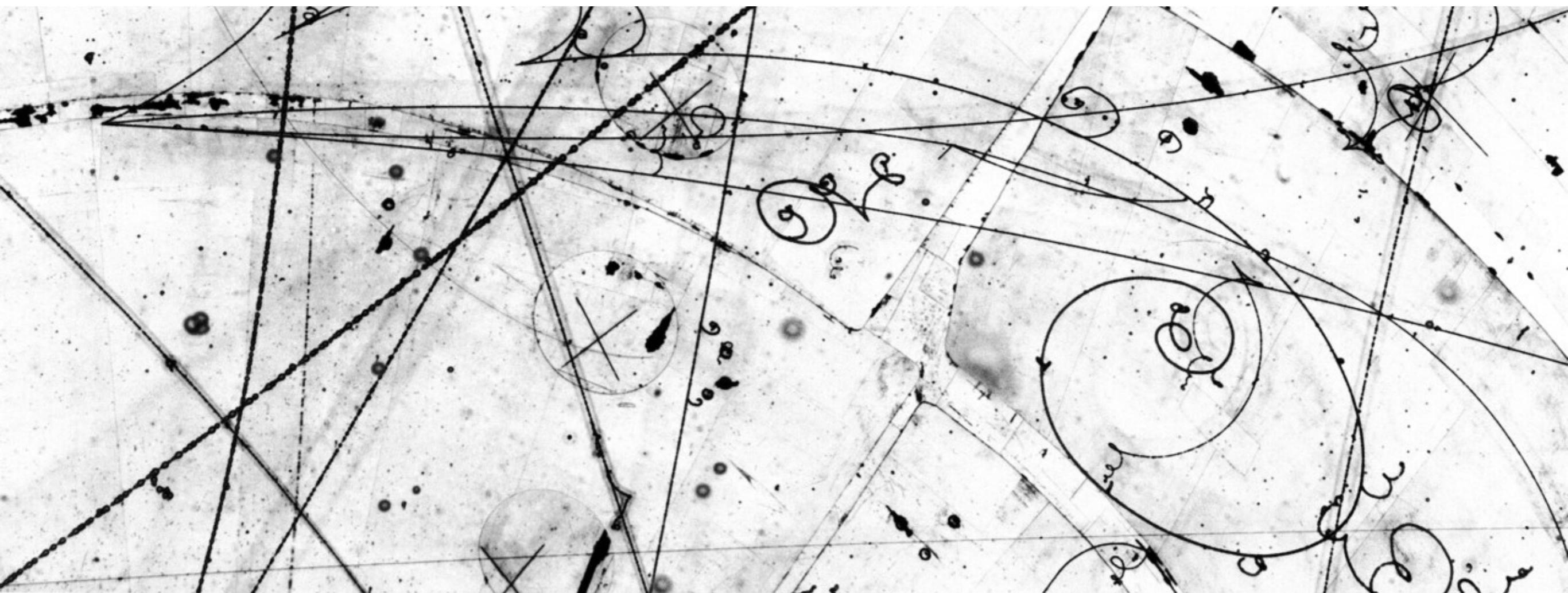


Particle Physics

Lecture WS 2020/21

Prof. H.-C. Schultz-Coulon



Some Organizational Issues

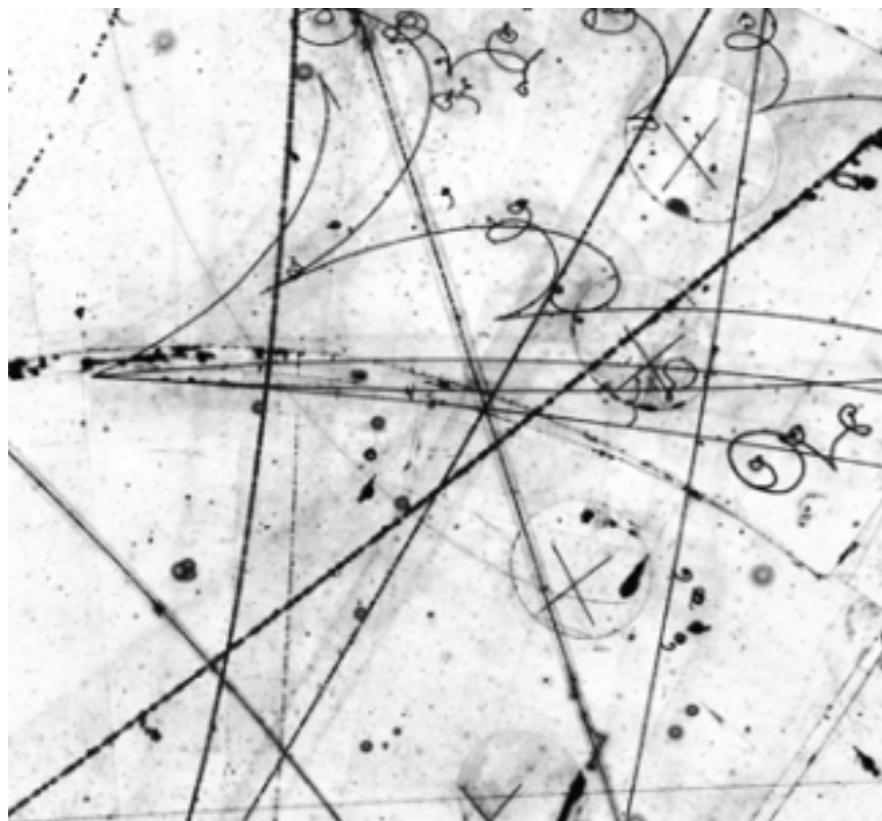
Particle Physics

winter term 2020/2021

Lecturer: Prof. Dr. Hans-Christian Schultz-Coulon

[Link zum LSF](#)

124 participants



Courtesy Fermilab Visual Media Services

Prof. Dr. H.-C. Schultz-Coulon

Lectures: INF 227, HS 1

Tue, 14:15 - 16:00

Thu, 14:15 - 16:00

The lecture focuses on modern particle physics;
it will discuss the building blocks of matter and
the forces between them.

The lecture is based on:

Modern Particle Physics

von M. Thomson

[available in library]

Some Organizational Issues

Covid-19 regulations

**THE FEDERATE STATE GOVERNMENT DECIDED TO SWITCH TO PURE
ONLINE TEACHING FOR NOVEMBER. WE VERY MUCH HOPE TO SWITCH
TO THE HYBRID FORMT DESCRIBED BELOW FROM DECEMBER ON.**

Homeworks and Tutorials:

Exercise sheets will be put online on Wednesdays and have to be upload by Wednesday the week after. The exercises will not be corrected in detail, but you will get 0 or 1 point depending if you did a decent attempt to solve the problem even if the solution is not 100% correct. You can hand in your exercises in groups of maximal three students. Please note all names on the sheet. We expect every student of the group to be able to present and explain their solution. 60% of the points on the sheets are required to participate in the exam. Admissions to exams from previous years are not valid this year.

The tutorials will start on 6th November with a repetition of PEP-IV material. The first sheet will be online 4.11.20 and has to be handed in by 11.11.20.

Some Product Placement ...

Statistical Methods in Particle Physics WS 2020/21

<https://uebungen.physik.uni-heidelberg.de/vorlesung/20202/1225>

Get to know the toolbox of statistical methods in particle physics

Systematic errors, confidence limits, maximum likelihood method, least square fits, unfolding, etc

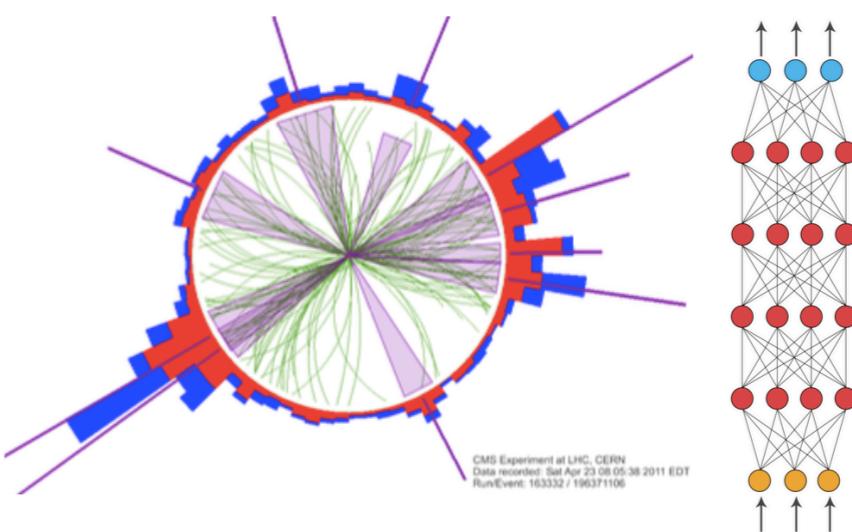
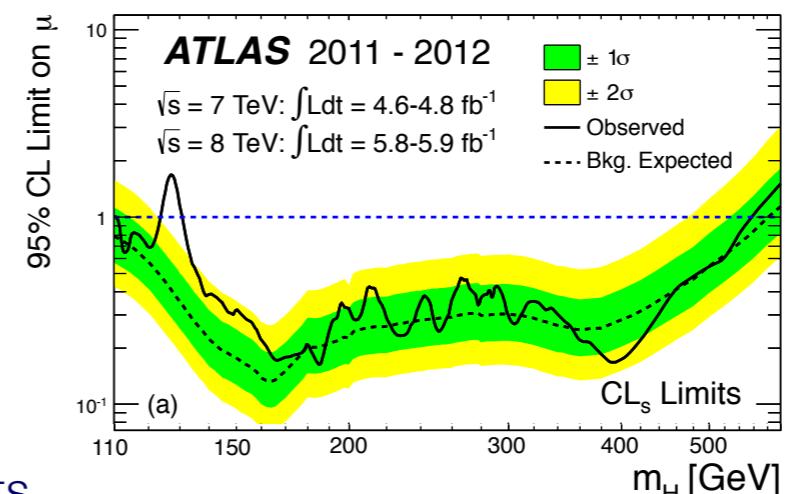
Understand and apply machine learning methods as used by the LHC experiments

Lecture (K. Reygers):

- ▶ flipped class room (videos/slides)
- ▶ discussion + quizzes (virtual):
Thursdays ~17:00

Tutorials (R. Stamen):

- ▶ Mondays, 16:00
- ▶ virtual
- ▶ python + jupyter notebooks



PEP 4 – Summer Term 2019 [Prof. U. Uwer]

I. Mehrelektronenatome

- 1. Wasserstoff
- 2. Helium
- 3. Mehrelektronensystem
- 4. Ordnung der Elemente
- 5. Angeregte Zustände
- 6. Röntgen-Strahlung

II. Fundamentale Materiebausteine und ihre Wechselwirkungen

- 1. Struktur der Materie
- 2. Fundamentale Bausteine
- 3. Fundamentale Wechselwirkungen
- 4. Streuexperimente
- 5. Relativistische Kinematik

III. Beschreibung von Streuprozessen

- 1. Feynman-Graphen
- 2. Wirkungsquerschnitt
- 3. Lebensdauer und Zerfallsbreiten
- 4. Fermi's Goldene Regel
- 5. e^+e^- -Annihilation
- 6. Lorentzinvariante Darstellung

IV. Wechselwirkung v. Teilchen mit Materie

- 1. Energieverlust durch Ionisation
- 2. Energieverlust von Elektronen
- 3. Cherenkov-Strahlung
- 4. Wechselwirkung von Photonen
- 5. Elektromagnetische Schauer
- 6. Hadronische Schauer
- 7. Detektorsysteme

V. Symmetrien und Erhaltungssätze

- 1. Erhaltungsgrößen und Transformationen
- 2. Kontinuierliche Raumtransformat.
- 3. Innere Symmetrien
- 4. Diskrete Symmetrien P, C, und T (auch P Verletzung)

VI. Kern- und Nukleonstruktur

- 1. Rutherford-Streuung
- 2. Streuung an ausgedehnten Ladungsverteilungen und Kernstruktur
- 3. Struktur der Nukleonen
- 4. Tiefinlastische Elektron-Nukleon Streuung

VII. Starke Wechselwirkung

- 1. Farbladung und Gluonen
- 2. Quark-Antiquark Potential, Confinement und Running Alphas
- 3. Statisches Quarkmodell

VIII. Schwache Wechselwirkung

- 1. W- und Z-Bosonen
- 2. Kopplungen von W- und Z-Bosonen
- 3. Beta-Zerfall

X. Kerne, Kernmodelle, Kernzerfälle

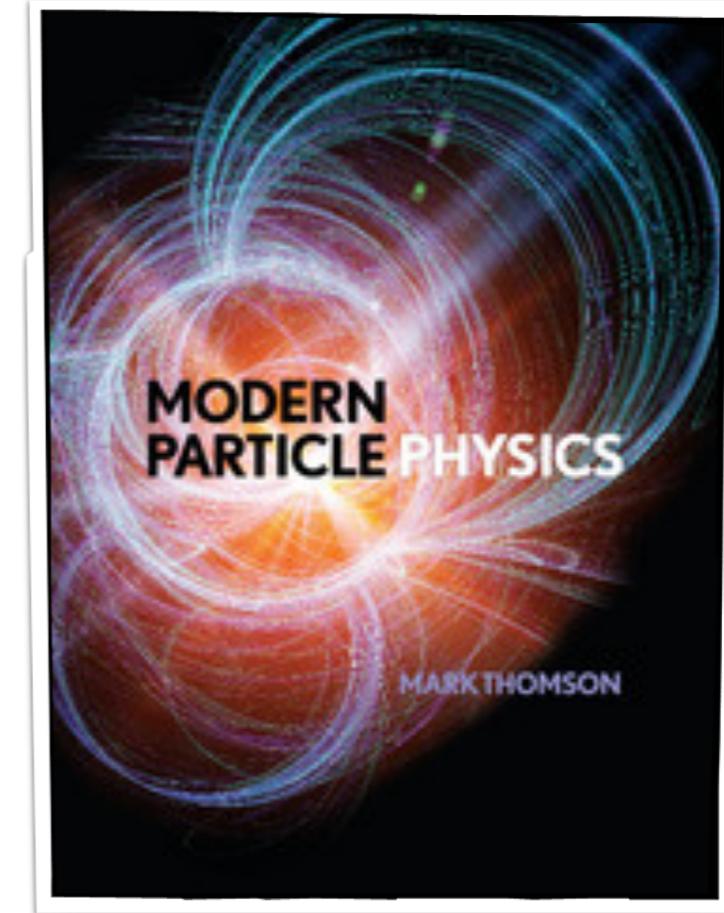
- 1. Massen-Spektrometrie und Bindungsenergie
- 2. Tröpfchenmodell und Massenformel
- 3. Kern-Zerfälle
- 4. Kernspaltung
- 5. Fermi-Gas Modell des Kerns
- 6. Schalenmodell des Kerns

X. Fusion und Elementsynthese

- 1. Wasserstofffusion in der Sonne
- 2. Fusionsreaktoren auf der Erde
- 3. Primordiale Elementsynthese
- 4. Sternenentwicklung und Elementsynthese bis Eisen
- 5. Synthese schwerer Elemente

Particle Physics – Winter Term 2019/20 [HCSC]

- 1 Introduction
- 2 Underlying Concepts
- 3 Decay Rates and Cross Sections
- 4 Dirac Equation
- 5 Interaction by Particle Exchange
- 6 Electron-Positron Annihilation
- 7 Electron-Positron Elastic Scattering
- 8 Deep-inelastic Scattering
- 9 Symmetries and Quark Model
- 10 Quantum Chromodynamics
- 11 The Weak Interaction
- 12 The Weak Interaction of Leptons
- 13 Neutrinos and Neutrino Oscillations
- 14 CP Violation and Weak Hadronic Interactions
- 15 Electroweak Unification
- 16 Tests of the Standard Model
- 17 The Higgs Boson
- 18 The Standard Model and Beyond



Titel: Modern particle physics
Author: Mark Thomson
Verlag: Cambridge University Press
ISBN: 978-1-107-03426-6
1-107-03426-4

[Available in Library]

Quarks

u	c	t
up	charm	top

d	s	b
down	strange	bottom

Forces

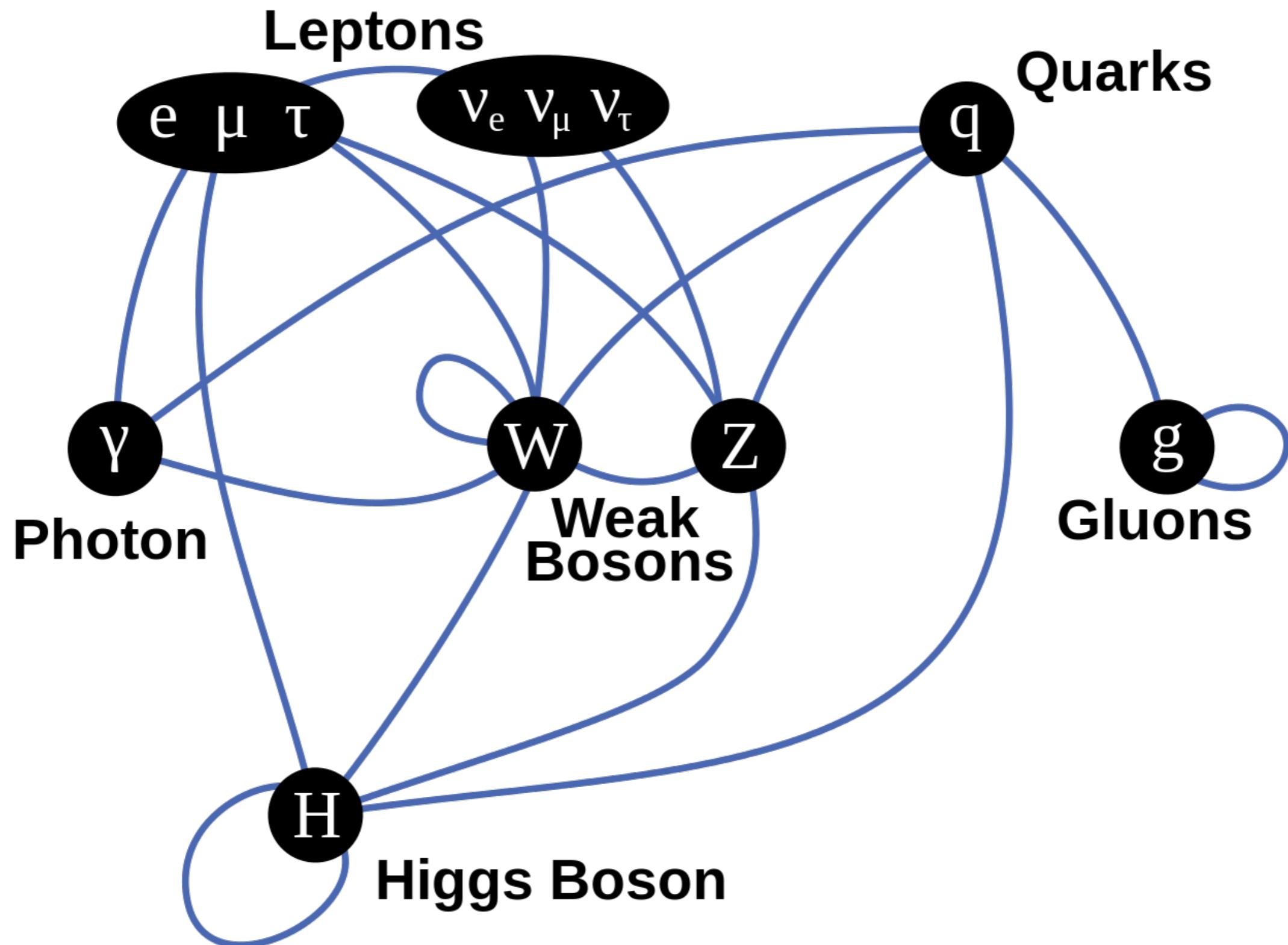
H	Z	γ
Higgs boson	Z boson	photon

W	g
W boson	gluon

e	μ	τ
electron	muon	tau

ν_e	ν_μ	ν_τ
electron neutrino	muon neutrino	tau neutrino

Leptons



spin- $\frac{1}{2}$
baryons

more
spin- $\frac{1}{2}$
baryons

spin- $\frac{3}{2}$
baryons

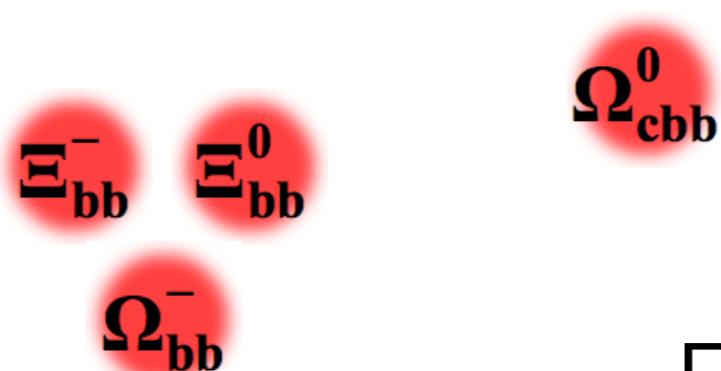
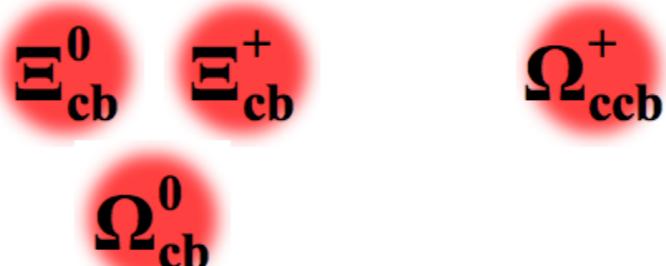
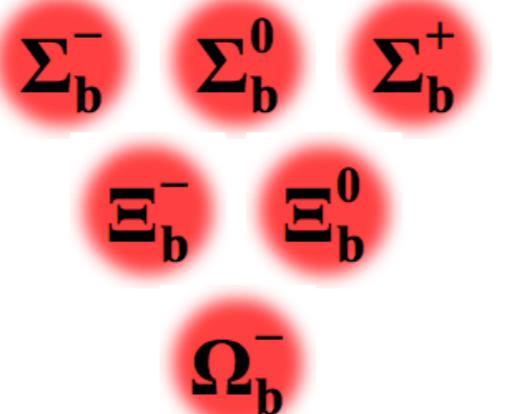
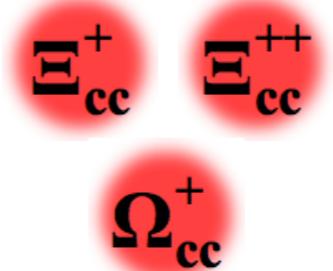
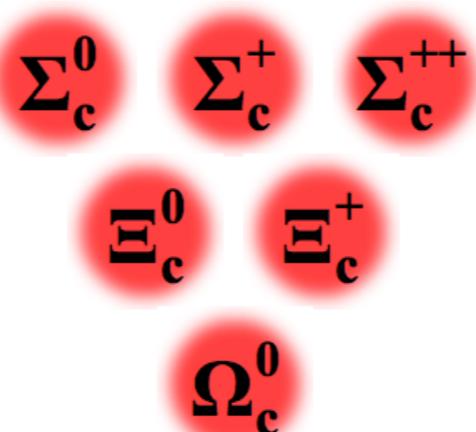
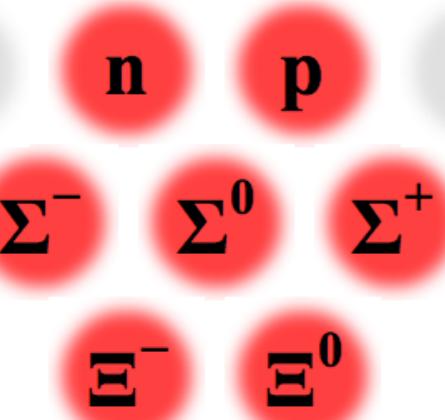
quarks
in
baryons

spin- $\frac{1}{2}$
anti-
baryons

more
spin- $\frac{1}{2}$
anti-
baryons

spin- $\frac{3}{2}$
anti-
baryons

anti-
quarks
in anti-
baryons



Baryons

<http://www.thingsmadethinkable.com/item/baryons.php>

spin- $\frac{1}{2}$
baryons

more
spin- $\frac{1}{2}$
baryons

spin- $\frac{3}{2}$
baryons

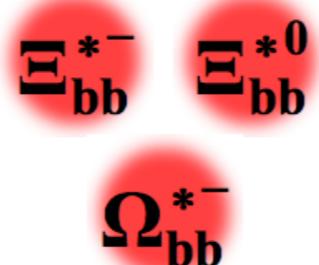
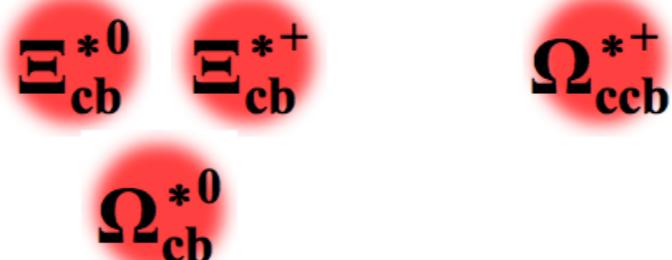
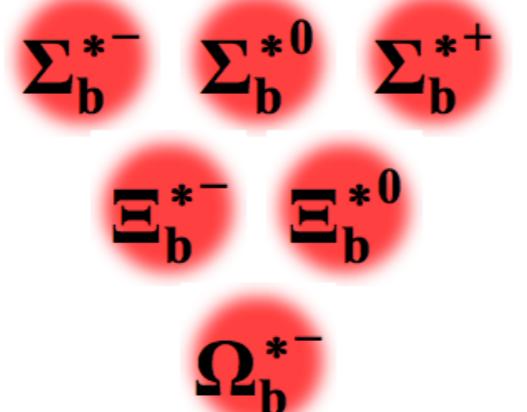
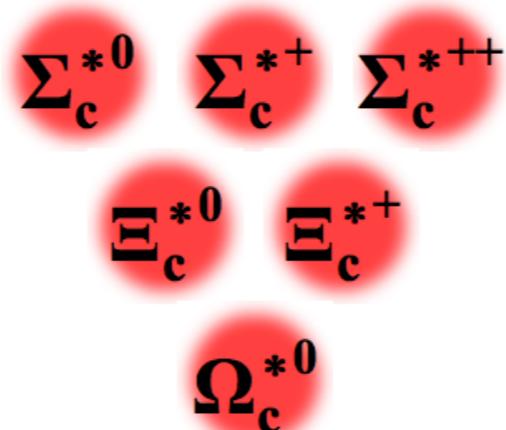
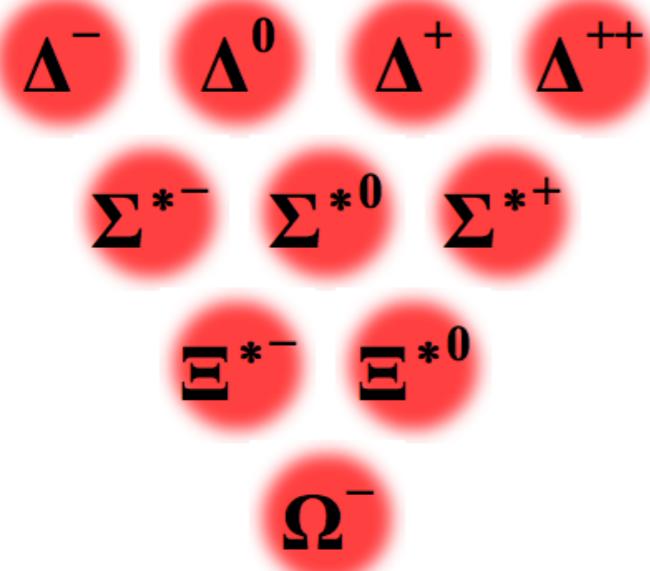
quarks
in
baryons

spin- $\frac{1}{2}$
anti-
baryons

more
spin- $\frac{1}{2}$
anti-
baryons

spin- $\frac{3}{2}$
anti-
baryons

anti-
quarks
in anti-
baryons



Baryons

<http://www.thingsmadethinkable.com/item/baryons.php>

**spin- $\frac{1}{2}$
baryons**

**more
spin- $\frac{1}{2}$
baryons**

**spin- $\frac{3}{2}$
baryons**

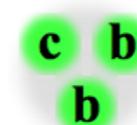
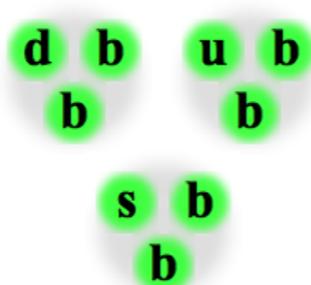
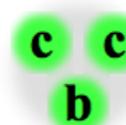
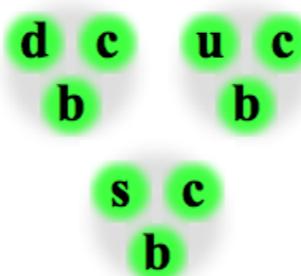
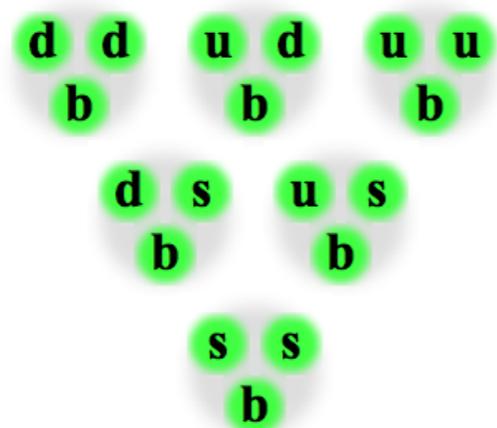
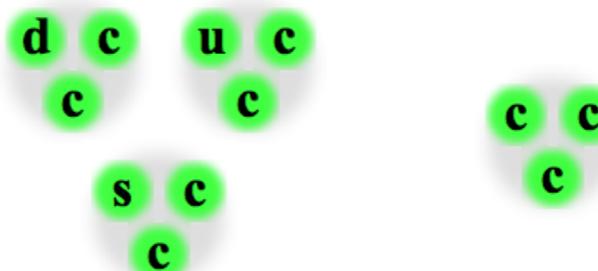
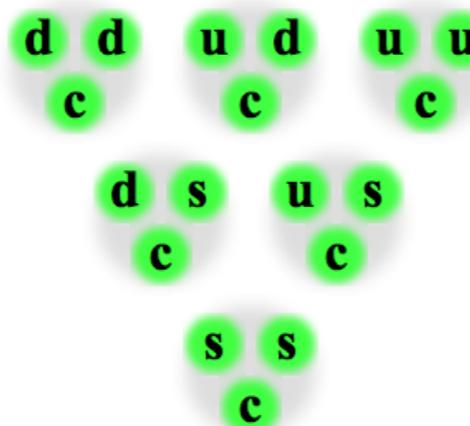
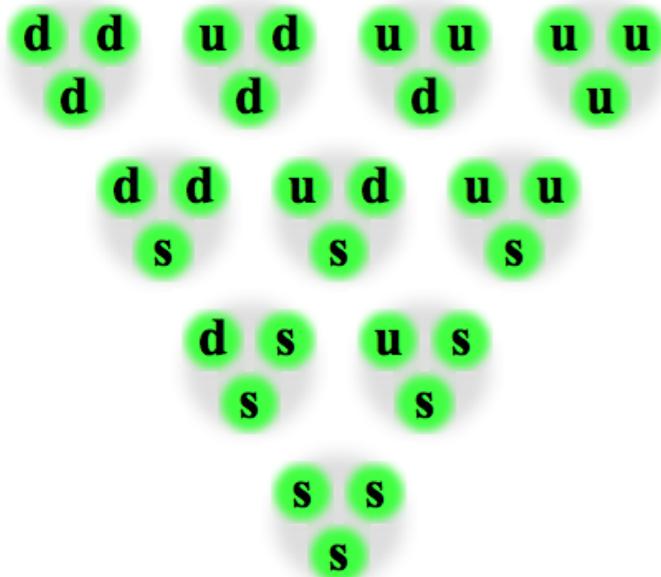
**quarks
in
baryons**

**spin- $\frac{1}{2}$
anti-
baryons**

**more
spin- $\frac{1}{2}$
anti-
baryons**

**spin- $\frac{3}{2}$
anti-
baryons**

**anti-
quarks
in anti-
baryons**



Baryons

<http://www.thingsmadethinkable.com/item/baryons.php>

pseudo-scalar
(spin-0)
mesons

vector
(spin-1)
mesons

(anti) quarks
in
mesons

B^0 B^+

B_s^0

B_c^+

D^- \bar{D}^0

D_s^-

K^0 K^+

π^- π^0 π^+

K^- \bar{K}^0

D_s^+

D^0 D^+

B_c^-

\bar{B}_s^0

B^- \bar{B}^0



η

η'

η_c

η_b

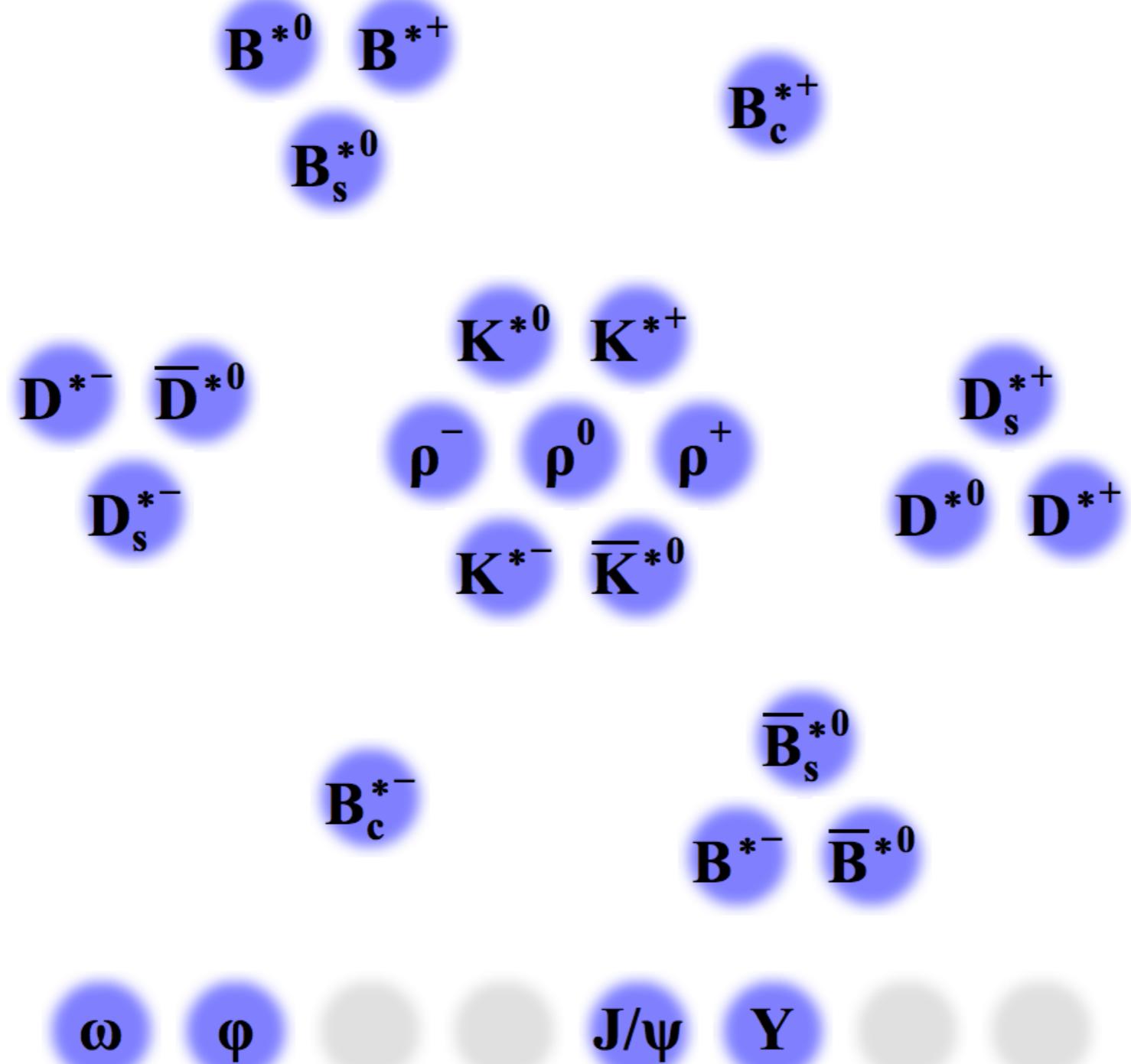
K_S^0 K_L^0

Mesons

pseudo-scalar
(spin-0)
mesons

vector
(spin-1)
mesons

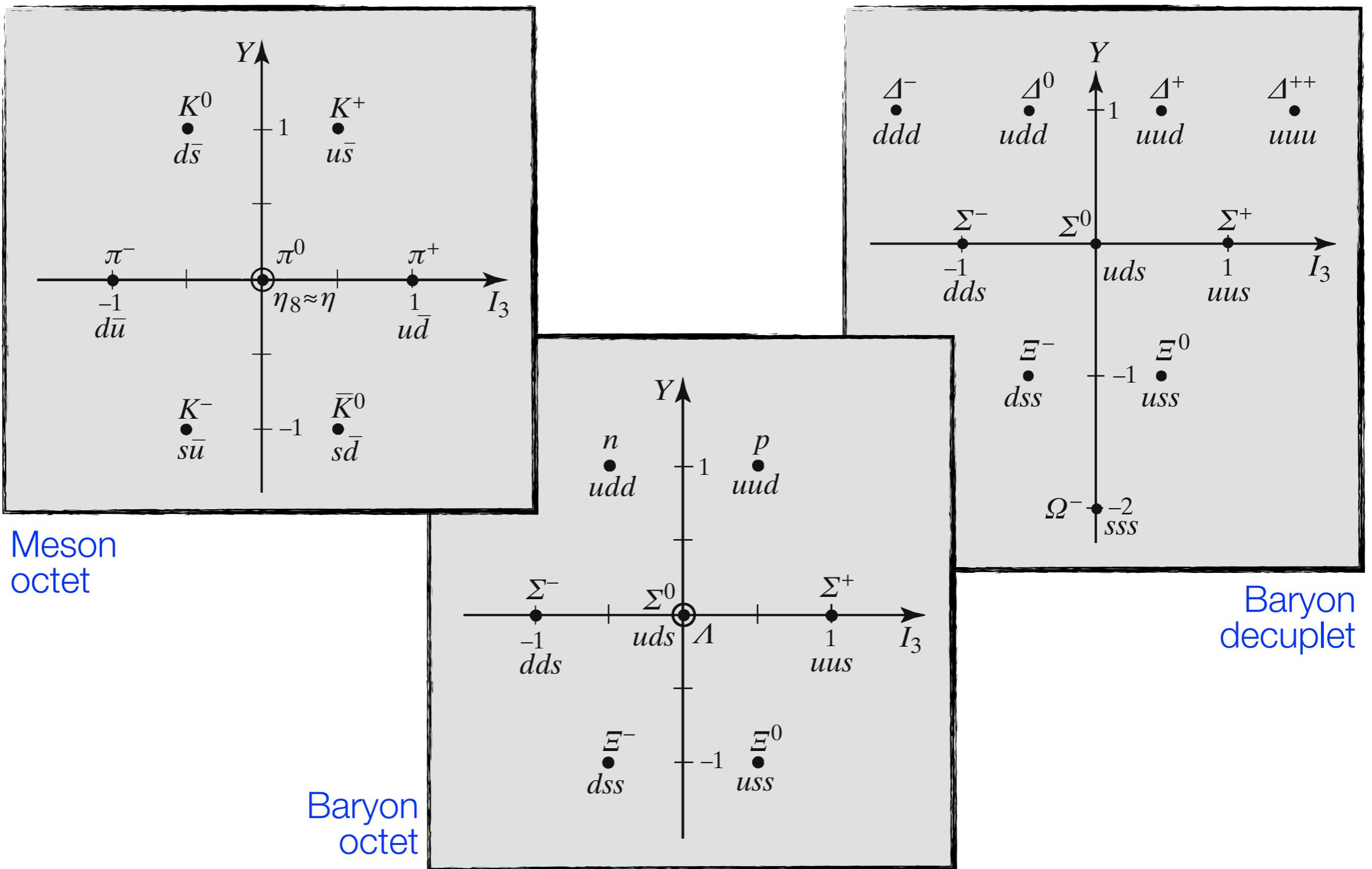
(anti) quarks
in
mesons



Mesons

<http://www.thingsmadethinkable.com/item/mesons.php>

Baryons and Mesons



ν_e e^-

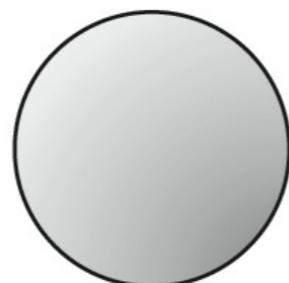
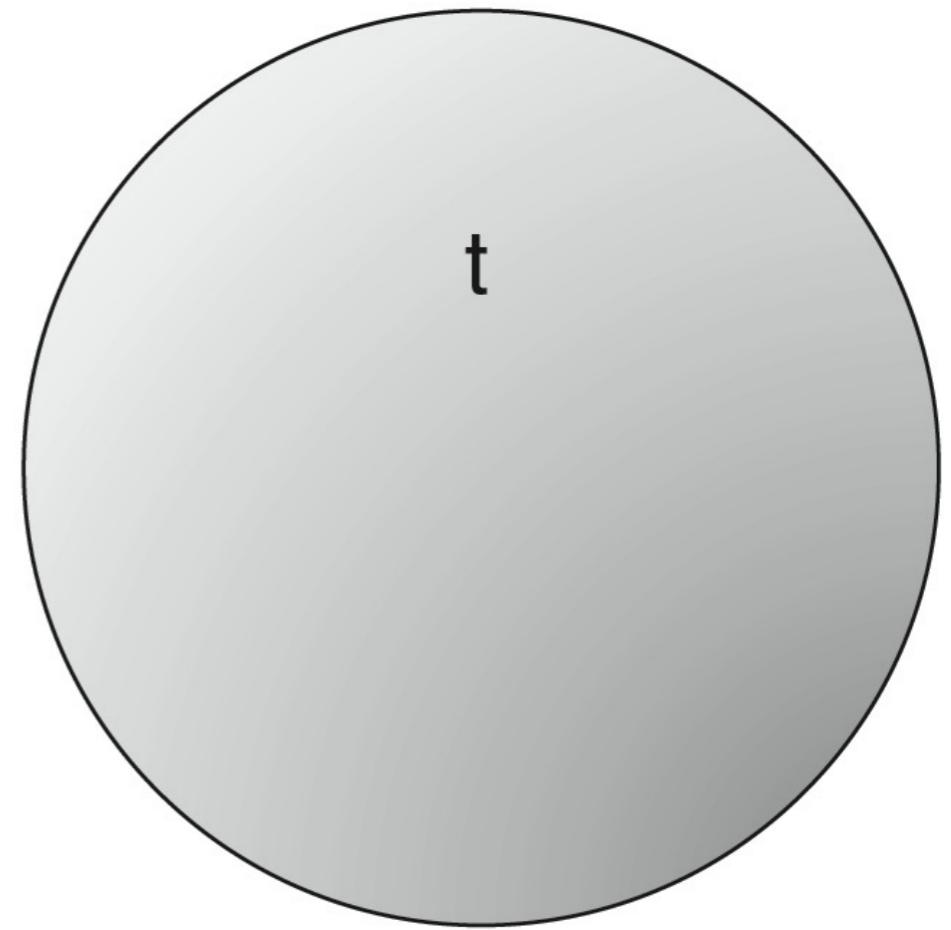
◦

 d

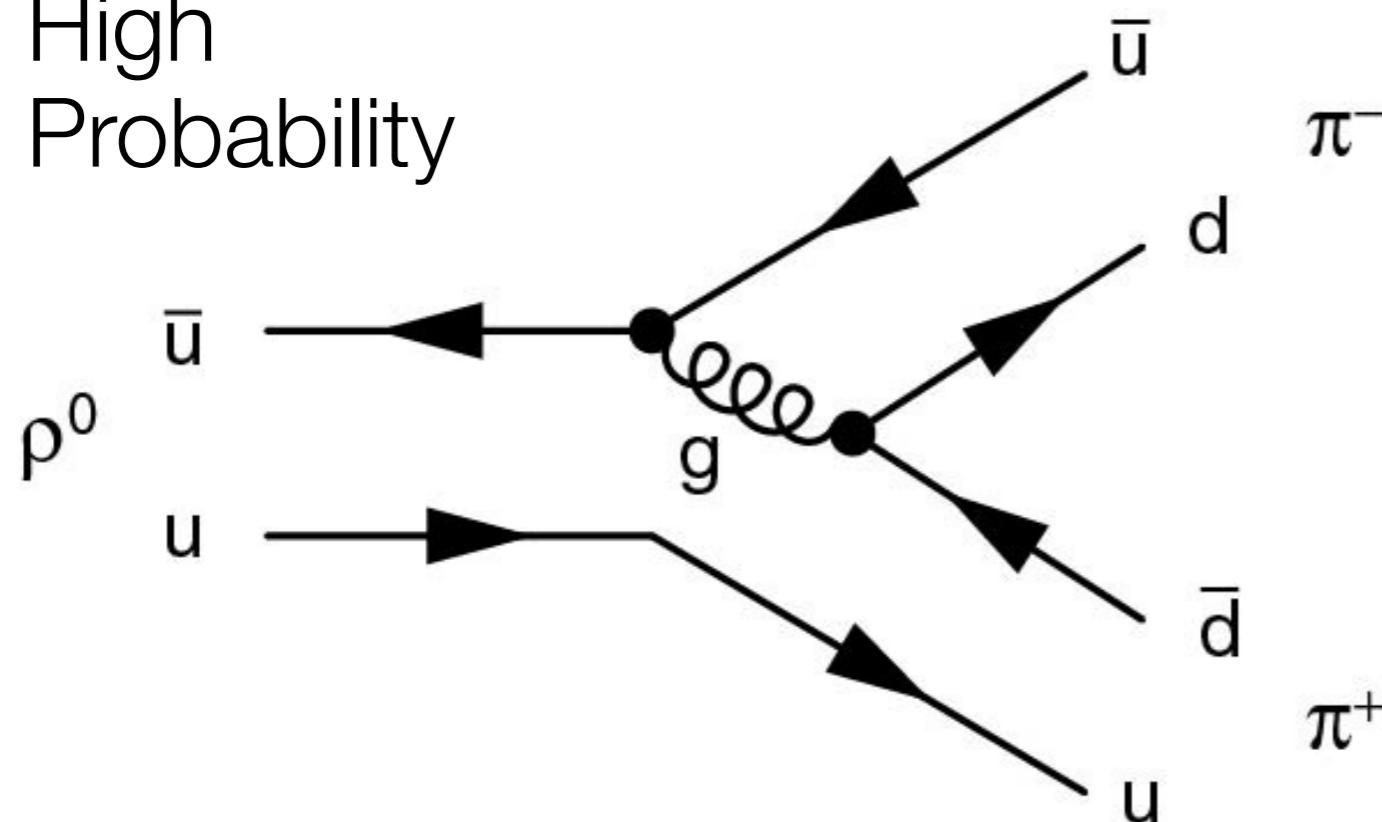
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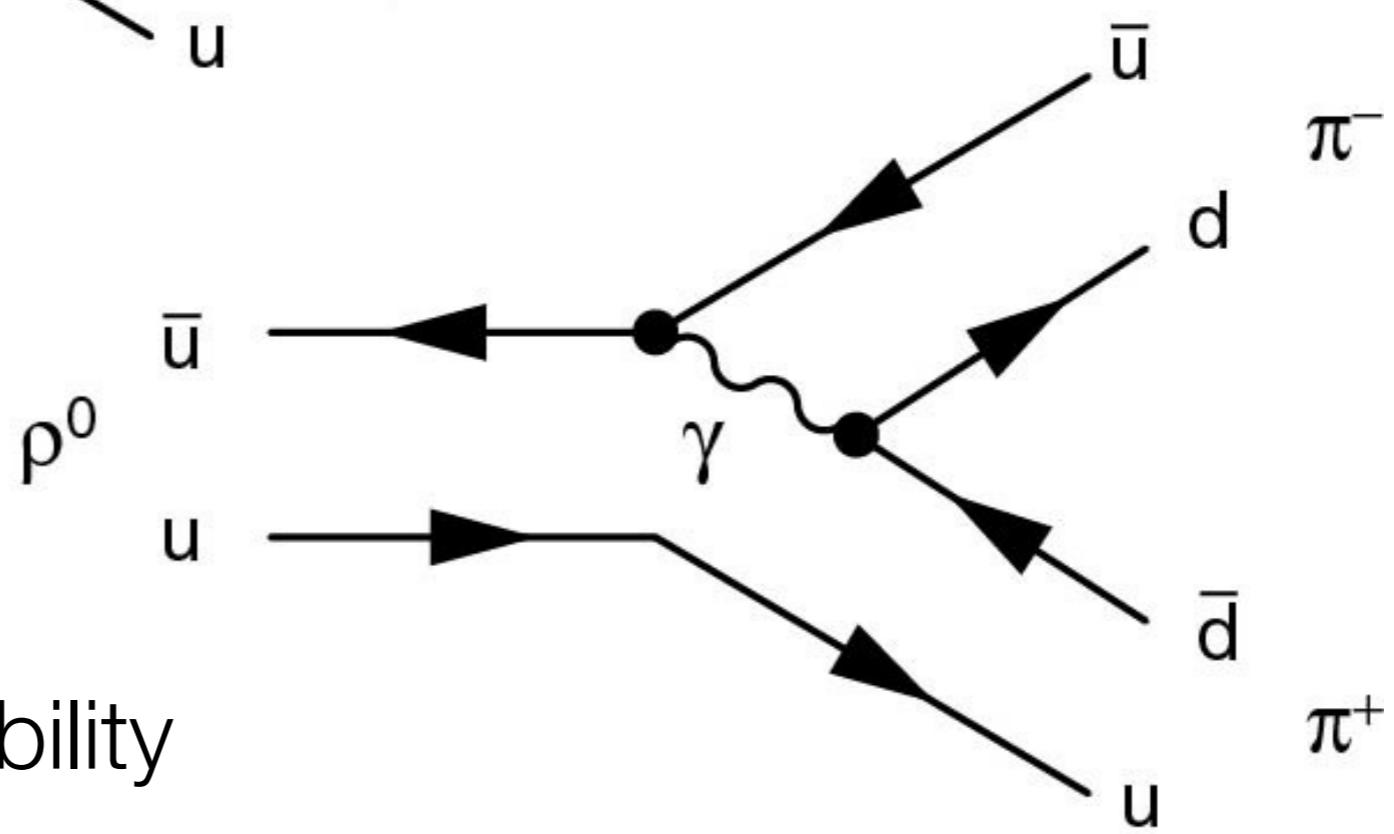
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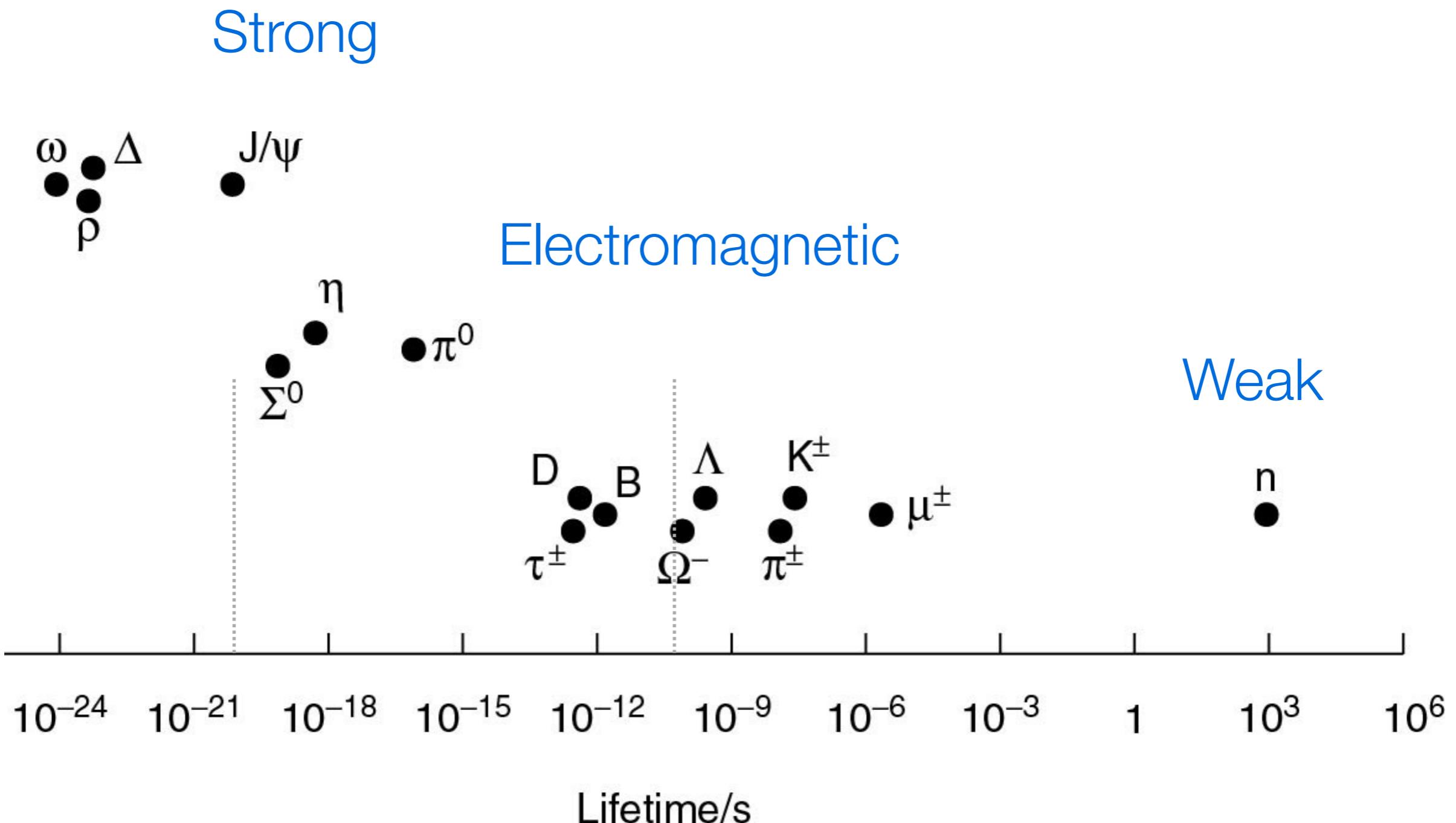
 ν_μ μ^-  s  c  ν_τ τ^-  b  t 

High
Probability



Low
Probability

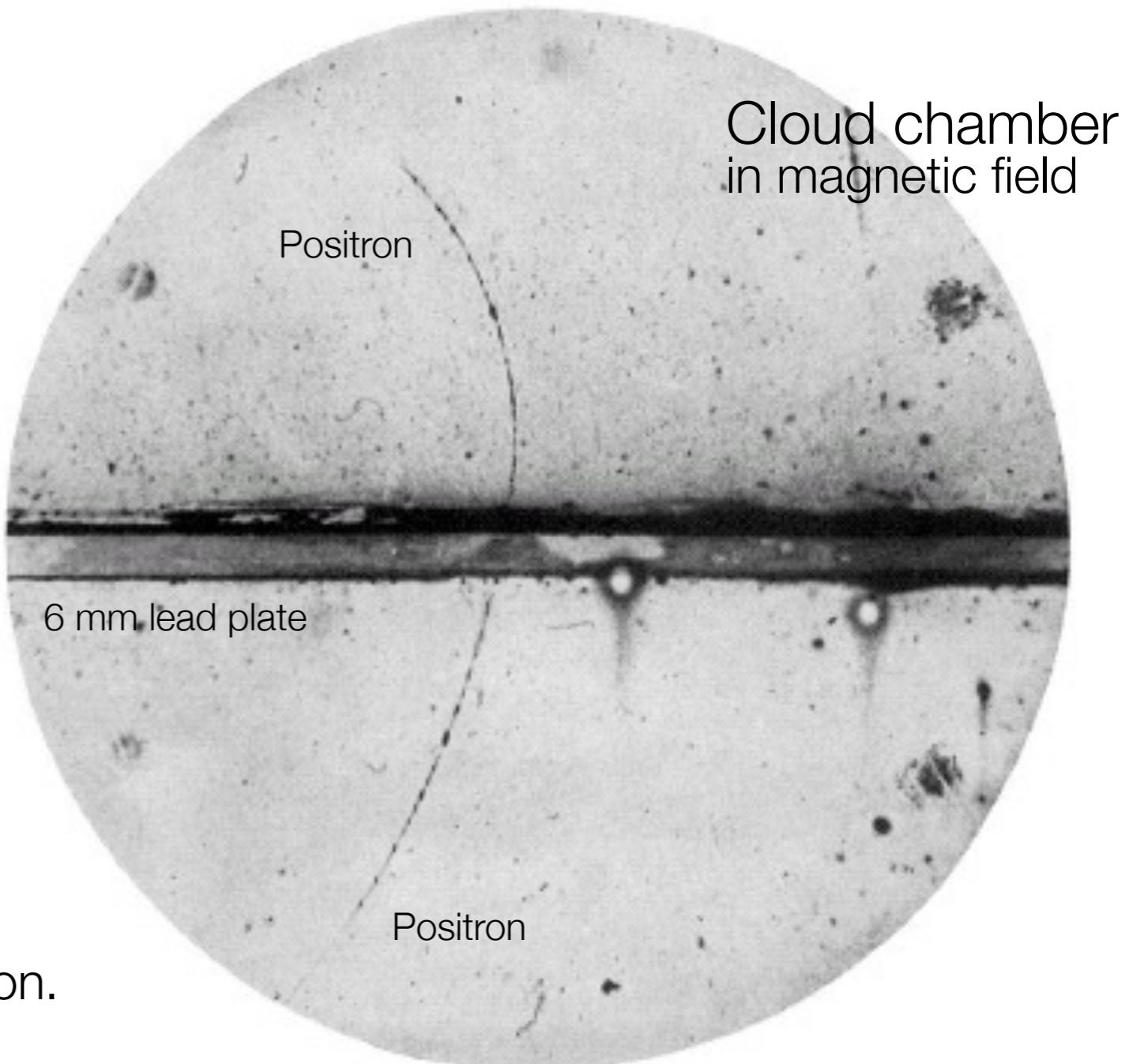




Historical Development

Discovery of antimatter

[Anderson 1932; Nobel prize 1936]



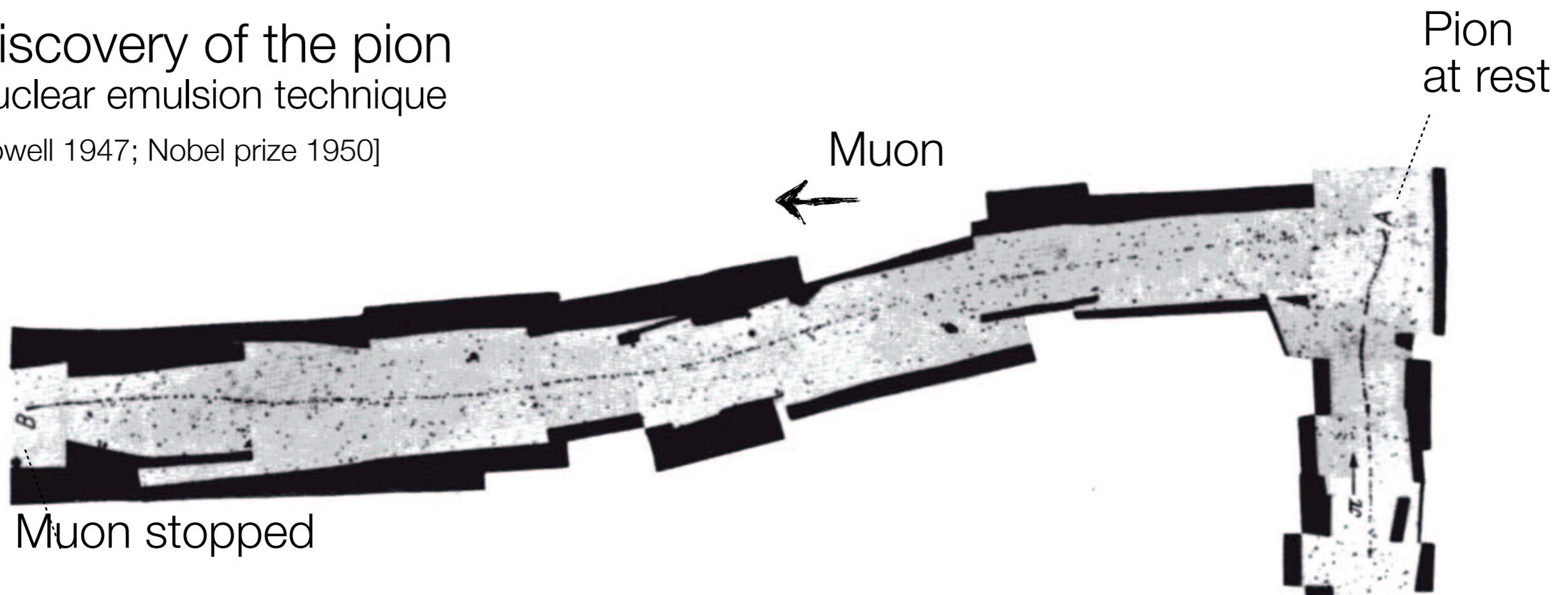
63 MeV positron passing through
lead plate emerging as 23 MeV positron.

The length of this latter pass is at least ten times
greater than the possible length of a proton path of this curvature.

Historical Development

Discovery of the pion
Nuclear emulsion technique

[Powell 1947; Nobel prize 1950]

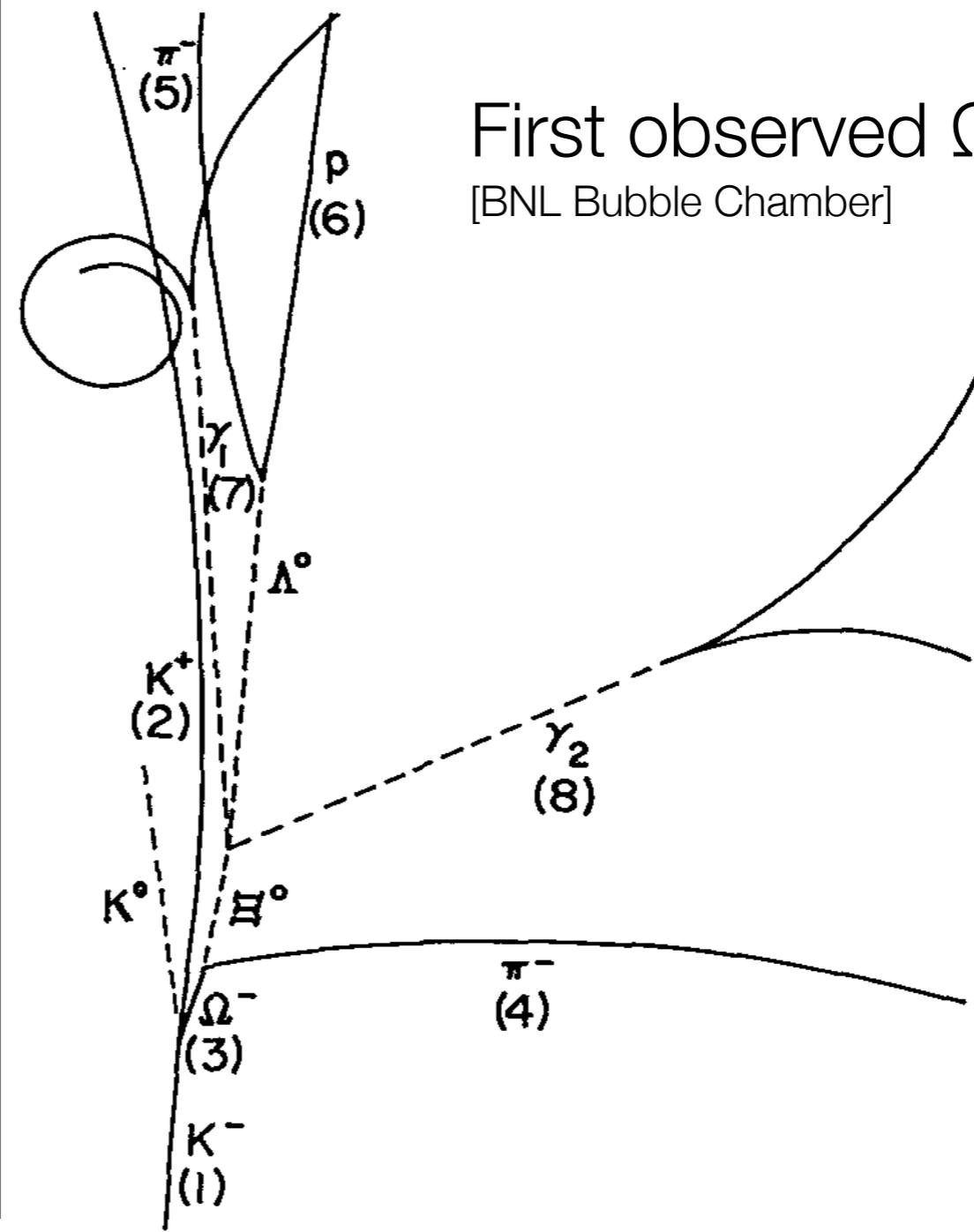
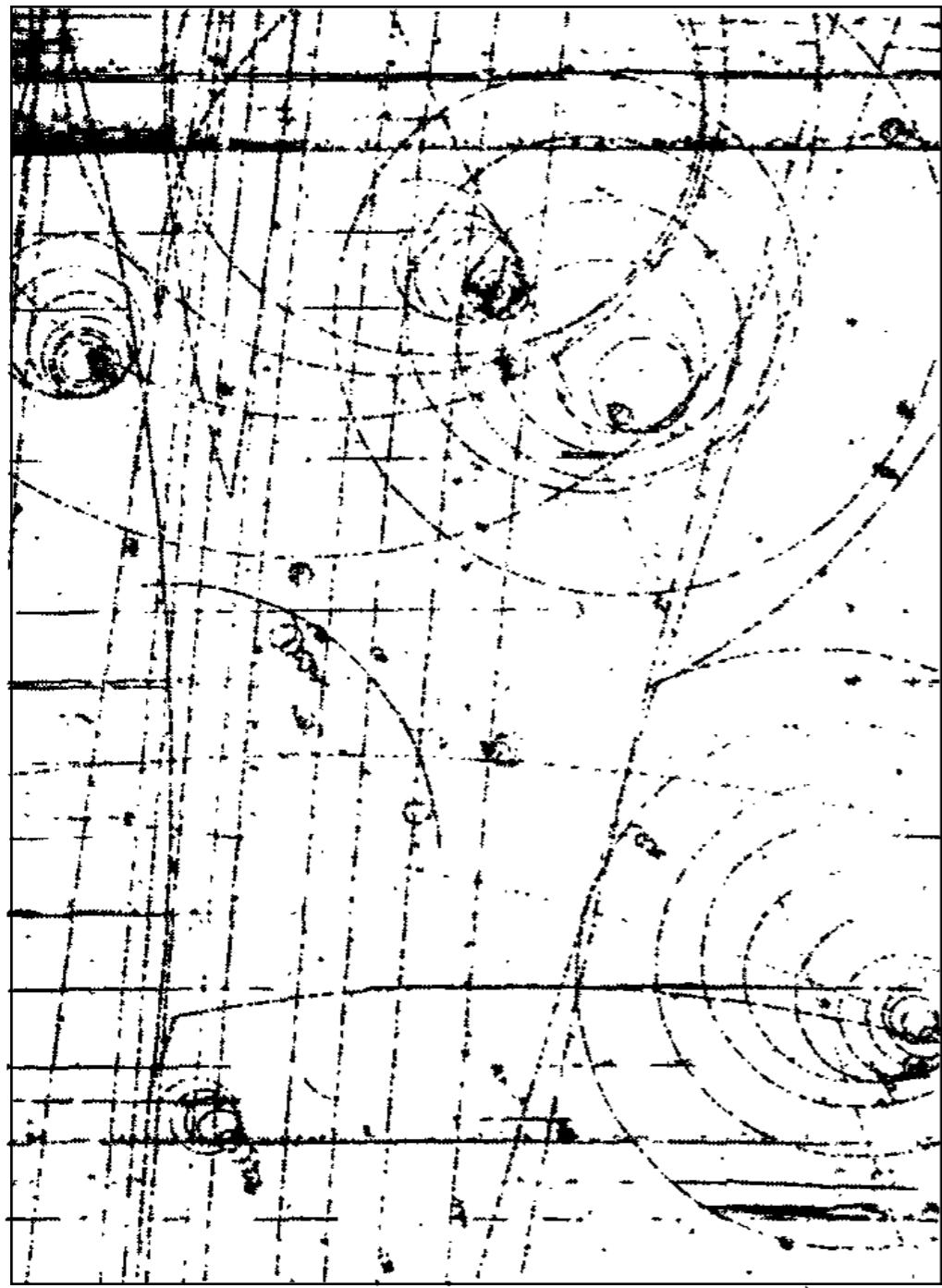


$$\pi \rightarrow \mu\nu$$

$$\mu \rightarrow e\nu\nu \text{ [not seen]}$$

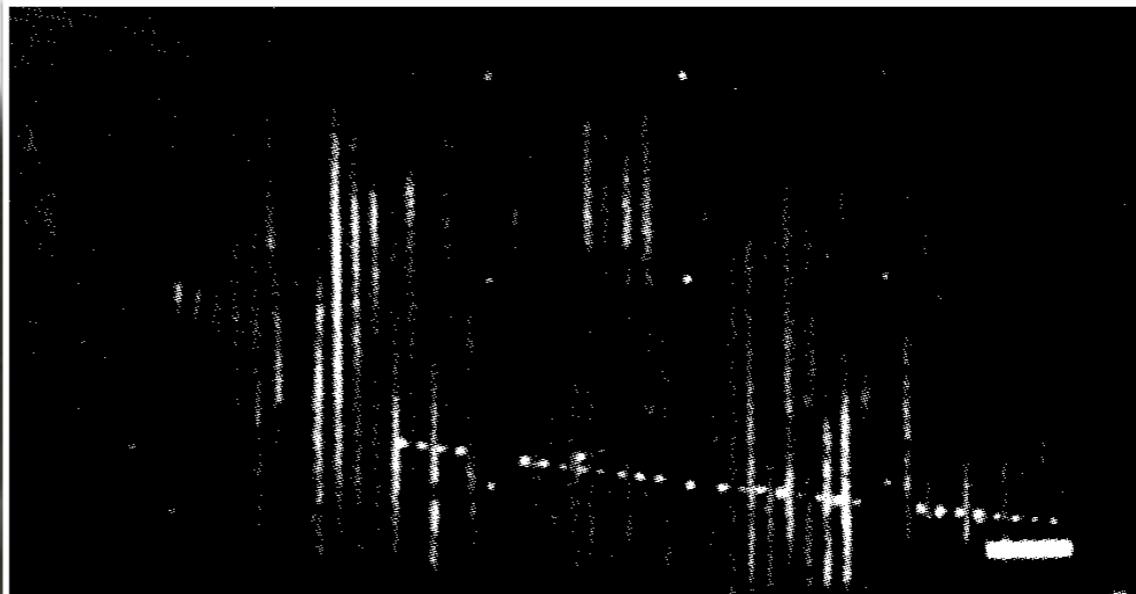
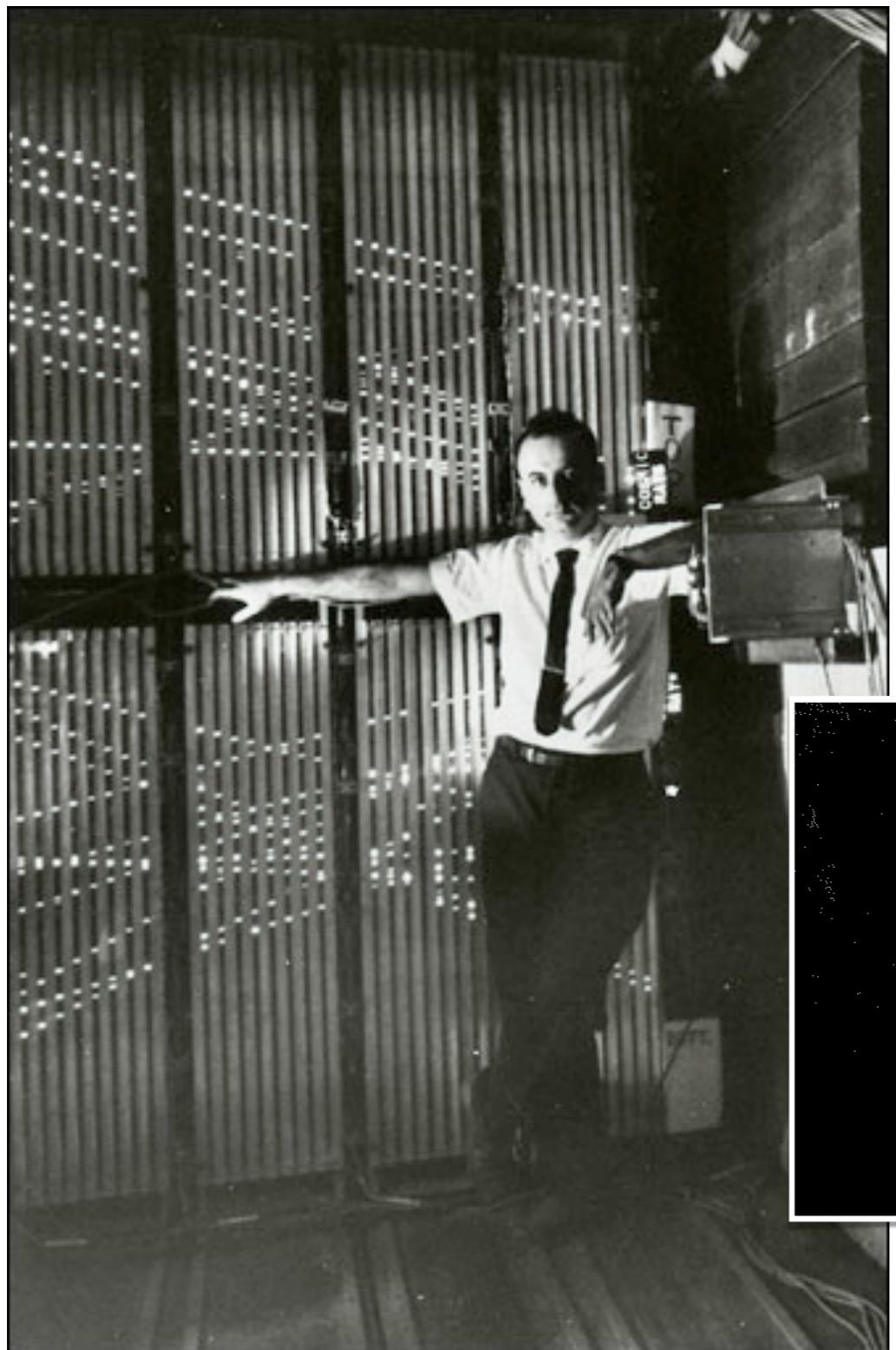
↑
Pion

Historical Development



First observed Ω^- event
[BNL Bubble Chamber]

Historical Development



Melvin Schwartz in front of the spark chamber used to discover the muon neutrino

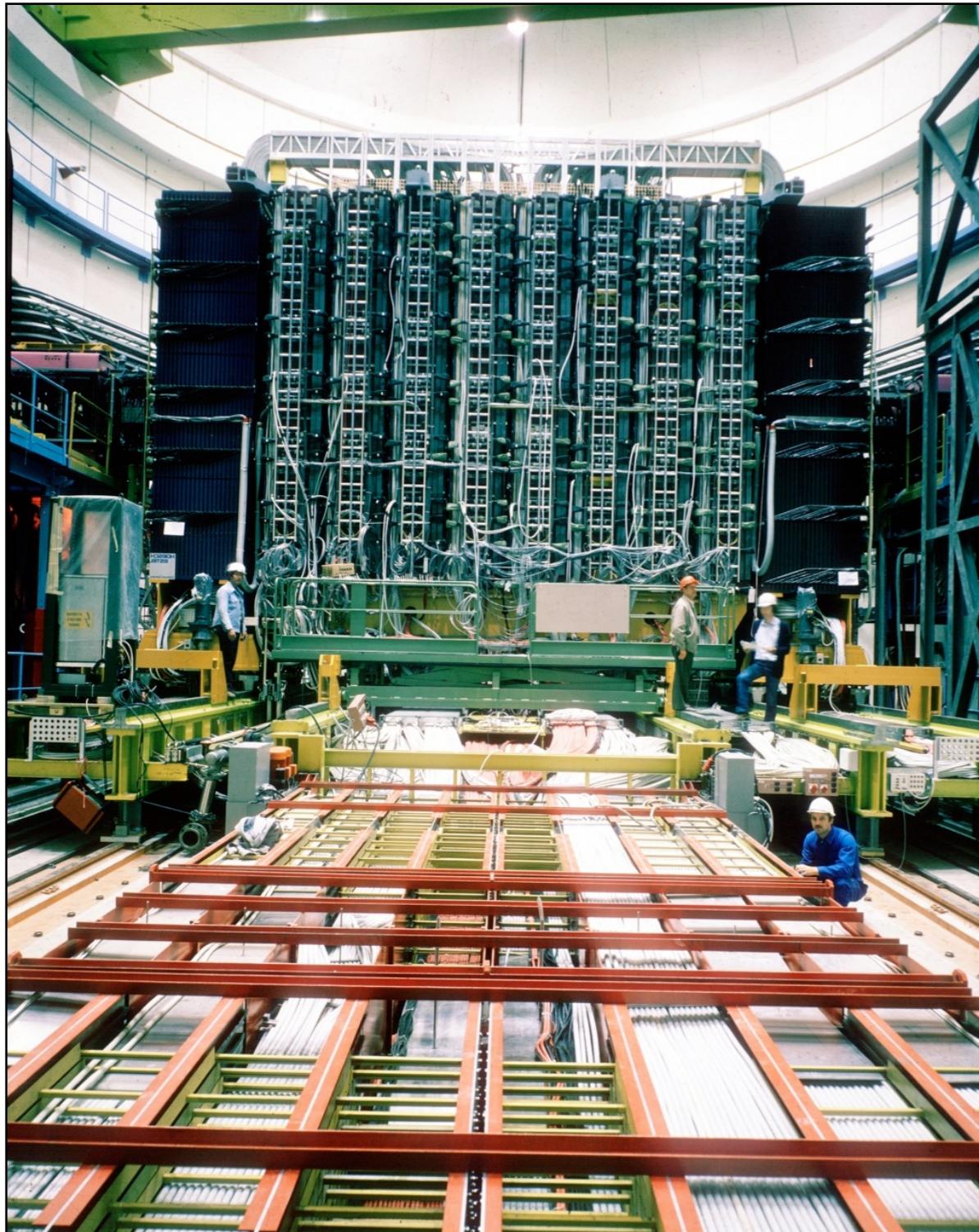
Discovery of the muon neutrino (1962)

Leon M. Lederman
Melvin Schwartz
Jack Steinberger

[Nobel prize 1988]

Single muon event from original publication

Historical Development

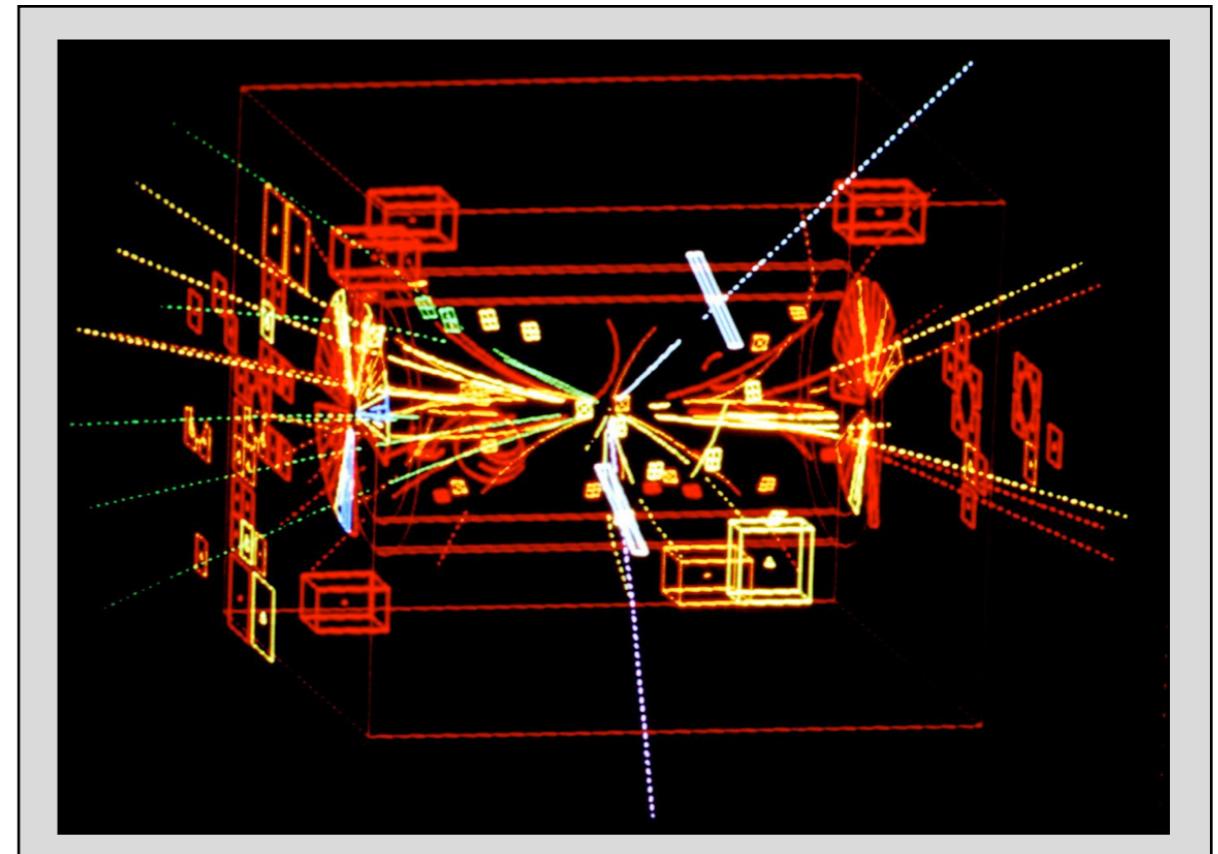


UA1
Detector

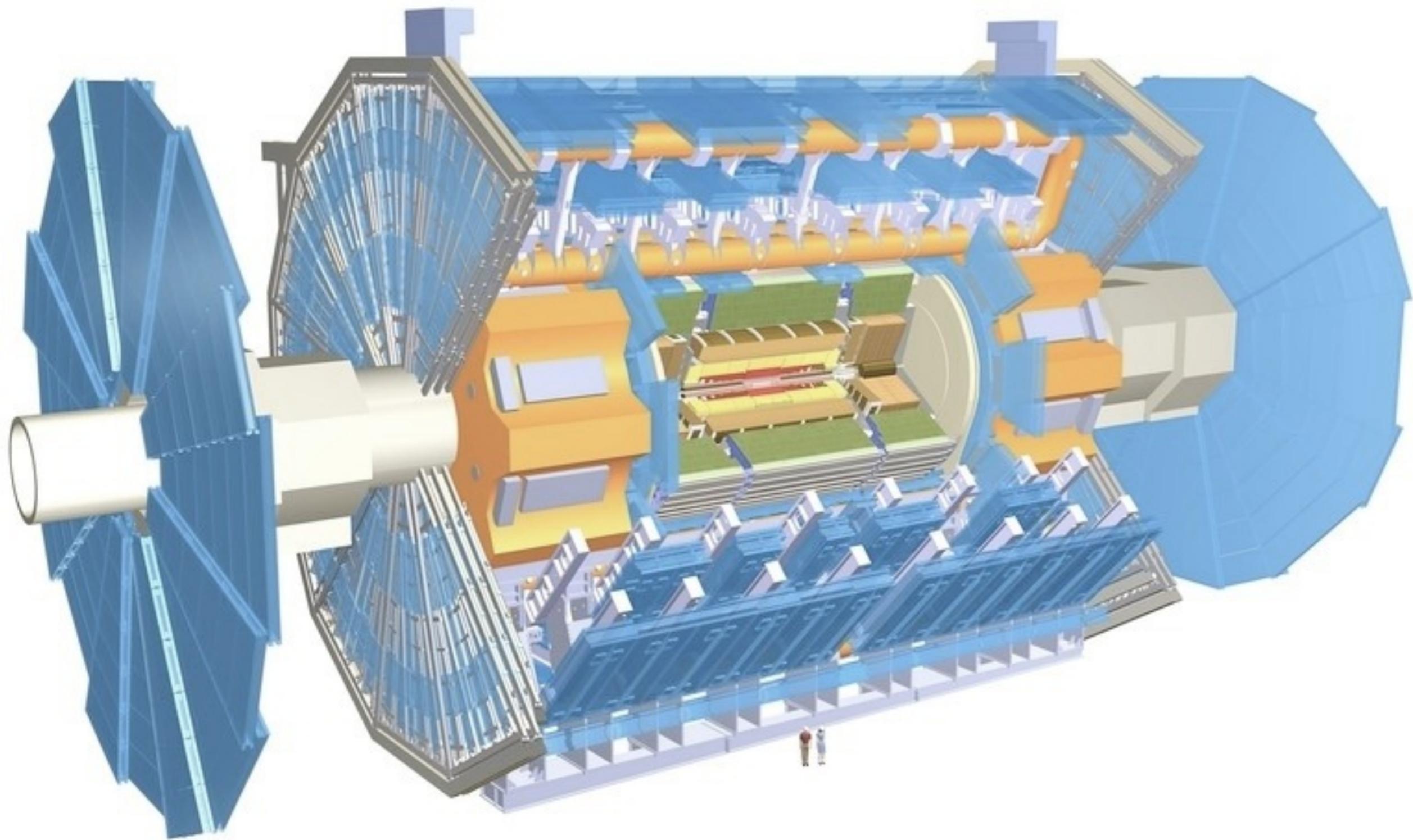
Discovery of the
W/Z boson (1983)

Carlo Rubbia
Simon Van der Meer
[Nobel prize 1984]

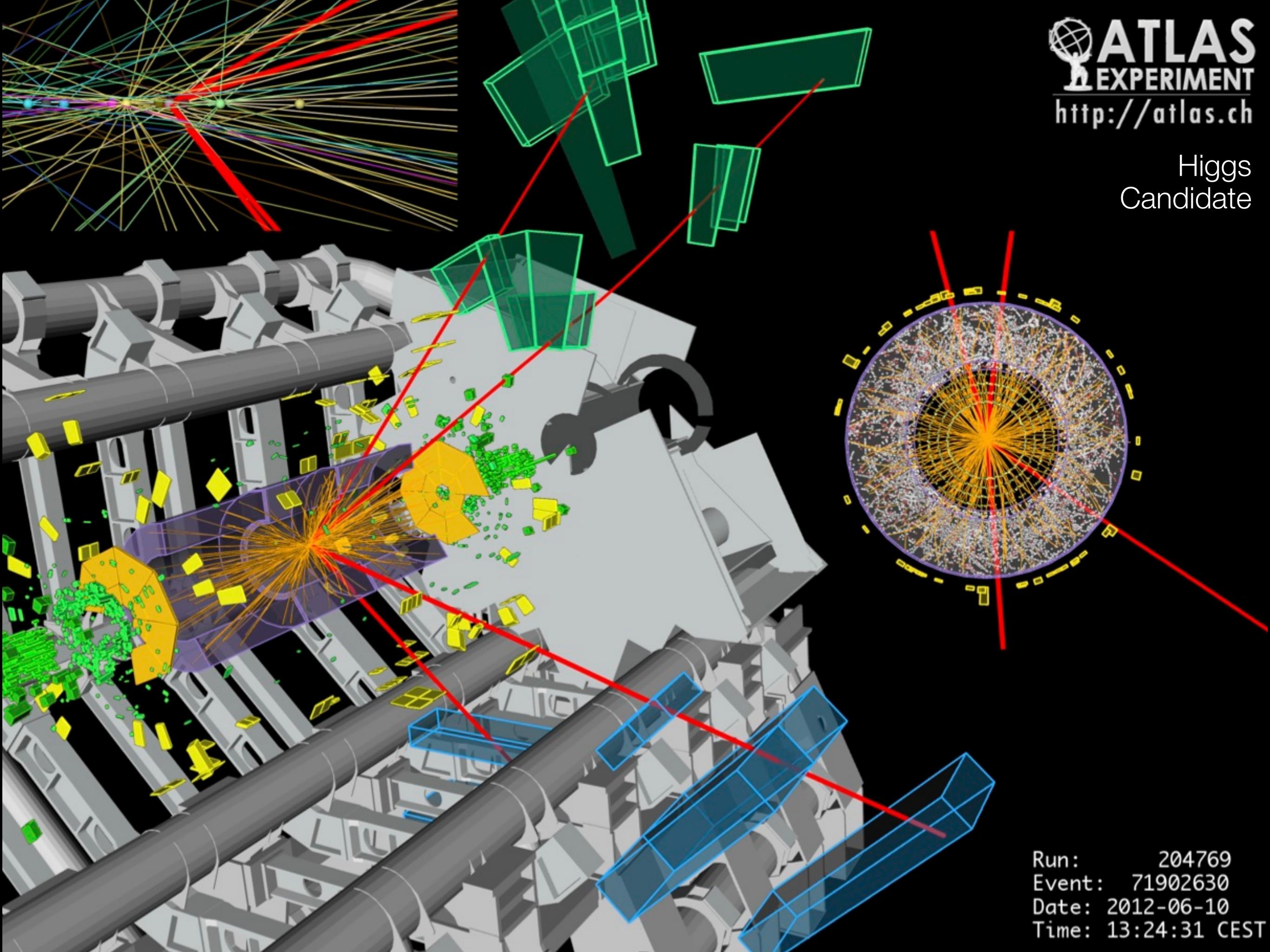
First Z^0 particle seen by UA1



The ATLAS Detector



Higgs
Candidate



Run: 204769
Event: 71902630
Date: 2012-06-10
Time: 13:24:31 CEST

