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Asymmetry of Matter-Antimatter

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CONTANTS

Part I
Particle Physics

The discovery of Elementary Particle

Elementary Particles: Quarks, Leptons(e, μ, τ, ν) and all Bosons (γ, Z^0, etc.)

1. **Photon** γ

   1900-1924, Planck, Einstein

   QFT: A quantum of the electromagnetic field

   carrier of the Electromagnetic Force,

   $m = 0$,

   boson ($s = \pm\hbar$)

   $\bar{\gamma} = \gamma$

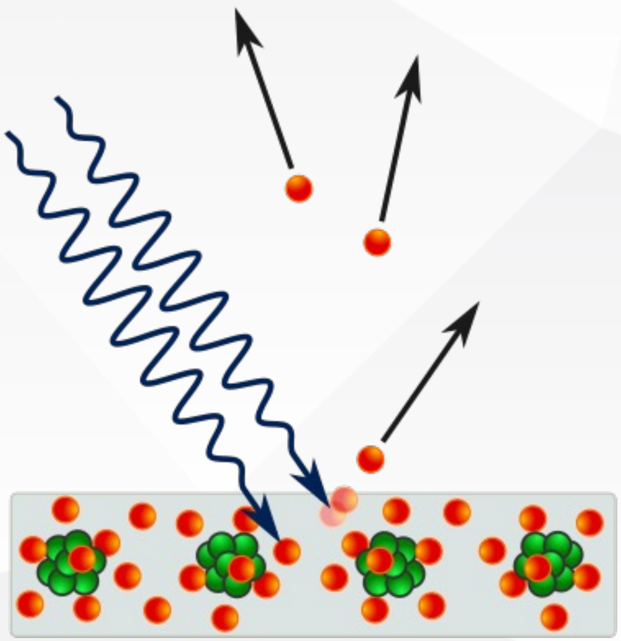


Fig.1: Photoelectric Effect

2. **Meson** π, K^0

1937-1947, Hideki Yukawa(1934): π

$m(\text{lepton}) < m(\text{Meson}) < m(\text{baryon})$

A type of Hardon,

carrier of the Nuclear Force(Strong Force),

$S = 0, 1\hbar,$

e.g. K^0 Meson.

(Not Elementary Particles.)

Fig.2: Hideki Yukawa

3. **Muon** μ^-

1936 in Cosmic Ray, a type of lepton.

mass similar with Meson,

no in Strong but in Weak /EM Interaction

unstable, decay: $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$

$S = \frac{1}{2}\hbar,$

$C = e,$

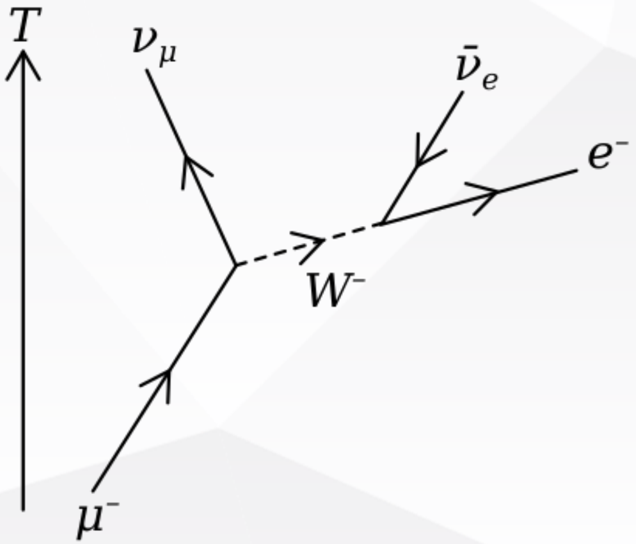


Fig.3: Feynman diagram of Muon decay

4. Neutrino ν

1930-1962, Pauli. Weak Interaction

$S = \frac{1}{2}\hbar, C = 0, m_{\mathrm{i}} = 0,$

Three Flavor ν_e, ν_τ, ν_μ

$\bar{\nu} \equiv \nu$? Majorana **Fermion**

From SN 1987A:

The beginning of Neutrino Astronomy

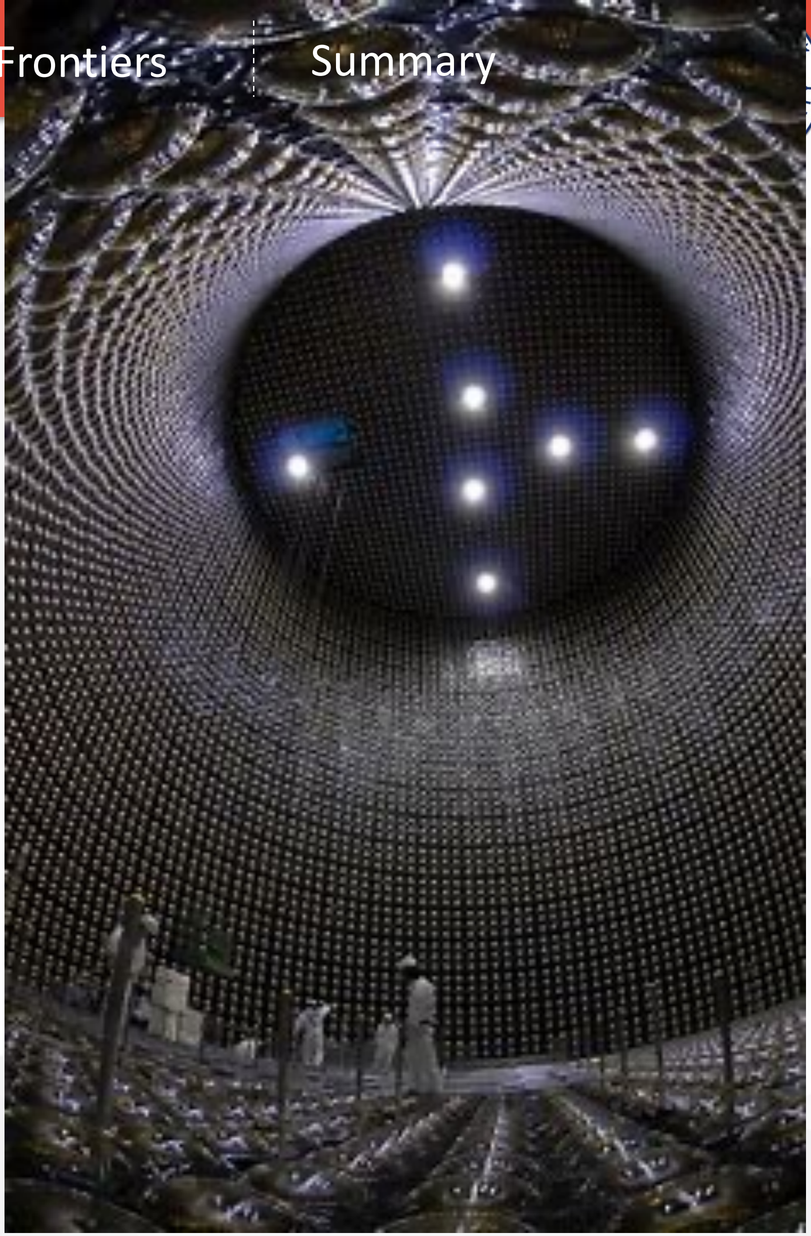


Fig.4: Super-Kamiokande

5. Lepton

Definition: **A type of elementary Fermion which do not participate in Strong Interaction**, including $e,\ \mu,\ \nu,\ \tau,\ S=\pm\frac{1}{2}\hbar$

Conservation of Lepton Number:

$$L=\begin{cases} 1, & \text{Leptons,} \\ -1, & \text{Antileptons,} \\ 0, & \text{others.} \end{cases}$$

6. Baryon

Definition: **A type of Composite, Fermion that participates in Strong Interaction.** It Contain three Quarks.

Δ, Nucleon(p, n), and Hyperon(Ω, etc.).

Conservation of Baryon Number:

$$B = \begin{cases} 1, & \text{Baryons,} \\ -1, & \text{Antibaryons,} \\ 0, & \text{others.} \end{cases}$$

*Essentially Baryon are composed of **Three different quarks of Color**.*

B Numbers → Conservation of Quark Number.

7. Hardon: Strong Interactions.

- Baryons
- Mesons

1961, **Eightfold way** , the Modern Particle Physics

8. Antiparticles

Dirac: Positrons, 1932

The Same: m, τ, S.

Different: B, C, μ_B, Strangeness Number

Annihilation: $a + \bar{a} \rightarrow \pi^0 \rightarrow \gamma$

e.g. electron-positron pair $e^- + e^+ \rightarrow \gamma + \gamma$

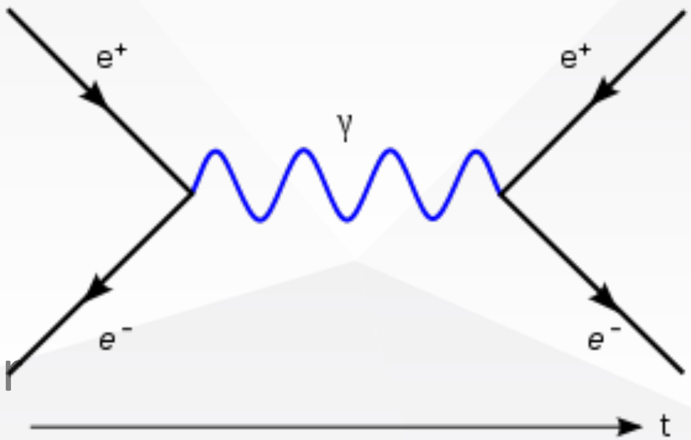


Fig.5 : Pair Annihilation

Summary of Part I

$$
\begin{cases}
\text{Elementary Particles} \begin{cases}
\text{Fermions} \begin{cases} \text{Quark,} & \text{udcstb} \\ \text{Leptons,} & e\mu\tau\nu \end{cases} \\
\text{Bosons,} \qquad \gamma, Z^0, \text{etc.}
\end{cases} \\
\text{Composite Particles} \begin{cases}
\text{Hardons} \begin{cases}
\text{Baryons} \begin{cases} & \Delta \\ \text{Neuclons,} & \boldsymbol{p}, \boldsymbol{n} \\ \text{Hyperons,} & \gamma, \Sigma, H, \Omega \end{cases} \\
\text{Mesons,} \qquad \pi, K, D, B, \text{etc.}
\end{cases} \\
\text{others,} \qquad \text{Nucleus, etc.}
\end{cases}
\end{cases}
$$

Part II
Three Necessary Conditions for Symmetry Breaking

Asymmetry of Matter-Antimatter

- How to distinguish Matter and Antimatter?
  - Not ν, hard to receive it. Not γ, $\gamma = \bar{\gamma}$
  - Annihilation of particles and antiparticles.
- α particle is stable: 1988, AMS. No news till now.
- Cannot observe antimatters in the area of $10\ \mathrm{Mpc}$
- Based on Observation facts:

Anti-matter Does Not Exist in the universe.

BAU and BSU

- BAU (Baryon Asymmertic Universe)

  BSU (Baryon Aymmertic Universe)

- A faith: God do not have predilection
- But, today is BAU and B numbers is conserved.

  How does the BSU evolve to the BAU?

- 1960, Sakharov: 3 Necessary Condition for the evolution

  1. **B numbers is not conserved,**
  2. **C Violation and CP violation,**
  3. **Deviation of Thermobalance in some stages.**

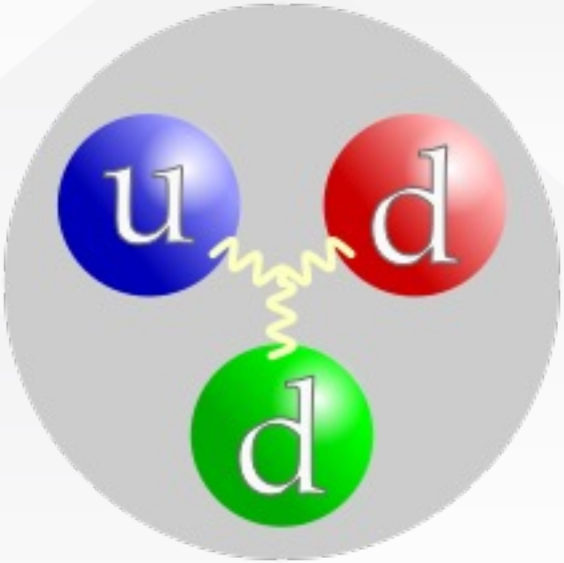
1. B numbers(& L Numbers) is not conserved

- Some unknown processes during the evolution of the universe broke the balance, consuming more anti-baryons.
- Some Grand Unification Theory(GUT) could guarantee

  Idea: Today's Particle Exp. condition: $< 10^3$ GeV,

  But the universe was much higer than this.

  New mechanisms in the *super* Higher Energy?



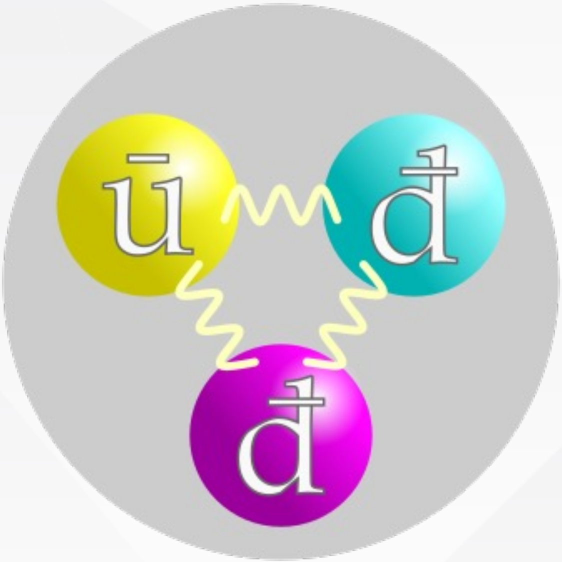


Fig 6: Neutrons, $B = \frac{1}{3} + \frac{1}{3} + \frac{1}{3}$

Fig 7: Antineutrons, $B = -1$

1956, Lawrence Berkeley National Laboratory, U.S.

3. Deviation from thermobalance

There must have been a period when the universe was substantially out of thermal equilibrium

$$a \leftrightharpoons b + c$$

2. C Violation & CP Violation

Four type of Discrete Symmetries:

- Charge Conjugation Symmetry (C)
- Parity Symmetry (P)
- $C + P = CP$ symmetry
- Time Reversal symmetry(T)

- P Transformation

    - P Conservation

- P Violation - J.X. Wu, 1956

$$\boxed{{}^{60}\mathrm{Co} \rightarrow {}^{60}\mathrm{Ni} + \mathrm{e} + \bar{\nu}_e}$$

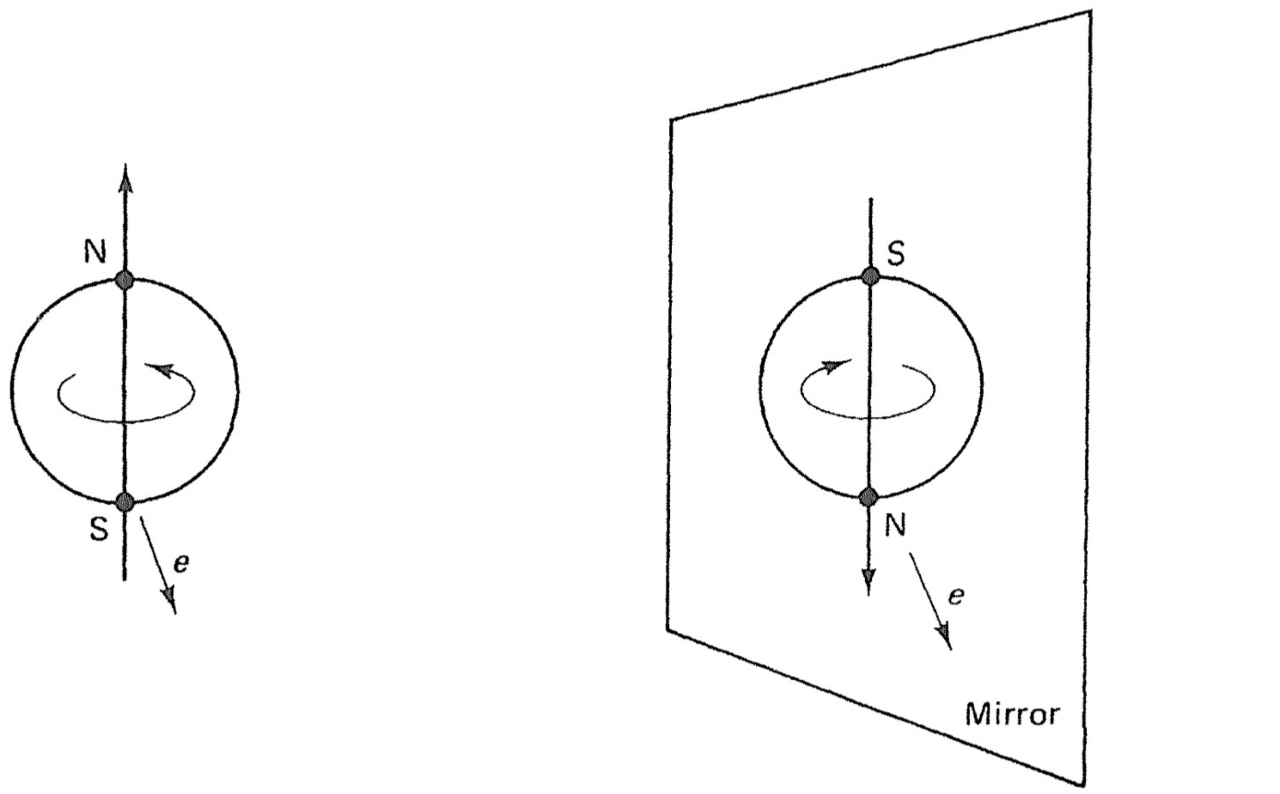


Fig. 4.7 In the beta decay of cobalt 60, most electrons are emitted in the direction opposite to the nuclear spin.

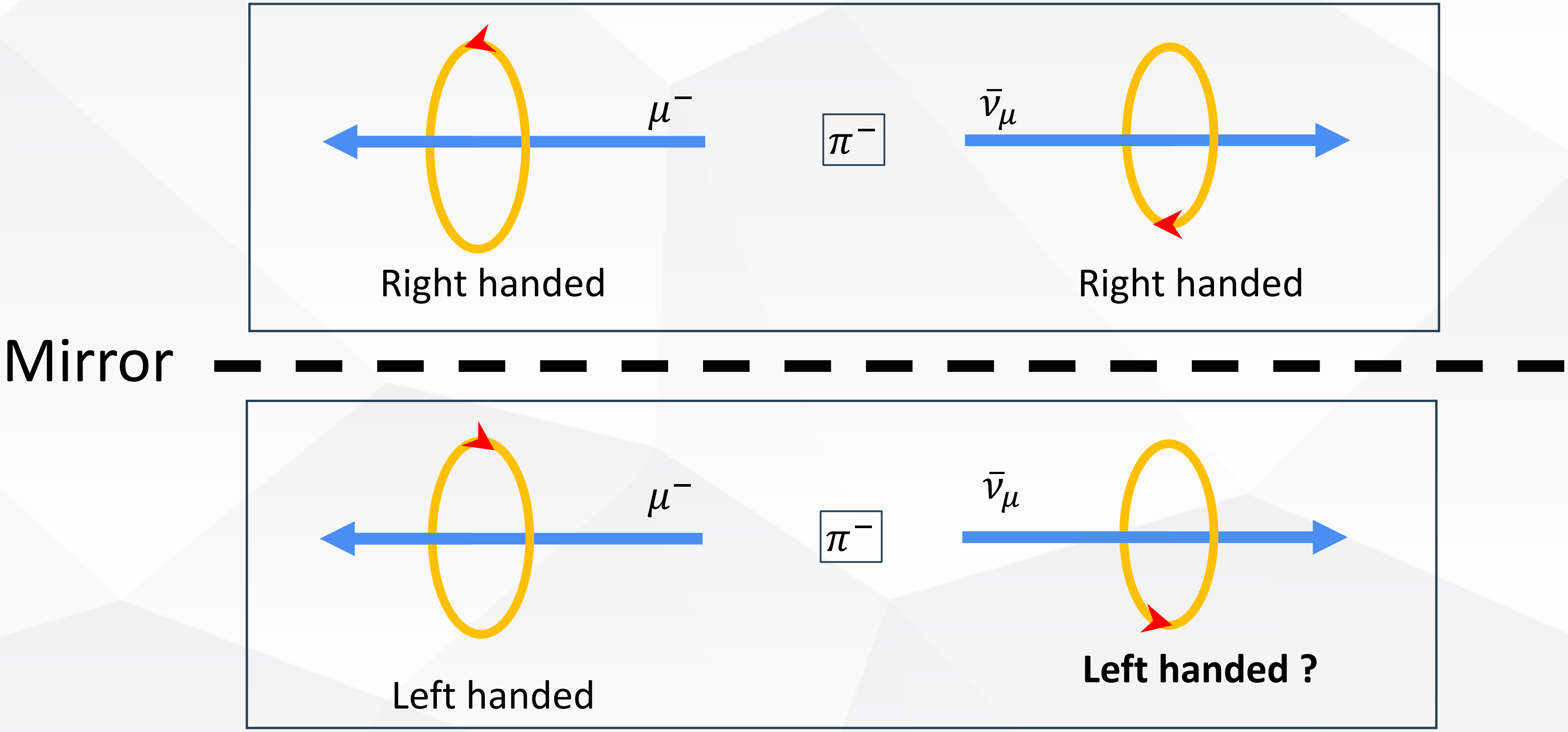
Fig. 4.8 Mirror image of Figure 4.7: Most electrons are emitted parallel to the nuclear spin.

P violation is a signature of Weak Interaction

Experiment result
ν: Left handed
$\bar{\nu}$: Right handed

- P Violation - π Decay

$$\pi^- \to \mu^- + \bar{\nu}_\mu$$



P transformation does not exist.

***P* violation is a signature of Weak Interaction**

C Transformation

- switch particles with their corresponding antiparticles.

  It **does not** changes Mass, Energy, Momentum, Spin

  It change e, B, L, etc.

- **C conservation**: The probabilities of Two processes are the same.

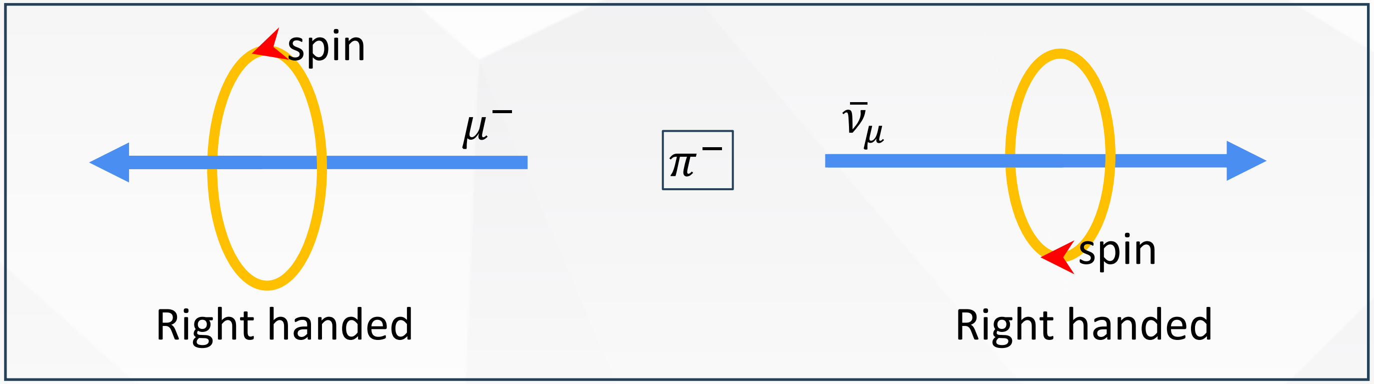
- It holds in Strong/EM Interaction. But not in Weak Interaction

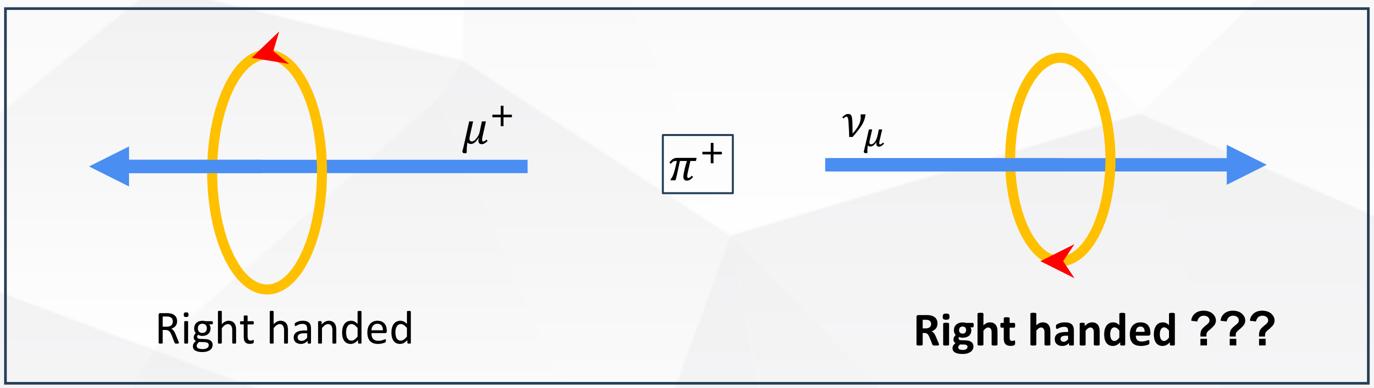
a must be consumed more than $\bar{a}$.

Experiment result
ν: Left handed
$\bar{\nu}$: Right handed

- C Violation

$$\pi^- \to \mu^- + \bar{\nu}_\mu$$





C transformation:

$$\pi^+ \to \mu^+ + \nu_\mu$$

Does not exist

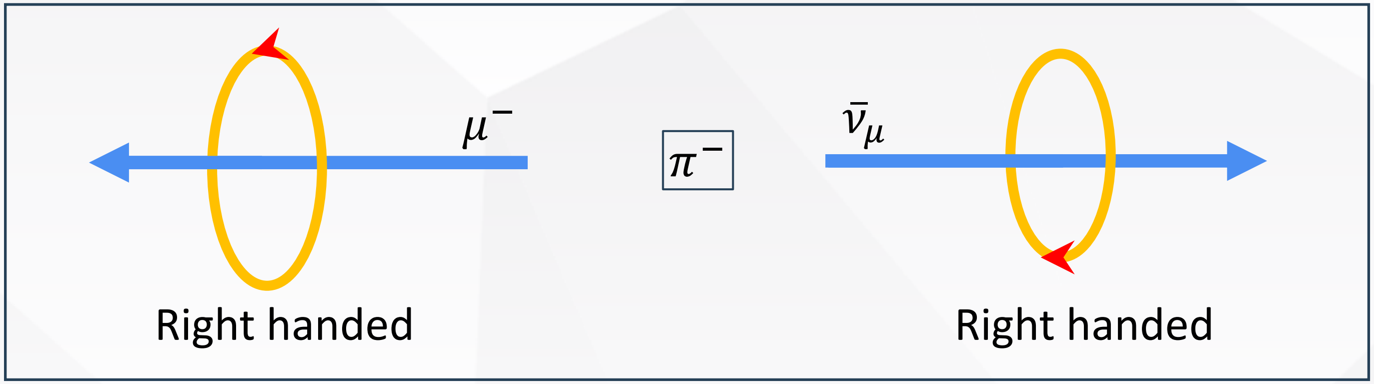
- CP violation

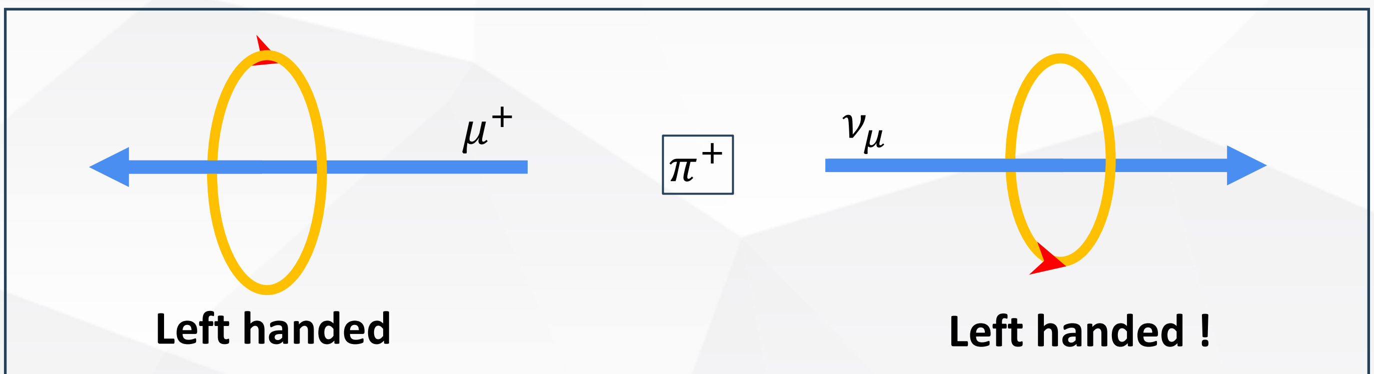
Again, a must be consumed more than $\bar{a}$.

Experiment result
ν: Left handed
$\bar{\nu}$: Right handed

- CP Symmetry

$$\pi^- \to \mu^- + \bar{\nu}_\mu$$





CP transformation:

$$\pi^+ \to \mu^+ + \nu_\mu$$

CP symmetry

- CP violation ?

$\boxed{\text{Neutral K Decay}}$

First reported by Cronin and Fitch, 1964

$\boxed{\text{Neutral B Decay}}$

Carter and Sanda, 1981

$\mathrm{B}^0 \to \mathrm{K}^+ + \pi^-$, 13%

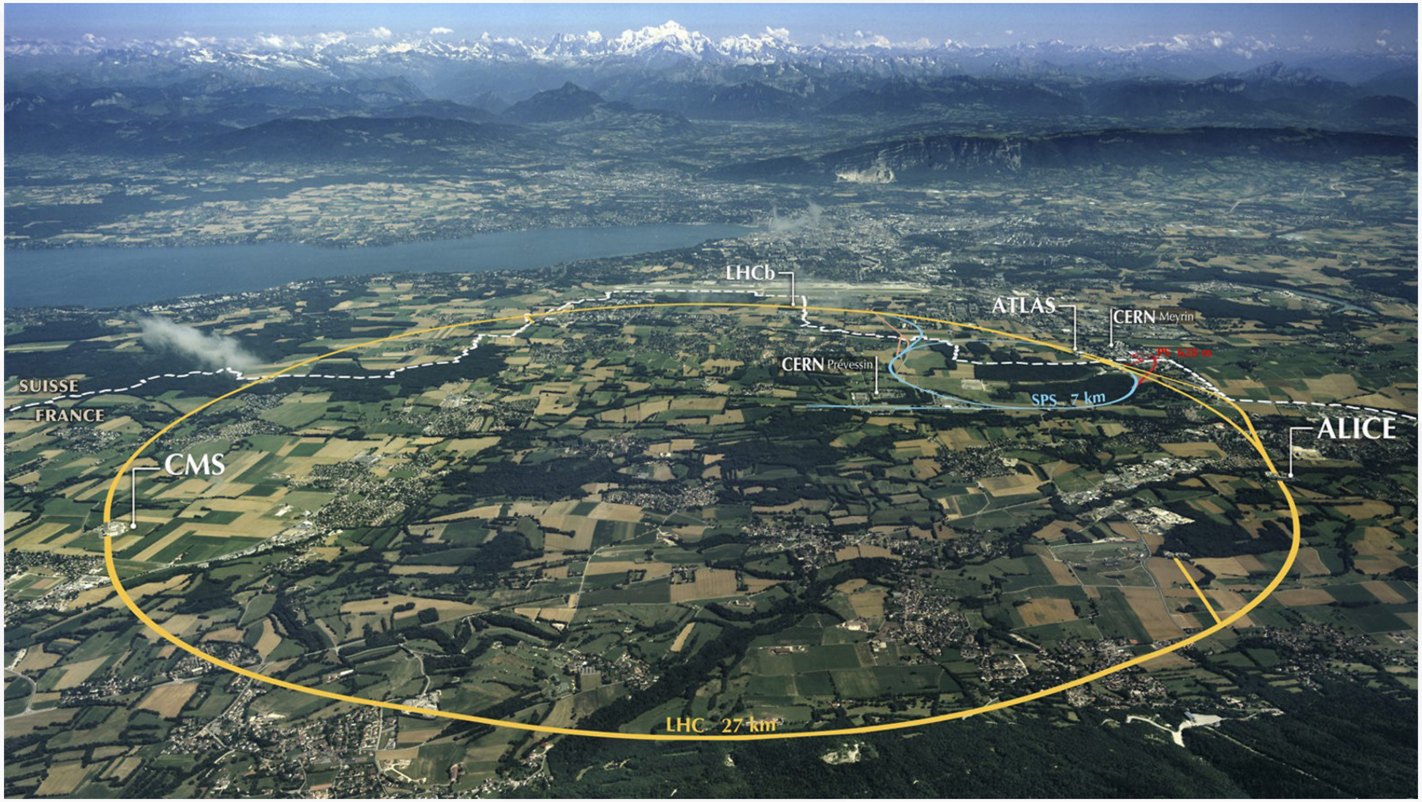
In the Frontier…

Summary

- If BSU → BAU: 3 conditions
  - B is not conserved
- Discrete Symmetry
  - P Symmetry: a signature of Weak Interaction
  - $\boldsymbol{C}$ **Symmetry – violation:** consume of antiparticle
  - $\boldsymbol{CP}$ **Symmetry - violation** (π Decay)
  - CPT Symmetry in Quantum Field Theory

Part III
Frontier

- CERN, European Organization for Nuclear Research, Geneva, Switzerland
- The Large Hadron Collider, LHC, The Largest Particle Experiment Instrument in the world



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Observation of *CP* violation in $B^{\pm} \to DK^{\pm}$ decays ☆

LHCb Collaboration

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ABSTRACT

An analysis of $B^{\pm} \to DK^{\pm}$ and $B^{\pm} \to D\pi^{\pm}$ decays is presented where the D meson is reconstructed in the two-body final states: $K^{\pm}\pi^{\mp}$, $K^{+}K^{-}$ and $\pi^{+}\pi^{-}$. Using 1.0 fb^{-1} of $\sqrt{s} = 7$ TeV pp collisions, measurements of several observables are made including the first observation of the suppressed mode $B^{\pm} \to [\pi^{\pm}K^{\mp}]_D K^{\pm}$. *CP* violation in $B^{\pm} \to DK^{\pm}$ decays is observed with 5.8σ significance.

B meson is a hot spot in the past 20 years

04/2012

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First Observation of CP Violation in the Decays of B_s^0 Mesons

R. Aaij *et al.* (LHCb Collaboration)

Phys. Rev. Lett. **110**, 221601 – Published 30 May 2013

Physics See Synopsis: Asymmetry in Strange-Beauty Mesons

Article | References | Citing Articles (83) | PDF | HTML | Export Citation

ABSTRACT

Using pp collision data corresponding to an integrated luminosity of $1.0\ \mathrm{fb}^{-1}$ and collected by LHCb in 2011 at a center-of-mass energy of 7 TeV, we report the measurement of direct CP violation in $B_s^0 \to K^-\pi^+$ decays, $A_{CP}(B_s^0 \to K^-\pi^+) = 0.27 \pm 0.04(\mathrm{stat}) \pm 0.01(\mathrm{syst})$, with significance exceeding 5 standard deviations. This is the first observation of CP violation in the decays of B_s^0 mesons. Furthermore, we provide an improved determination of direct CP violation in $B^0 \to K^+\pi^-$ decays, $A_{CP}(B^0 \to K^+\pi^-) = -0.080 \pm 0.007(\mathrm{stat}) \pm 0.003(\mathrm{syst})$, which is the most precise measurement of this quantity to date.

Issue

Vol. 110, Iss. 22 — 31 May 2013

05/2013, cited 100+

CERN Accelerating science

News › New

The new LHCb results focus on “direct” CP violation: a phenomenon where the same decay process has a different probability for a particle than for an antiparticle. The strongest global asymmetry was observed for the decay into two kaons and one pion, where the probability of a $B^+ \to \pi^+ K^+ K^-$ decay is about 20% higher than for the $B^- \to \pi^- K^+ K^-$ decay (corresponding to a measured CP asymmetry A_{CP} of -0.114). A global CP asymmetry has also been observed with a significance of more than five standard deviations for the first time in decays into three pions and decays into three kaons. For the final state with two pions and one kaon, CP violation is still not confirmed.

Voir en franç

Largest matter-antimatter asymmetry observed

New results from the LHCb experiment on CP asymmetry in charmless three-body charged B meson decays include the largest CP asymmetry ever observed

18 MARCH, 2022 | By Piotr Traczyk

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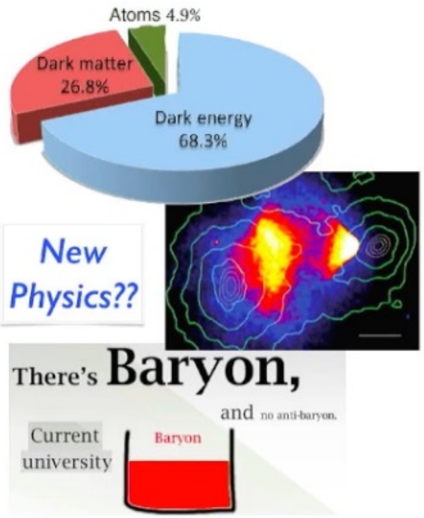
有助进一步揭示宇宙为何由物质而非反物质组成

03/2022

仍待解决的基本问题

标准模型有根本性缺陷，远未揭示物质最深层次结构与规律的终极答案



- 暗物质的本质是什么?
- 宇宙加速膨胀的起源是什么?
- 中微子是其自身的反粒子吗?
- 物质为何多于反物质?
- 量子力学和引力的结合问题
- 黑洞的本质是什么?
- 质量的起源是什么?
- ……

05/ 2024，彭桓武论坛，中科院高能所-任婧《利用天文观测寻找新物理》

Part IV
Summary

Asymmetry of Matter-Antimatter

1. An Introduction to Particle Physics

   Two ways: Experiment and Theory

2. Three necessary conditions for symmetry breaking

   Use discrete symmetries to describe the behavior of the microscopic particles.

3. To find CP violation in high energy experiments.

   Beyond the Standard Model? Gravitational Waves.

   Particle Physics & Cosmology

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THANKS

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