische („Rutherford“) Streuung zweier Quarks im Gluonfeld.

Am Fermilab und jetzt am LHC: elastische Streuung an Coulomb-artigen Potential bis $r \sim 10^{-19}$ m

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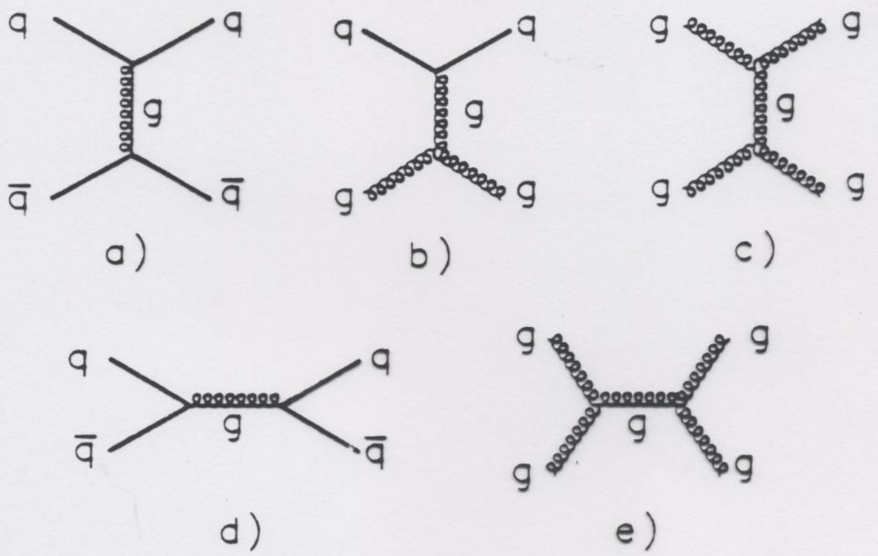
Konseq



Leading order diagrams for parton-parton scattering.

Dominant: $gg \to gg$; for small θ^*

$$\frac{d\sigma}{d\Omega} \approx \frac{\alpha_s^2}{4p^2 \sin^4 \theta/2}$$

=> QCD potential at small distances

$\propto \frac{1}{r}$

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OBSERVATION OF VERY LARGE TRANSVERSE MOMENTUM JETS AT THE CERN p̄p COLLIDER

The UA2 Collaboration

M. BANNER [f], Ph. BLOCH [f], F. BONAUDI [b], K. BORER [a], M. BORGHINI [b], J.-C. CHOLLET [d], A.G. CLARK [b], C. CONTA [e], P. DARRIULAT [b], L. Di LELLA [b], J. DINES-HANSEN [c], P.-A. DORSAZ [b], L. FAYARD [d], M. FRATERNALI [e], D. FROIDEVAUX [b,d], J.-M. GAILLARD [d], O. GILDEMEISTER [b], V.G. GOGGI [e,1], H. GROTE [b], B. HAHN [a], H. HÄNNI [a], J.R. HANSEN [b], P. HANSEN [c], T. HIMEL [b], V. HUNGERBÜHLER [b], P. JENNI [b], O. KOFOED-HANSEN [c], M. LIVAN [e], S. LOUCATOS [f], B. MADSEN [c], B. MANSOULIÉ [f], G.C. MANTOVANI [e,2], L. MAPELLI [b], B. MERKEL [d], M. MERMIKIDES [b], R. MØLLERUD [c], B. NILSSON [c], C. ONIONS [b], G. PARROUR [b,d], F. PASTORE [b], H. PLOTHOW-BESCH [d], J.-P. REPELLIN [d], J. RINGEL [b], A. ROTHENBERG [b], A. ROUSSARIE [f], G. SAUVAGE [d], J. SCHACHER [a], J.L. SIEGRIST [b], F. STOCKER [a], J. TEIGER [f], V. VERCESI [e], H.H. WILLIAMS [b], H. ZACCONE [f] and W. ZELLER [a]

[a] *Laboratorium für Hochenergiephysik, Universität Bern, Sidlerstrasse 5, Bern, Switzerland*
[b] *CERN, 1211 Geneva 23, Switzerland*
[c] *Niels Bohr Institute, Blegdamsvej 17, Copenhagen, Denmark*
[d] *Laboratoire de l'Accélérateur Linéaire, Université de Paris-Sud, Orsay, France*
[e] *Istituto di Fisica Nucleare, Università di Pavia and INFN, Sezione di Pavia, Via Bassi 6, Pavia, Italy*
[f] *Centre d'Etudes Nucléaires de Saclay, Gif sur Yvette, France*

Received 25 August 1982

The distribution of total transverse energy ΣE_T over the pseudorapidity interval $-1 < \eta < 1$ and an azimuthal range $\Delta\phi = 300°$ has been measured in the UA2 experiment at the CERN p̄p collider ($\sqrt{s} = 540$ GeV) using a highly segmented total absorption calorimeter. In the events with very large ΣE_T ($\Sigma E_T \gtrsim 60$ GeV) most of the transverse energy is found to be contained in small angular regions as expected for high transverse momentum hadron jets. We discuss the properties of a sample of two-jet events with invariant two-jet masses up to 140 GeV/c^2 and we measure the cross section for inclusive jet production in the range of jet transverse momenta between 15 and 60 GeV/c.

1. Introduction. The suggestion that hard scattering of hadron constituents should result in two jets with the same momenta as the scattered partons [1] has motivated an intense experimental effort [2]. Earlier ISR experiments [3] have reported observations of such double-jet structures. However these jets were not as clearly identified as they are in the hadronic final states of high-energy e^+e^- annihilations [4], because in hadronic collisions the jets carry only a fraction of the total energy available. As a consequence, jets are accompanied by several soft hadrons which may make their identification more difficult and in general they are not collinear.

The recent successful operation of the CERN p̄p collider [5] has opened a new possibility to observe high transverse momentum hadron jets. At $\sqrt{s} = 540$ GeV the yield of jets with $E_T > 20$ GeV is expected to increase by about four orders of magnitude with respect to the top ISR energy [6] whereas the average particle density in the central region for an ordinary collision has increased by less than a factor of 2 [7].

We report here on results from the UA2 experiment at the CERN p̄p collider. This experiment uses a large

[1] Now also at Istituto di Fisica, Università di Udine, Italy.
[2] Now also at Istituto di Fisica, Università di Perugia, Italy.

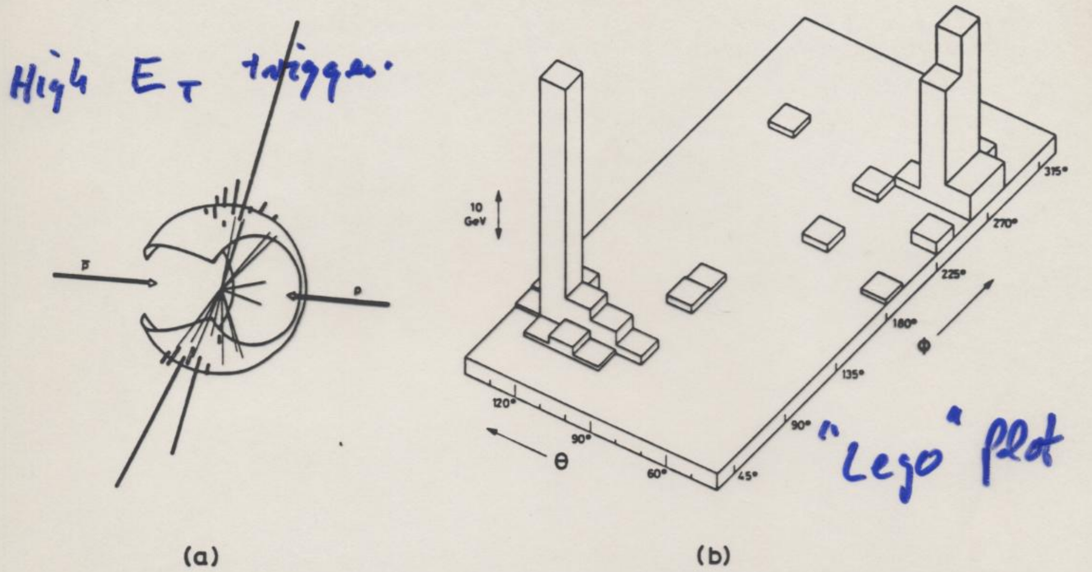


Fig. 4. Configuration of the event with the largest value of ΣE_T, 127 GeV (M = 140 GeV): (a) charged tracks pointing to the inner face of the central calorimeter are shown together with cell energies (indicated by heavy lines with lengths proportional to cell energies). (b) the cell energy distribution as a function of polar angle θ and azimuth ϕ.

(C1, C2) in each event (we assign to each cluster a four-momentum $(E\boldsymbol{u}, E)$, E being the cluster energy and $\boldsymbol{u}$ the unit vector pointing from the event vertex to the cluster center). We measure P_T to be 6 GeV/c on the average, of which at least 3 GeV/c are of instrumental nature (non-inclusion of large angle frag-

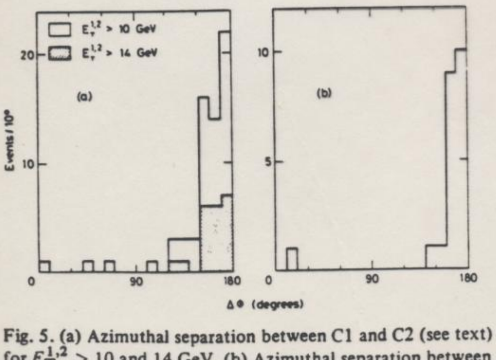


Fig. 5. (a) Azimuthal separation between C1 and C2 (see text) for $E_T^{1,2} > 10$ and 14 GeV. (b) Azimuthal separation between C1 and the forward/backward sector having $E_T > 5$ GeV for $E_T^1 > 10$ GeV and $E_T^2/E_T^1 < 0.4$ (see text).

ments in the cluster, energy resolution, edge effects, etc.).

The above observations support the interpretation of S_{JJ} as a sample of two-jet events resulting from a hard parton collision. We remark however that the spectacular configuration illustrated in fig. 4 is not representative of the whole sample. As shown in fig. 3a the two-jet system accounts for only a fraction of ΣE_T. The rest of the transverse energy in the event, $\widetilde{E}_T$, is distributed among clusters, of which typically 2 to 3 are in excess of 1 GeV. Their detailed study is beyond the scope of the present report. We simply remark that they are only weakly correlated with the jet directions and that their multiplicity and transverse energy distributions are the same as in events having $\Sigma E_T = \widetilde{E}_T$.

Given the presence of relatively abundant and hard clusters accompanying the two-jet system, we further ascertain the emergence of a two-jet (as opposed to multi-jet) structure by measuring the dependence upon ΣE_T of the ratios $r_{21} = E_T^2/E_T^1$ and $r_{32} = E_T^3/E_T^2$. As ΣE_T increases, r_{21} increases and r_{32} decreases (fig. 3b), again illustrating the dominance of two-jet events for ΣE_T exceeding $\simeq$60 GeV.

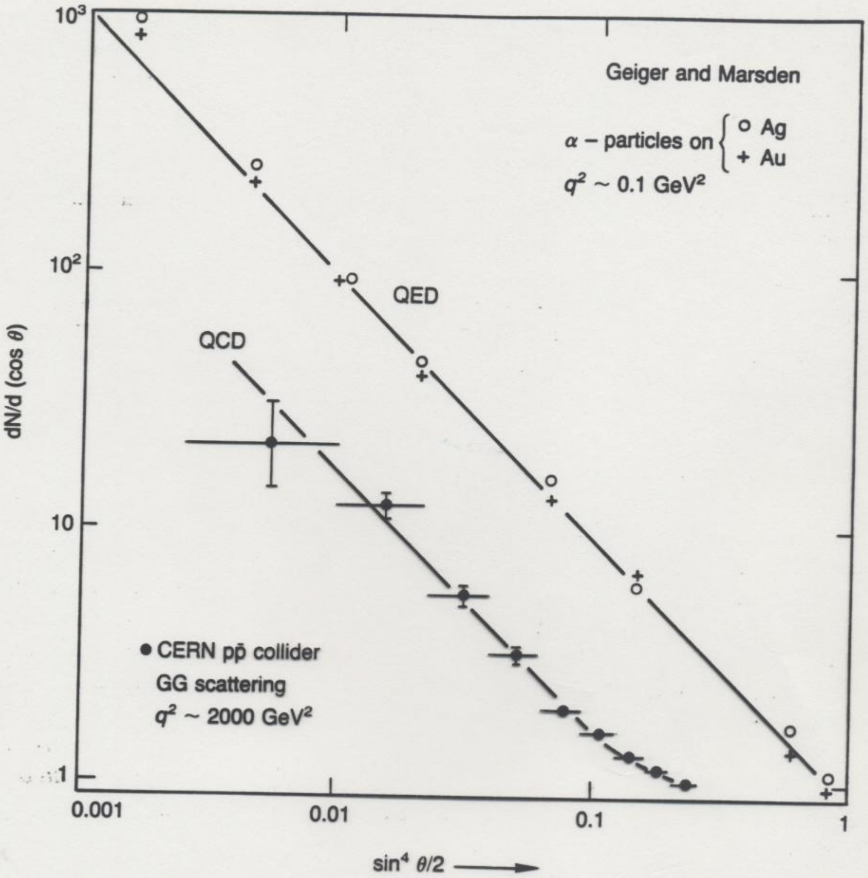
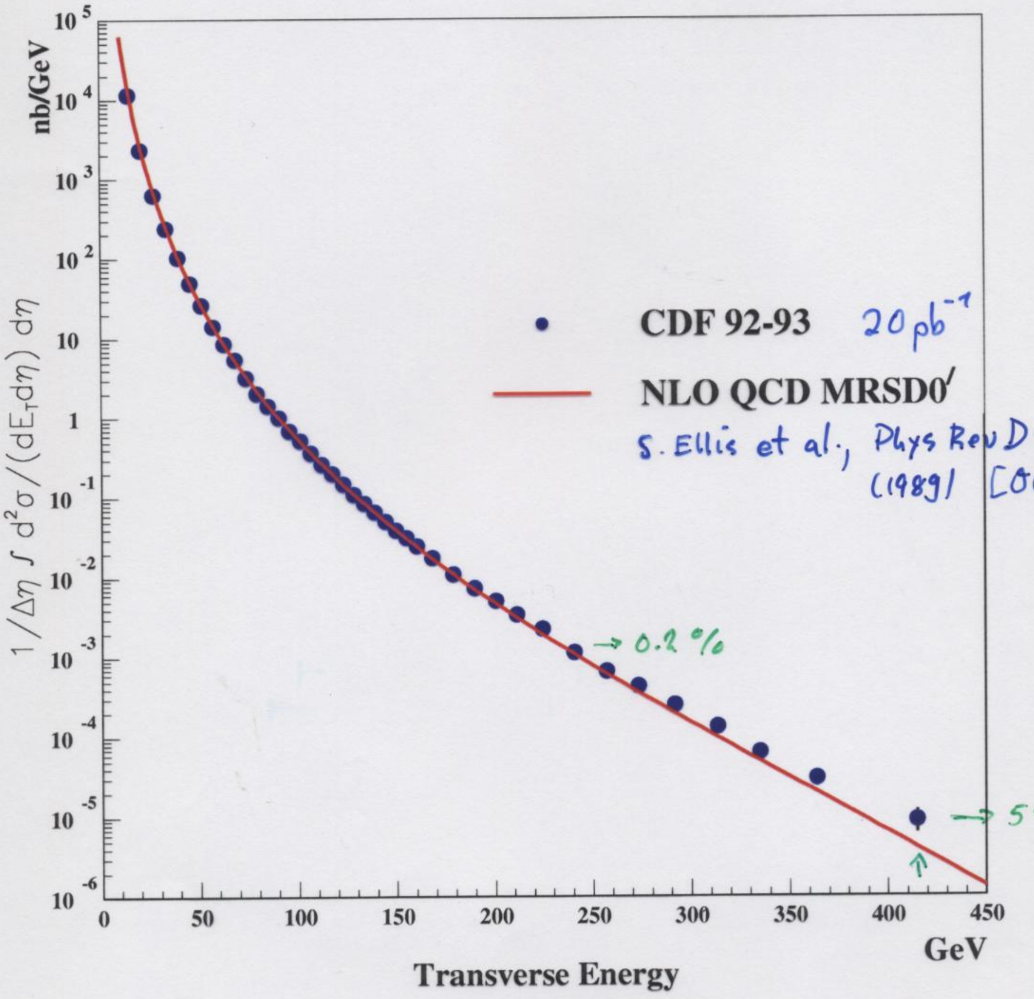


Figure 8.21 Examples of differential cross-sections for pointlike scattering via a $1/r$ potential. The upper plot is of the results of Geiger and Marsden (1911) for scattering of α-particles from radioactive sources by gold and silver foils, demonstrating the existence of a nucleus to the atom, scattering the α-particles through the Coulomb field. Their results involved momentum transfers $\simeq 0.1$ GeV^2 and are consistent with the Rutherford formula $dN/d\Omega \propto \sin^{-4}(\theta/2)$.

The lower plot is the two-jet angular distribution found at the CERN $p\bar{p}$ collider, at $q^2 \simeq 2000$ GeV^2, showing that the scattering of pointlike (quark or gluon) constituents of the nucleon also obeys the Rutherford law at small angles, and hence that the QCD potential varies as $1/r$ at small distances. At large angles, deviations from the straight line occur because of relativistic (spin) effects and because scatters of $\theta > \pi/2$ have to be folded into the distribution for $\theta < \pi/2$. The full-line curve is the QCD prediction for single vector gluon exchange. Scalar (spin-0) gluons are excluded, as they predict a very much weaker angular dependence.

1. Inklusives Jet - Spektrum von CDF

[F. Abe et al. (CDF), PRL 77 (1996)]

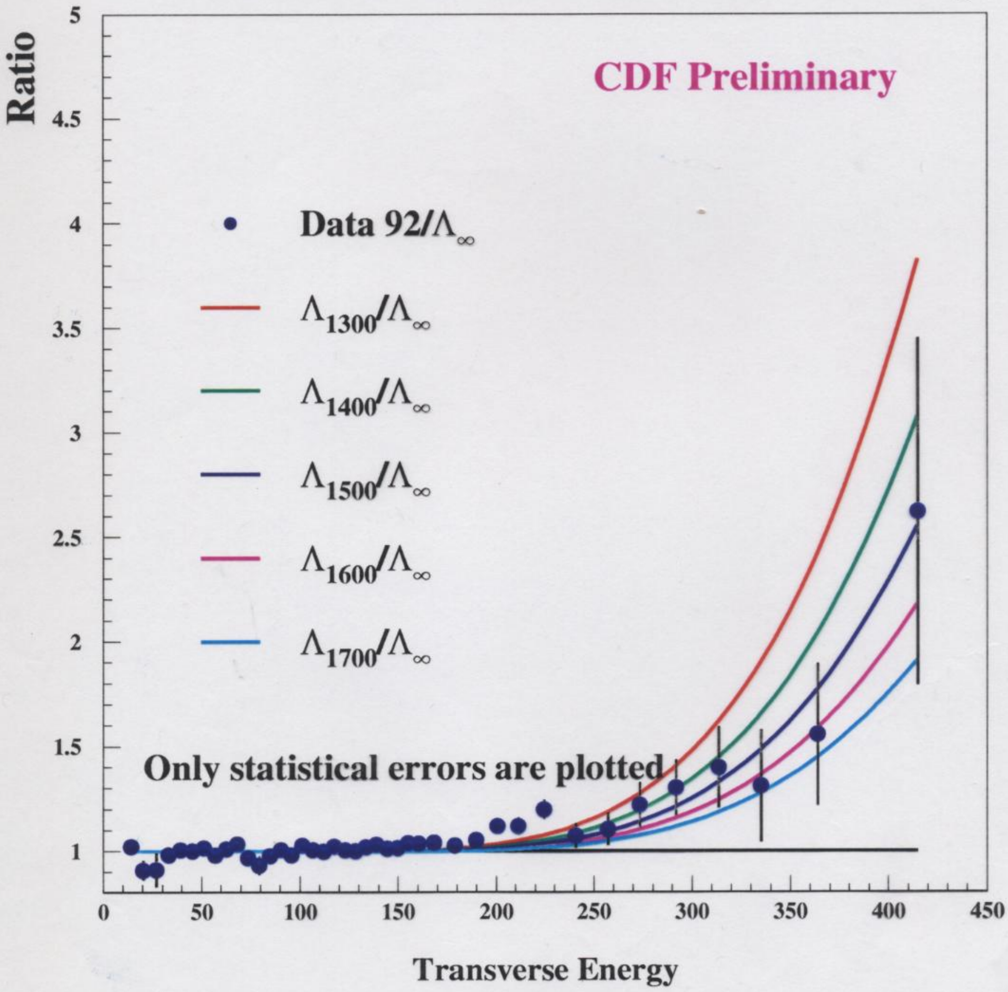


Jet: Kalor. - Energie

in $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.7$

Note: $\frac{E\, d^3\sigma}{d^3p} = \frac{d^3\sigma}{d^2p_T\, dy} \rightarrow \frac{1}{2\pi E_T} \frac{d\sigma}{d\eta} \frac{d\sigma}{dE_T}$ L. inv. Xsection

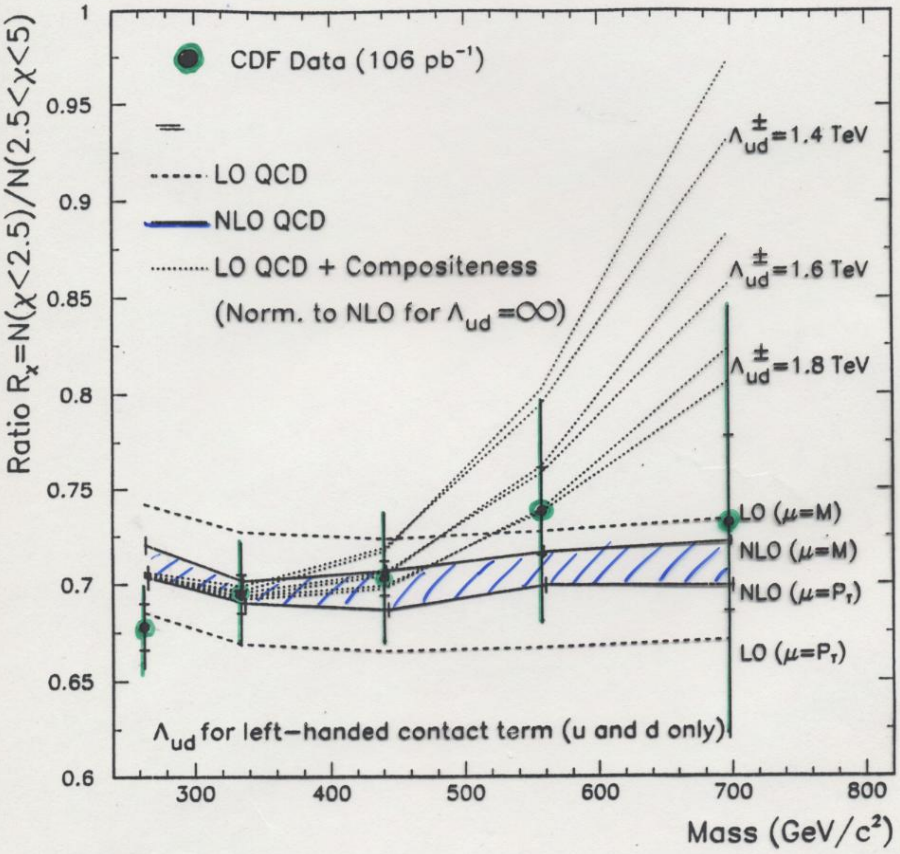
Cross section for various compositeness scales Λ_C



Bs: $\Lambda_c = 1700$ GeV :

$r_c \sim \frac{\hbar c}{\Lambda_c} \sim 1.2 \; 10^{-4}$ fm

Grenze für Substruktur aus Winkelverteilung



CDF $\begin{cases} \Lambda^- > 1.6 \text{ TeV} \\ \Lambda^+ > 1.8 \text{ TeV} \end{cases}$ [95% C.L.]

DØ $\begin{cases} \Lambda^- > 2.2 \text{ TeV} \\ \Lambda^+ > 2.1 \text{ TeV} \end{cases}$ [95% CL.]