IoP Masterclass

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B PHYSICS

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The Standard Model

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Fermions ("matter")	Bosons ("forces")
Quarks: uuu ccc ttt / ddd sss bbb Leptons: e μ τ / ν_e ν_μ ν_τ $\times$ {MATTER, ANTIMATTER}	$gggggggg$ γ W^+ W^- Z H

Some Questions

- What is antimatter?
- Why are there three “colours” of quarks?
- Why are there so many bosons?

These questions have well-understood answers

Some More Questions

- Why are there so many fermions?
- Why are there three "generations" of both quarks and leptons?

("flavour")

- Why are matter and antimatter different?

("CP violation")

We do not know the answers to these questions!

Matter *vs.* antimatter

- In the Big Bang, matter and antimatter should have been produced in equal quantities
- In the Universe today, we observe only matter

⇒ need *CP violation*

Asymmetry of the Universe

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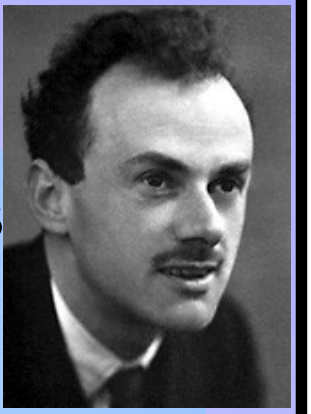


- Paul Dirac, one of the greatest British physicists of all time, won the 1933 Nobel Prize for his prediction of the existence of antimatter
- In his Nobel lecture, Dirac concludes:

"... we must regard it rather as an accident that [the solar system] contains a preponderance of negative electrons and positive protons. It is quite possible that for some of the stars it is the other way about, these stars being built up mainly of positrons and negative protons. In fact, there may be half the stars of each kind."

- It turns out there are not any antimatter stars
- Dirac did not know about CP violation!

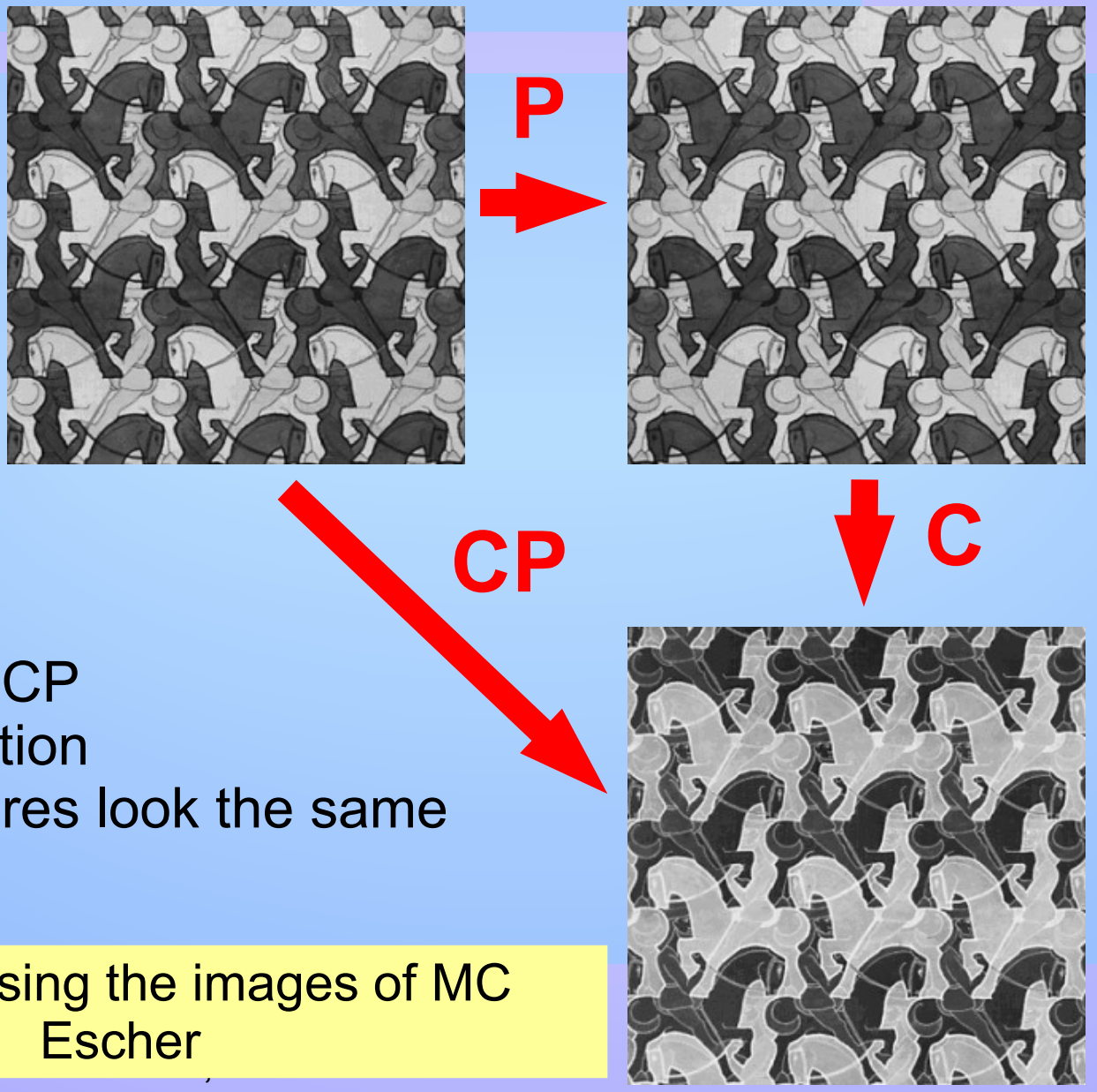
What is CP Violation?

- Symmetries are powerful tools to understand nature

- Two important discrete symmetries are
  - C : charge conjugation
    (exchange particle and antiparticle)
  - P : parity
    (mirror transform all spatial coordinates)

Need violation of combined CP symmetry to distinguish absolutely between matter & antimatter

CP Symmetry

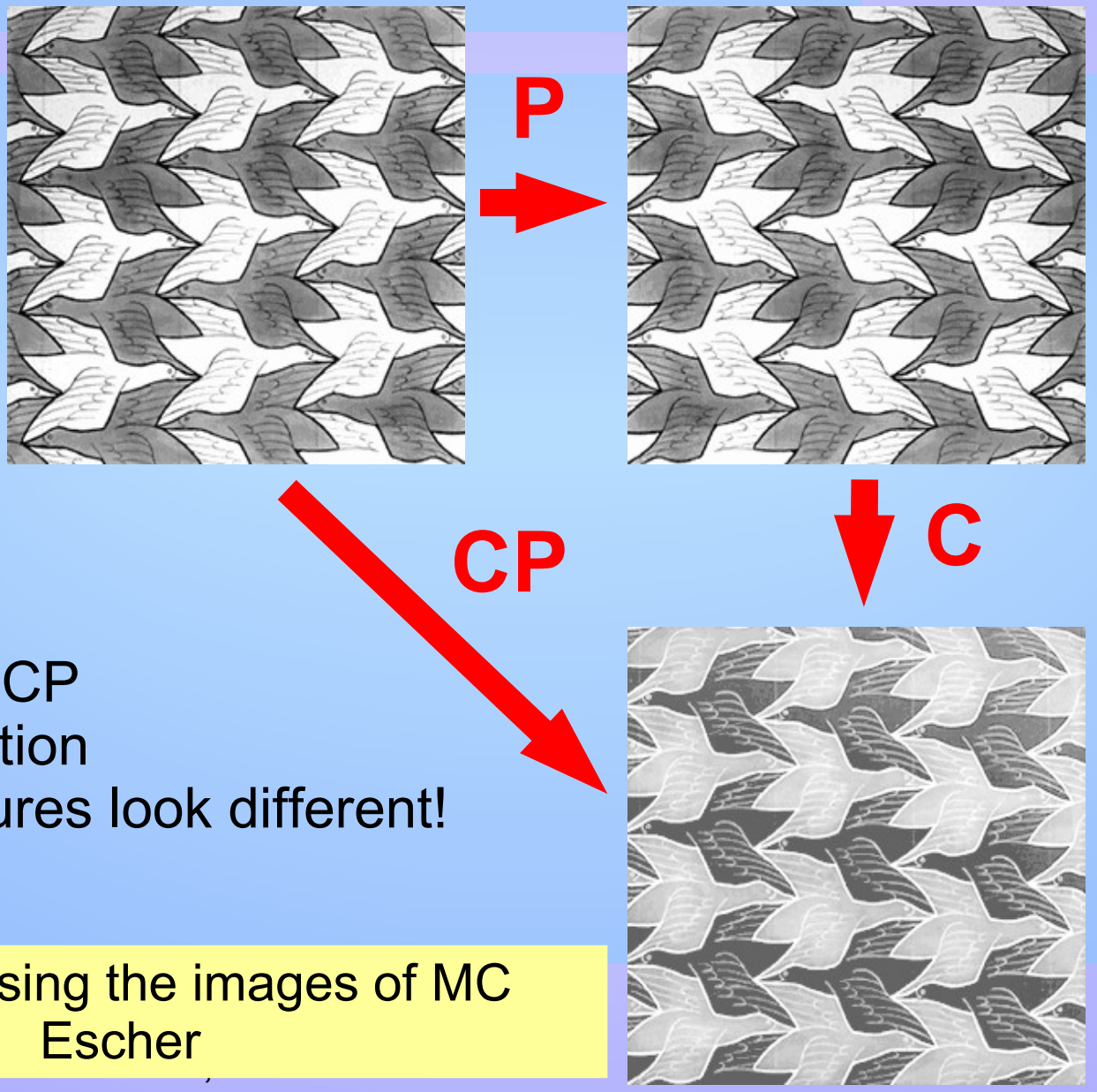


Combined CP transformation

⇒ pictures look the same

Illustrated using the images of MC Escher

CP Violation



Combined CP transformation

⇒ pictures look different!

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Why B Physics?

- CP violation appears to be central to understanding the questions discussed above
  - *eg*. as shown by Kobayashi & Maskawa (1973), need at least three generations for CP violation to occur
- Kobayashi-Maskawa mechanism predicts large CP violation effects in particles containing b quarks
  - need dedicated experiments to test KM predictions
  - Warwick is involved in two: **BABAR** and **LHCb**
- (Also interesting possibilities of CP violation in leptons, especially neutrinos)

The CKM Matrix

- Quark mixing described by Cabibbo-Kobayashi-Maskawa matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

down-type quarks as seen by the weak interaction

physical down-type quarks (with well-defined masses)

- Matrix elements are complex numbers
  - interactions of quarks and antiquarks can be different

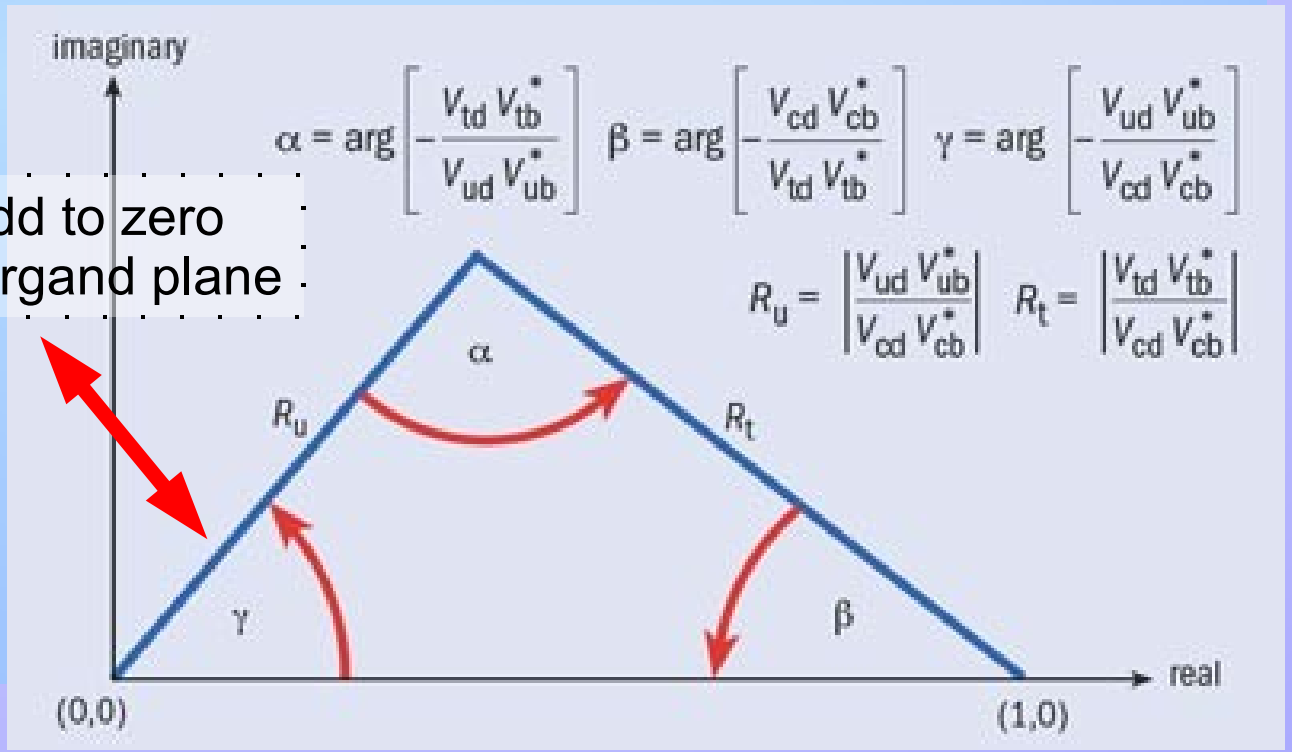
⇒ CP violation!

The Unitarity Triangle

- Squares of CKM matrix elements describe probabilities
  ⇒ matrix must be *unitary*

$$V_{ud}V_{ub}^{*}+V_{cd}V_{cb}^{*}+V_{td}V_{tb}^{*}=0$$

Three complex numbers add to zero
⇒ triangle in Argand plane



The BABAR Experiment

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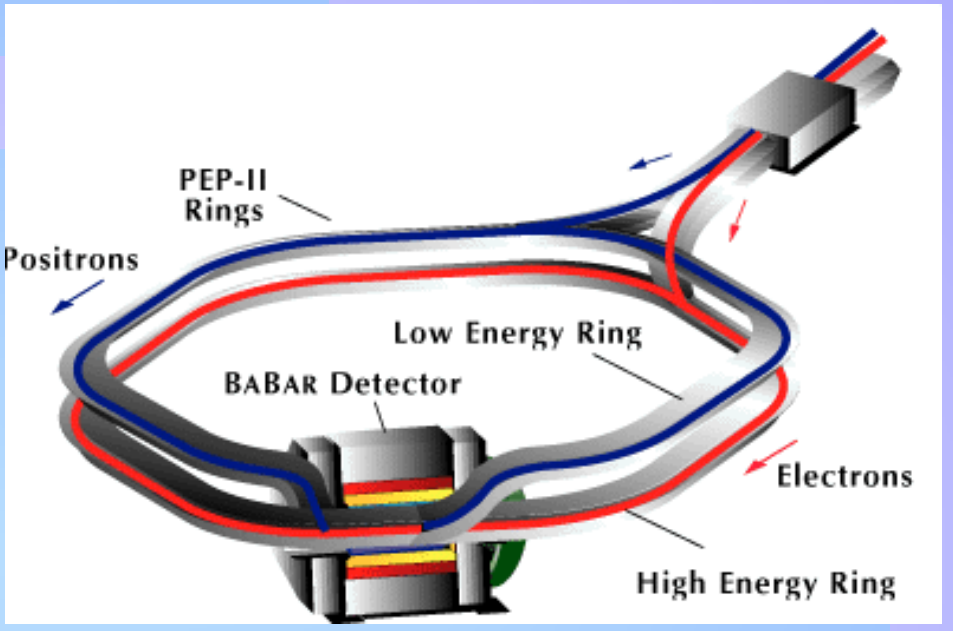
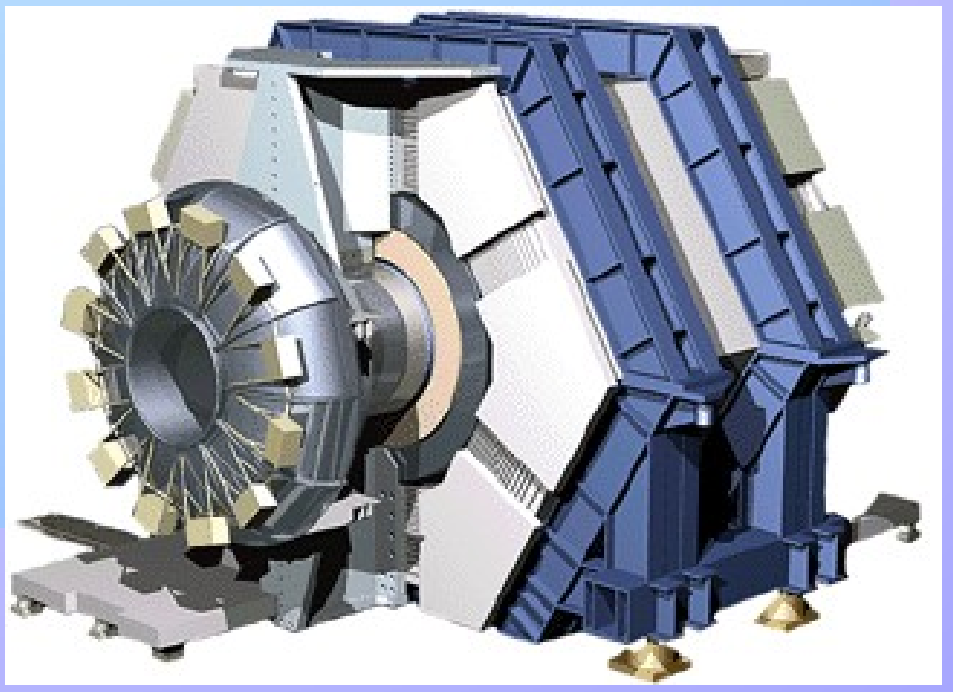
- PEP-II accelerator collides electrons and positrons at energies tuned to produce pairs of B mesons
- Electron/positron energies are *asymmetric* – produced B particles are moving → time to decay can be measured
- BABAR detector reconstructs decay products of B mesons

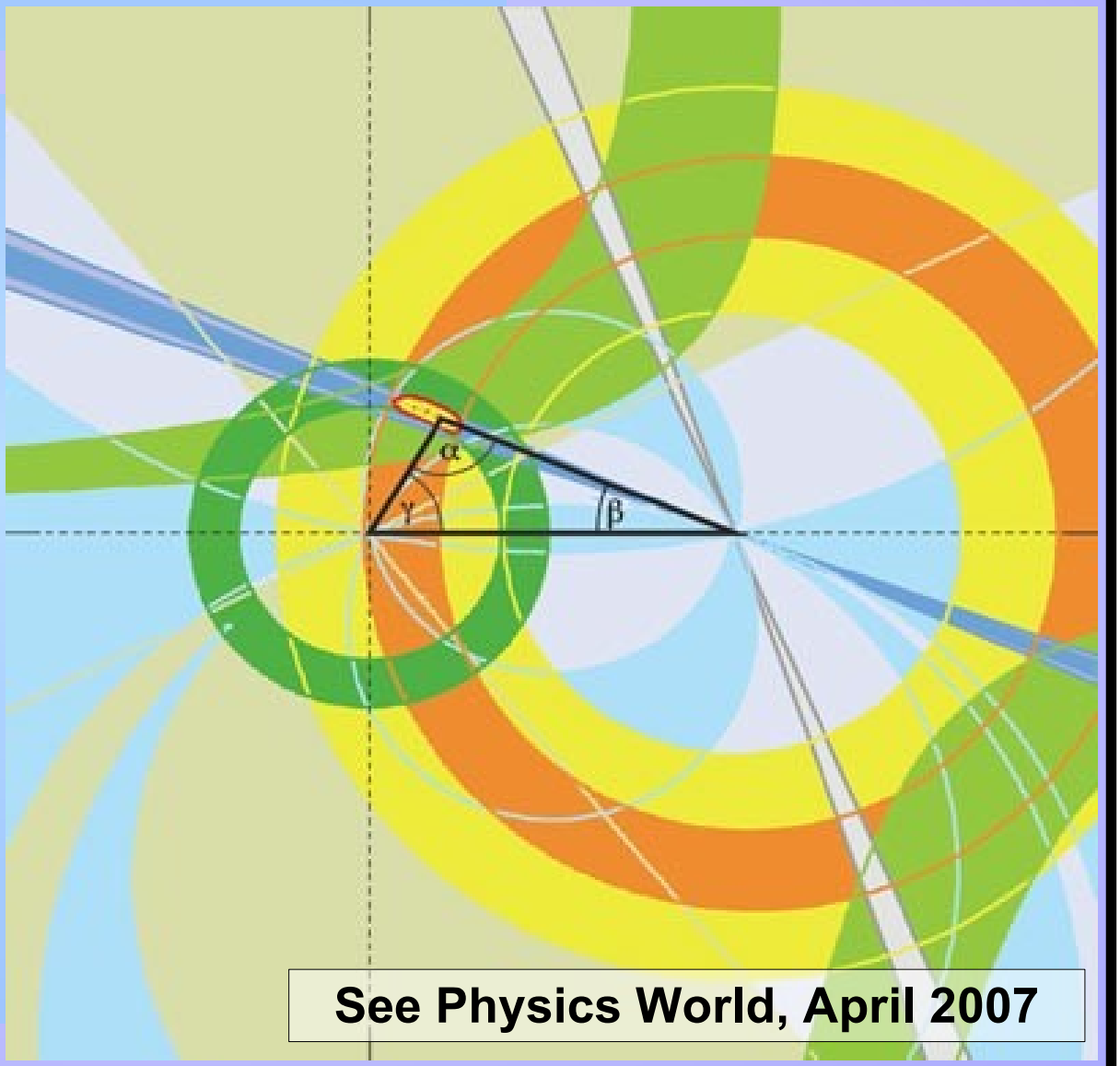




Current Status

- Measurements of Unitarity Triangle parameters test CKM picture
- So far, all results are consistent
- Nobel Prize 2008

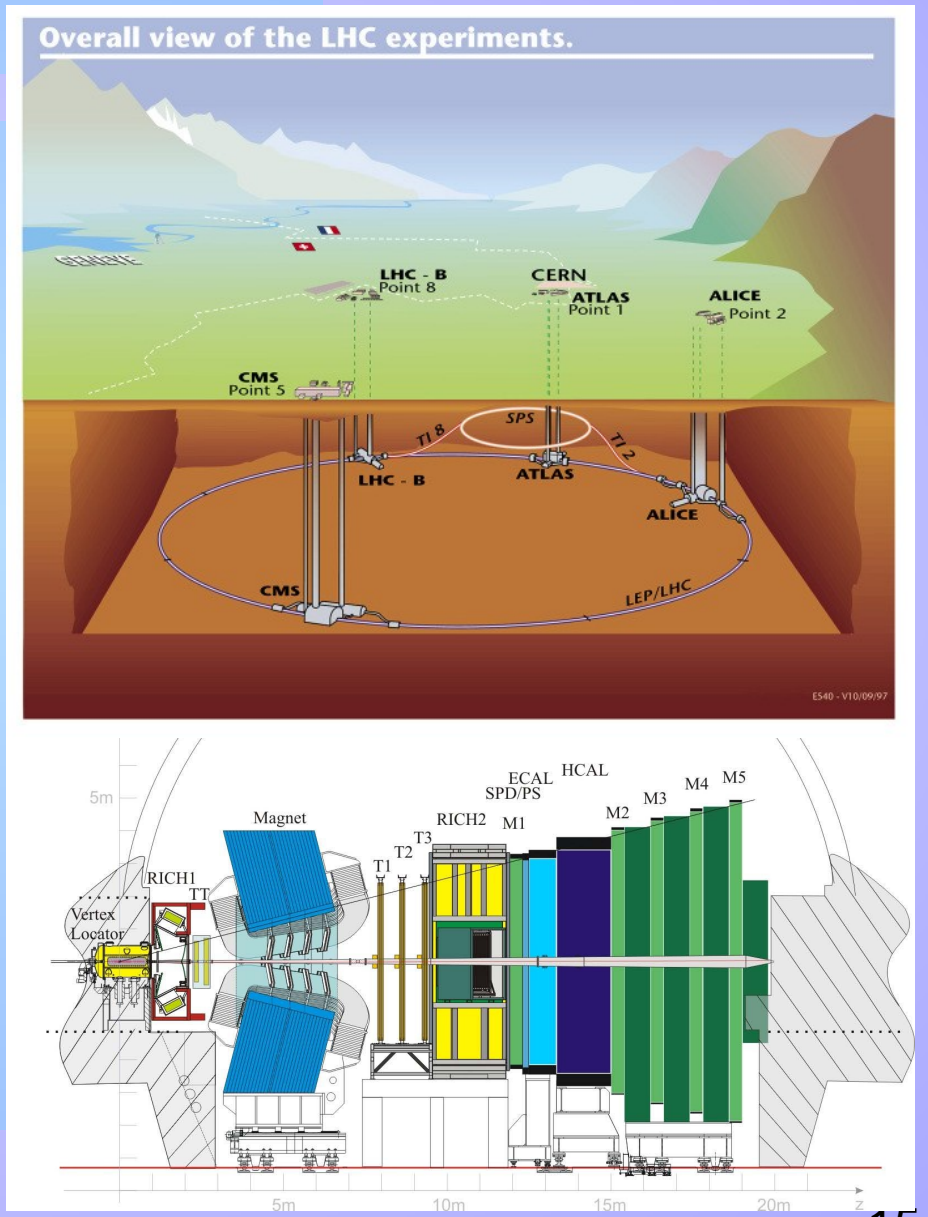
Kobayashi & Maskawa



See Physics World, April 2007

The LHCb Experiment

- CP violation encoded in the CKM matrix not sufficient to explain Universe's asymmetry
  - there must be more CP violation out there
  - search for disagreement with Standard Model
- Use the world's most advanced accelerator (LHC) to produce unprecedented numbers of B mesons and search for unexpected effects



Summary

- Studies of B physics provide excellent opportunities to address one of the biggest questions about our Universe
  - What causes the excess of matter over antimatter?
- By learning more about B physics and CP violation we hope to find clues about the theoretical structure of the Standard Model (and any theories beyond it)
  - Why are there three generations of quarks and leptons?
- The Warwick group is actively involved in experiments at the forefront of this exciting area of research
  - We hope the LHCb experiment will provide some answers!