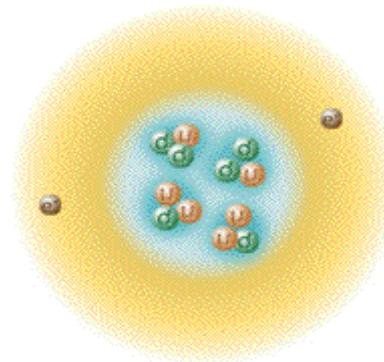


Bei **Licht** betrachtet ein Blick in's Innere des **Nukleons**

Hartmut Schmieden
Physikalisches Institut



dies academicus 4. Juni 2003



Aufbau der Materie

Die Vorstellungen im Wandel der Zeit

~450 v.Chr. **Empedokles** Feuer, Wasser, Erde, Luft

~450 v.Chr. **Anaxagoras, Demokrit** **ατομον** (Atomon)

~350 v.Chr. **Aristoteles** Äther

~1800 **Dalton** kleinste, unteilbare Bestandteile der Elemente

~1870 **Meyer, Mendelejew** Periodensystem

~1920 **Planck, Einstein, Bohr** Atomphysik, Quantentheorie

Aufbau der Materie

Die Vorstellungen im Wandel der Zeit

Das Periodensystem der Elemente																									
Hauptgruppen								Nebengruppen								Hauptgruppen									
I	II	III	IV	V	VI	VII	VIII									I	II	III	IV	V	VI	VII	VIII		
¹ H																² He									
³ Li	⁴ Be															⁵ B	⁶ C	⁷ N	⁸ O	⁹ F	¹⁰ Ne				
¹¹ Na	¹² Mg															¹³ Al	¹⁴ Si	¹⁵ P	¹⁶ S	¹⁷ Cl	¹⁸ Ar				
¹⁹ K	²⁰ Ca	²¹ Sc	²² Ti	²³ V	²⁴ Cr	²⁵ Mn	²⁶ Fe	²⁷ Co	²⁸ Ni	²⁹ Cu	³⁰ Zn	³¹ Ga	³² In	³³ Ge	³⁴ As	³⁵ Se	³⁶ Br	³⁷ Kr							
³⁷ Rb	³⁸ Sr	³⁹ Y	⁴⁰ Zr	⁴¹ Nb	⁴² Mo	⁴³ Tc	⁴⁴ Ru	⁴⁵ Rh	⁴⁶ Pd	⁴⁷ Ag	⁴⁸ Cd	⁴⁹ In	⁵⁰ Sn	⁵¹ Sb	⁵² Te	⁵³ I	⁵⁴ Xe								
⁵⁵ Cs	⁵⁶ Ba		⁷² Hf	⁷³ Ta	⁷⁴ W	⁷⁵ Re	⁷⁶ Os	⁷⁷ Ir	⁷⁸ Pt	⁷⁹ Au	⁸⁰ Hg	⁸¹ Tl	⁸² Pb	⁸³ Bi	⁸⁴ Po	⁸⁵ At	⁸⁶ Rn								
⁸⁷ Fr	⁸⁸ Ra		¹⁰⁴ Ku	¹⁰⁵ Ha	¹⁰⁶ Sg	¹⁰⁷ Ns	¹⁰⁸ Hs	¹⁰⁹ Mt	¹¹⁰ Uuu	¹¹¹ Uun	¹¹² Uub		¹¹⁴ Uuq												
Lanthanoide								⁵⁷ La	⁵⁸ Ce	⁵⁹ Pr	⁶⁰ Nd	⁶¹ Pm	⁶² Sm	⁶³ Eu	⁶⁴ Gd	⁶⁵ Tb	⁶⁶ Dy	⁶⁷ Ho	⁶⁸ Er	⁶⁹ Tm	⁷⁰ Yb	⁷¹ Lu			
Actinoide								⁸⁹ Ac	⁹⁰ Th	⁹¹ Pa	⁹² U	⁹³ Np	⁹⁴ Pu	⁹⁵ Am	⁹⁶ Cm	⁹⁷ Bk	⁹⁸ Cf	⁹⁹ Es	¹⁰⁰ Fm	¹⁰¹ Md	¹⁰² No	¹⁰³ Lr			
Hintergrundfarbe ■ = Metall								Schriftfarbe ■ = Festkörper								Hintergrundfarbe ■ = Halbmetall									
Hintergrundfarbe ■ = Nichtmetall								Schriftfarbe ■ = Flüssigkeiten								Hintergrundfarbe ■ = Gase									

Feuer, Wasser, Erde, Luft

Atomokrit

ατομον (Atomon)

Äther

Unteilbare Bestandteile der Elemente

W

Periodensystem

~1920

Planck, Einstein, Bohr Atomphysik, Quantentheorie

Standardmodell

Aufbau der Materie

FERMIONS			matter constituents spin = 1/2, 3/2, 5/2, ...		
Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge	Flavor	Approx. Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0	u up	0.003	2/3
e electron	0.000511	-1	d down	0.006	-1/3
ν_μ muon neutrino	<0.0002	0	c charm	1.3	2/3
μ muon	0.106	-1	s strange	0.1	-1/3
ν_τ tau neutrino	<0.02	0	t top	175	2/3
τ tau	1.7771	-1	b bottom	4.3	-1/3

1.

2.

3.

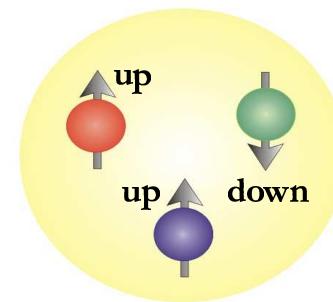
Familie**Familie****Familie**

PROPERTIES OF THE INTERACTIONS

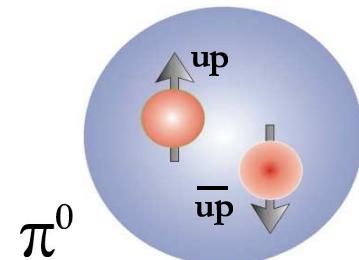
Property	Interaction	Gravitational		Weak (Electroweak)		Strong	
		Fundamental	Residual				
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note		
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons		
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons		

Gebundene Quarks

drei Quarks
(Baryonen)

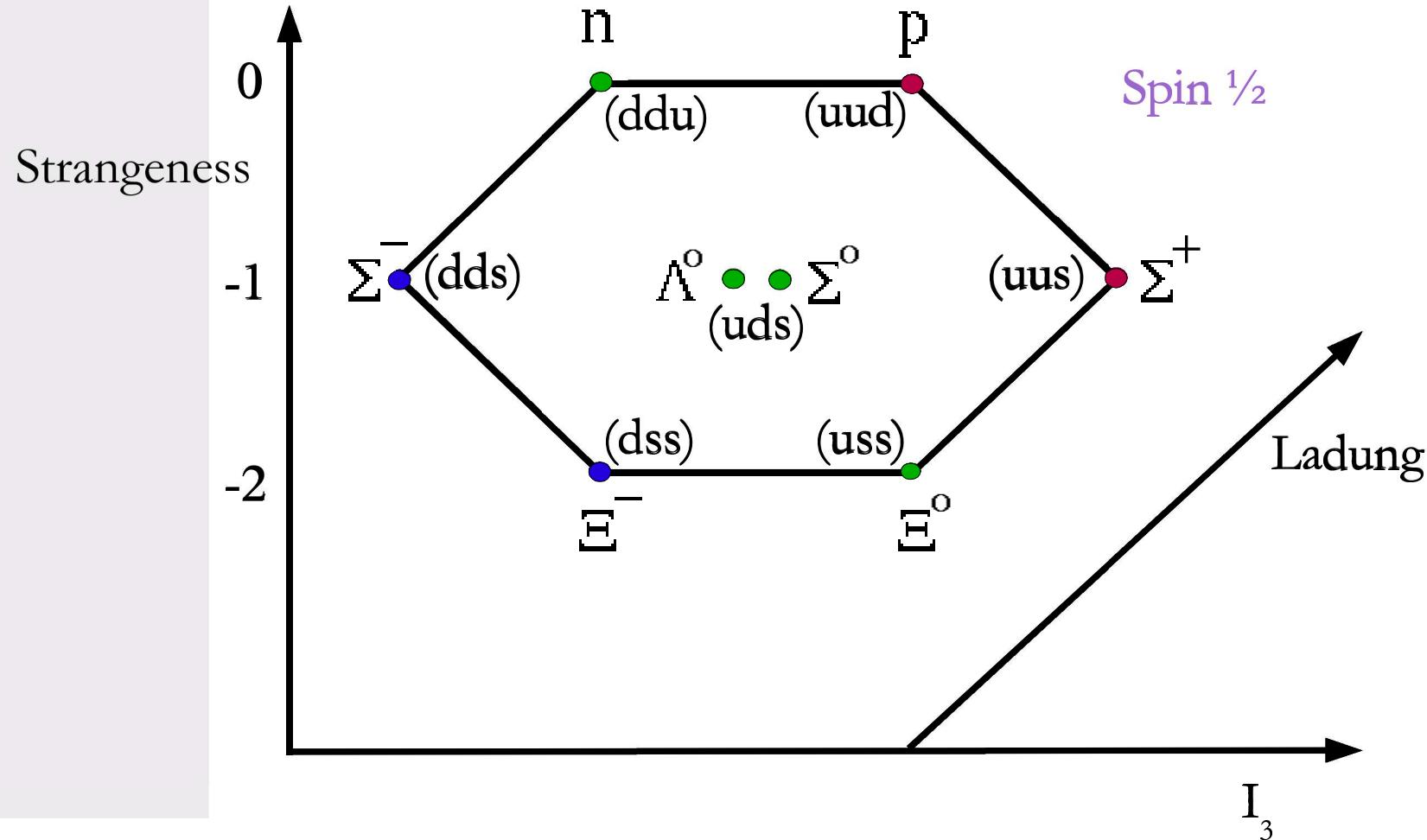


Proton



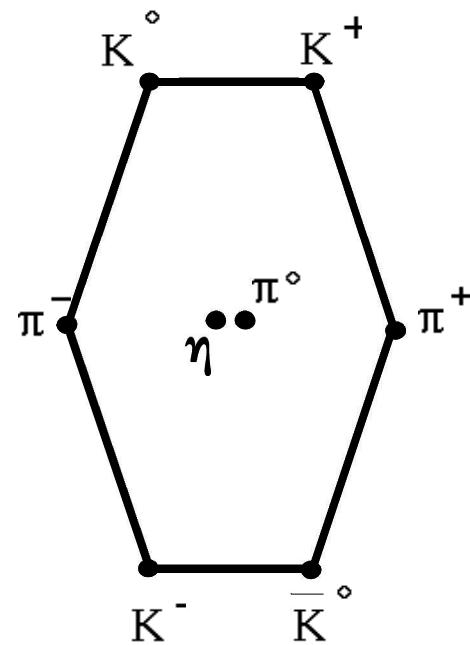
Quark und Anti-Quark
(Mesonen)

Teilchen – Multipletts Baryonen

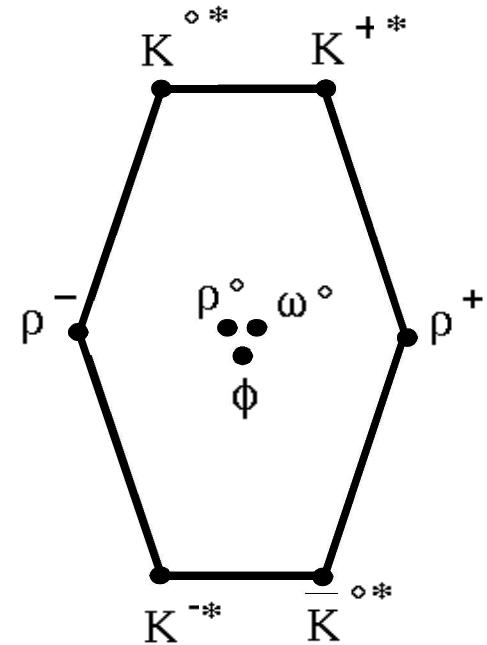


Teilchen – Multipletts

Mesonen

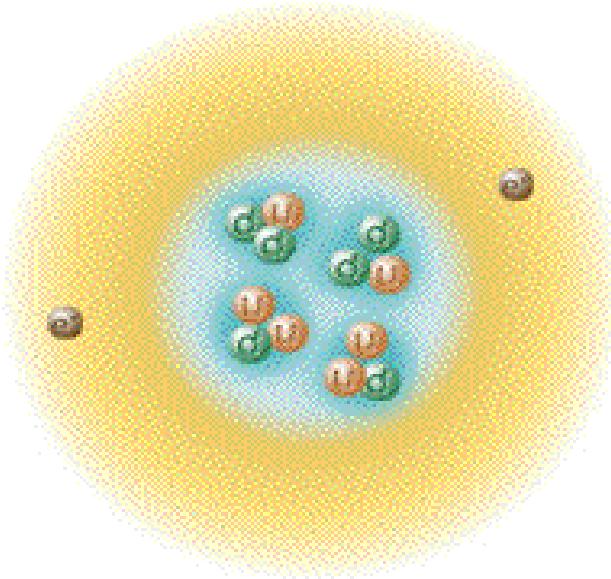


Pseudoskalar
Spin 0



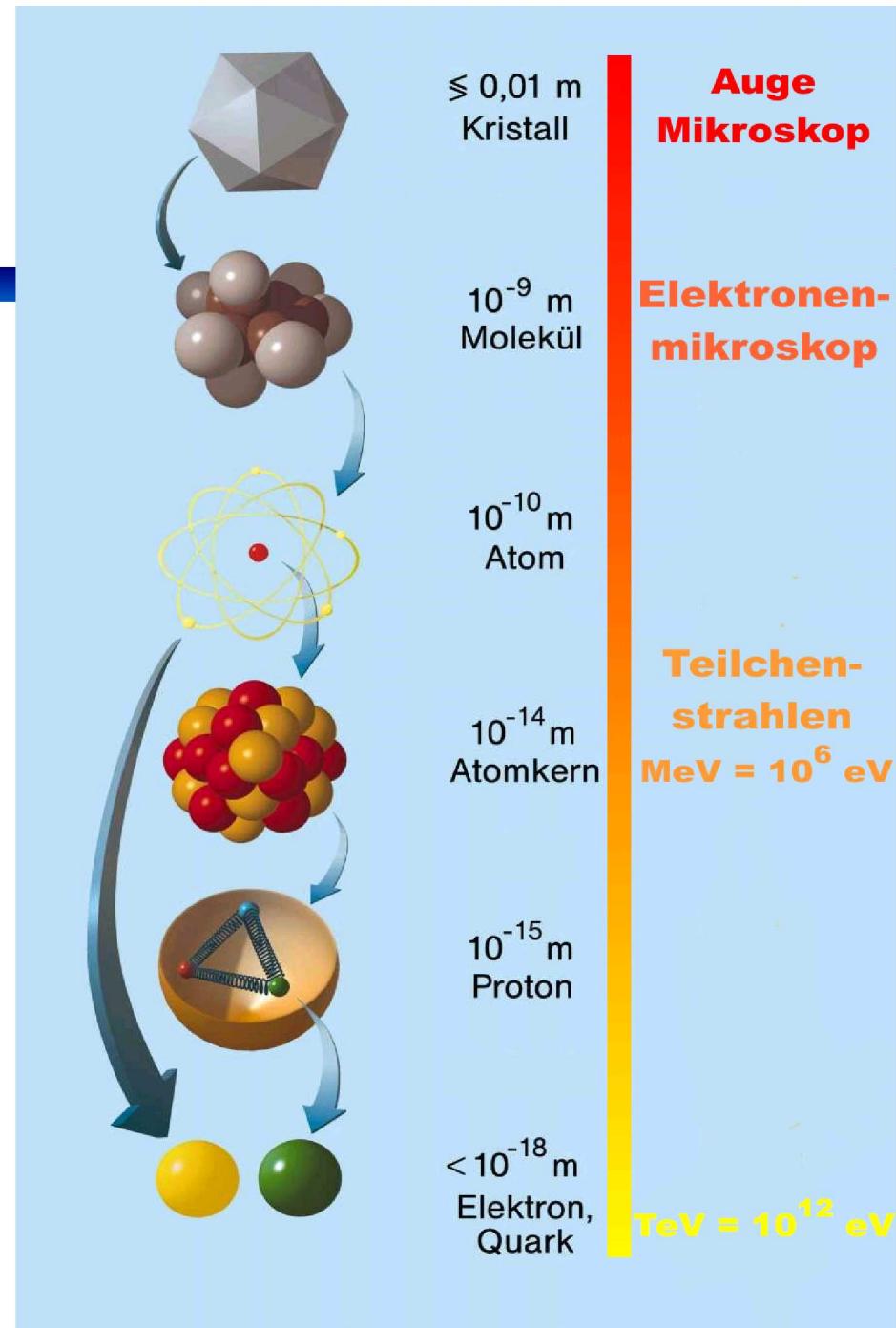
Vektor
Spin 1

Aufbau des Atoms

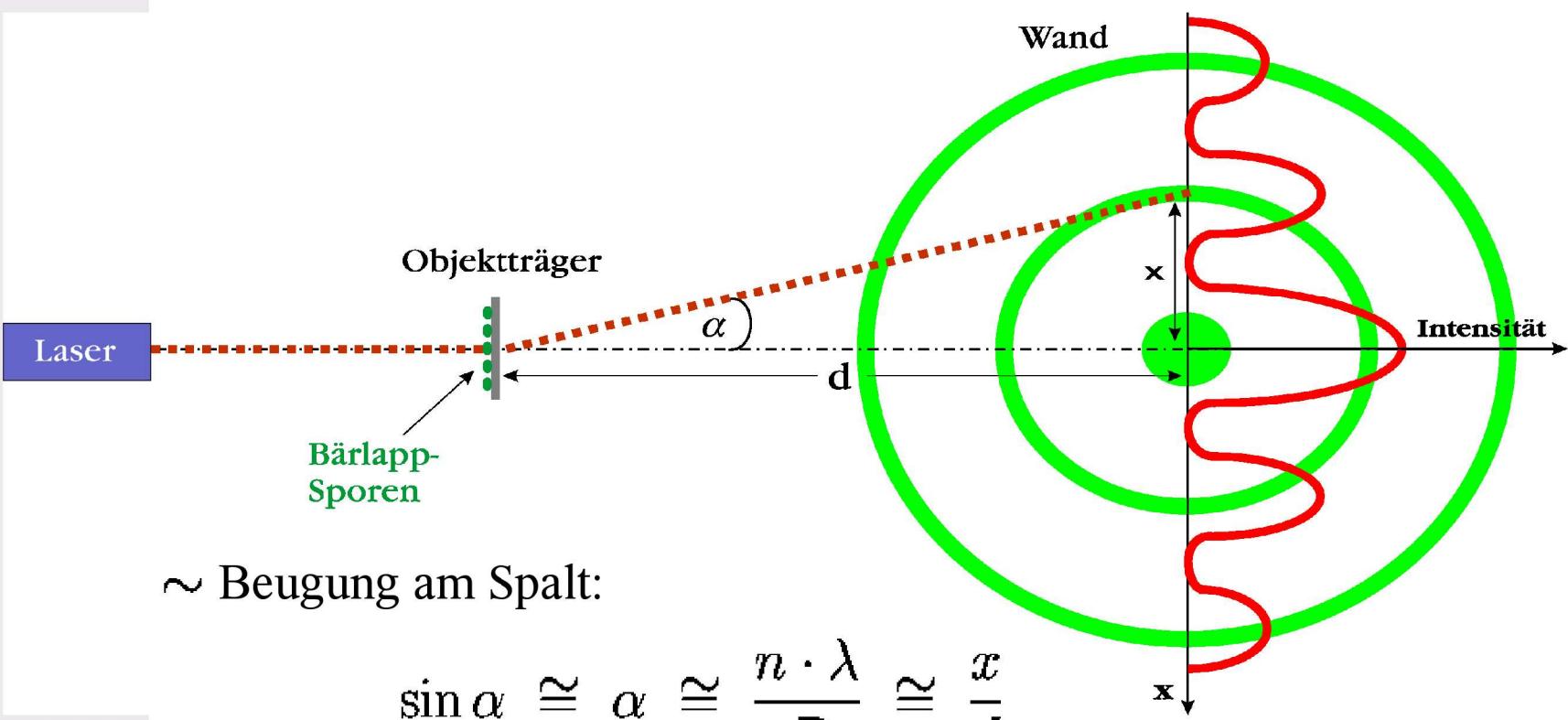


nicht maßstäblich !!

Skalen



Biologische Struktur: Größe von Bärlapp-Sporen



~ Beugung am Spalt:

$$\sin \alpha \cong \alpha \cong \frac{n \cdot \lambda}{R} \cong \frac{x}{d}$$
$$\rightarrow R \cong 10^{-5} \text{ m} = 10 \mu\text{m}$$

Materiewellen

quantenmechanisch:

$$\lambda = \frac{h}{p}$$

Louis de Broglie 1924

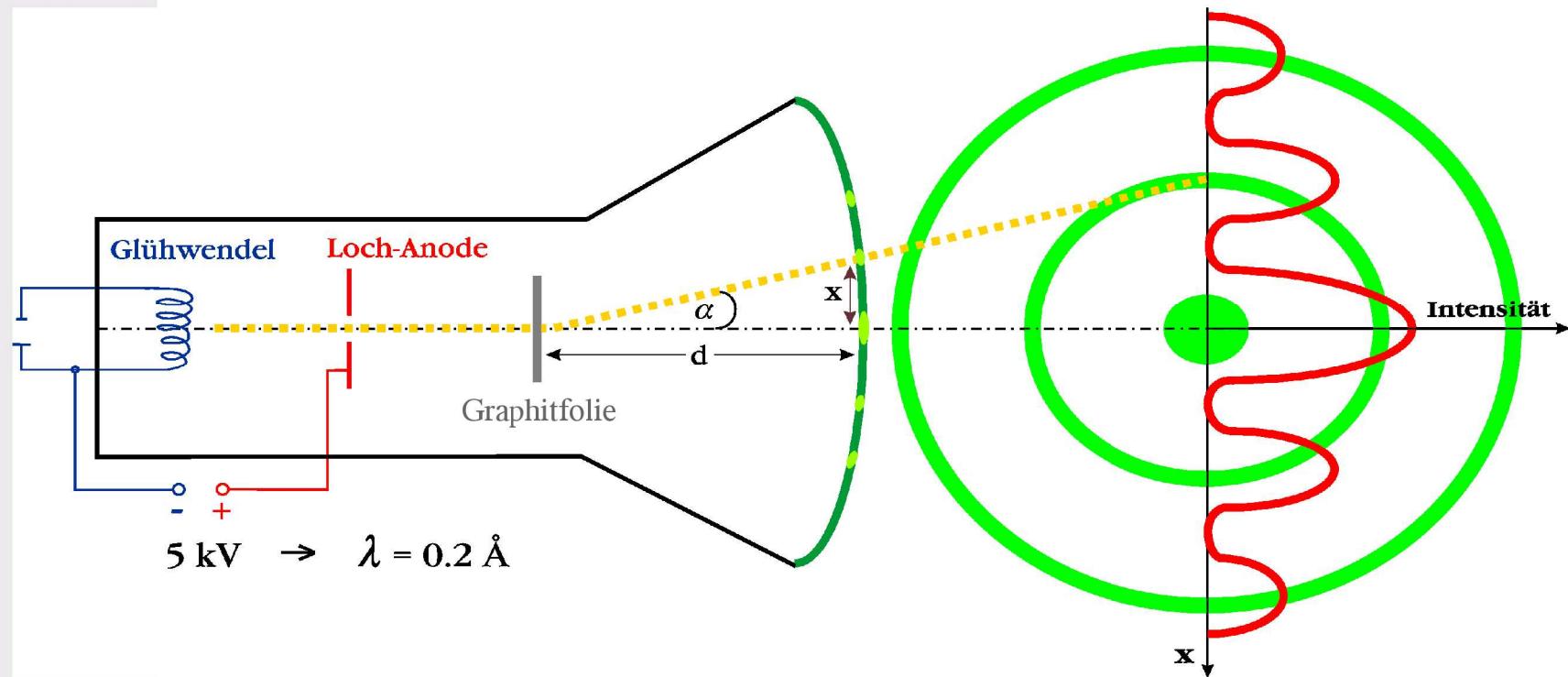
Bsp. Elektron $U = 5 \text{ kV} \rightarrow E_{\text{kin}} = 5 \text{ keV}$

$$p = \sqrt{2mE_{\text{kin}}} \rightarrow \lambda = 2 \cdot 10^{-11} \text{ m} = 0.02 \text{ nm}$$

z.Vgl. $\lambda_{\text{Licht}} = 500 \text{ nm}$ (grün)



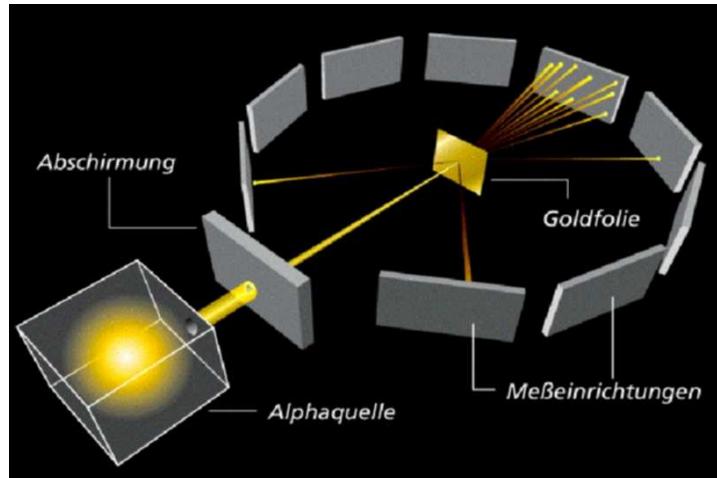
Elektronenbeugung



$$R \cong \frac{d}{x} \cdot \lambda \cong 2,5 \cdot 10^{-10} \text{ m} = 2,5 \text{ \AA}$$

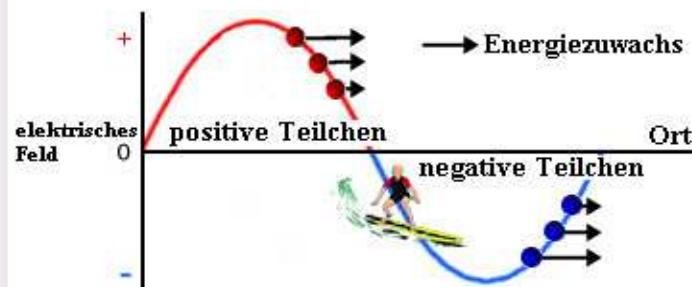
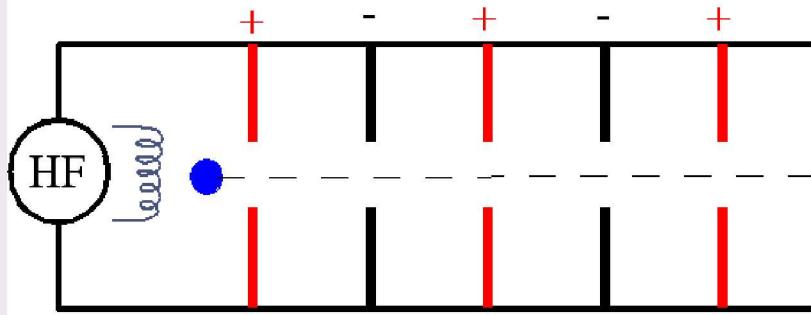
Rutherford Experiment

Geiger & Marsden 1909

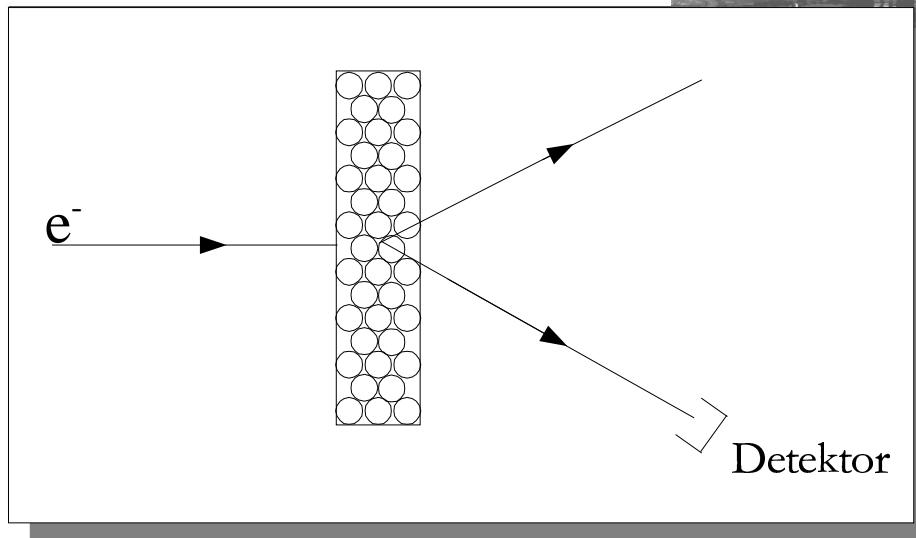
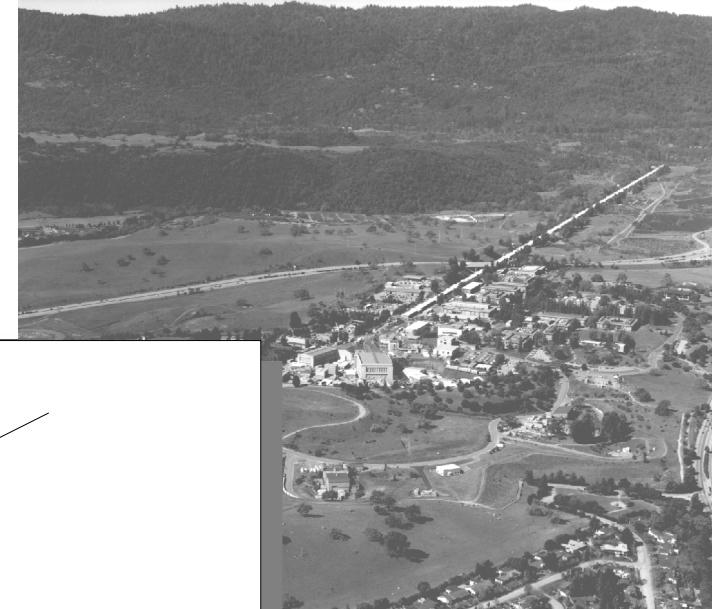
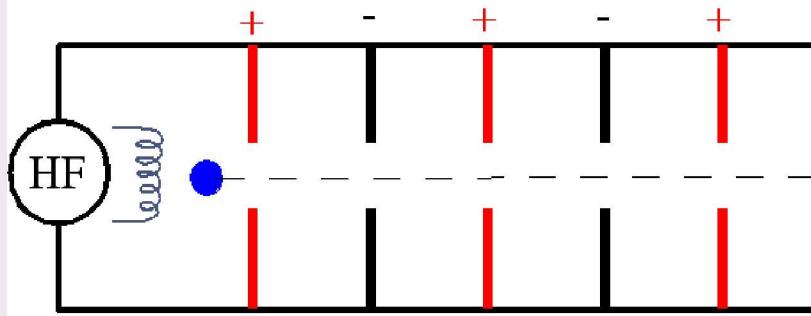


- die meisten α -Teilchen ungestreut
 ↳ Raum im Atom fast „leer“
- einige α -Teilchen werden rückwärtsgestreut
$$\frac{d\sigma}{d\Omega} \sim \frac{1}{\sin^4 \frac{\Theta}{2}}$$
 ↳ „punktförmiger“ Kern

Linearbeschleuniger



Linearbeschleuniger

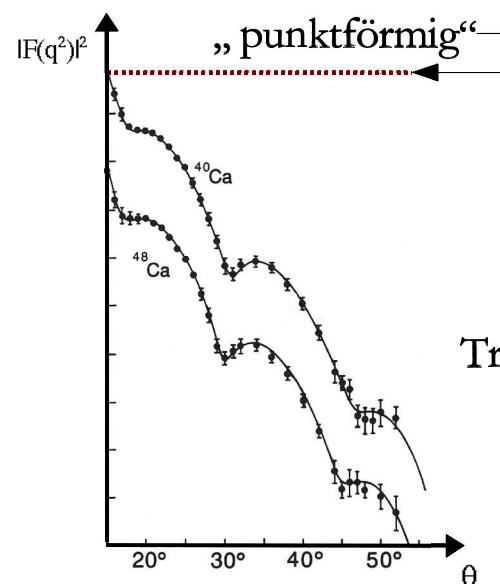


Ausgedehnter Atomkern - Ladungsverteilung

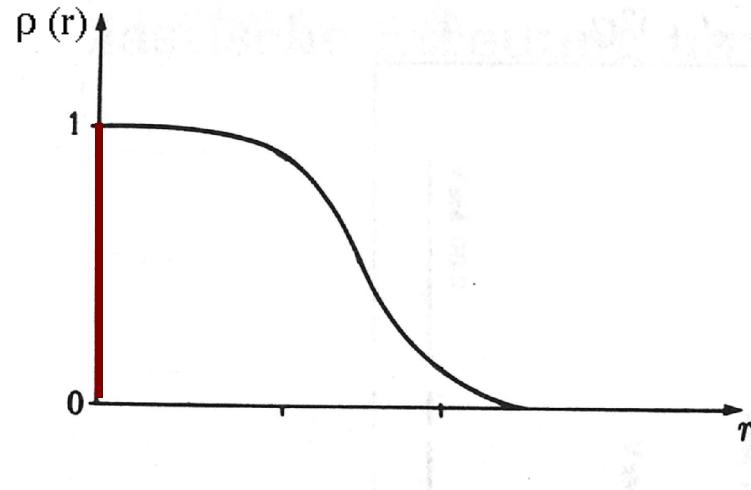
R Hofstadter (Stanford):
Nobelpreis 1961

elastische e^- -Streuung
 $E \approx 100$ MeV

$$\lambda \approx 10 \text{ fm}$$

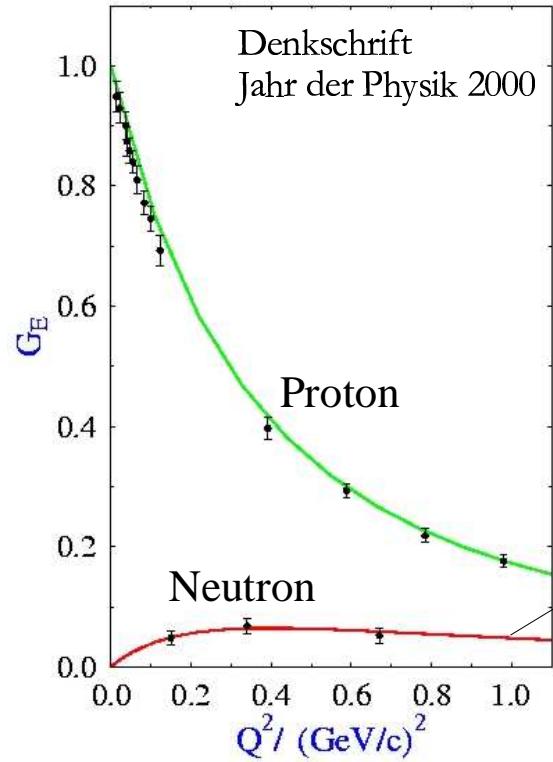


Fourier-
Transformation

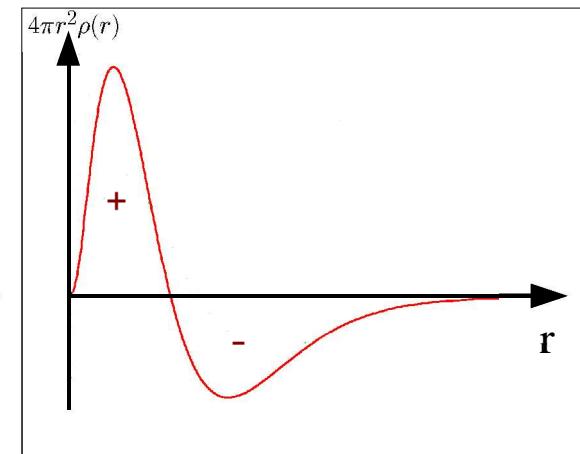


Ausgedehntes Nukleon Ladungsverteilung Proton & Neutron

elastische e^- -Streuung: $E \approx 1 \text{ GeV} \rightsquigarrow \lambda \approx 1 \text{ fm}$

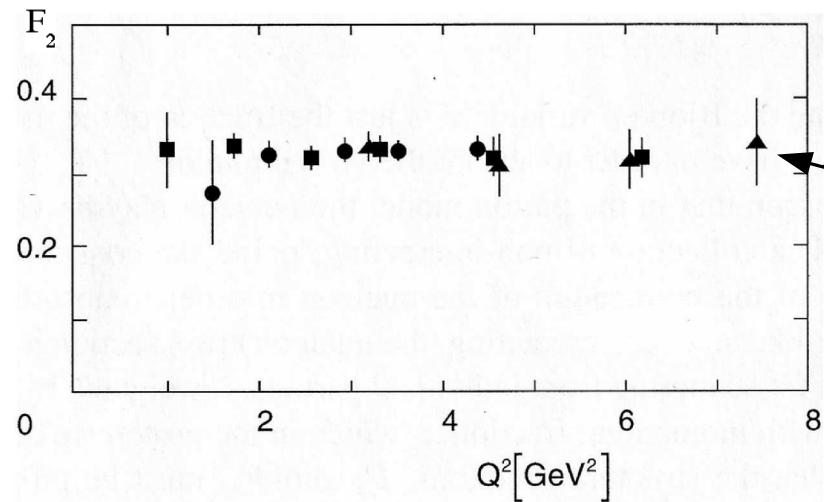


$$p : \sqrt{\langle r_E^2 \rangle} \sim 0.8 \text{ fm}$$
$$n : \langle r_E^2 \rangle \sim -0.1 \text{ fm}^2$$



Tiefinelastische Streuung

scaling



- punktförmige Partonen



- masselose Quarks

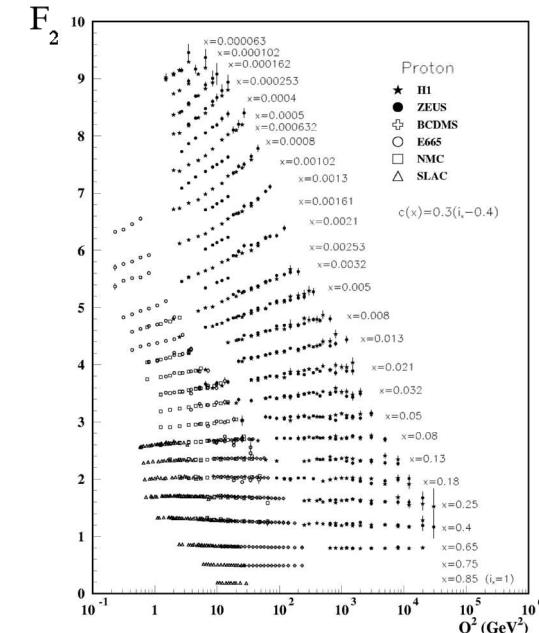
$$m_u \approx 4 \text{ MeV}$$

$$m_d \approx 8 \text{ MeV}$$

$$m_s \approx 160 \text{ MeV}$$

H. W. Kendall, Nobel Lecture
Rev. Mod. Phys. 63 (1991) 597

konstant
 ↴ punktförmige Konstituenten
 → Quarks



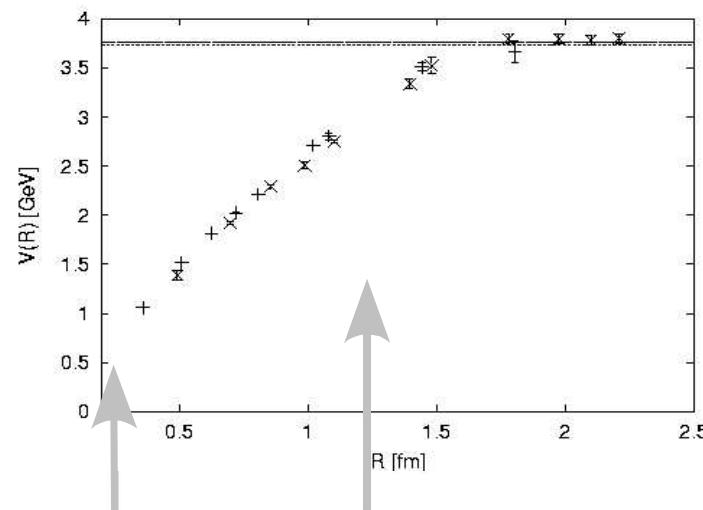
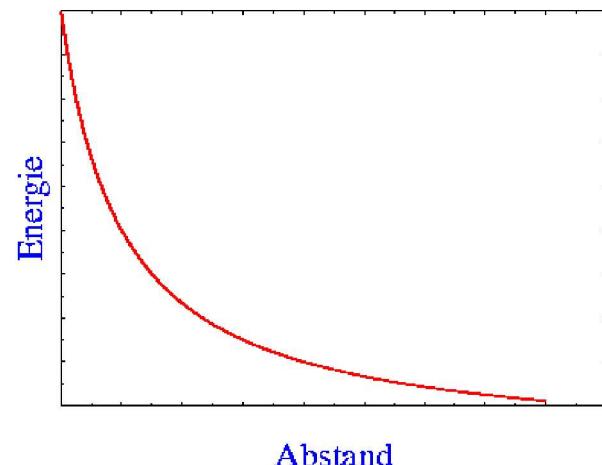
Freiheit im Gefängnis

$$F_{Lad.} \sim \frac{e^2}{r^2} \sim \frac{\alpha}{r^2}$$

$$E_{Lad.} \sim \frac{1}{r}$$

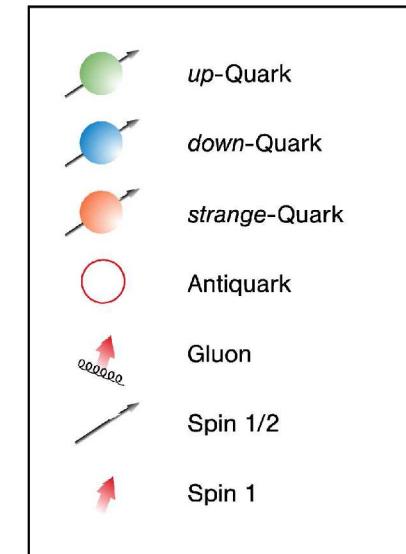
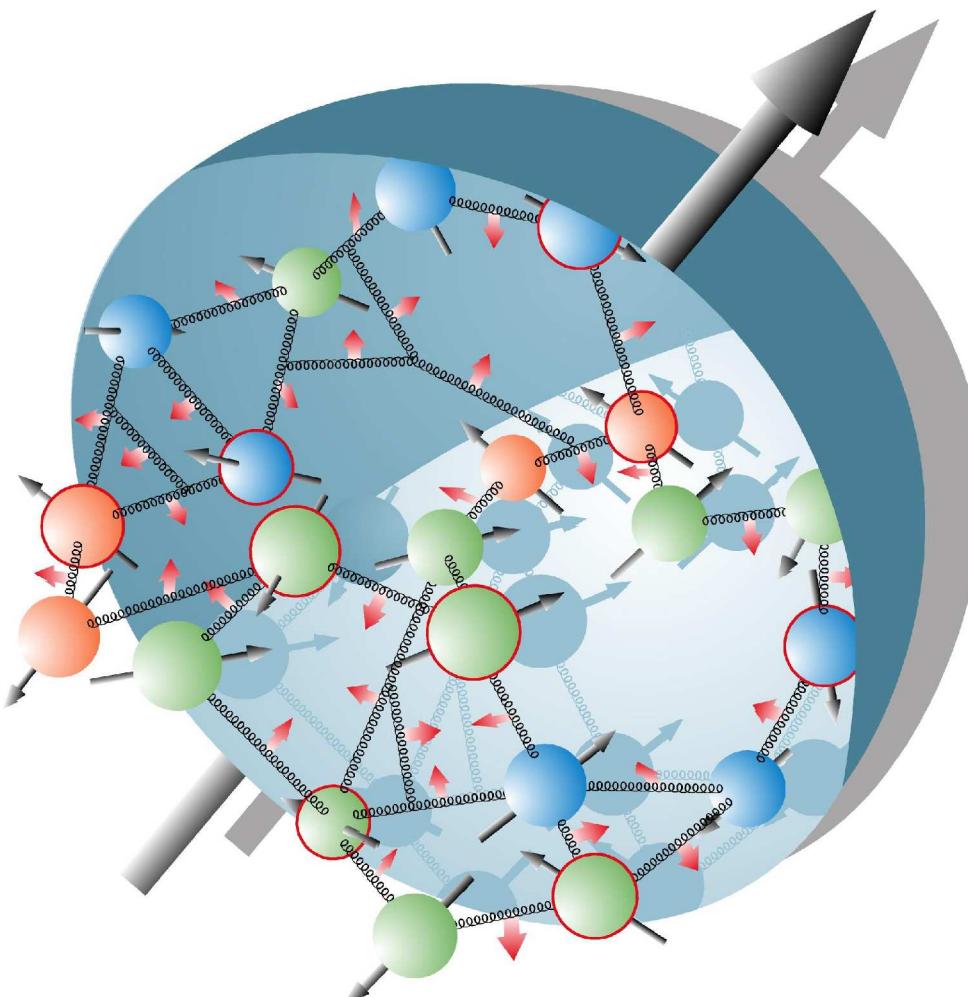
$$F_{Farb.} \sim \frac{q_{Farb}^2}{r^2} \sim \frac{\alpha_{\text{eff}}}{r^2}$$

$$E_{Farb.} \sim r !$$

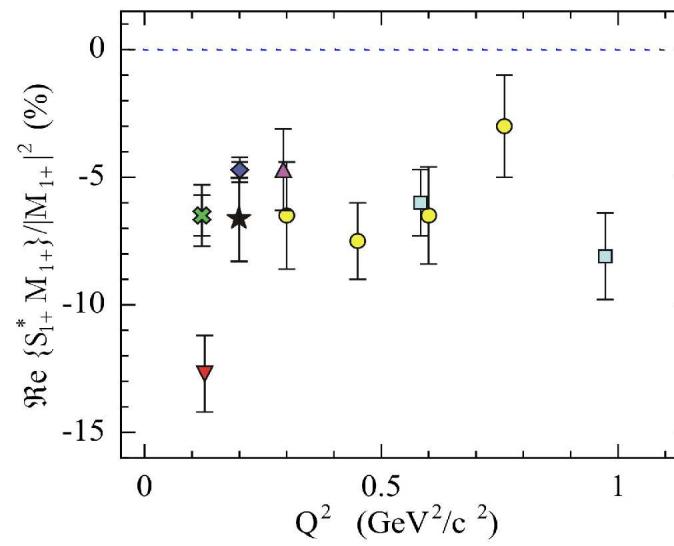
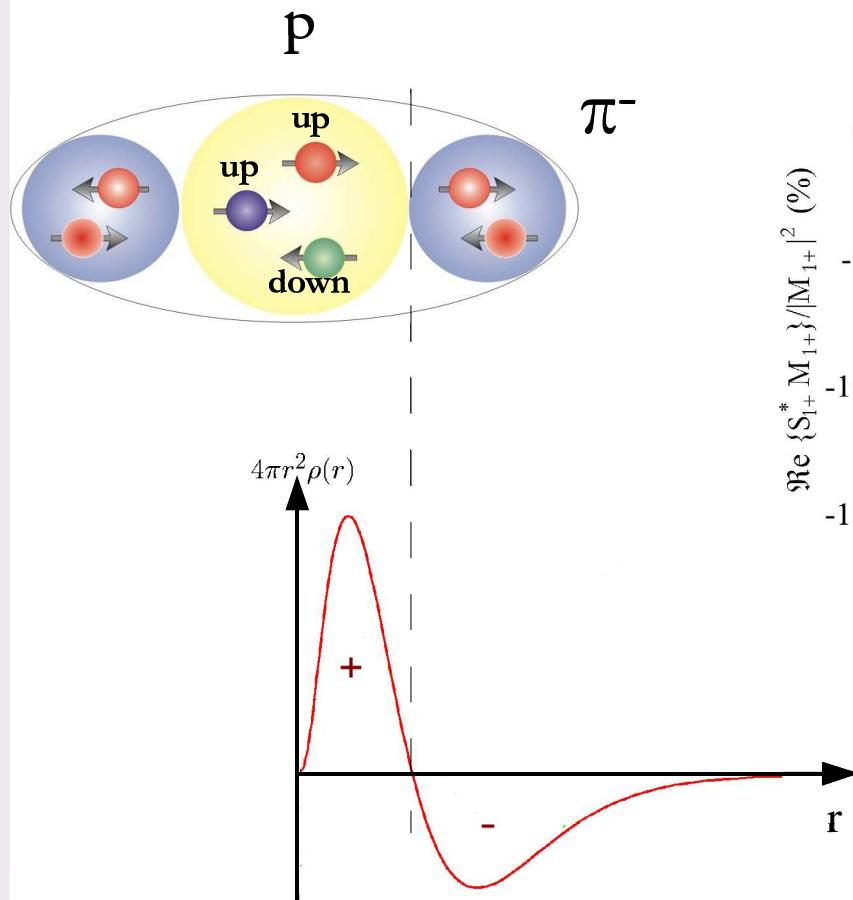


asymptotische Freiheit confinement

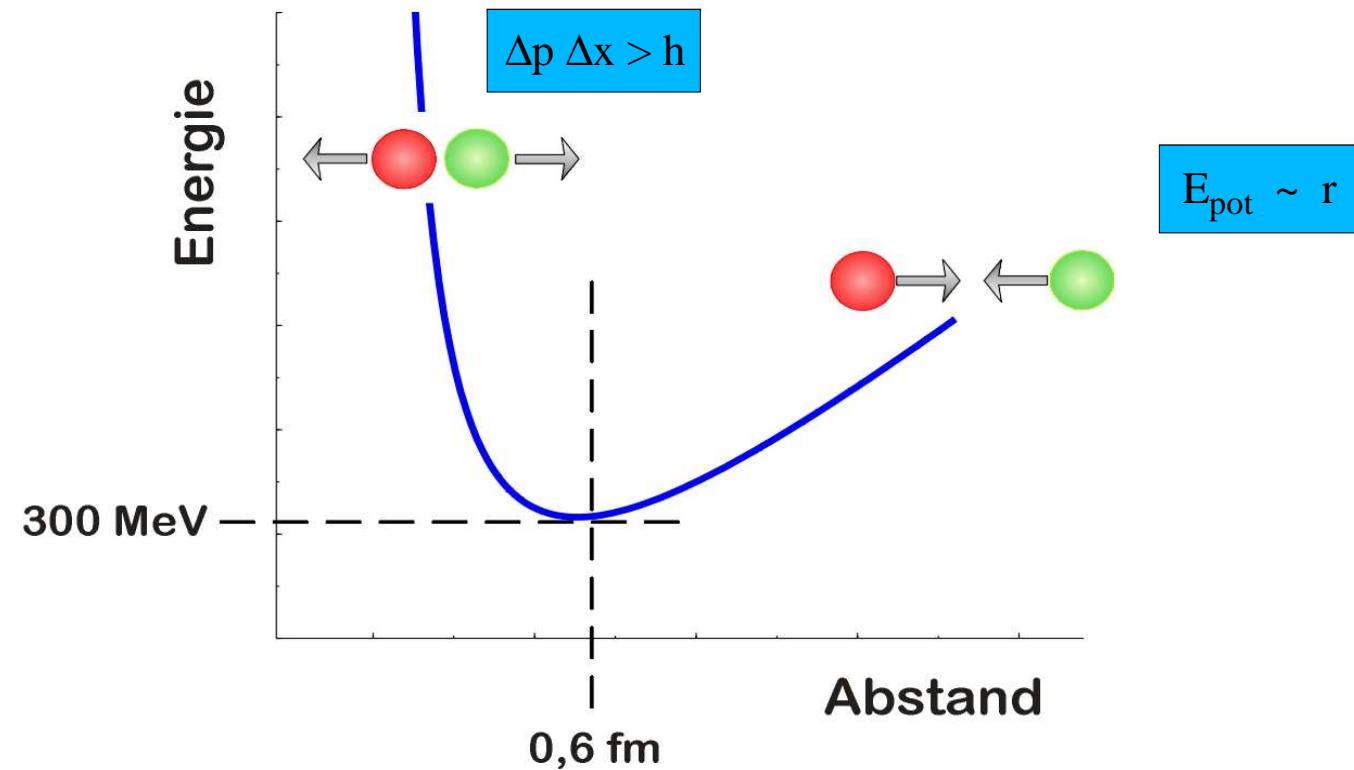
Das Vielteilchen – Nukleon



Mesonische Struktur



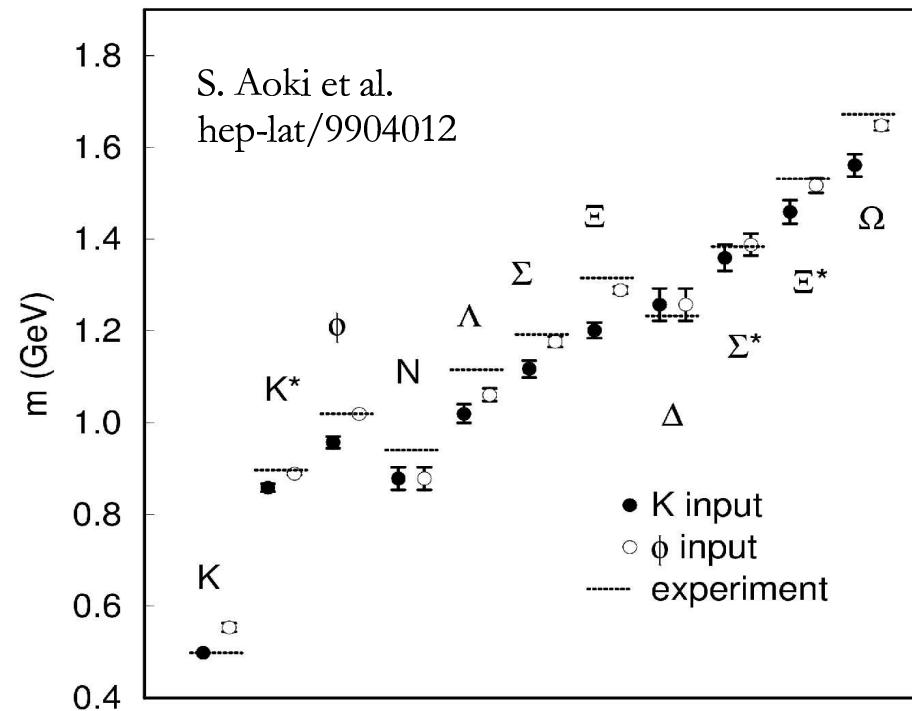
Masse & Ausdehnung



Anregung des Nukleons

Atombau \longleftrightarrow Elektrodynamik \longleftrightarrow Spektrallinien

Nukleonbau \longleftrightarrow Quark- Gluondynamik \longleftrightarrow Anregungsspektrum



qualitativ ok

Anzahl

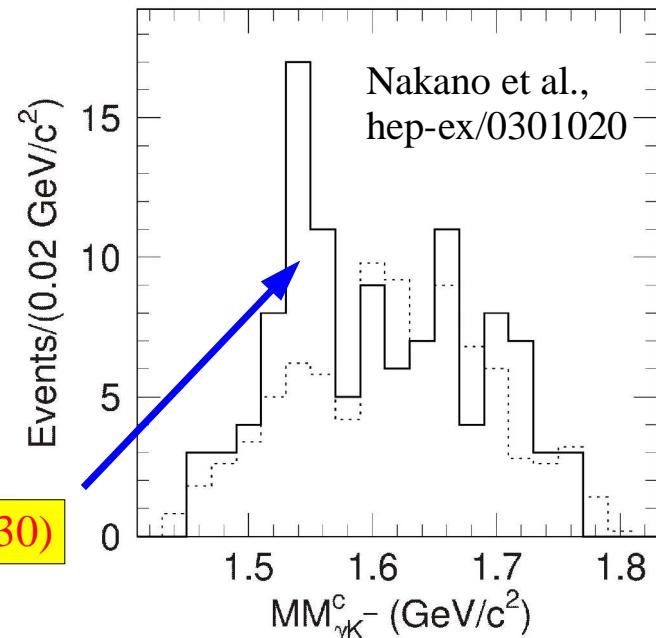
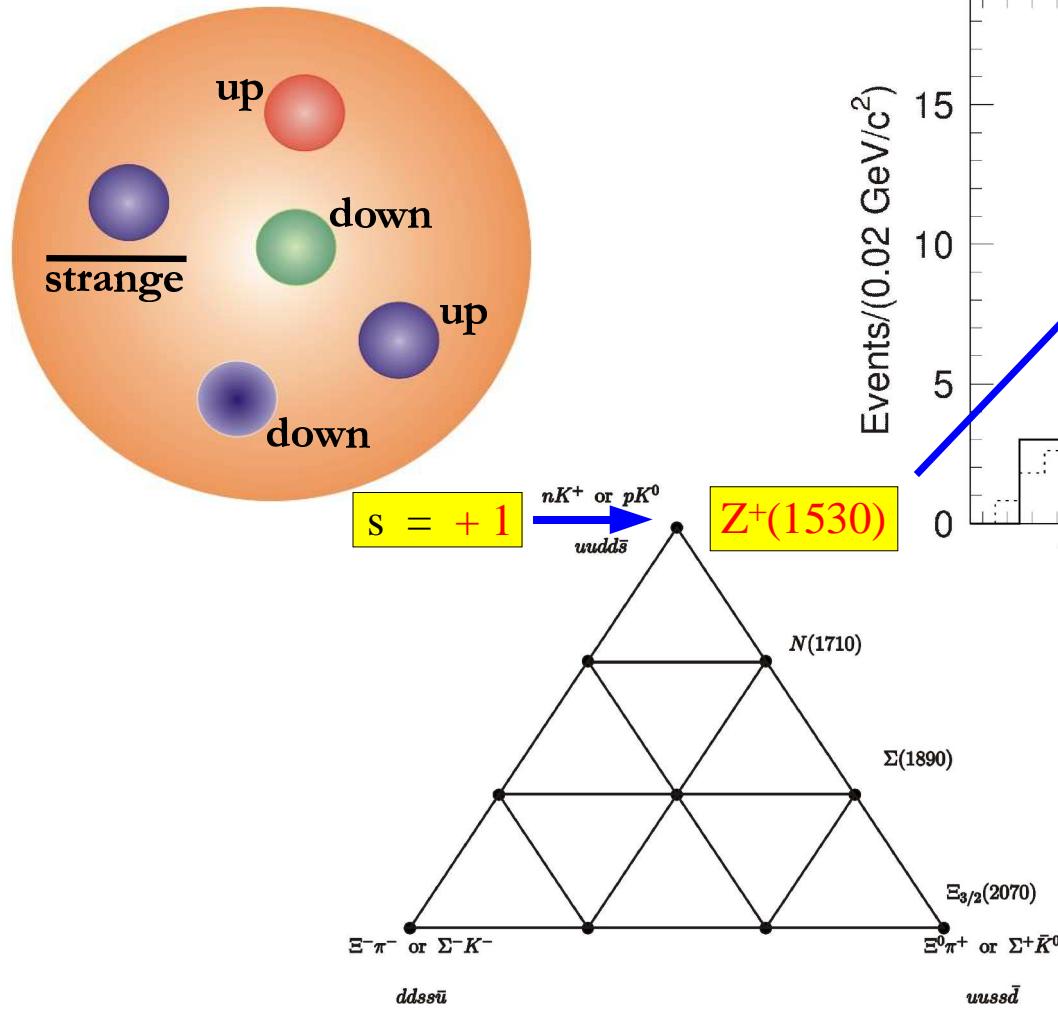


&

Struktur

„fehlende“ Resonanzen
exotische Zustände

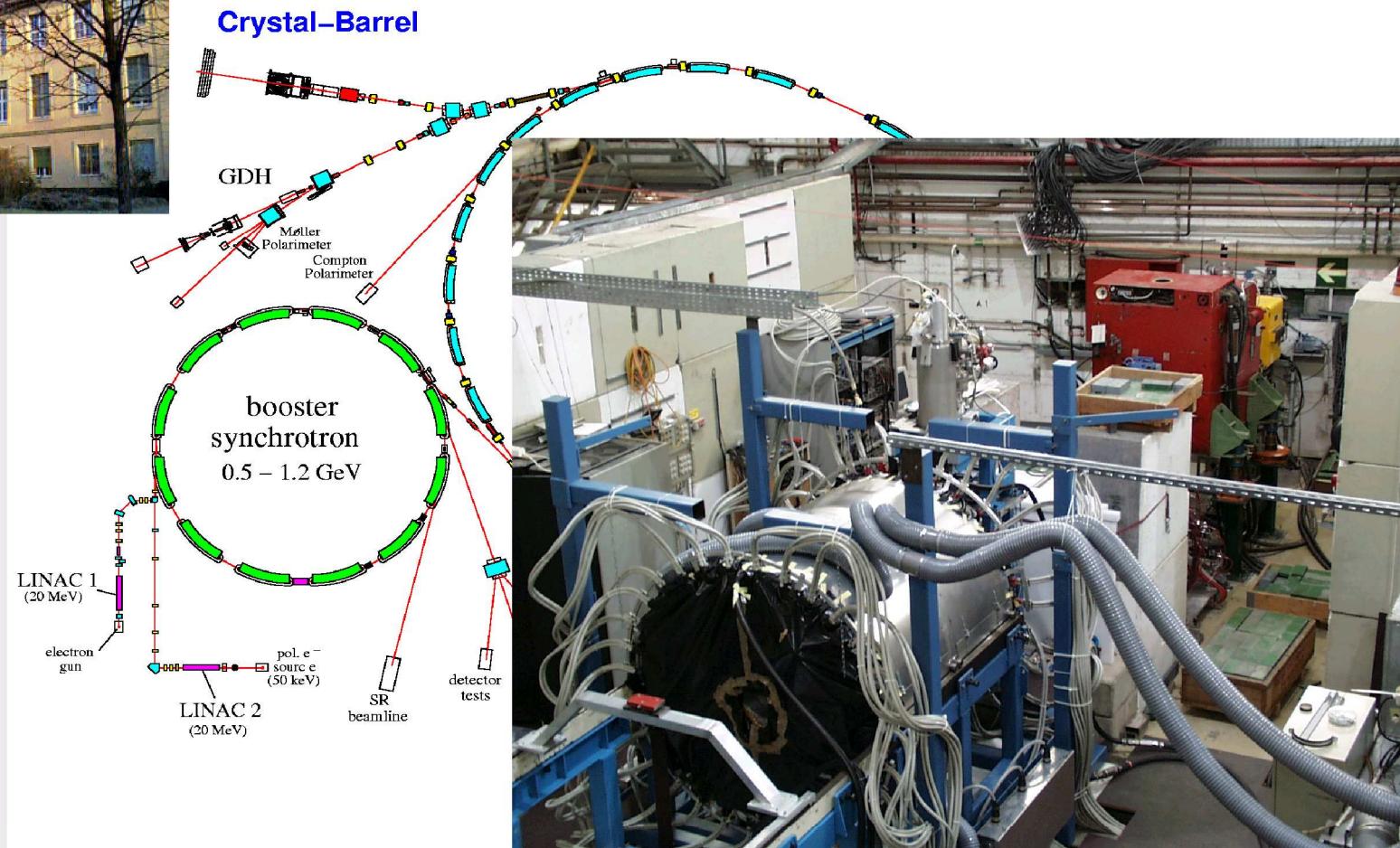
Exotika : *pentaquarks ?*



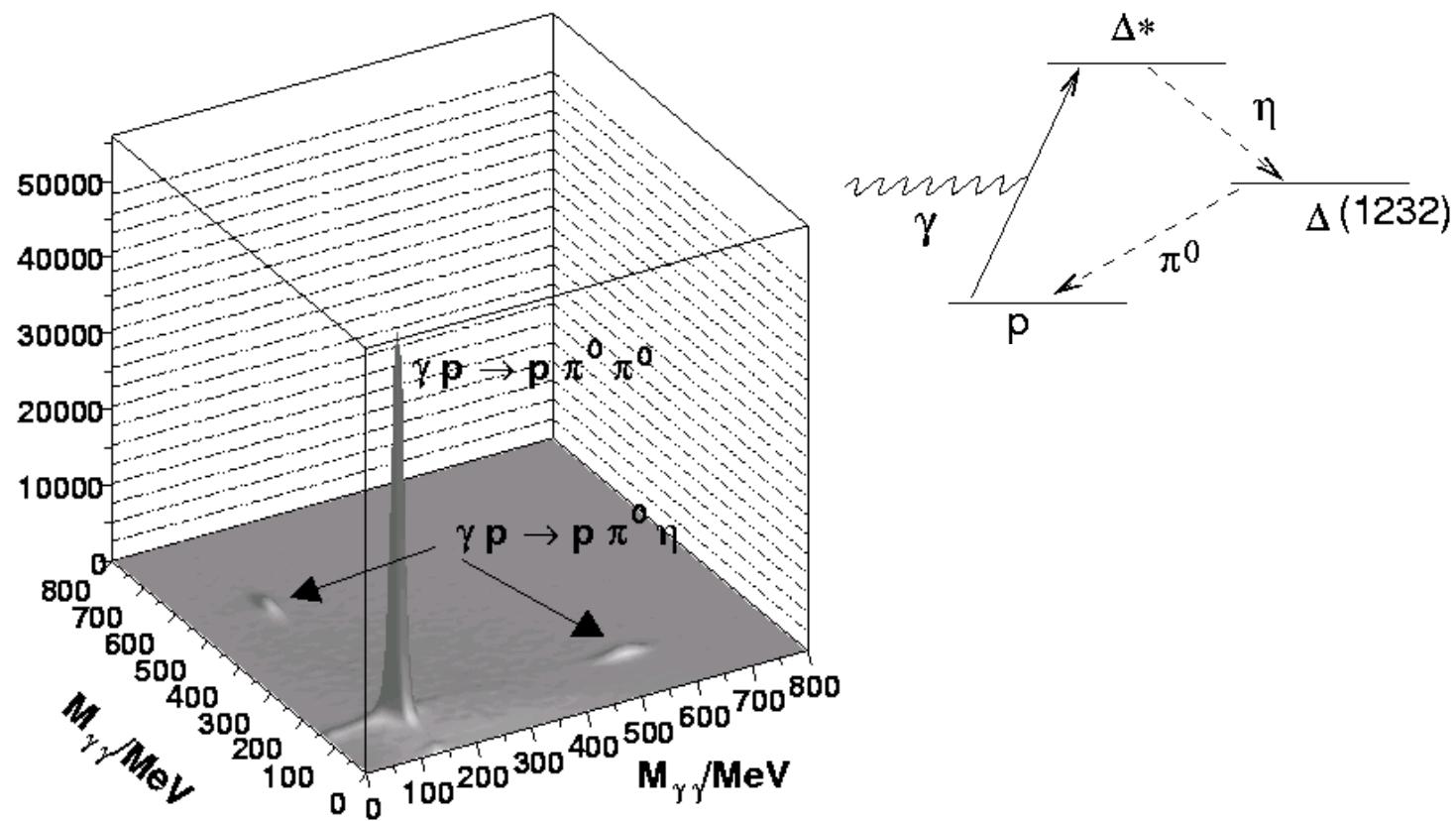


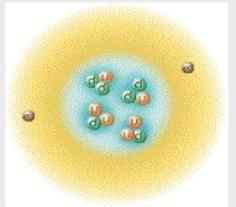
ELektronen Stretcher Anlage

Physikalisches Institut Universität Bonn



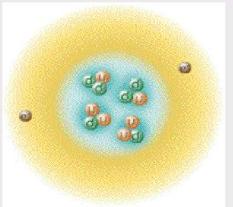
Zerfalls-Kaskaden CB@ELSA





Bei **Licht** betrachtet ein Blick in's Innere des **Nukleons**

- Standardmodell
- Mikroskop & Teilchenbeschleuniger
- scaling & Partonen
- Asymptotische Freiheit & Confinement
- Masse & Ausdehnung
- Anregung



Bei **Licht** betrachtet ein Blick in's Innere des **Nukleons**

- Standardmodell
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- scaling & Partonen
- Asymptotische Freiheit & Quarks
- Masse & Ausdehnung
- Anregungsspektrum

DANK AN

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F. Klein

A. Süle

M. Kortmann

<http://hsag.physik.uni-bonn.de>