CP Violation In Heavy Flavour Physics

Agnieszka Obłąkowska-Mucha, Tomasz Szumlak
AGH UST Kraków

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Outline

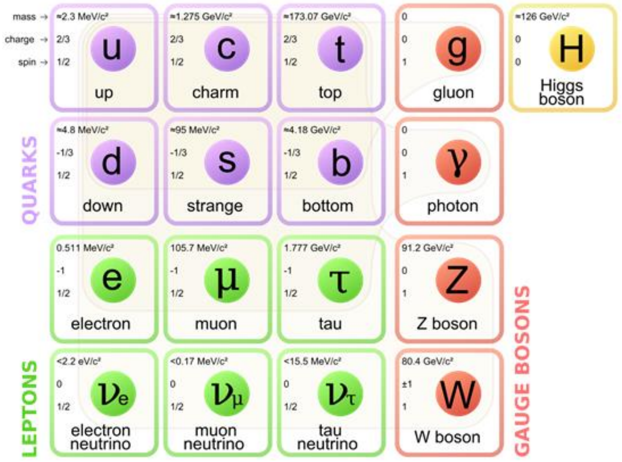
I. Introduction.
II. Dirac equation
III. CP Violation in the Standard Model.
IV. CP Violation in the in K physics.
V. CP Violation in the B mesons
VI. B physics – experimental issues.
VII. CP Violation and charm physics.
VIII. Overall CKM triangle fits
- Data analysis × 2

Theoretical Concepts

Experiments

Precondition:

Standard Model



16 hours of lectures
6 hours for tutorial
6 hours for computer lab/project

Final grade consist of:
1/3 Activity
1/3 Exercises
1/3 Project

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Bibiography:

M.Thomson "Modern Particle Physics„
D. Griffiths „introduction to elementary particles”, JW.& Sons 1987
A.J. Buras "CP Violation in B and K decays" hep-ph/0307203
B. Kayser "CP Violation in the K and B systems" hep-ph/9702264
J. Rosner "CP Violation in B decays" hep-ph/0011355

Why do we need CPV?

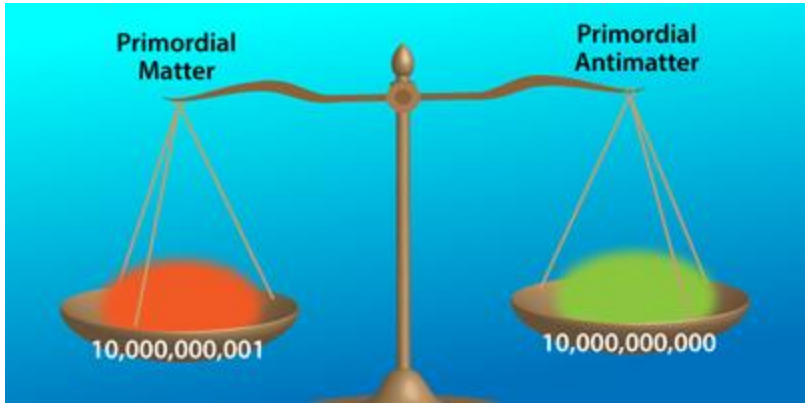
1. A long, long time ago, in the early Universe, there were an equal number of baryons and antibaryons…..

   High energy photons constantly produces protons and antiprotons which later annihilate:

$$\gamma + \gamma \rightleftharpoons p + \overline{p}$$

2. Then comes the time when temperature decreases and photons have not enough energy for particle creation.
3. As the Universe expanded the density of baryons and antibaryons decreased and annihilation was less and less probable.
4. The number of baryons and antibaryons was equal and related to number of photons:

$$n_B = n_{\overline{B}} \sim 10^{-18}\, n_\gamma$$



5. Meanwhile in the experiment…

… we observe that the Universe is dominated by baryons:

$$n_B - n_{\overline{B}} \sim 10^{-9}\, n_\gamma$$

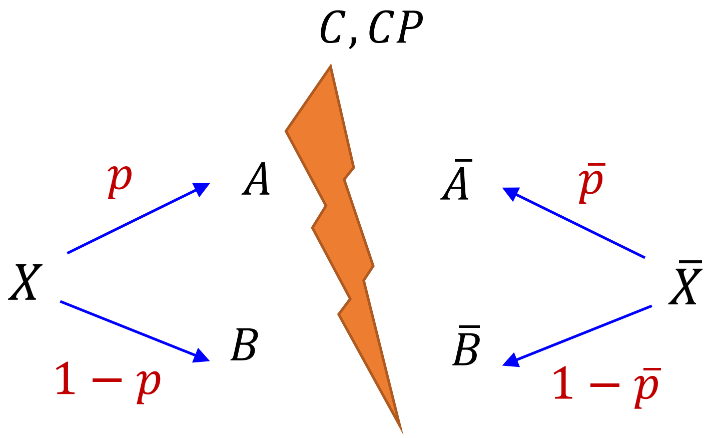
It means that in order to generate this asymmetry we need to have $10^9 + 1$ baryons annihilating with 10^9 antibaryons (one baryon survives)

CPV might help?

Baryon Asymmetry

Generation of Baryon Asymmetry in the Universe:

1. Suppose we have equal amounts of matter X and antimatter $\bar{X}$
    - X decays to
        - A (baryon number N_A) with probability p
        - B (baryon number N_B) with probability $(1-p)$
    - $\bar{X}$ decays to
        - $\bar{A}$ (baryon number $-N_A$) with probability $\bar{p}$
        - $\bar{B}$ (baryon number $-N_B$) with probability $(1-\bar{p})$



2. Let's calculate the net baryon number resulting from these decays:

$$N_{tot} = N_A\, p + N_B(1-p) + \{-N_A\bar{p} - N_B(1-\bar{p})\} = (p-\bar{p})(N_A - N_B)$$

If X has $B = 0$, then any decay to non-zero baryon final states would generate baryon asymmetry:

$$\text{if} \quad N_{tot} \neq 0 \quad \text{then} \quad p \neq \bar{p} \quad \text{and} \quad N_A \neq N_B$$

The different number of baryons and antibaryons may occur when both the baryon number is violated $N_A \neq N_B$ **AND** a difference in partial widths of particles and antiparticles $p \neq \bar{p}$ occur.

What's the matter with antimatter?

I. Do baryons decay to non-baryons?

Apparently YES: the baryon number is violated and $n_B - n_{\bar{B}}$ is not constant.

II. Is there any process that creates baryon and destroys antibaryon?

If CP parity is conserved: NO, there is not…

For every reaction that creates more baryons than antibaryons there would be a CP conjugate process that generates more antibaryons than baryons. Even if the baryon number is not conserved.

III. When the matter and antimatter disbalance started, the system was far for equilibrium.

Otherwise two processes would go simultaneously. In thermal equilibrium all state with the same energy must be equally populated.

The universe is assumed initially to be in thermal equilibrium.

Matter-antimatter asymmetry

Sakharov conditions for matter-antimatter asymmetry of the universe (1967):

1. **There must be a process that violates baryon number conservation.**

   Proton – the lightest baryon should decay, so far this is unobserved, the lifetimes of proton is greater than 10^{35} years.

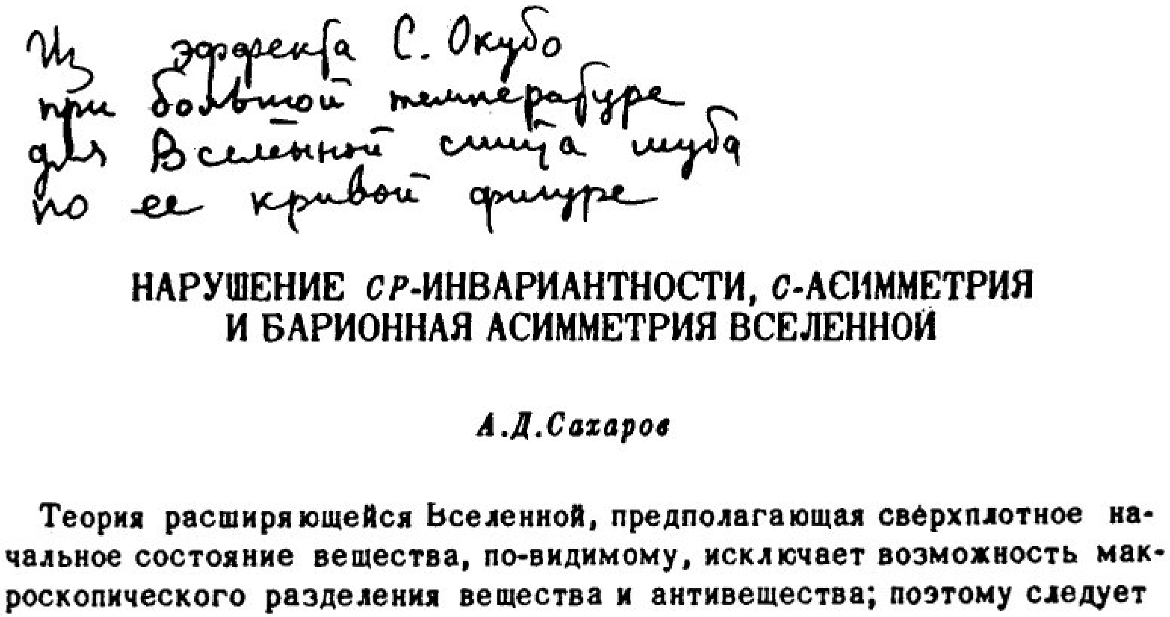
2. **Both C and CP symmetries should be violated.**

   $$p \neq \overline{p}$$

   This the subject of the following story.

3. **These two conditions must occur in a phase when there was no thermal equilibrium.**

Otherwise $N_{baryons} = N_{\overline{baryons}}$

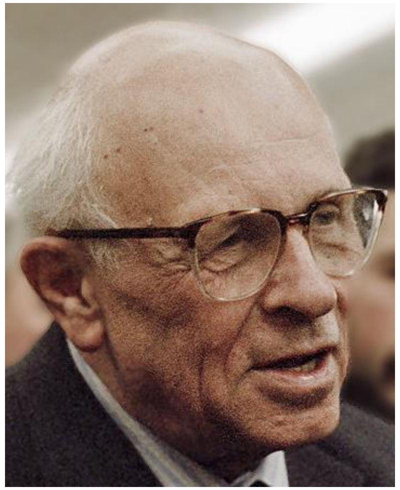


Из эффекта С. Окубо
при большой температуре
для Вселенной сшита шуба
по ее кривой фигуре

НАРУШЕНИЕ *CP*-ИНВАРИАНТНОСТИ, *C*-АСИММЕТРИЯ И БАРИОННАЯ АСИММЕТРИЯ ВСЕЛЕННОЙ

А.Д.Сахаров

Теория расширяющейся Вселенной, предполагающая сверхплотное начальное состояние вещества, по-видимому, исключает возможность макроскопического разделения вещества и антивещества; поэтому следует



Andrei Sakharov:
- „father" of Soviet hydrogen bomb
- Dissident
- Nobel Peace Prize Winner

CP Violation? Where?

I. The Standard Model includes the possible violation of CP symmetry in weak interaction of quarks and leptons.
II. Currently, clear signals of CPV have been seen in weak b- hadron decays.
III. But it is not sufficient to explain matter-antimatter in the Universe…

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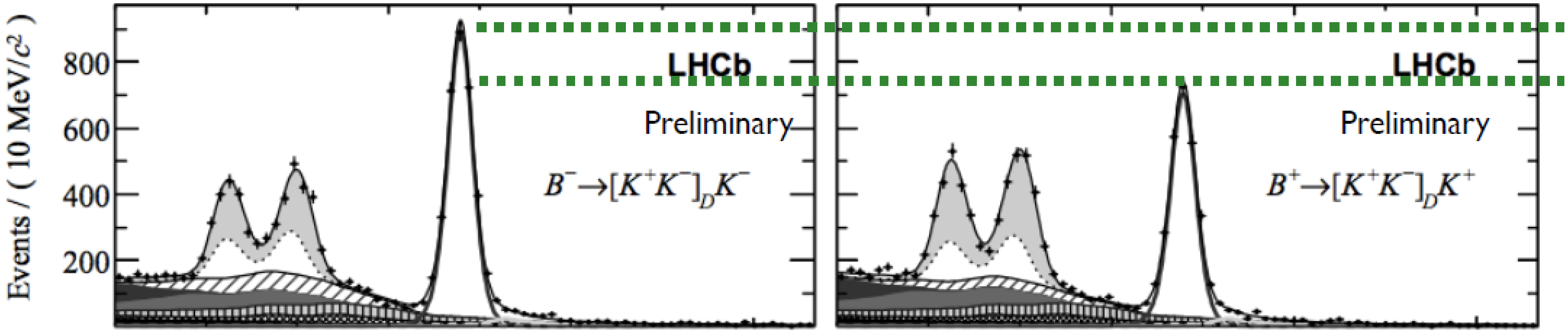

Plan for the next weeks:

- Matter and antimatter – a few equations.
- Symmetries and conservation laws – two approaches.