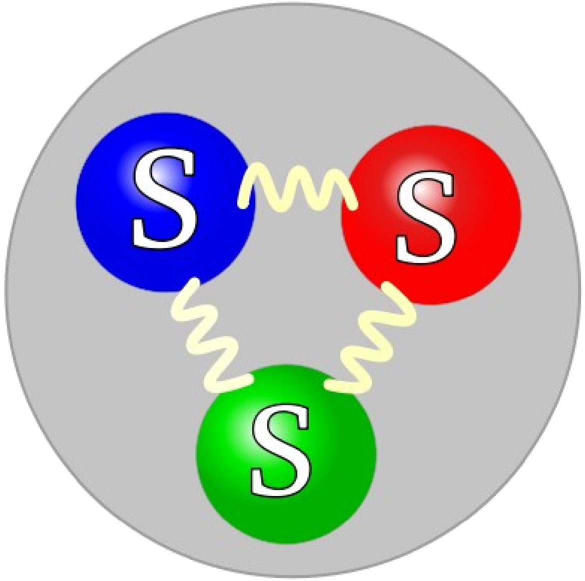
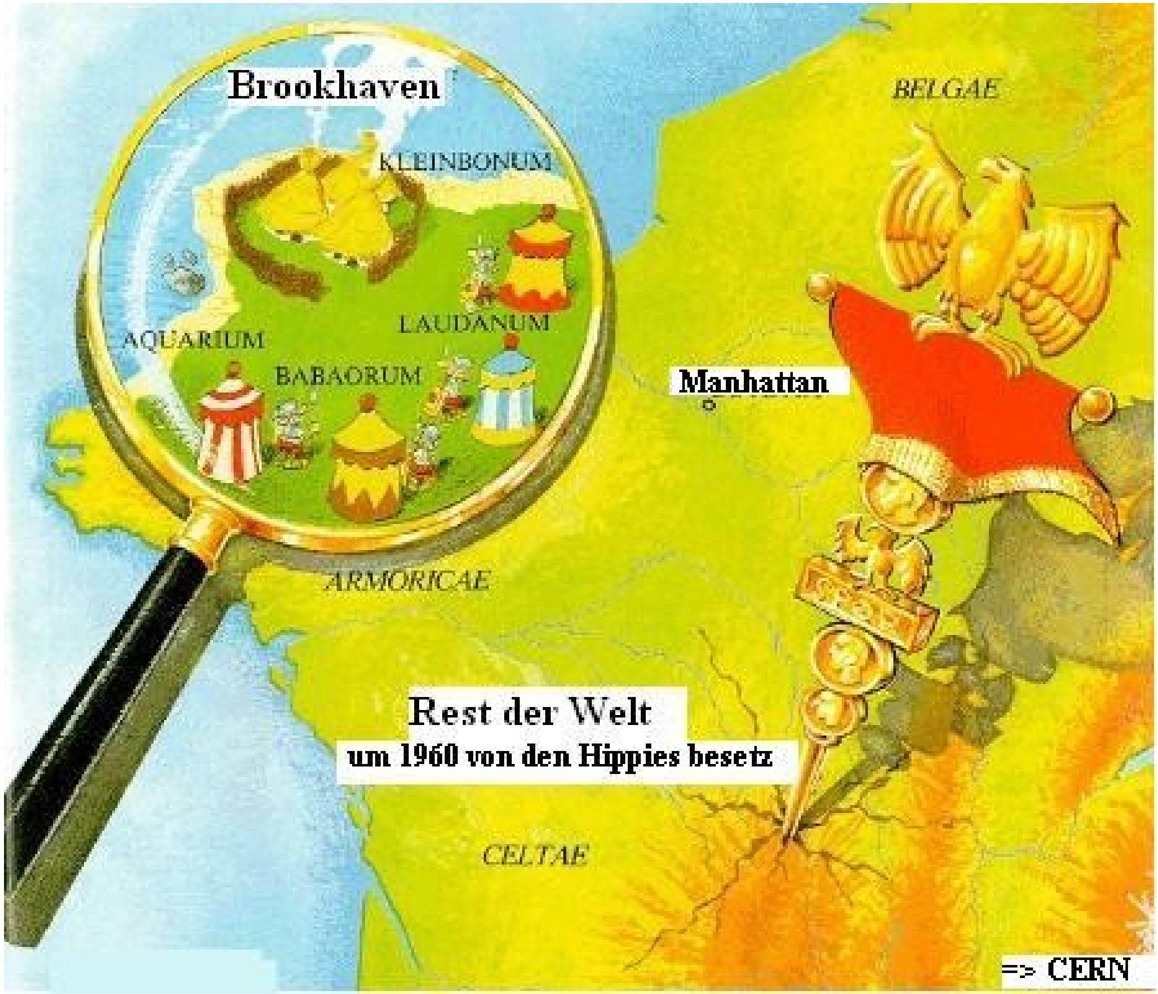
Die Entdeckung des Omega$^-$



Von Nadine Gröner

Back to the 1960‘s…


Brookhaven
KLEINBONUM
LAUDANUM
AQUARIUM
BABAORUM
Manhattan
BELGAE
ARMORICAE
Rest der Welt
um 1960 von den Hippies besetz
CELTAE
=> CERN

„Wir befinden uns im Jahr 1964 n. Chr. Die ganze Welt ist von den Hippies besetzt. Die ganze Welt? Nein! Ein von unbeugsamen Physiker bevölkertes Labor hört nicht auf, den Eindringlingen Widerstand zu leisten…“

frei nach R Goscinny & A Uderzo

Wo?

- BNL = Brookhaven National Laboratory
    - US-amerikanisches Forschungszentrum
    - ’47 gegründet
    - altes Armeegelände auf Long Island

Kurze Übersicht

- Systematik des Teilchenzoos
  - Symmetrie!
- Technische Komponenten
  - AGS
  - Blasenkammer
- Entdeckung des Ω^-

bekannte Quantenzahlen

- Einige bekannte Teilchen: K^+ Δ^0 π^+ Δ^{++} Σ^- Ξ^{*0} Σ^0 Δ^+ η n Ξ^- K^0 Ξ^0 K^- Λ Σ^+ π^0 p π^- Σ^{*-} Δ^- Σ^{*0} Σ^{*+} Ξ^{*-}

- „Eigenschaften“:
  - Spin
  - Parität
  - Strangeness
  - Hyperladung
  - Baryonenzahl…

- Keine Quark-Strukturen!

Der Weg aus dem Teilchenchaos

- Versuch einer Ordnung
  - Gell-Mann & Ne‵eman:
    => “The Eightfold Way‟
    => SU(3)-Gruppe

- Entstehung von Multiplets
  - teilen 2 gleiche Quantenzahlen
    - Parität & Spin

„Eightfold Way": SU(3)

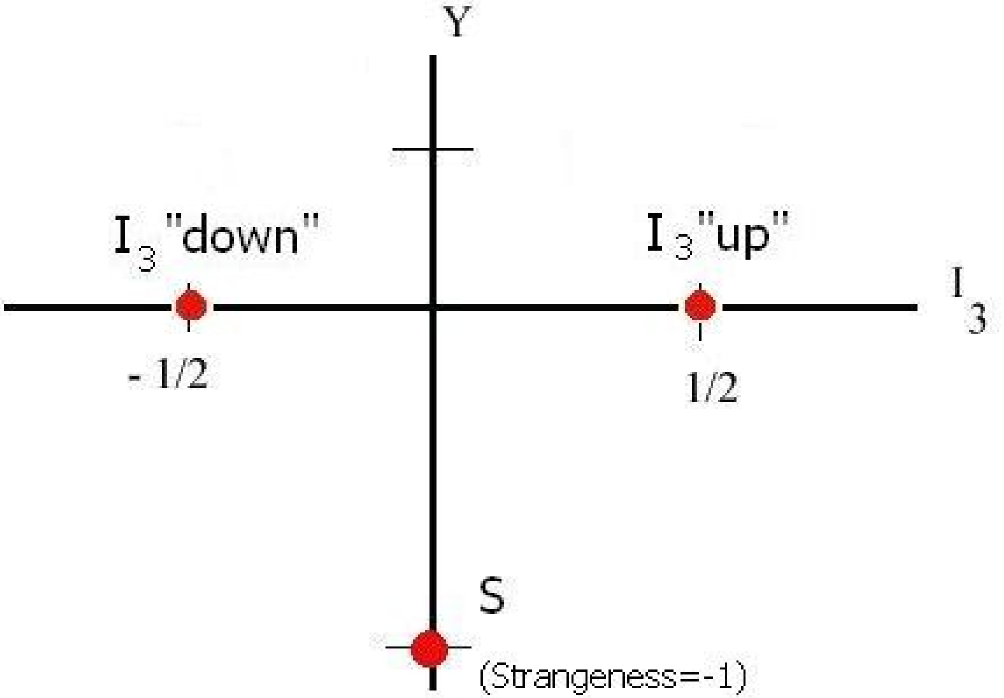
Idee: für n & p: (1) $m_{Proton} \approx m_{Neutron}$

(2) invariant unter starker WW

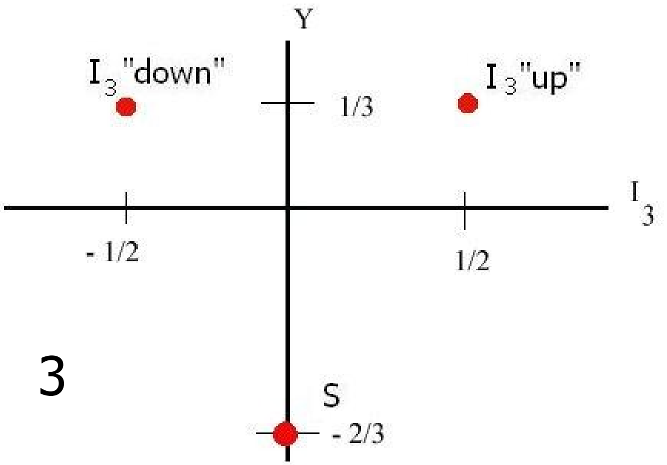
=> 2 Isospin-Zustände eines Teilchens: $\left|p\right\rangle = \left|\frac{1}{2},\frac{1}{2}\right\rangle$ $\left|n\right\rangle = \left|\frac{1}{2},-\frac{1}{2}\right\rangle$

Einbinden der Strangeness:

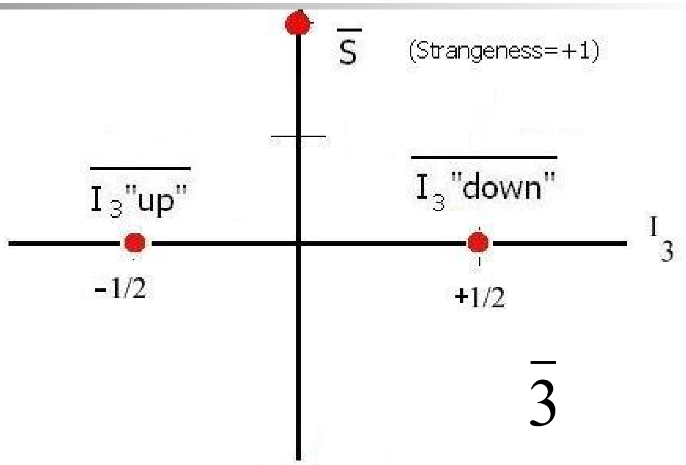
Hyperladung $Y=S+B=2(Q-I_3)$


Y
I3 "down"
I3 "up"
I3
- 1/2
1/2
S
(Strangeness=-1)

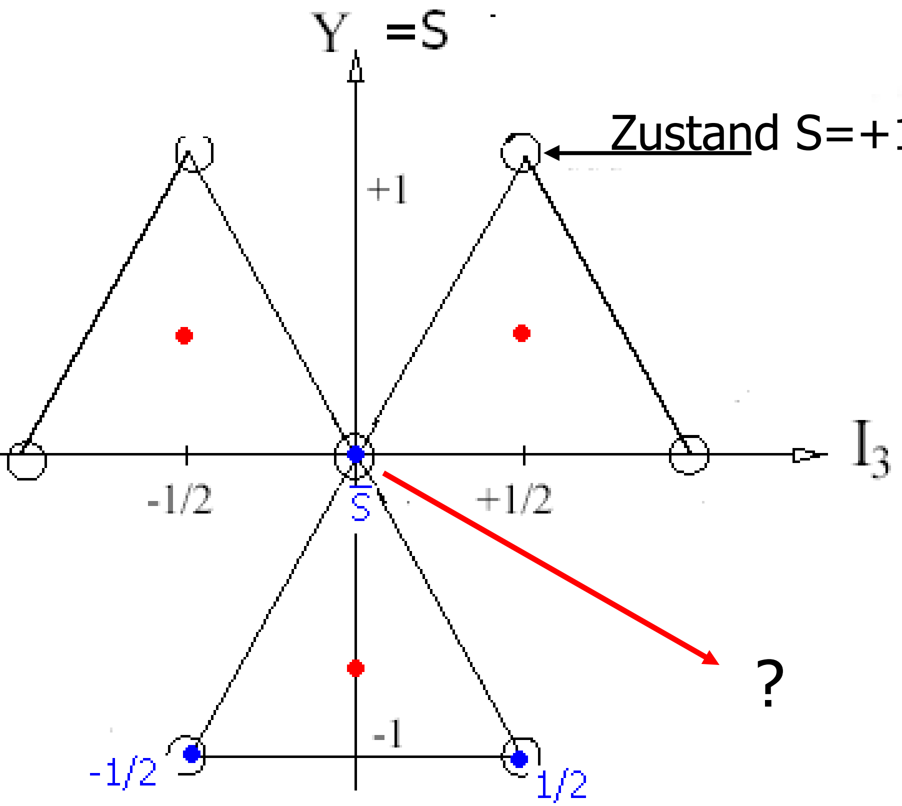
SU(3): Mesonen


Y
I_3"down"
1/3
I_3"up"
I_3
- 1/2
1/2
S
- 2/3

3


$\bar{S}$
(Strangeness=+1)
$\overline{I_3\text{"up"}}$
$\overline{I_3\text{"down"}}$
I_3
-1/2
+1/2

$\bar{3}$


Y =S
+1
I_3
-1/2
+1/2
$\bar{S}$
-1
-1/2
1/2
?

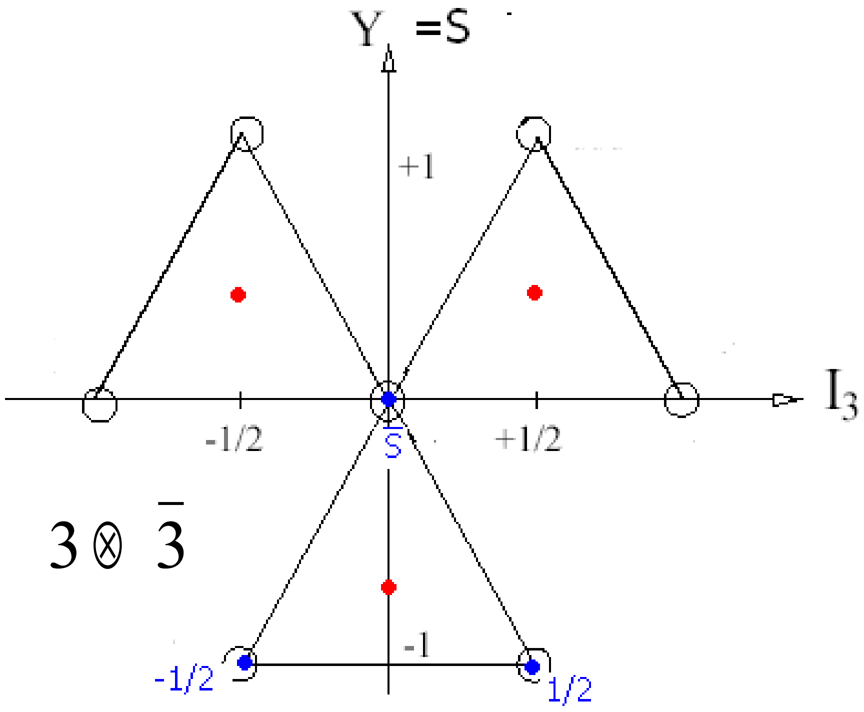
Zustand S=+1 I_3=1/2

Zustand S=0

I_3=(-1/2)+(-1/2)=-1

$3 \otimes \bar{3}$

I_3=0,S=0 – Zustände



$3 \otimes \bar{3}$

$$C = N_C \cdot \left[\frac{1}{2}\overline{\frac{1}{2}} + \left(-\frac{1}{2}\right)\overline{\left(-\frac{1}{2}\right)} + S\bar{S} \right]$$

C: S=0 I_3=[1/2+(-1/2)]+[(-1/2)+1/2]=0

„freier“ Singulett-Zustand

$$\boxed{Mesonen: \quad 3 \otimes \bar{3} = 8 \oplus 1}$$

$$A = N_A \left[\frac{1}{2}\overline{\frac{1}{2}} - \left(-\frac{1}{2}\right)\overline{\left(-\frac{1}{2}\right)} \right]$$

A: S=0 I=1 I_3=0

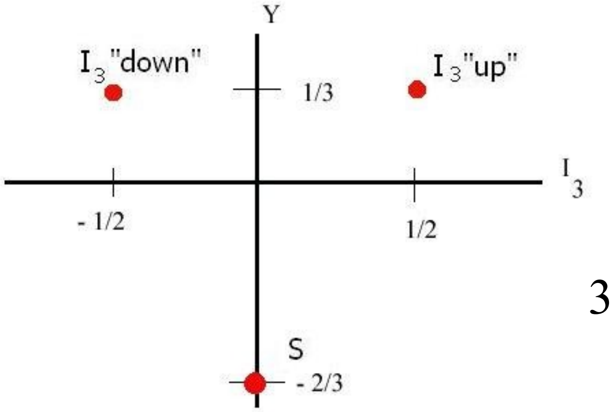
Mitglied des I=1 – Tripletts

$$B = N_B \left[\frac{1}{2}\overline{\frac{1}{2}} + \left(-\frac{1}{2}\right)\overline{\left(-\frac{1}{2}\right)} - 2S\bar{S} \right]$$

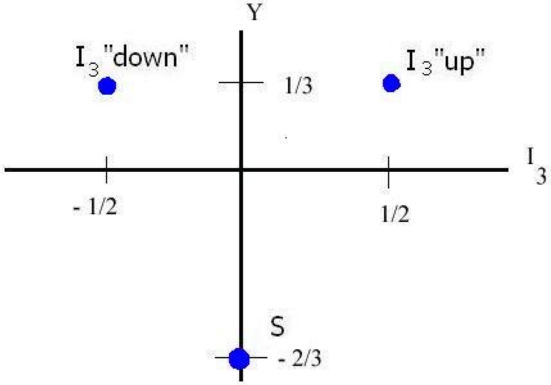
B: S=0 I=0 I_3=0

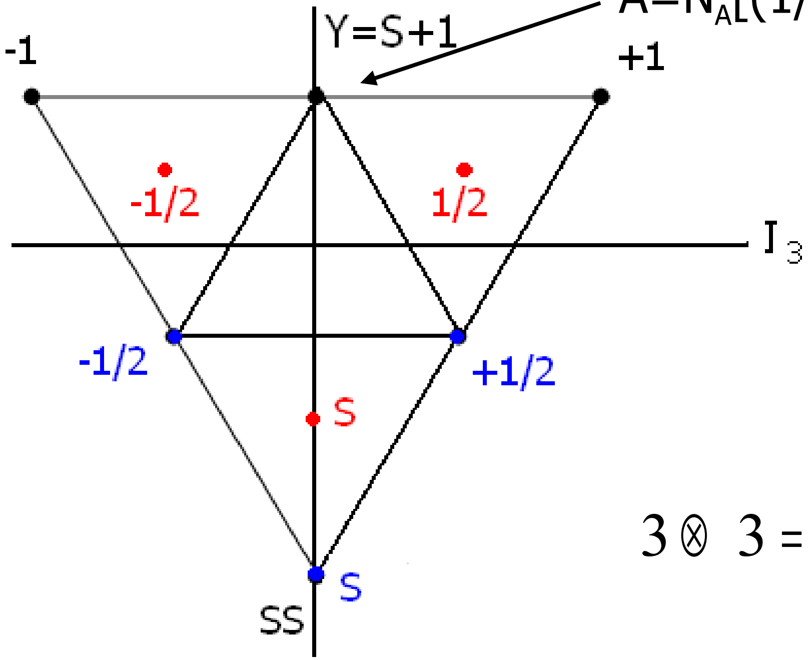
Mitglied des I=0 – Singuletts

SU(3): Baryonen


Y
I3"down"
I3"up"
1/3
I3
- 1/2
1/2
S
- 2/3

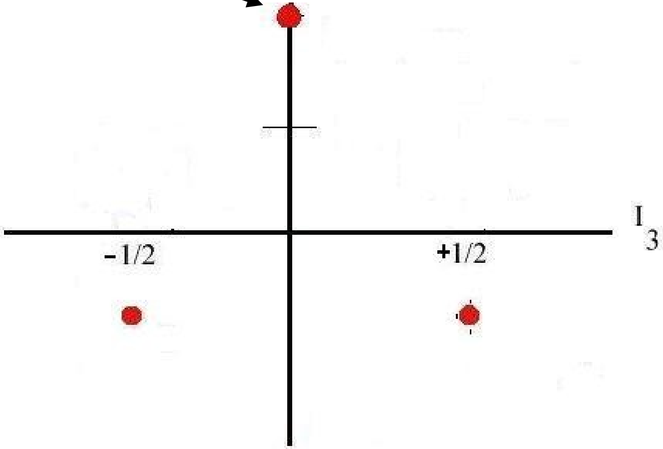
$3 \otimes 3$


Y
I3"down"
I3"up"
1/3
I3
- 1/2
1/2
S
- 2/3


Y=S+1
-1
+1
-1/2
1/2
I3
-1/2
+1/2
S
S
SS

$A=N_A[(1/2)(-1/2)+(-1/2)(1/2)]$

$B=N_B[(1/2)(-1/2)-(-1/2)(1/2)]$

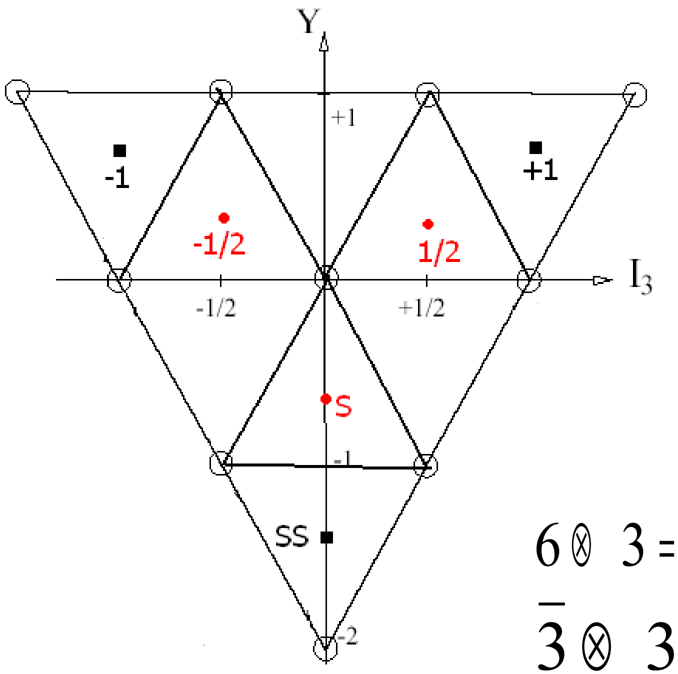


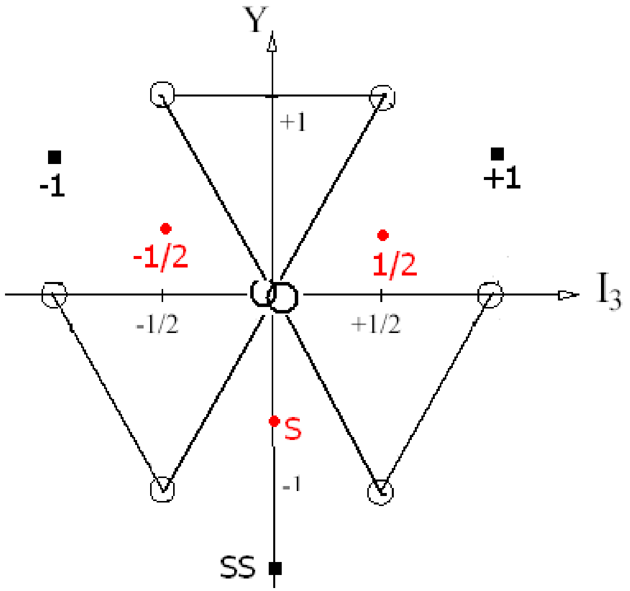
$3 \otimes 3 = 6 \oplus \bar{3}$

SU(3): Baryonen

$$[3\otimes 3]\otimes 3 = [6\oplus \bar{3}]\otimes 3 = [6\otimes 3]\oplus[\bar{3}\otimes 3]$$

3^3=27 Möglichkeiten


Y
+1
-1
+1
-1/2
1/2
I_3
-1/2
+1/2
S
-1
SS
-2


Y
+1
-1
+1
-1/2
1/2
I_3
-1/2
+1/2
S
-1
SS

$$6\otimes 3 = 10\oplus 8$$

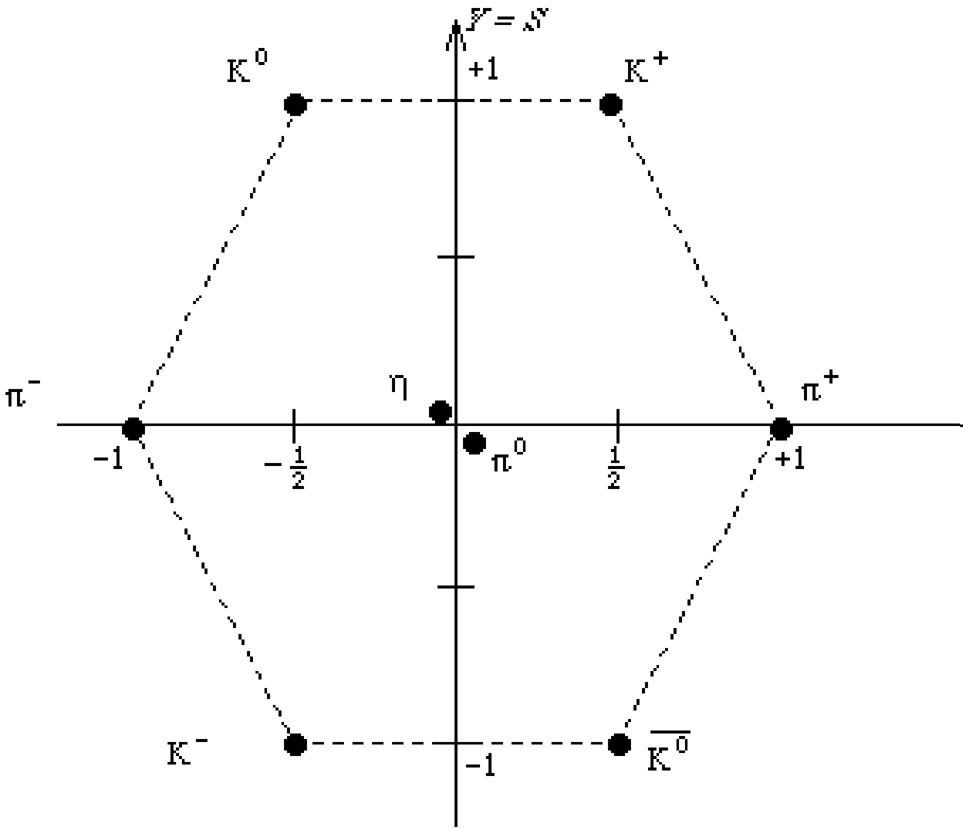
$$\bar{3}\otimes 3 = 8\oplus 1$$

$$\mathit{Baryonen:}\quad 3\otimes 3\otimes 3 = 10\oplus 8\oplus 8\oplus 1$$

Die Oktetts

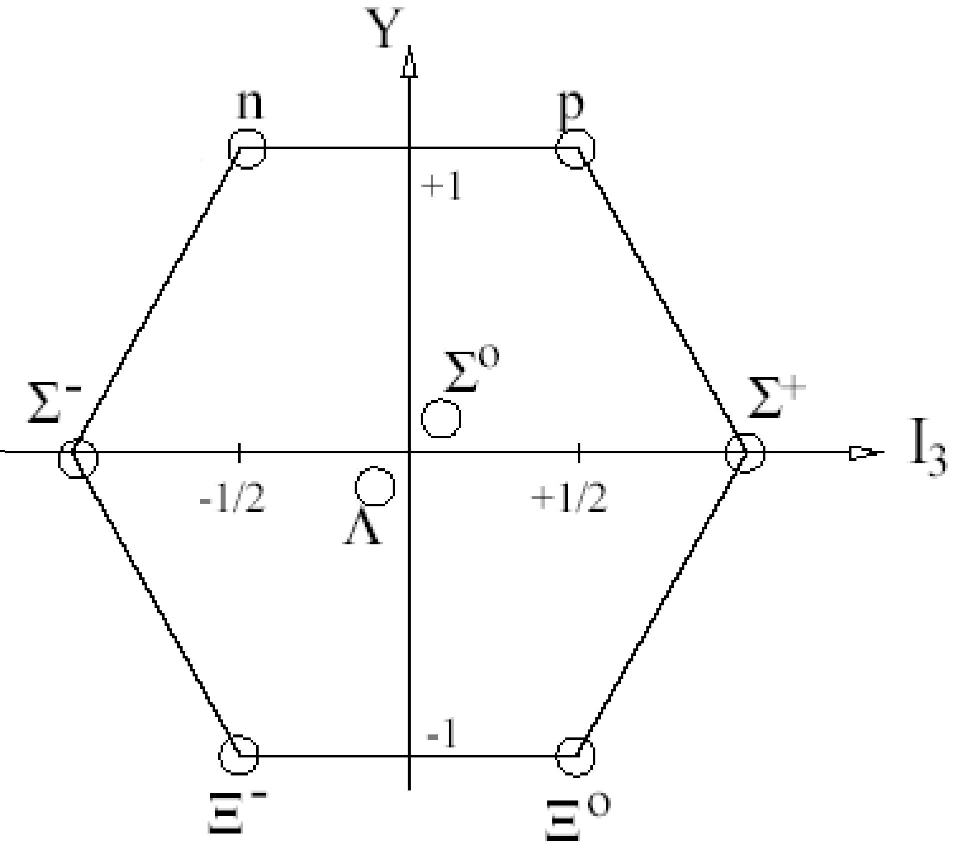
Meson-Oktett

$J^P=0^-$

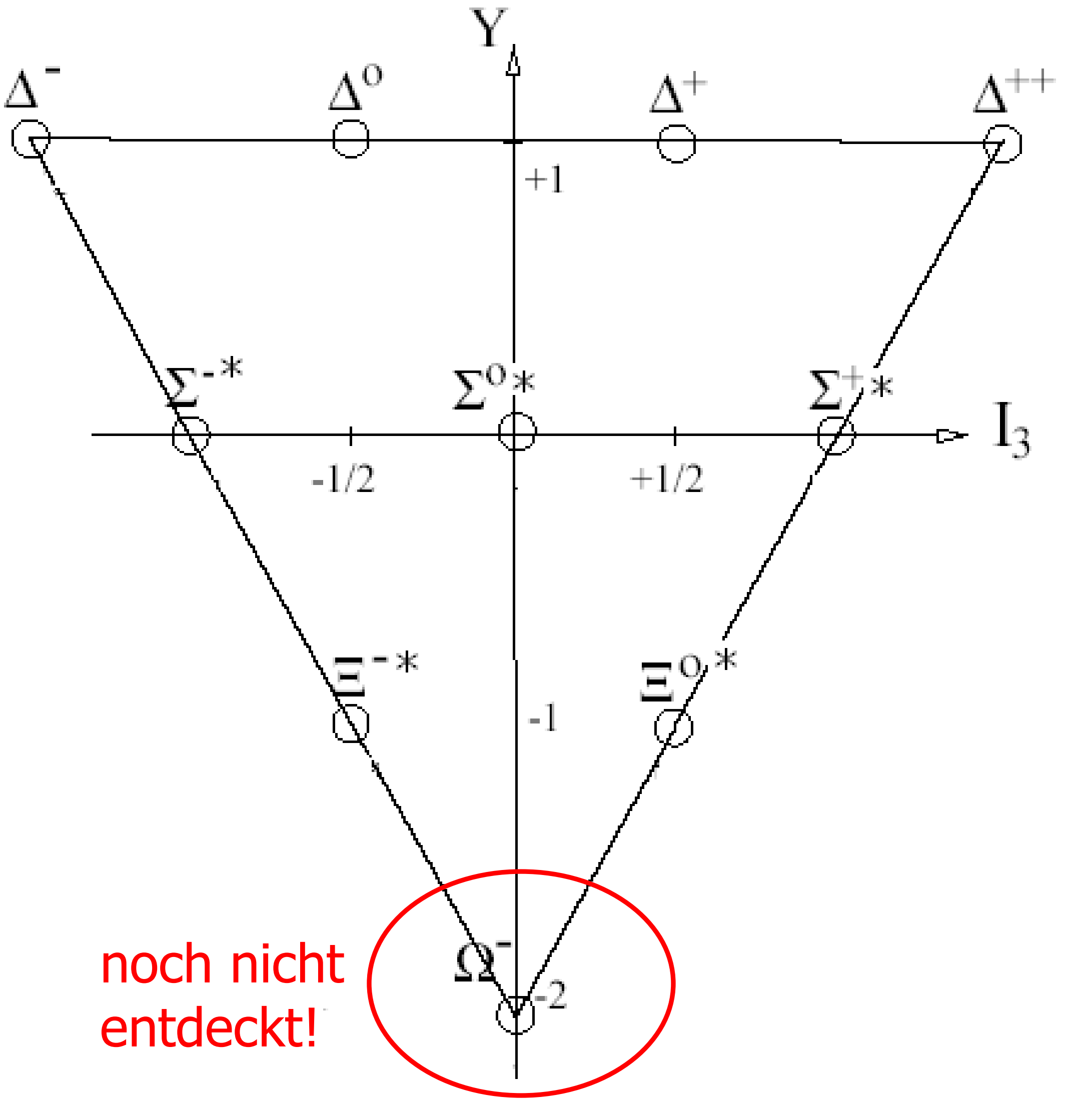

Y = S
+1
K⁰
K⁺
η
π⁻
π⁺
π⁰
-1
$-\frac{1}{2}$
$\frac{1}{2}$
+1
K⁻
$\overline{K^0}$
-1

Baryon-Oktett

$J^P=1/2^+$


Y
n
p
+1
Σ⁰
Σ⁻
Σ⁺
I₃
-1/2
+1/2
Λ
-1
Ξ⁻
Ξ⁰

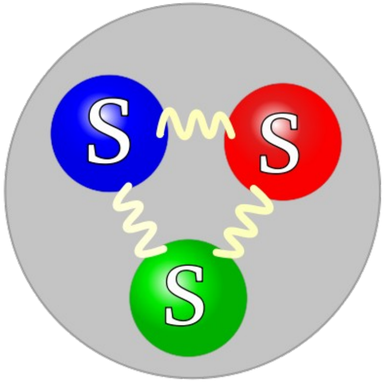
Baryon-Decouplet $J^P=3/2^+$


Y
Δ^-
Δ^0
Δ^+
Δ^{++}
+1
Σ^{-*}
Σ^{0*}
Σ^{+*}
I_3
-1/2
+1/2
Ξ^{-*}
Ξ^{0*}
-1
Ω^-
-2

noch nicht entdeckt!

Eigenschaften des Ω^-

- $I = 0$ & $I_3=0$
- Spin & Parität $(3/2)^+$
- Baryonenzahl $B=+1$
- Hyperladung $Y=-2$
- Strangeness $S=-3$
- $m \approx 1680$ MeV/c^2
  - nur Vorhersage!



Produktion von S=-3

- Strangeness-Erhaltung: nur in starker WW
  - Strangeness-Produktion: nur in starker WW
  - ΔS=0 - Produktion möglich!

p + N(S=0) -> $"K \quad \overline{K}" + \dots$

S=-1 S=1

HOCHENERGIE

Beschleuniger

(AGS)

N -> $\Omega^- + \dots$

S=-3 S=2

Schwerpunktsenergie:

$$Collider: \quad E_{CMS} = E_a + E_b$$

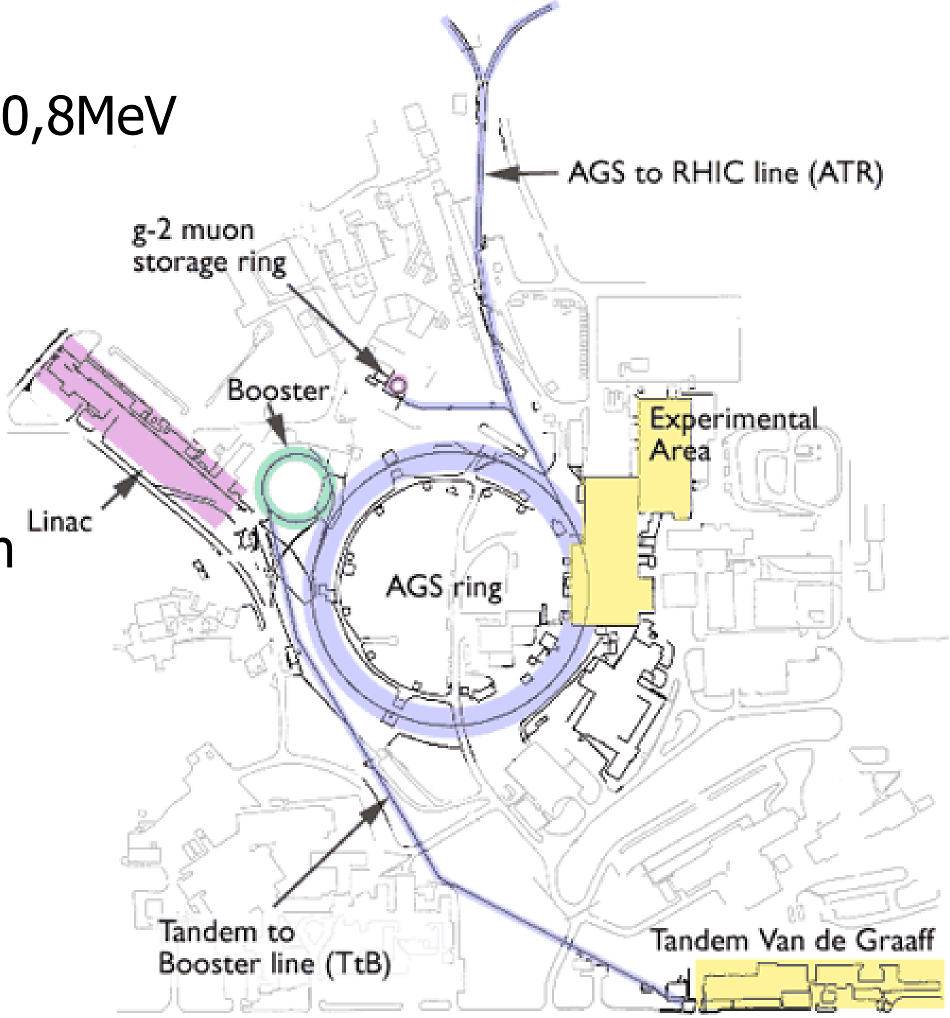
$$fixed \quad target: \quad E_{CMS} = \sqrt{2mE_a}$$

=> ≈ 3GeV Kaon-Strahl

Proton-Synchrotron AGS

- Vorbeschleuniger:
  - Cockcroft-Walton-Generator: 0,8MeV
  - LINAC: 50MeV
- AGS:
  - Beschleunigung: HF-Stationen
  - Vakuumröhren: 240 Magnete
  - 33GeV Protonen

  => hochenerget. Beschleuniger


AGS to RHIC line (ATR)
g-2 muon storage ring
Booster
Experimental Area
Linac
AGS ring
Tandem to Booster line (TtB)
Tandem Van de Graaff

Alternating Gradient Synchrotron

Bisher: Cosmotron

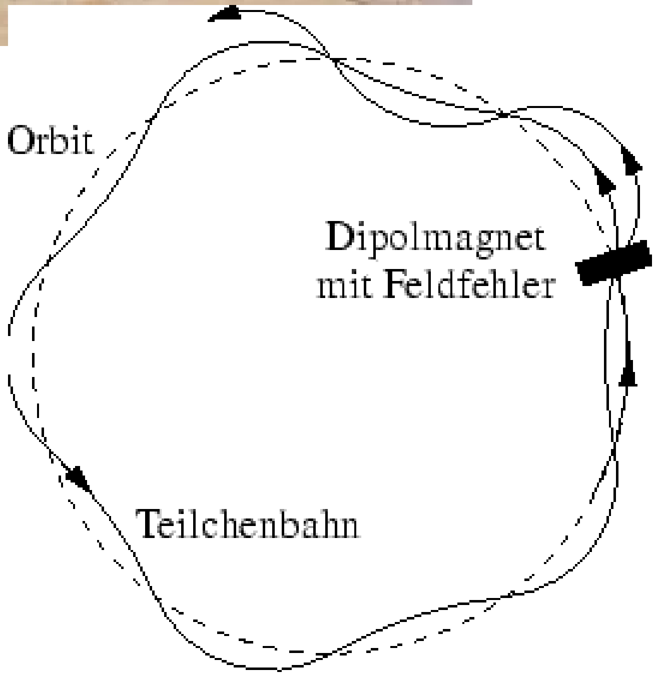
  - 3,3 GeV Protonen

Doch:

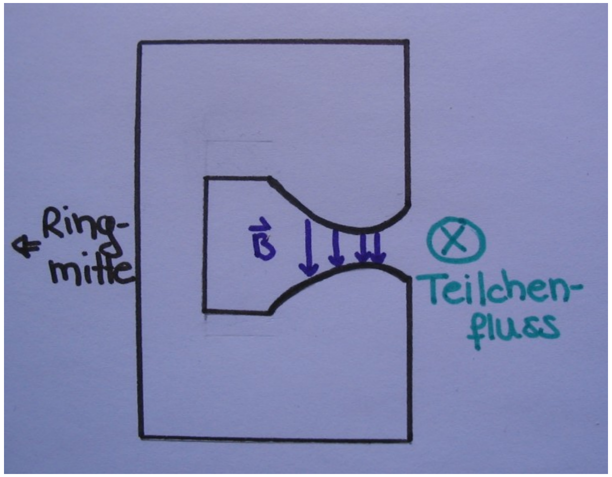
- 10mal Energie = 100mal Stahl
  - $2*10^8$ kg Gewicht

Lösung:

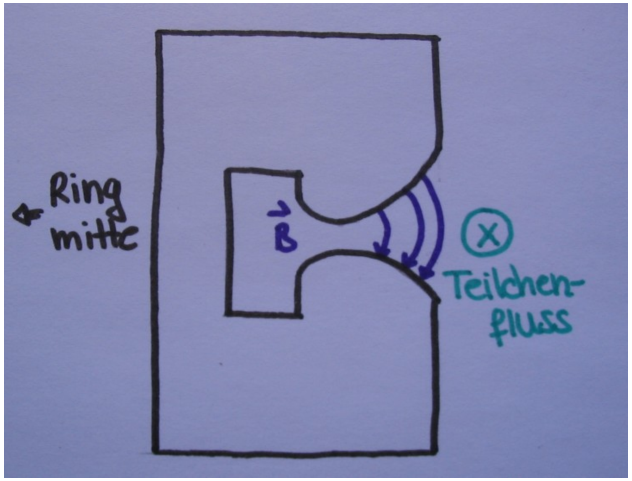
- "strong-focusing principle of propelling protons"
  - von Courant, Livingston, Snyder


Orbit
Dipolmagnet mit Feldfehler
Teilchenbahn

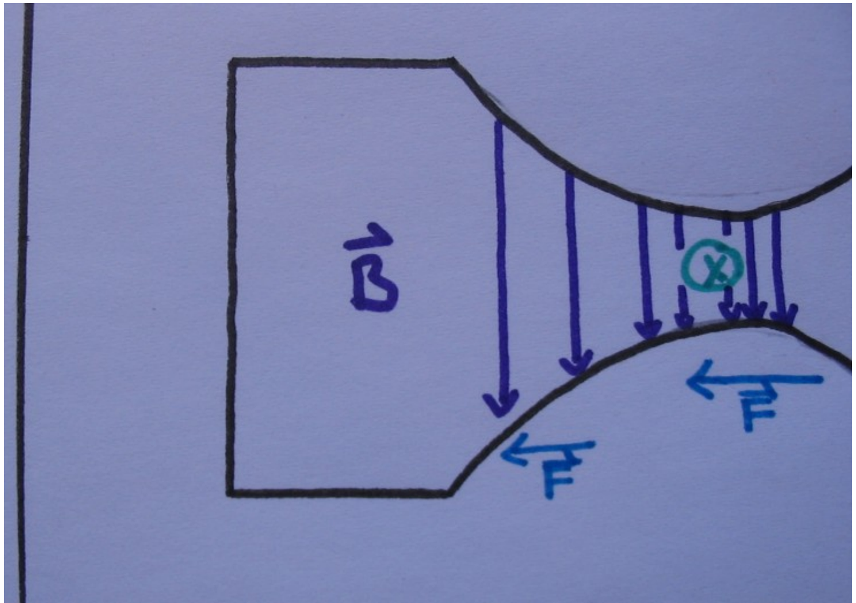
Starke Fokussierung

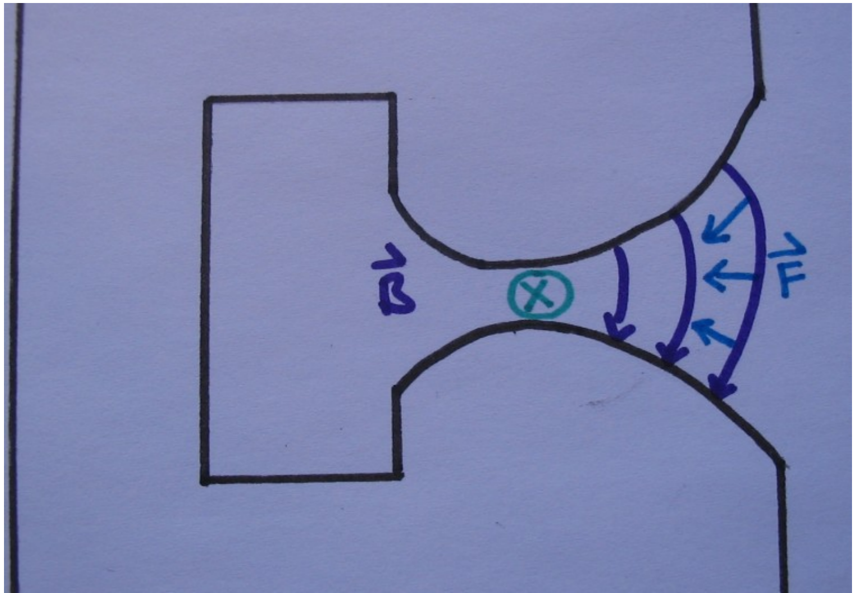

Ring-
mitte
$\vec{B}$
⊗
Teilchen-
fluss

radiale Fokussierung


Ring
mitte
$\vec{B}$
⊗
Teilchen-
fluss

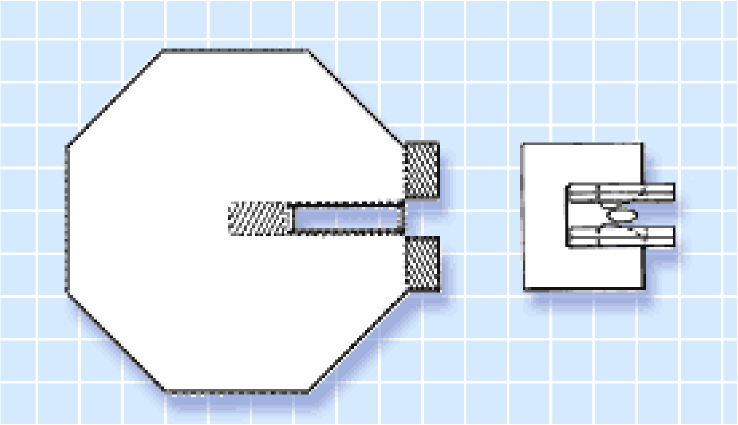
vertikale Fokussierung


$\vec{B}$
⊗
$\vec{F}$
$\vec{F}$



Daten zum AGS

- Juli 1960: 33GeV Protonen
- Bis 1968 höchstenergetischer Beschleuniger
- Durchmesser: 250m
- 3*10^8 Protonen pro Puls



Magnetstrukturen:
Cosmotron (links) AGS (rechts)

- Heute: Vorbeschleuniger für RHIC

Kaon-Selektion

- Konvertierung p -> K
  - Beschuss auf fixed target

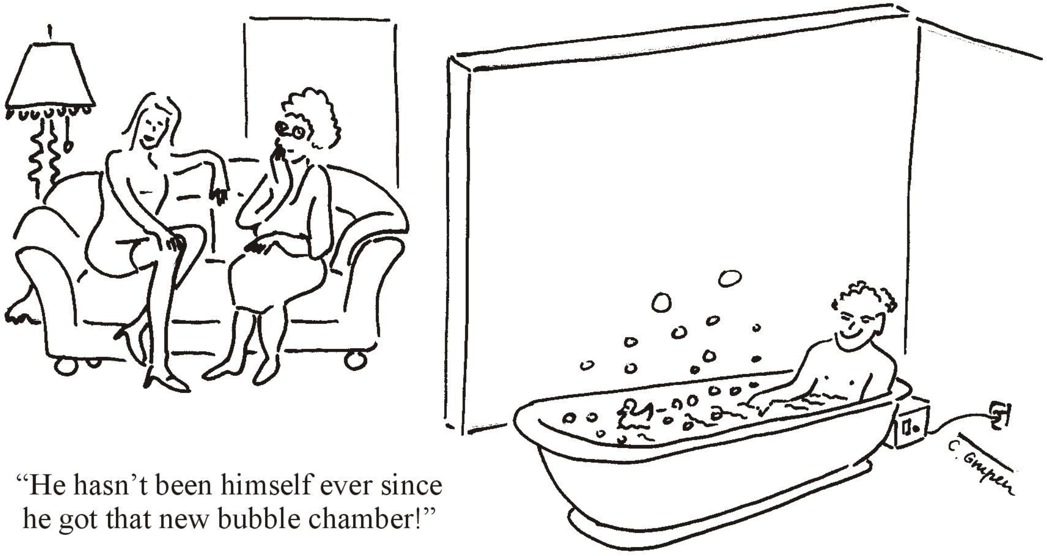
- Selektion der Teilchen
  - Magnetfeld: Impuls & Ladung
  - Fokussierung
  - Elektrisches Feld: Masse
  - Fokussierung

-> erreichen Blasenkammer

  - 5GeV Kaonstrahl
  - 10-20 Kaons pro Sekunde

Blasenkammer

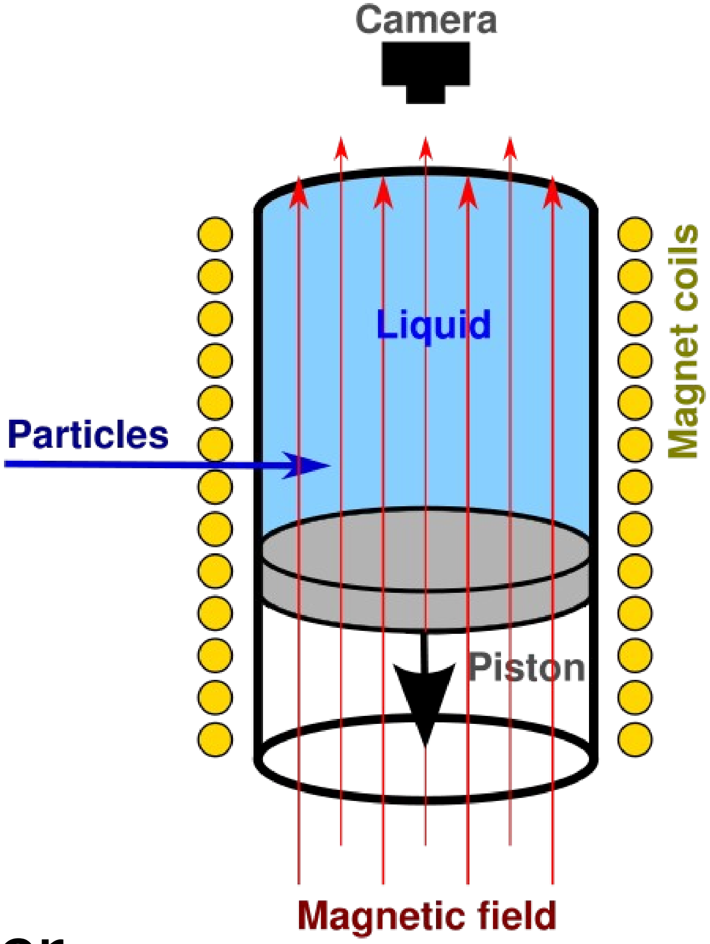
- bisher:
  - Tropfenspur in Nebelkammer
  - fl. Target dichter als Gas
    - besserer Nachweis
- Donald A. Glaser:
  - Erfindung: 1952
  - Nobelpreis: 1960
- BNL:
  - 80“-Bubblechamber
  - 1000l fl. Wasserstoff
  - 1. Fotografie 1963
    - größter Detektor

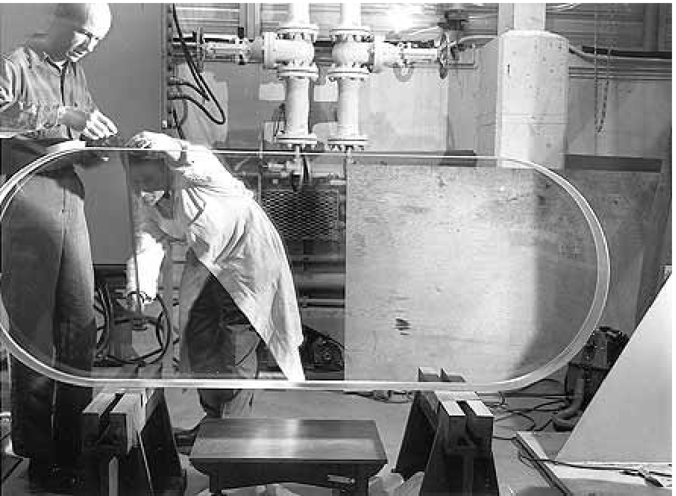


“He hasn’t been himself ever since he got that new bubble chamber!”

Aufbau einer BC

- Kammer
  - −240°C fl. Wasserstoff
- Kolben:
  - 150kg, d=90cm, h=81cm
  - Temperaturabfall
- Starkes Magnetfeld
  - Ablenkung der Teilchen


Camera
Liquid
Particles
Magnet coils
Piston
Magnetic field



- Glasfenster

Belichtung & Fotographie

Funktionsweise

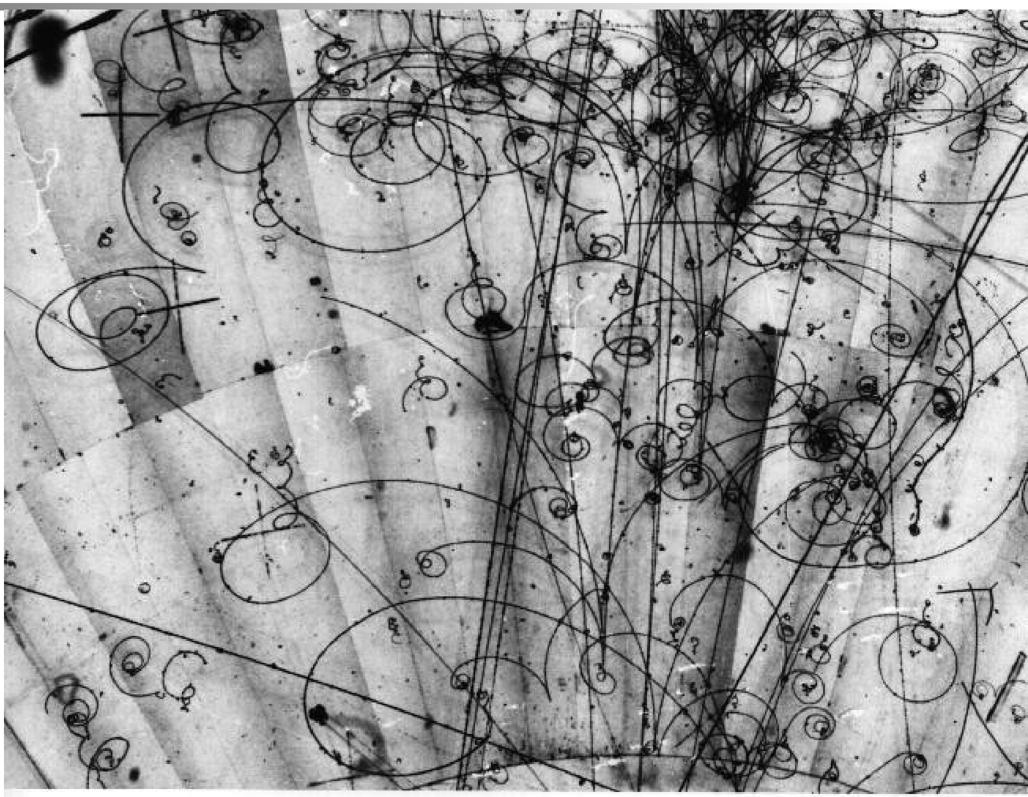
- Prinzip der überhitzten Flüssigkeit
  - knapp unter Siedepunkt
  - Druckabsenkung

  -> Siedetemperatur fällt

  -> instabiler Zustand

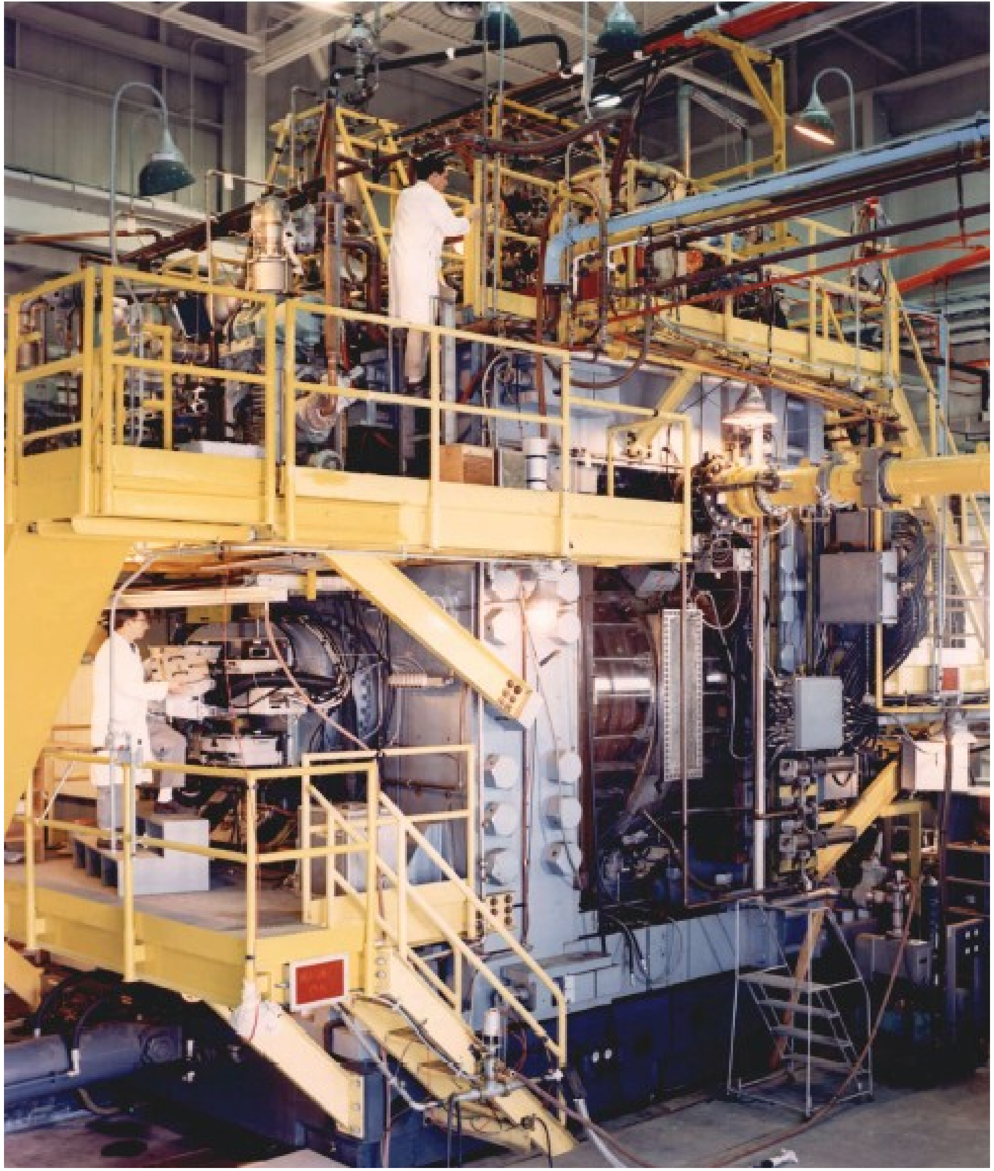
- Kolbenbewegung
  - Belüftung oberhalb: Druckdifferenz
  - Bewegung: 1cm
  - Kammervolumen: +0,5%
  - 1 Aufnahme pro s möglich

Enormer Aufwand



- Genaues Timing
- „Einheitliche“ Blasen
- Kontrolle
  - Temperatur
  - Magnetfeld
- Spur genau messen
  - auf 1tausendstel pro inch
- Gute Optik

Foto: 80‟ Blasenkammer



Skala

0 1m

Kammer

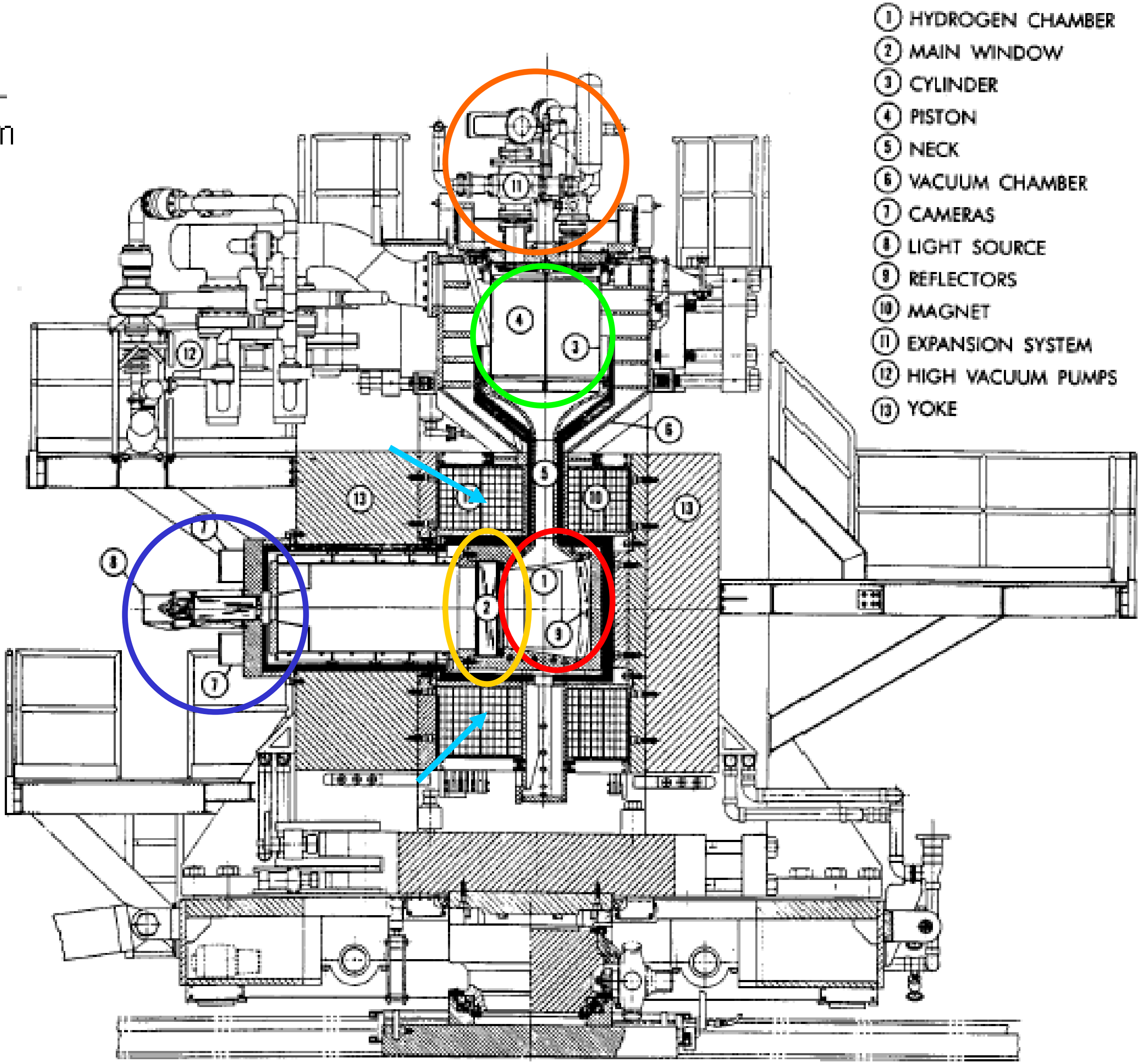
Glasfenster

Blitz & Kamera

Magnet

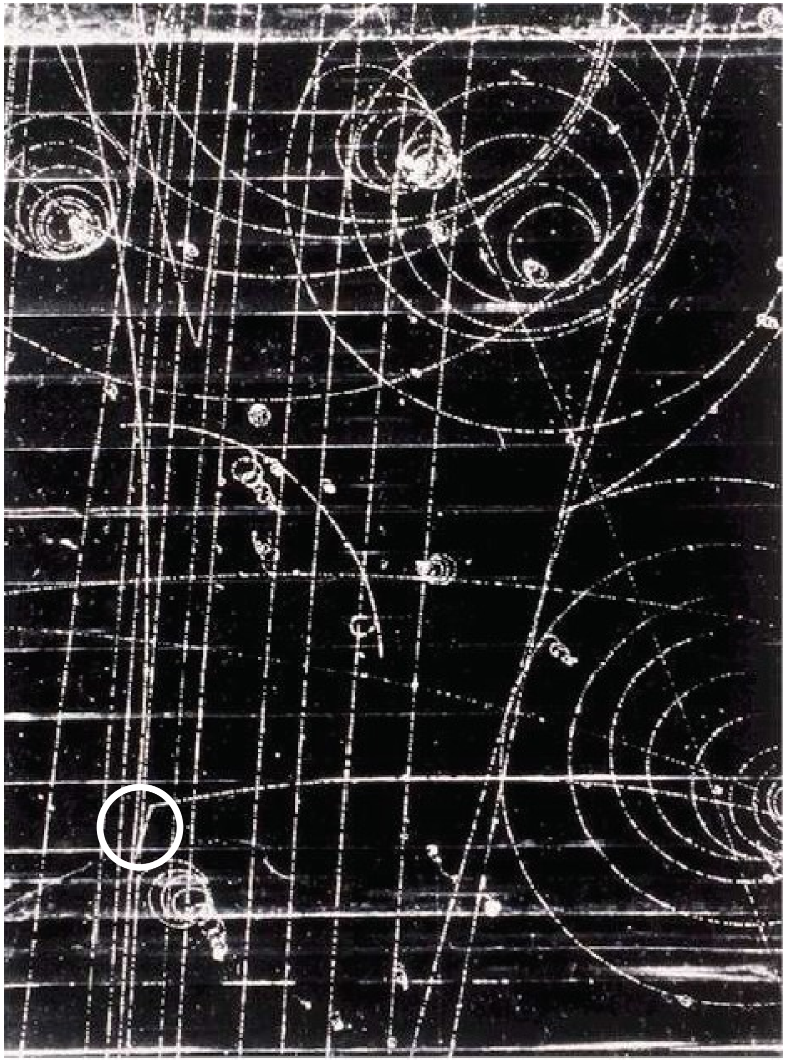
Kolben

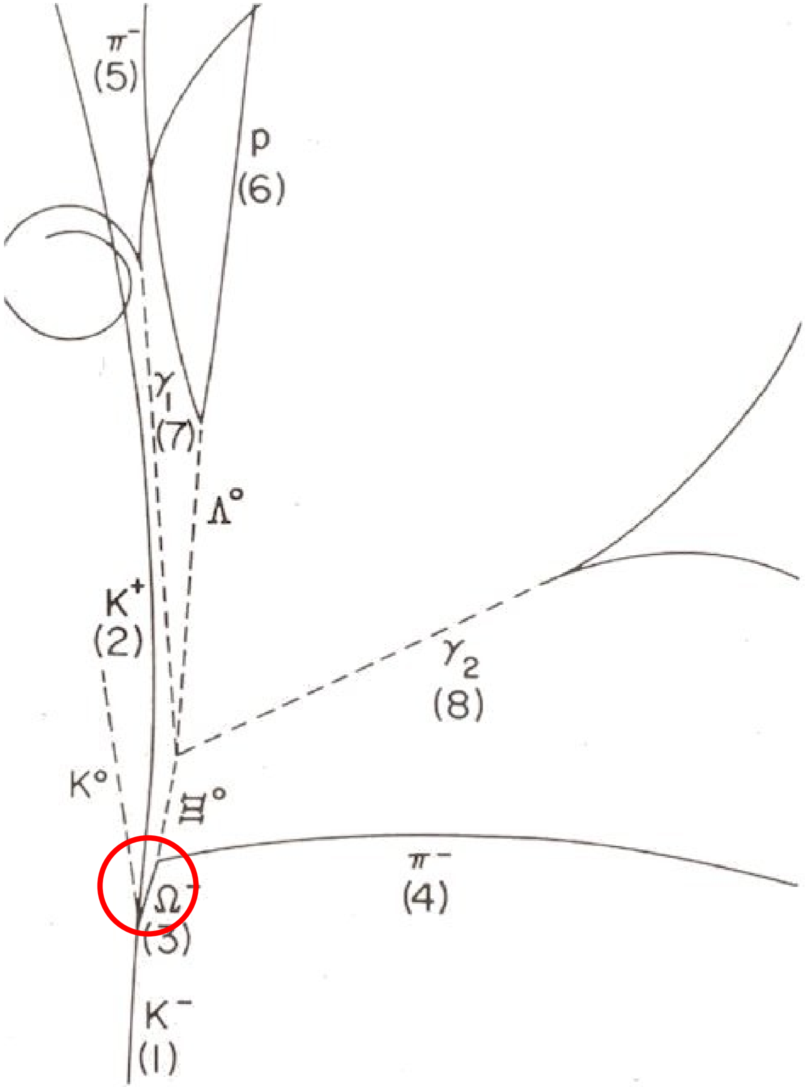
Expansionssystem


① HYDROGEN CHAMBER
② MAIN WINDOW
③ CYLINDER
④ PISTON
⑤ NECK
⑥ VACUUM CHAMBER
⑦ CAMERAS
⑧ LIGHT SOURCE
⑨ REFLECTORS
⑩ MAGNET
⑪ EXPANSION SYSTEM
⑫ HIGH VACUUM PUMPS
⑬ YOKE

Schematic cross section of the 80-inch liquid hydrogen bubble chamber showing major components.

Blasenkammer-Event: Ω^-

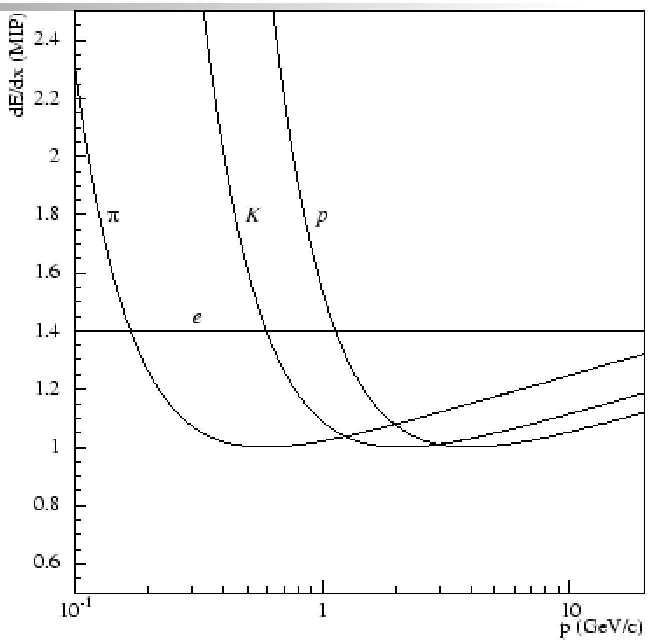




π^-
(5)
p
(6)
γ_1
(7)
Λ^0
K^+
(2)
γ_2
(8)
K^0
Ξ^0
π^-
(4)
Ω^-
(3)
K^-
(1)

Spurenanalyse (1)

- Blasendichte ~ dE/dx
- Bethe-Bloch-Formel: dE/dx (p)
  - charakteristisch für Teilchen

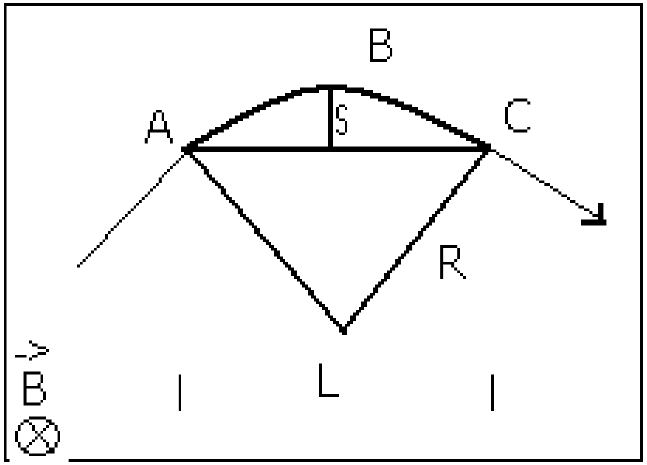


- 2 Kameras = 3dim Teilchenspur!
- Ablenkung im Magnetfeld:

$$\textit{Näherung}: \quad R[m] = \frac{p_t[GeV]}{0{,}3 \cdot q \cdot B[T]}$$

$$S = \frac{L^2}{8 \cdot R} \quad mit \quad \theta \approx \frac{L}{R}$$

$$p_t[GeV] = \frac{0{,}3 \cdot q \cdot B[T] \cdot L^2[m^2]}{8 \cdot S[m]}$$



Spurenanalyse (2)

- Neutrale Teilchen?
  - invariante Masse!

$$P_4 = \begin{pmatrix} E \\ \vec{p} \end{pmatrix} \qquad P_4^2 = M^2 \qquad E^2 = p^2 + m^2$$

$$(P_{4,1} + P_{4,2})^2 = P_{4,1}{}^2 + P_{4,2}^2 + 2P_{4,1}P_{4,2}$$

$$P_{4,1} \cdot P_{4,2} = E_1 \cdot E_2 - \vec{p}_1 \cdot \vec{p}_2$$

$$\boxed{M^2 = m_1^2 + m_2^2 + 2 \cdot \sqrt{m_1^2 + p_1^2}\sqrt{m_2^2 + p_2^2} - 2p_1 p_2 \cdot \cos\alpha}$$

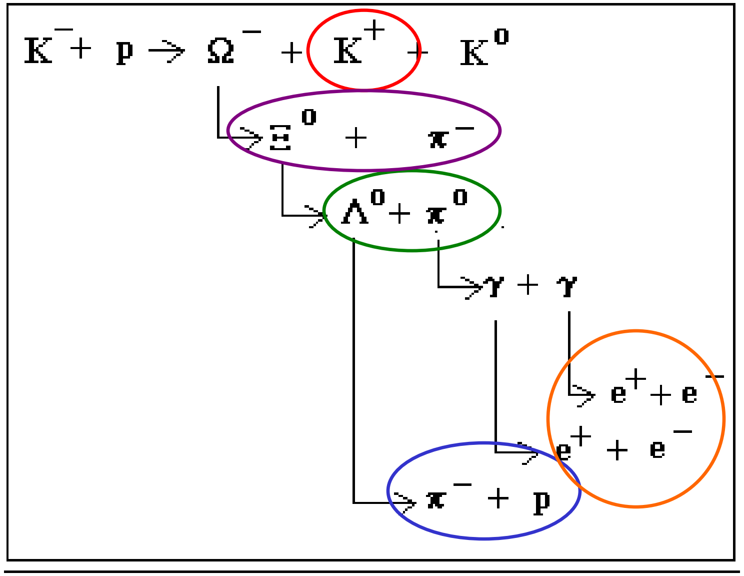
- Teilchenbahnen verlängern
  - Schneiden sich genau auf wenigen mm!

Spurenanalyse (3)

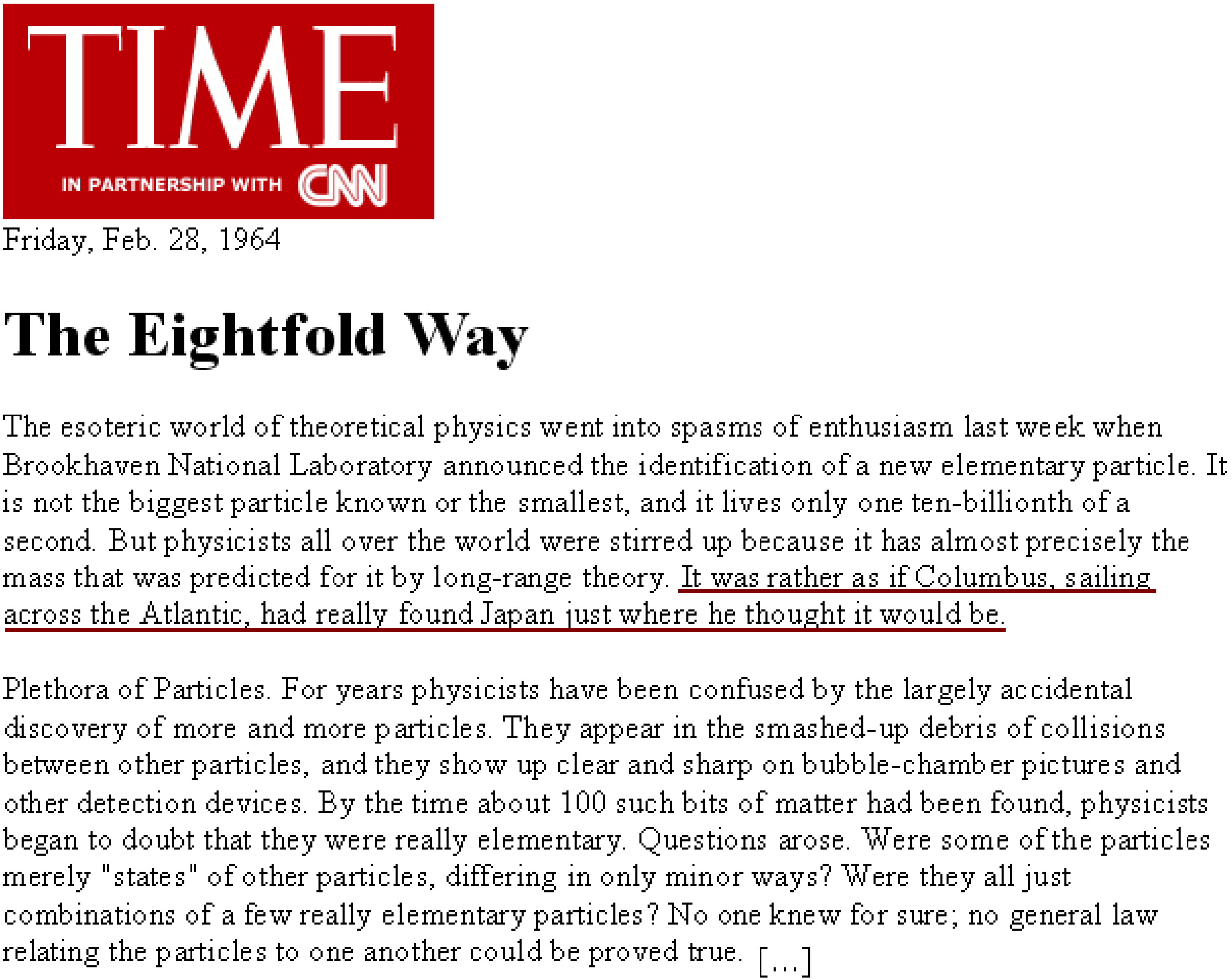
- K^+
- $\pi^- + p$ -> Λ^0
- $\gamma + \gamma$ -> π^0
- $\pi^0 + \Lambda^0$ -> Ξ^0

- $\Xi^0 + \pi^-$ -> ?
  - $m = 1686\ \mathrm{MeV}/c^2 < m_K$
  - $\Delta S=1$ Zerfall -> $S=-2$ System
  - $\tau = 0{,}7 \cdot 10^{-10}\,\mathrm{s}$ -> $S=-3$

- Δm -> K^0


$K^- + p \to \Omega^- + K^+ + K^0$
$\Xi^0 + \pi^-$
$\Lambda^0 + \pi^0$
$\gamma + \gamma$
$e^+ + e^-$
$e^+ + e^-$
$\pi^- + p$

Ω^- entdeckt!



TIME
IN PARTNERSHIP WITH CNN
Friday, Feb. 28, 1964

The Eightfold Way

The esoteric world of theoretical physics went into spasms of enthusiasm last week when Brookhaven National Laboratory announced the identification of a new elementary particle. It is not the biggest particle known or the smallest, and it lives only one ten-billionth of a second. But physicists all over the world were stirred up because it has almost precisely the mass that was predicted for it by long-range theory. It was rather as if Columbus, sailing across the Atlantic, had really found Japan just where he thought it would be.

Plethora of Particles. For years physicists have been confused by the largely accidental discovery of more and more particles. They appear in the smashed-up debris of collisions between other particles, and they show up clear and sharp on bubble-chamber pictures and other detection devices. By the time about 100 such bits of matter had been found, physicists began to doubt that they were really elementary. Questions arose. Were some of the particles merely "states" of other particles, differing in only minor ways? Were they all just combinations of a few really elementary particles? No one knew for sure; no general law relating the particles to one another could be proved true. […]

http://www.time.com/time/magazine/article/0,9171,873833,00.html

Vielen herzlichen Dank!

Jetzt bleibt nur noch eines zu tun:

ZURÜCK
IN DIE ZUKUNFT

BNL-Homepage zum Omega:

http://www.bnl.gov/bnlweb/history/Omega-minus.as