V. Fizika čestica na ubrzivačima (I)

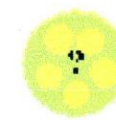
PRODUKCIJE ČESTICA PRIJE ERE HADRONSKIH SUDARIVAČA

- OD OKUSNIH MULTIPLETA DO SUDARA:
- ELEKTRON - PROTON
- ELEKTRON - POZITRON
- PROTON - AT. JEZGRE
- PROTON - ANTIPROTON
- PROTON - PROTON (LHC)

KRATKA POVIJEST HADRONSKE FIZIKE

1932: Discovery of the neutron

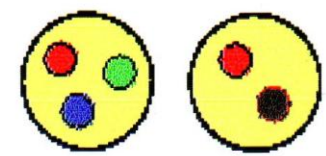
1933: $\vec{\mu}_p \equiv 2.5 \frac{e}{2\, m_p} \vec{\sigma} \Rightarrow$ Substructure of the proton



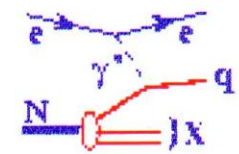
1947: Discovery of π-mesons and of long-lived V-particles (K^0, Λ) in cosmic rays

1953: V-particles produced at accelerators; new inner quantum number ('strangeness').

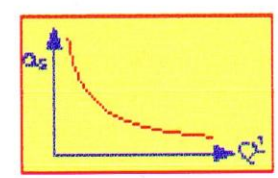
1964: Static Quark-Model; new inner quantum number: color.



1969: Dynamic Parton Model:

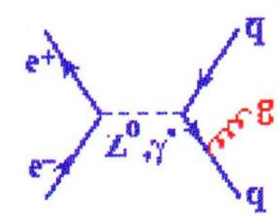


1973: Concept of Asymptotic Freedom; non-abelian gauge theory: QCD.



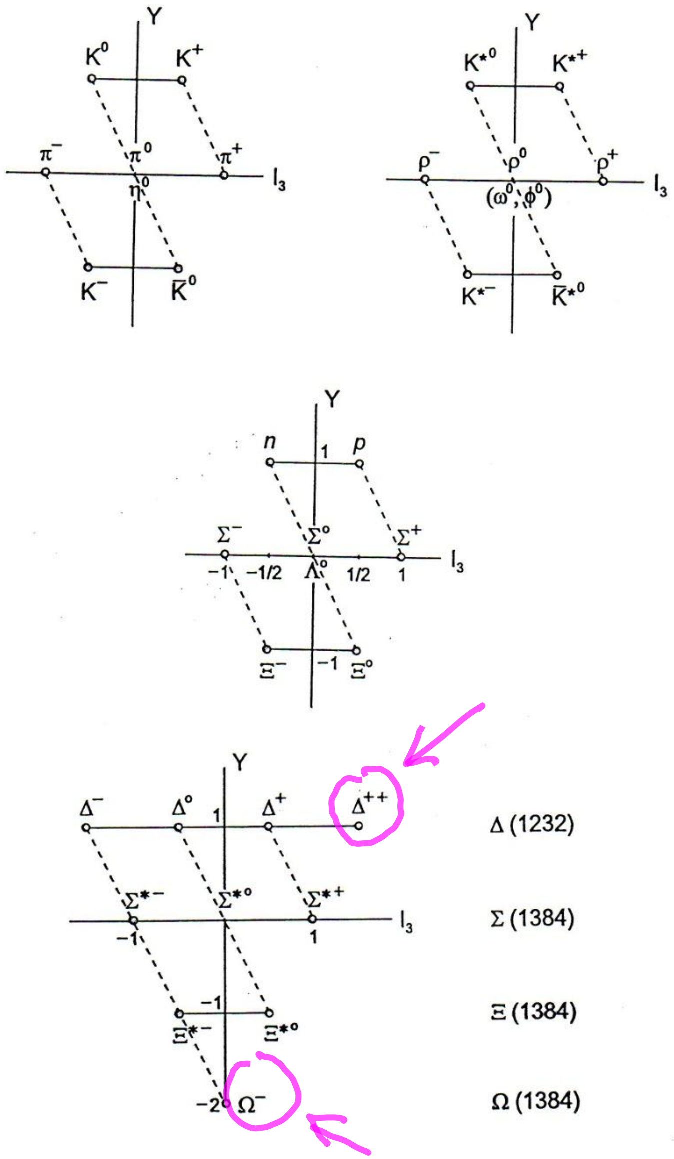
1975: 2-Jet structure in e^+e^--annihilation: confirmation of Quark-Parton-Model.

1979: Discovery of the gluon in 3-Jet-events of e^+e^--annihilation.



OD IZOSPINA DO OKUSA

DIJAGRAMI KVARKOVSKOG TOKA



PRODUKCIJA STRANOSTI

- DIJAGRAMI KVARKOVSKOG TOKA
- KVARKOVSKA STANJA

(uuu) i (sss) & "BOJA"

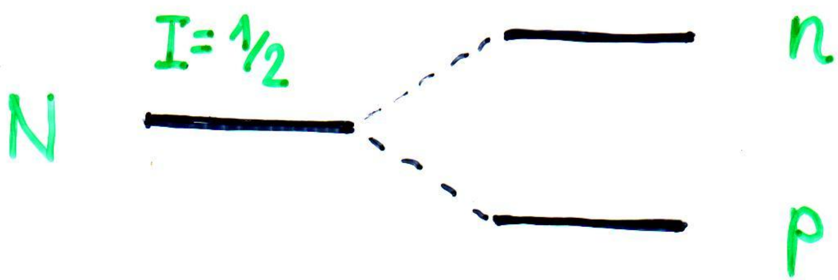
POJAM PRIBLIŽNE SIMETRIJE

- JAKO MEĐUDJELOVANJE POKAZUJE NAJVIŠE SIMETRIJA
- OD NABOJNE SIMETRIJE JAKE SILE DO IZOSPINA
  (FEČ § 2.1.3 str. 58)
- OD IZOSPINA DO OKUSA
  (FEČ § 4.1.2, str. 188)

SLOMLJENA SIMETRIJA

ČESTIČNOG SPEKTRA *

SU(2)$_{\text{IZOSPIN-a}}$ narušena u prisutnosti elektromagnetskog međudjelovanja



n (939.566 MeV) $I_3 = -1/2$

p (938.272 MeV) $I_3 = 1/2$

~ MeV

* Wigner-Weylova realizacija simetrije

SU(2) $e^{i\varepsilon^a \frac{\tau^a}{2}}$ NE ABELOVSKA Yang-Millsova

primjerice, rotacije u apstraktnom izospinskom internom prostoru, povezuju

PROTON i NEUTRON

Globalni ε – istodobno isti posvuda ;
ista rotacija (konvencija) primjenjuje se na svim nukleonskim stanjima u svemiru!

(simetrija jakog nuklearnog međudjelovanja

$$[H, \vec{I}\,] = 0 \quad \text{za} \quad H = H_{jaki} ,$$

no $[H, I_3] = 0$ za $H = H_{jaki} + H_{e.m.}$)

CASIMIROV OPERATOR – KOMUTIRA SA SVIM GENERATORIMA GRUPE

$$S^2 = S_x^2 + S_y^2 + S_z^2$$

Explicit construction: $S_\pm = S_x \pm iS_y$

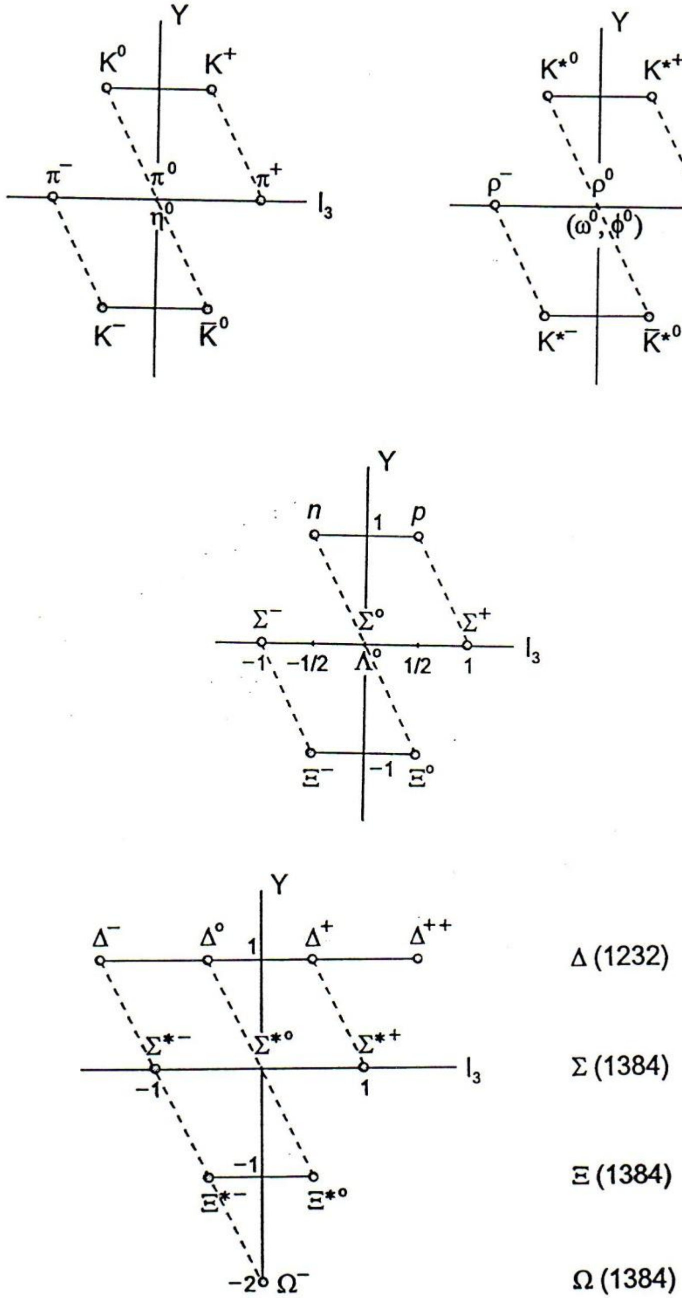
$m = -s, -s+1, ..., s$

$s = 0,\ 1/2,\ 1,\ 3/2, \ldots$

$$[S_z, S_\pm] = \pm S_\pm \qquad S_z|s,m\rangle = m|s,m\rangle$$

$$[S_+, S_-] = 2S_z \qquad S^2|s,m\rangle = s(s+1)|s,m\rangle$$

$$[S^2, S_i] = 0 \qquad S_\pm|s,m\rangle = \sqrt{[(s\mp m)(s\pm m+1)]}|s,m\pm 1\rangle$$



35. CLEBSCH-GORDAN COEFFICIENTS, SPHERICAL HARMONICS, AND *d* FUNCTIONS

Note: A square-root sign is to be understood over *every* coefficient, *e.g.*, for −8/15 read $-\sqrt{8/15}$.

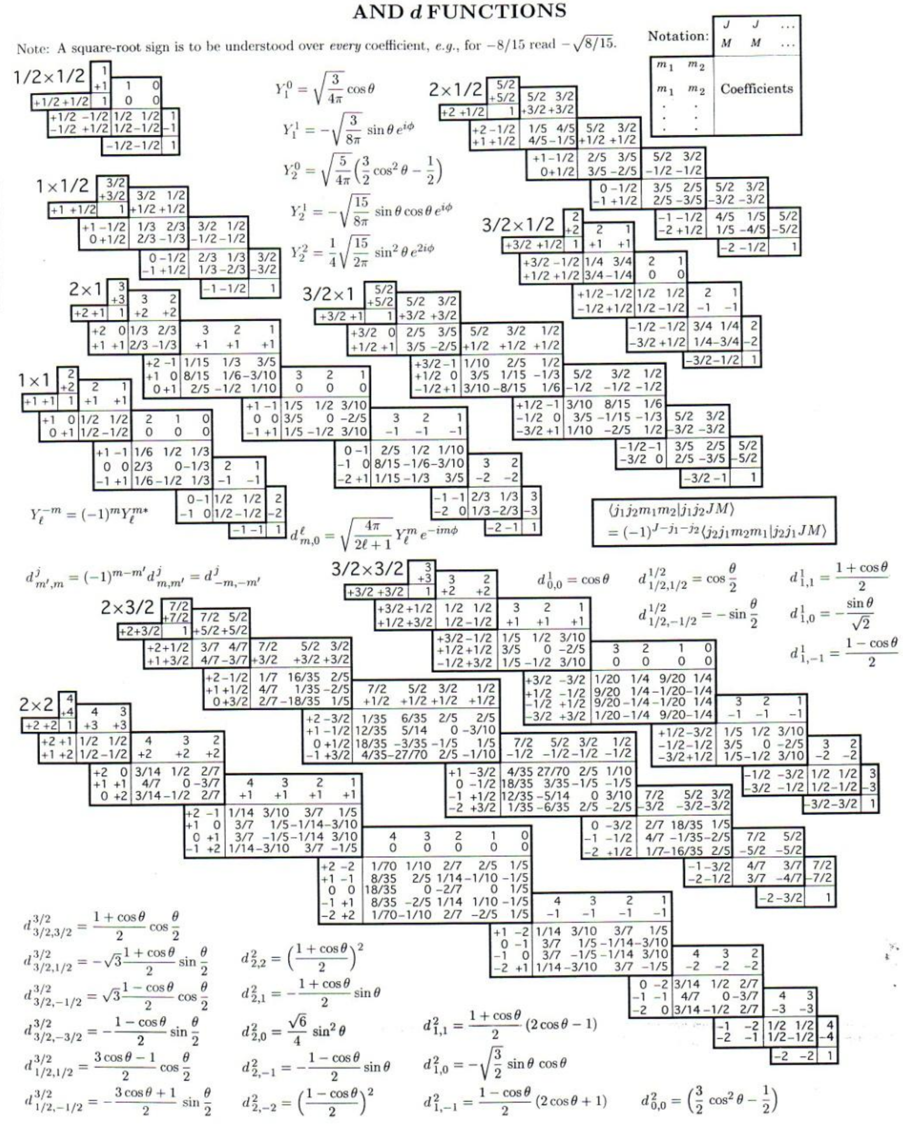


Figure 35.1: The sign convention is that of Wigner (*Group Theory*, Academic Press, New York, 1959), also used by Condon and Shortley (*The Theory of Atomic Spectra*, Cambridge Univ. Press, New York, 1953), Rose (*Elementary Theory of Angular Momentum*, Wiley, New York, 1957), and Cohen (*Tables of the Clebsch-Gordan Coefficients*, North American Rockwell Science Center, Thousand Oaks, Calif., 1974). The coefficients here have been calculated using computer programs written independently by Cohen and at LBNL.

BARIONSKA REZONANCIJA

$I = 3/2$

$\Delta(1232)$ $J^P = 3/2^+$

$I = 1/2$

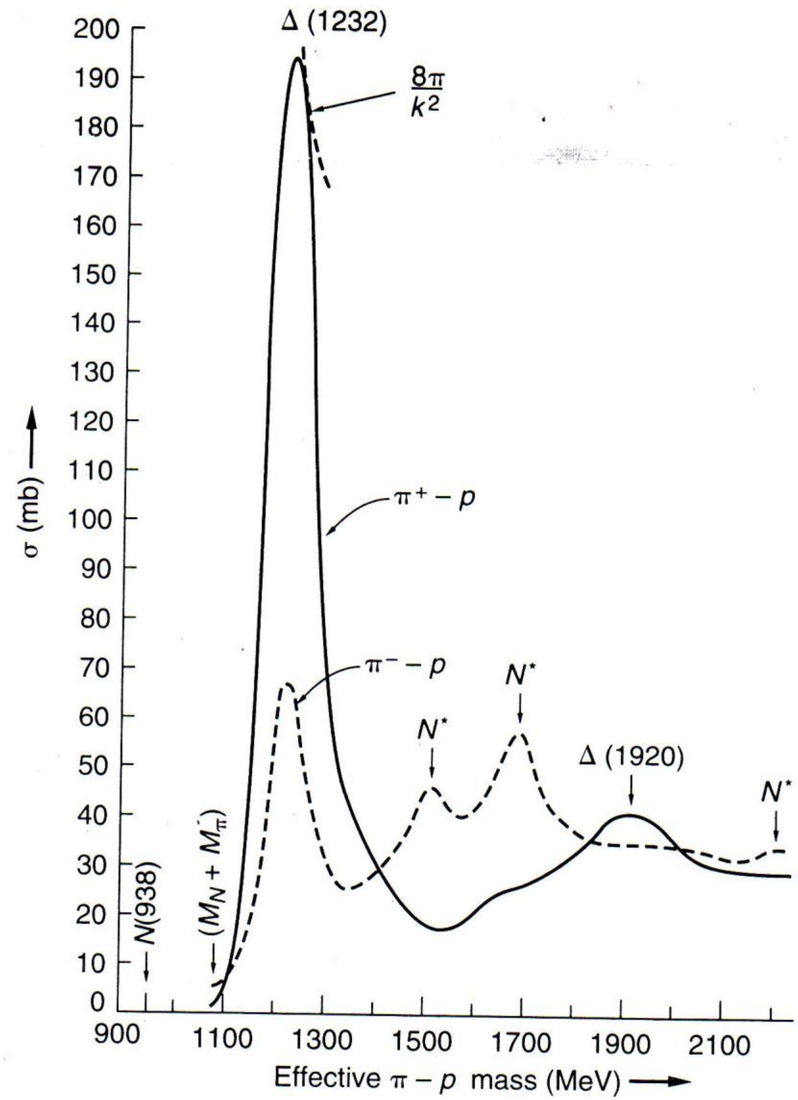
$N(1525)$ $J^P = 3/2^-$

Za K.E.π 195 MeV $A_{3/2} \gg A_{1/2}$

$\sigma_{\pi^+ p} / \sigma_{\pi^- p} \simeq 3 : 1$

Za K.E.π 600 MeV $A_{1/2} \gg A_{3/2}$

$$\frac{\sigma_{\pi^- p \to \pi^- p}}{\sigma_{\pi^- p \to \pi^0 n}} = 2 : 1$$



In December 1947,Rochester and Butler published the cloud chamber photograph which turned out to be the production of a neutral K-meson: $K^0 \to \pi^+ + \pi^-$

In 1949, Powell published the decay of a charged Kaon: $K^+ \to \pi^+ + \pi^+ + \pi^-$

In 1950, Anderson discovered the Lambda baryon: $\Lambda \to p^+ + \pi^-$

All those particles seemed "strange" in the sense that they are produced copiously (10^{-23} s), but they decay relatively slowly (10^{-10} s)!

Gell-Mann assigned those particles a new quantum number called strangeness besides their respective charge:

- Production of two strange particles:

$$\pi^- + p^+ \to K^+ + \Sigma^-$$

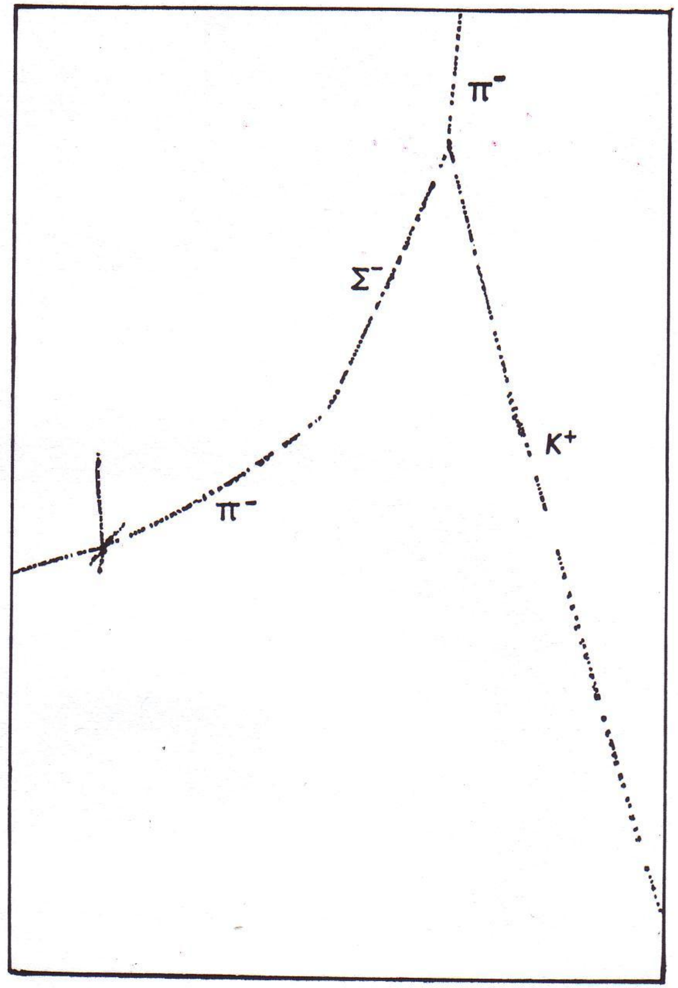
$$\pi^- + p^+ \to K^0 + \Sigma^0$$

$$\pi^- + p^+ \to K^0 + \Lambda$$

- Assign strangeness quantum number S: S=+1 for Σ and S=-1 for Λ with S=0 for p,n and π

AMPLITUDE – MATRIČNE ELEMENTE JAKIH PRIJELAZA – MOŽEMO POVEZIVATI POMOĆU IZOSPINSKE SIMETRIJE

PRODUKCIJA STRANOSTI



PRODUKCIJA STRANOSTI

(1) $\pi^- + p \to K^+ + \Sigma^-$

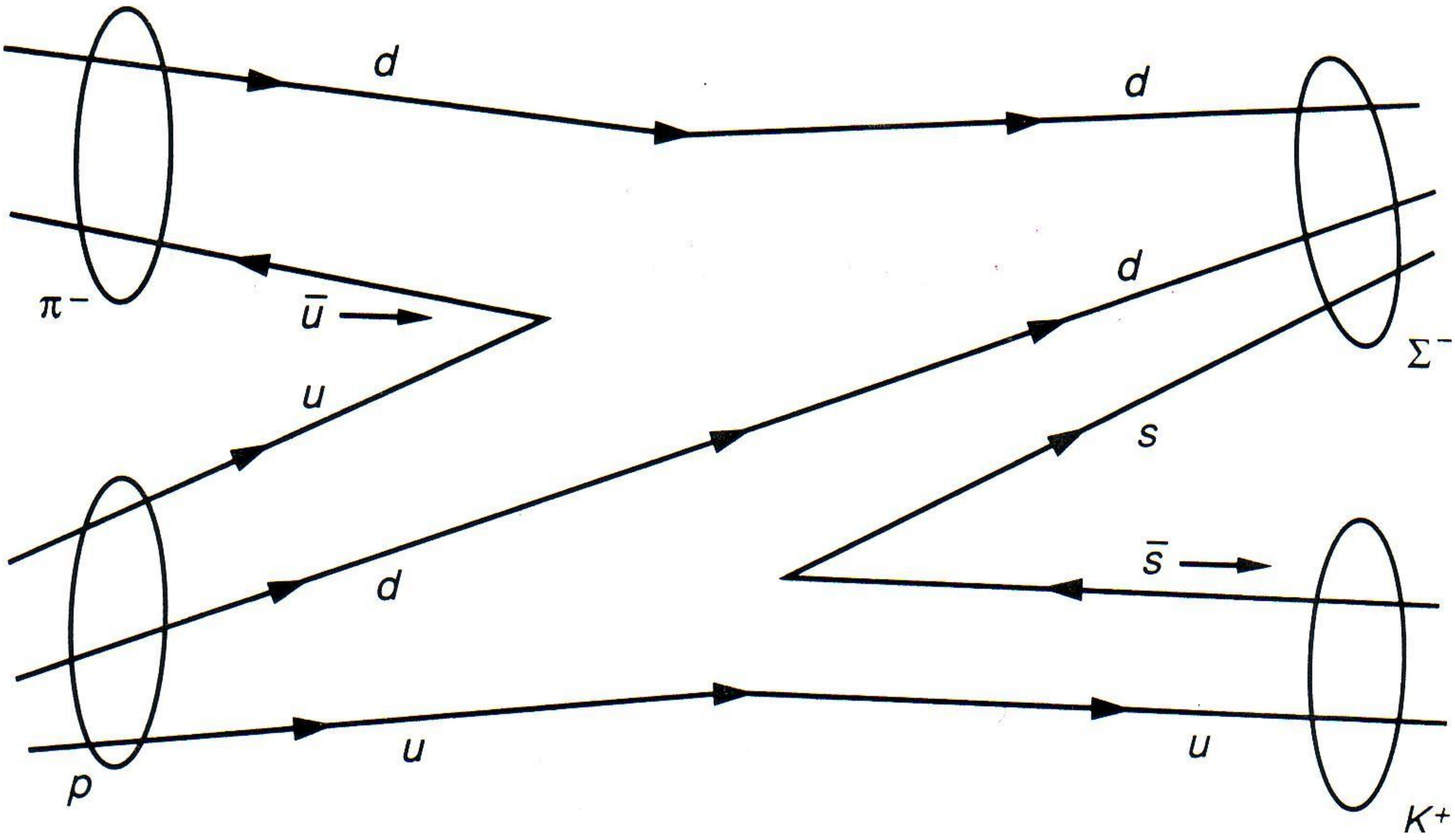
(2) $K^- + p \to \Lambda + \phi \to \Lambda + K^+ + K^-$

$K^+ K^-$	49 %
$K^0 \overline{K^0}$	34 %
$\rho \pi$	13 %
$\pi^+ \pi^- \pi^0$	2 %

Okubo-Zweig-Iizuka (OZI-) potisnuti → $\pi^+ \pi^- \pi^0$ 2 %

(3) $K^- + p \to \Omega^- + K^+ + K^0$

DIJAGRAM KVARKOVSKOG TOKA



DOGAĐAJ Ω HIPERONA

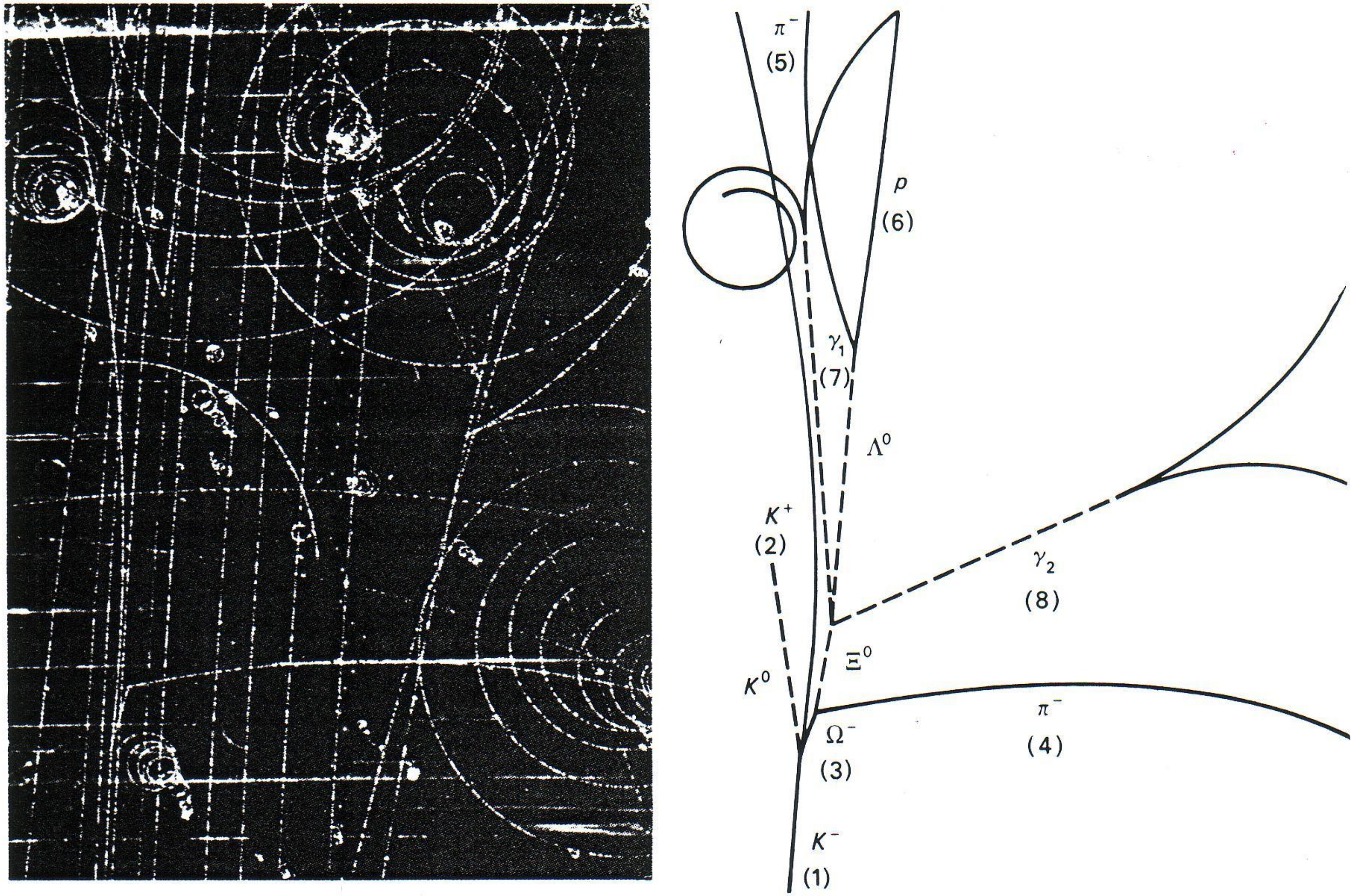
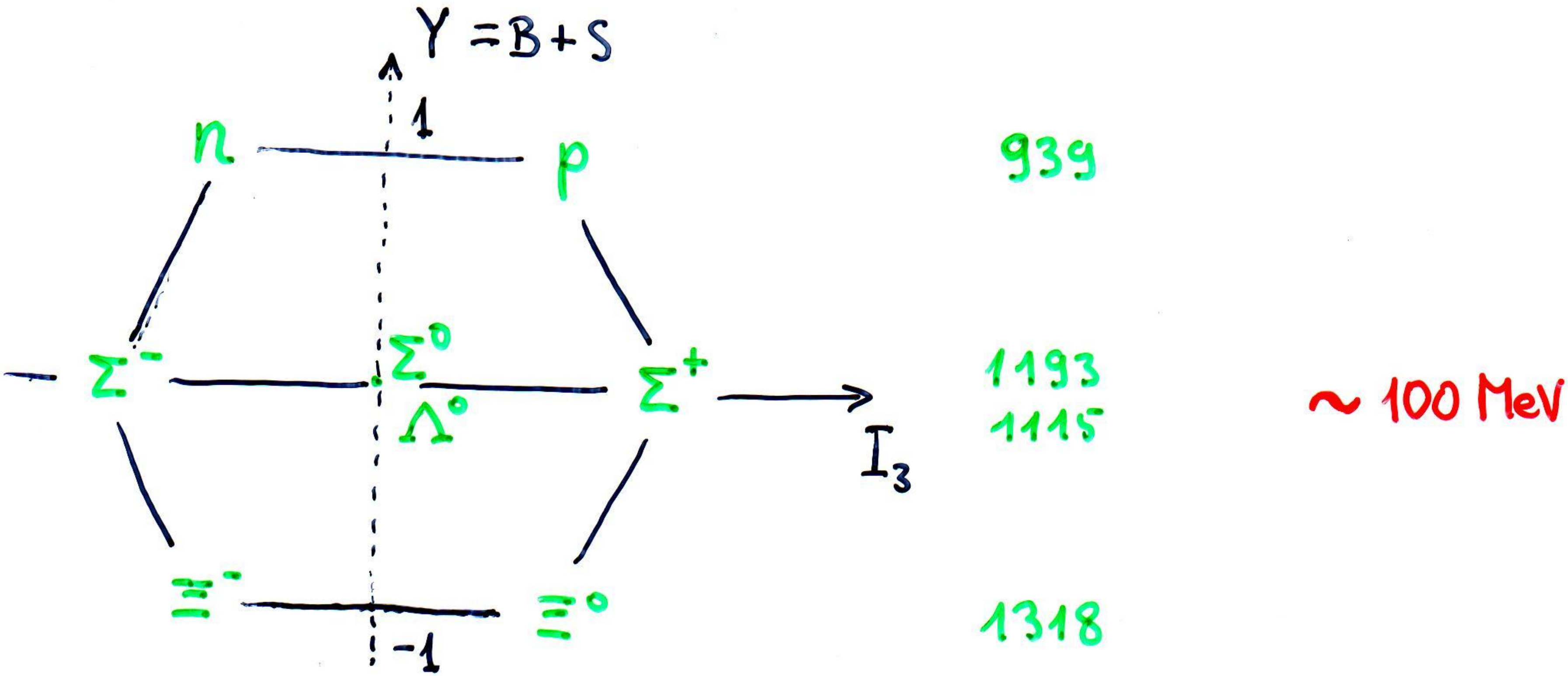


FIGURE 6.4

SU(3) OSMEROSTRUKOG PUTA



PRODUKCIJE NOVIH STANJA

1974: The J/Psi (charm) discovery

$$p+N \rightarrow J/\psi$$

... *1976 Nobel Prize*

1977: The Upsilon (bottom) discovery

$$p+N \rightarrow \Upsilon$$

1983: The W and Z discovery

$$p + \overline{p} \rightarrow W/Z$$

... *1984 Nobel Prize*

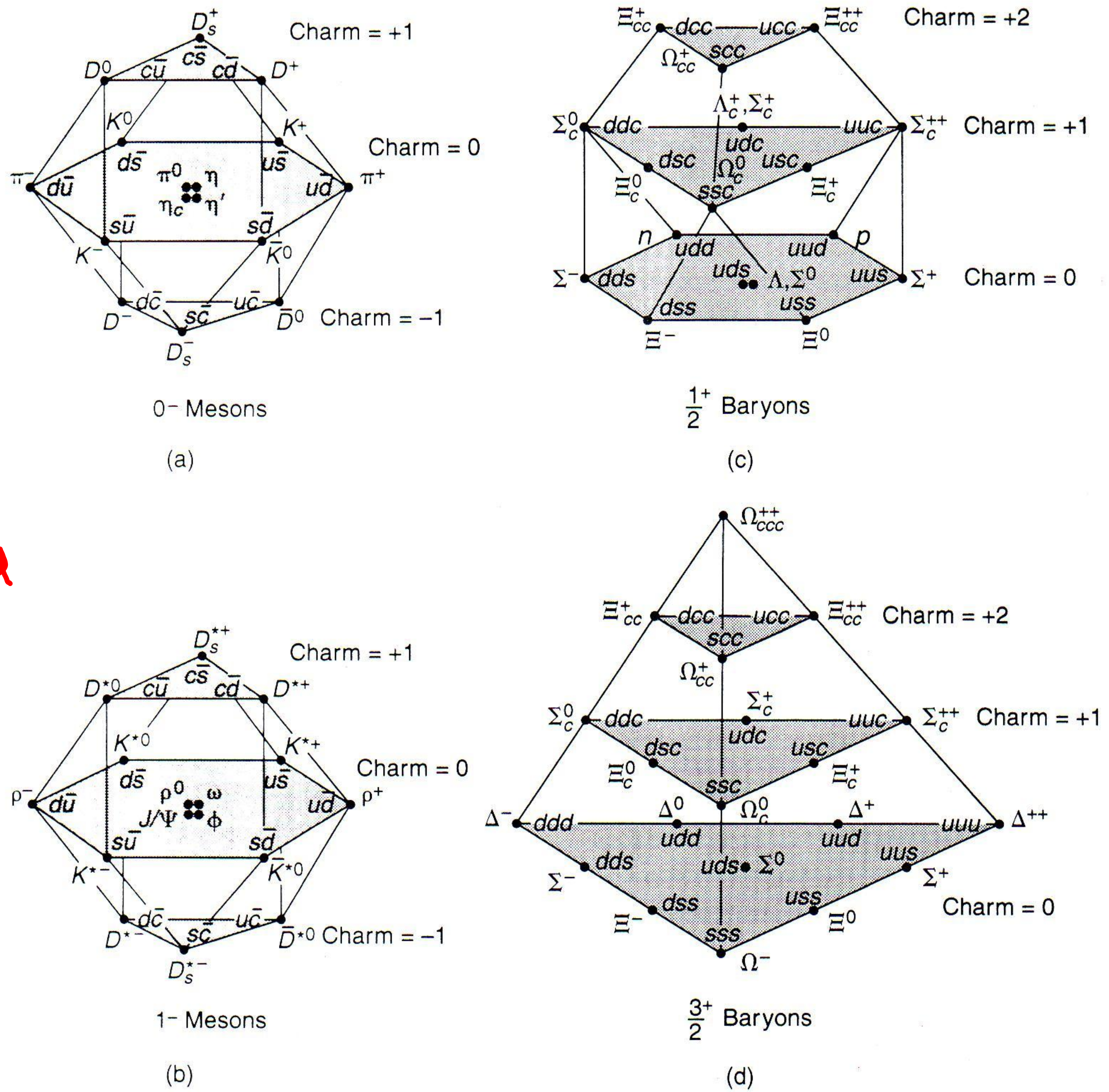
TEŽI OKUSI

SU(4)

15-plet mezona

20-plet bariona

FEČI str. 192



TREBA IZUČITI DINAMIKU -SILU KVARKOVSKOG VEZANJA

$$
\begin{array}{llll}
\pi^+ = u\bar{d}, & K^+ = u\bar{s}, & K^0 = d\bar{s}, & \pi^0 = (u\bar{u} - d\bar{d})/\sqrt{2} \\
D^+ = c\bar{d}, & D^0 = c\bar{u}, & D_s^+ = c\bar{s} & \ldots \\
B^+ = u\bar{b}, & B^0 = d\bar{b}, & B_s^0 = s\bar{b}, & B_c^+ = c\bar{b}
\end{array}
$$

$$
\begin{array}{llll}
p = uud, & n = udd, & \Sigma^+ = uus, & \Sigma^0 = uds \\
\Sigma_c^+ = udc, & \Sigma_c^{++} = uuc, & \Xi_c^+ = usc, & \Xi_c^0 = dsc \\
\Xi_{cc}^+ = dcc, & \Xi_{cc}^{++} = ucc, & \Omega_{cc}^+ = scc & \ldots
\end{array}
$$

O SUDARIVAČIMA – FEČ 1.2.2

Table 1. Recent and future energy-frontier particle colliders. (Parameters listed for the LHC and the ILC are design values.)

Name	Type	$\sqrt{s}$ (GeV)	L_{int} (pb^{-1})	Years of operation	Detectors	Location
LEP	e^+e^-	91.2 (LEP-1)	≈ 200 (LEP-1)	1989-95 (LEP-1)	ALEPH, OPAL,	CERN
		130-209 (LEP-2)	≈ 600 (LEP-2)	1996-2000 (LEP-2)	DELPHI, L3	
SLC	e^+e^-	91.2	20	1992-98	SLD	SLAC
HERA	$e^{\pm}p$	320	500	1992-2007	ZEUS, H1	DESY
Tevatron	$p\bar{p}$	1800 (Run-I)	160 (Run-I)	1987-96 (Run-I)	CDF, DØ	FNAL
		1960 (Run-II)	6 K (Run-II, 06/09)	2000-??? (Run-II)		
LHC	pp	14000	10 K/yr ("low-L")	2010? - 2013?	ATLAS, CMS	CERN
			100 K/yr ("high-L")	2013?? - 2016???		
ILC	e^+e^-	500-1000	1 M???	???	???	???

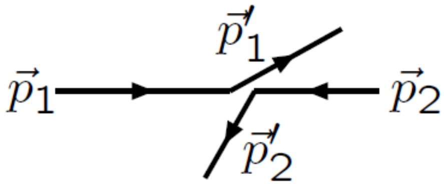
Table 1. Comparison of the LHC and Tevatron accelerator statistics.

	LHC (design)	Tevatron (achieved)
Center-of-mass energy	14 TeV	1.96 TeV
Number of bunches	2808	36
Bunch spacing	25ns	396ns
Energy stored in beam	360MJ	1MJ
Peak Luminosity	$10^{33} - 10^{34} cm^{-2}s^{-1}$	3.87×10^{32} (April 2010)
Integrated Luminosity / year	10-100 fb^{-1}	$> 2fb^{-1}$ (2008)

PARAMETRI SUDARIVAČA:

- ENERGIJA
- LUMINOZNOST

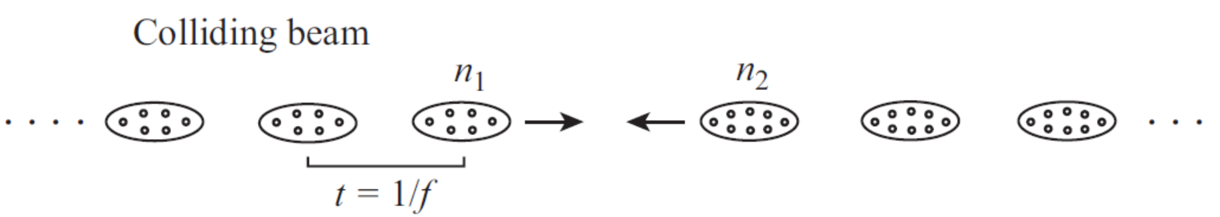
The energy:



$$s \equiv (p_1 + p_2)^2 = \begin{cases} (E_1 + E_2)^2 & \text{in the c.m. frame } \vec{p}_1 + \vec{p}_2 = 0, \\ m_1^2 + m_2^2 + 2(E_1 E_2 - \vec{p}_1 \cdot \vec{p}_2). \end{cases}$$

$$E_{cm} \equiv \sqrt{s} \approx \begin{cases} 2E_1 \approx 2E_2 & \text{in the c.m. frame } \vec{p}_1 + \vec{p}_2 = 0, \\ \sqrt{2E_1 m_2} & \text{in the fixed target frame } \vec{p}_2 = 0. \end{cases}$$

The luminosity:

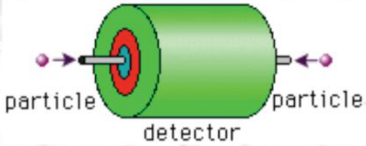


$$\mathcal{L} \propto f n_1 n_2 / a,$$

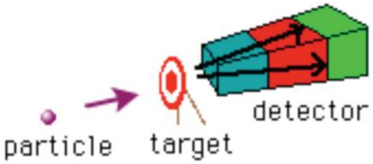
#particles/cm^2/s $\quad 10^{33}\ \text{cm}^{-2}\text{s}^{-1} = 1\ \text{nb}^{-1}\ \text{s}^{-1} \approx 10\ \text{fb}^{-1}/\text{year}$

Hadron Electron Ring Accelerator

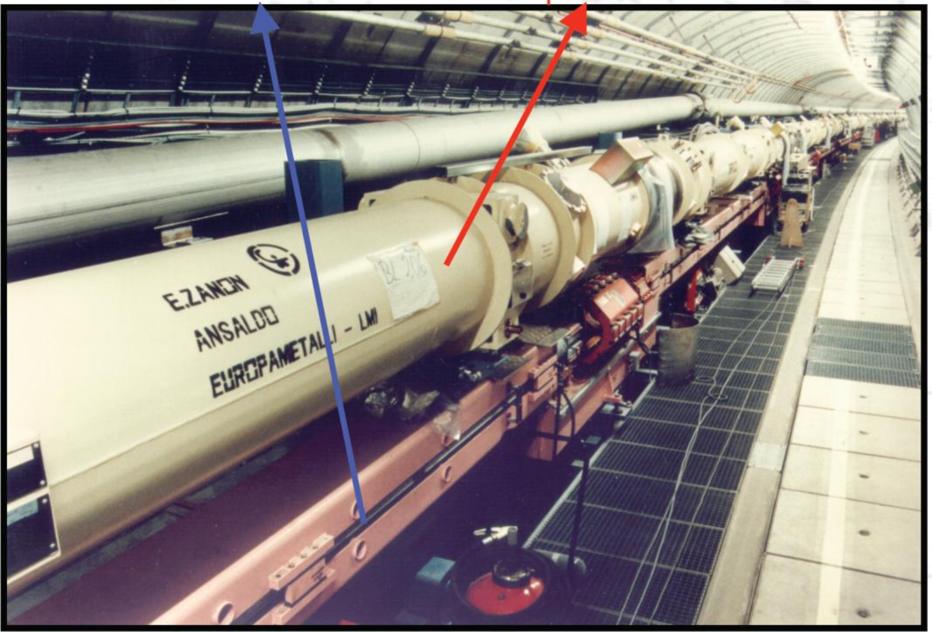
- Collider experiment: Electron-Proton collisions at HERA (DESY, Hamburg, Germany)

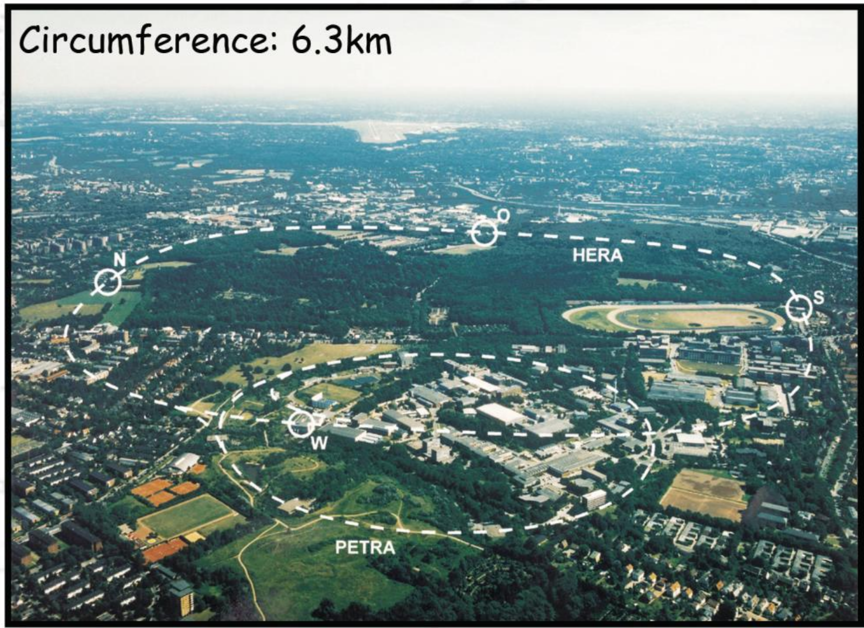


Equivalent to fixed target of
E_e = 50600 GeV:



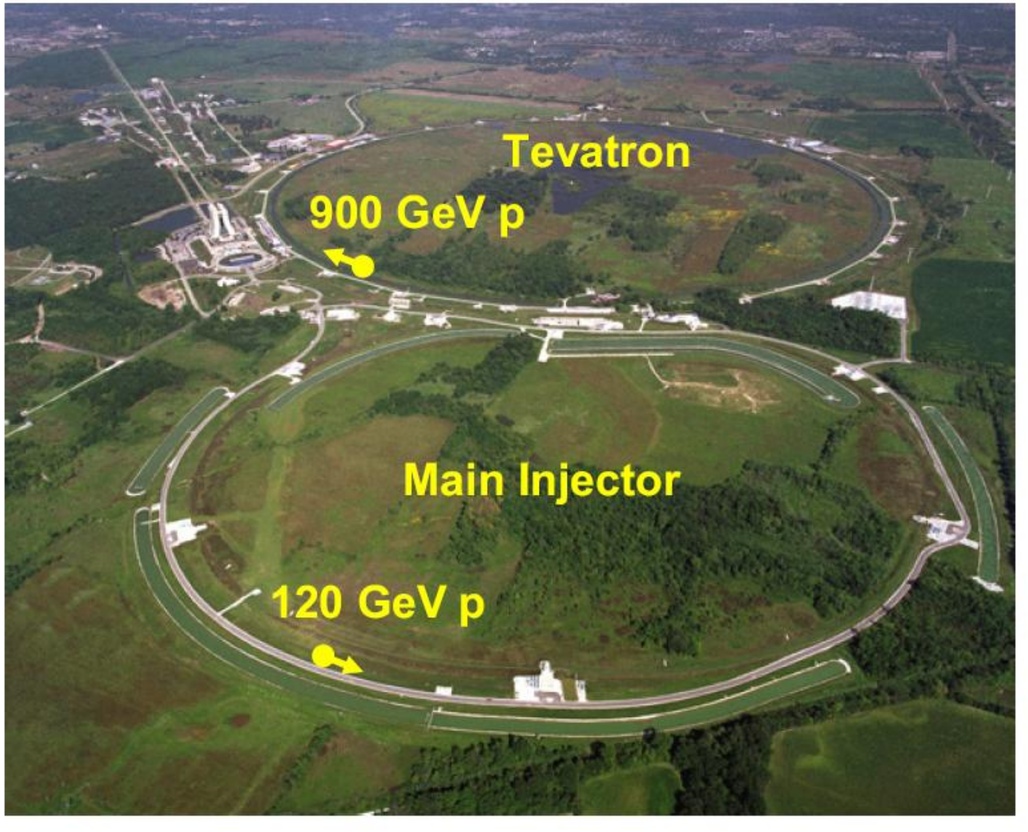
E_e = 27.5 GeV E_p = 920 GeV





SUDARI PROTONA i ANTIPROTONA NA TEVATRONU

★ $p\bar{p}$ collisions at $\sqrt{s}$ = 1.8 TeV



Two main accelerators:

★ Main Injector
- Accelerates 8 GeV p to 120 GeV
- also $\bar{p}$ to 120 GeV
- Protons sent to Tevatron & MINOS
- $\bar{p}$ all go to Tevatron

★ Tevatron
- 4 mile circumference
- accelerates $p/\bar{p}$ from 120 GeV to 900 GeV

LHC

supra-vodljivi magneti

opsega 27 km

energ. Ecm 14TeV