Quantum Penguins Investigate Antimatter

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Durham University

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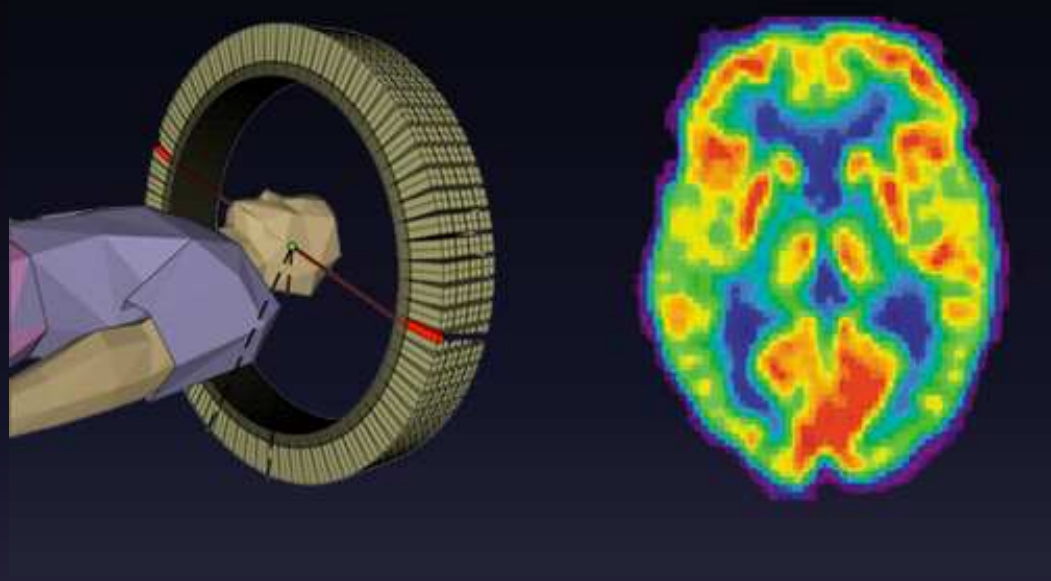
Antimatter: not just sci-fi

We know antimatter is great for warp travel.

Antimatter: not just sci-fi



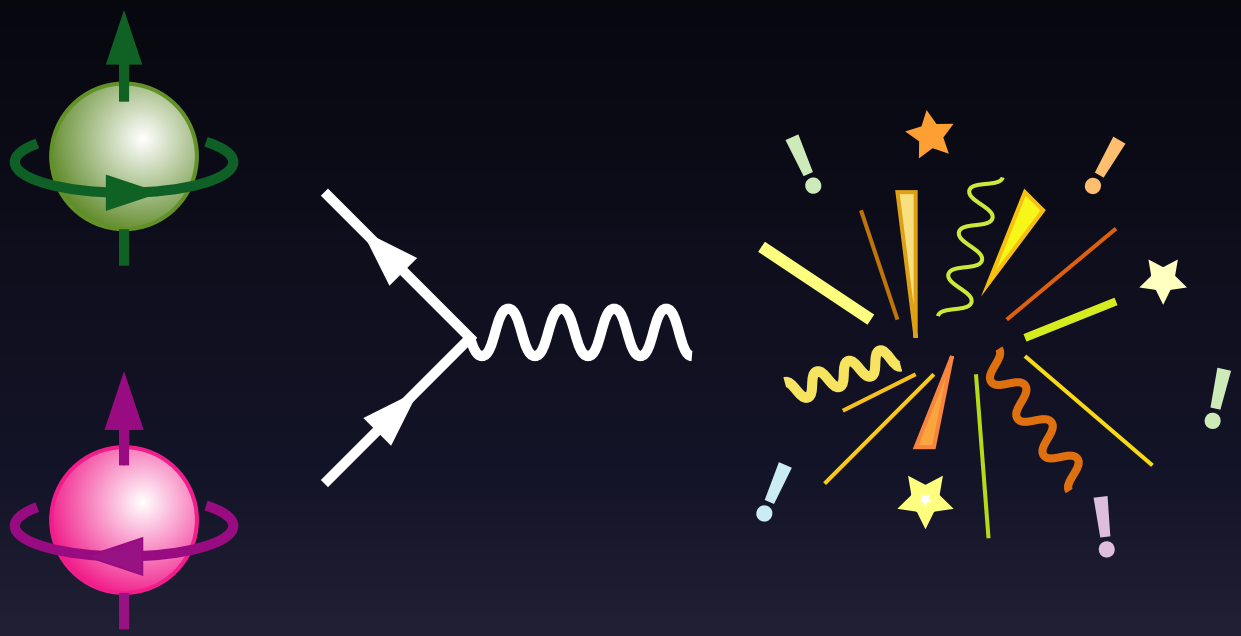
More common uses: PET scans, nuclear energy, nonproliferation...

Antimatter: not just sci-fi

Matter and antimatter are related by $\mathcal{CP}$ **symmetry**, which swaps charge and handed-ness.

Sci-fi accurately captures a key property of antimatter...

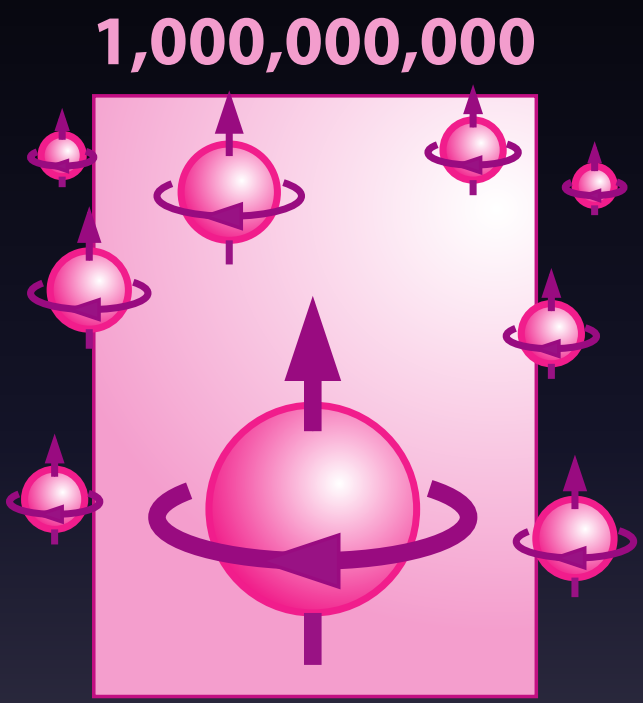
Antimatter: not just sci-fi



Matter and antimatter annihilate into energy.

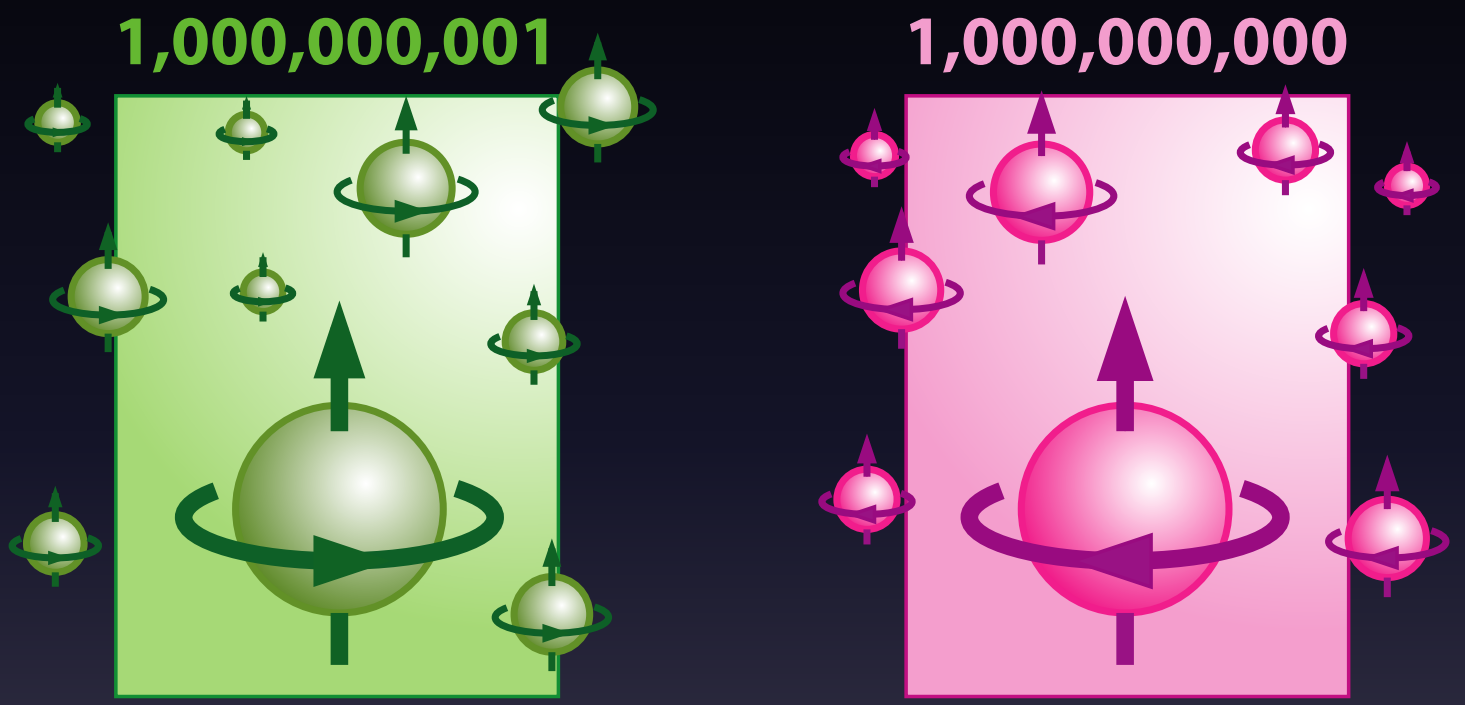
(Example of simple Feynman diagram.)

What's the matter with antimatter?



If antimatter is so symmetric, *why are we here?*

What's the matter with antimatter?



There must have been some small initial asymmetry...

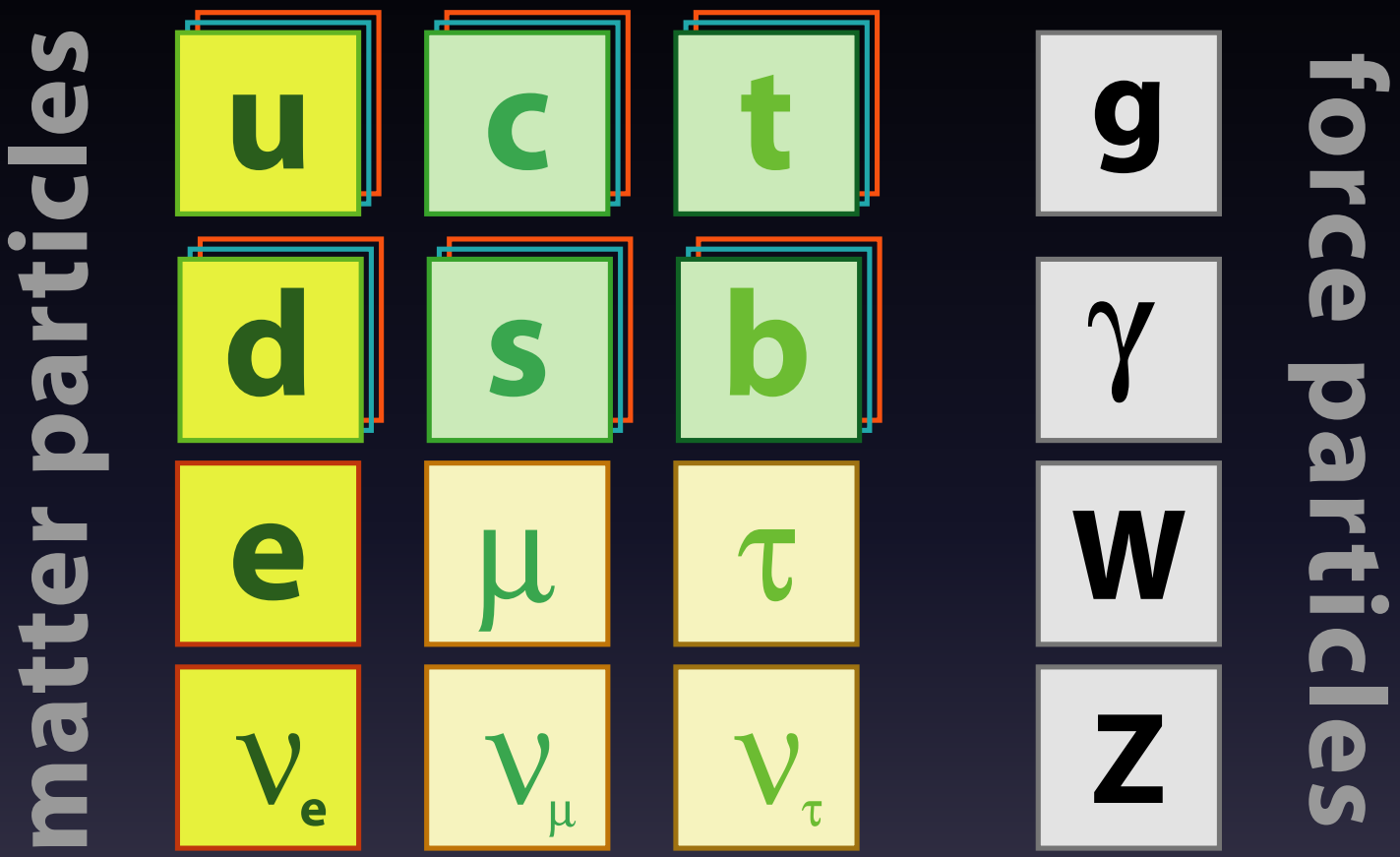
What's the matter with antimatter?

'Great annihilation' of the early universe, we're the survivors. Why?

What's the matter with antimatter?

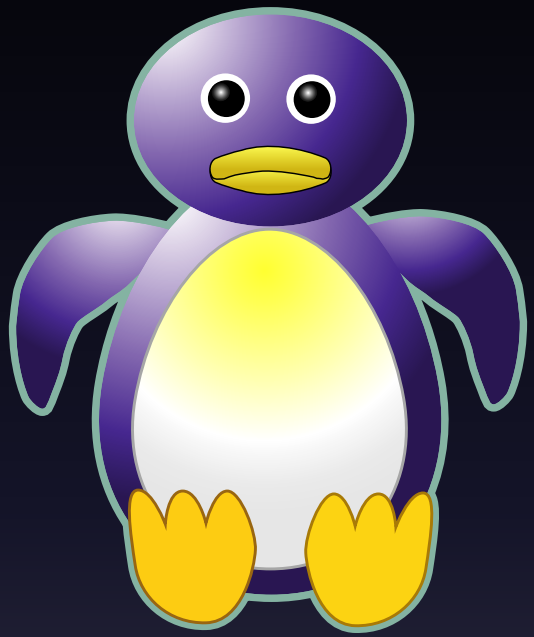
It turns out that $\mathcal{CP}$ asymmetry is deeply related to another curiosity of our current model.

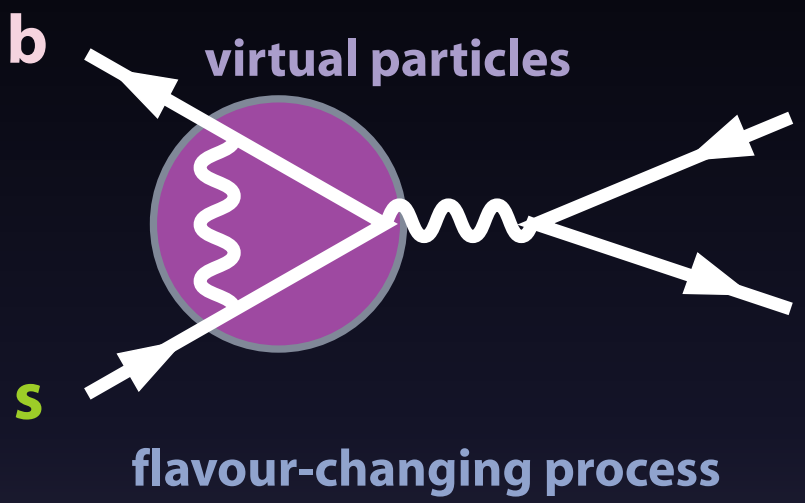
Why are there three copies of matter?



Chemistry only requires the first copy ('flavour'). Why three?
We need three for matter-antimatter ($\mathcal{CP}$) asymmetry!

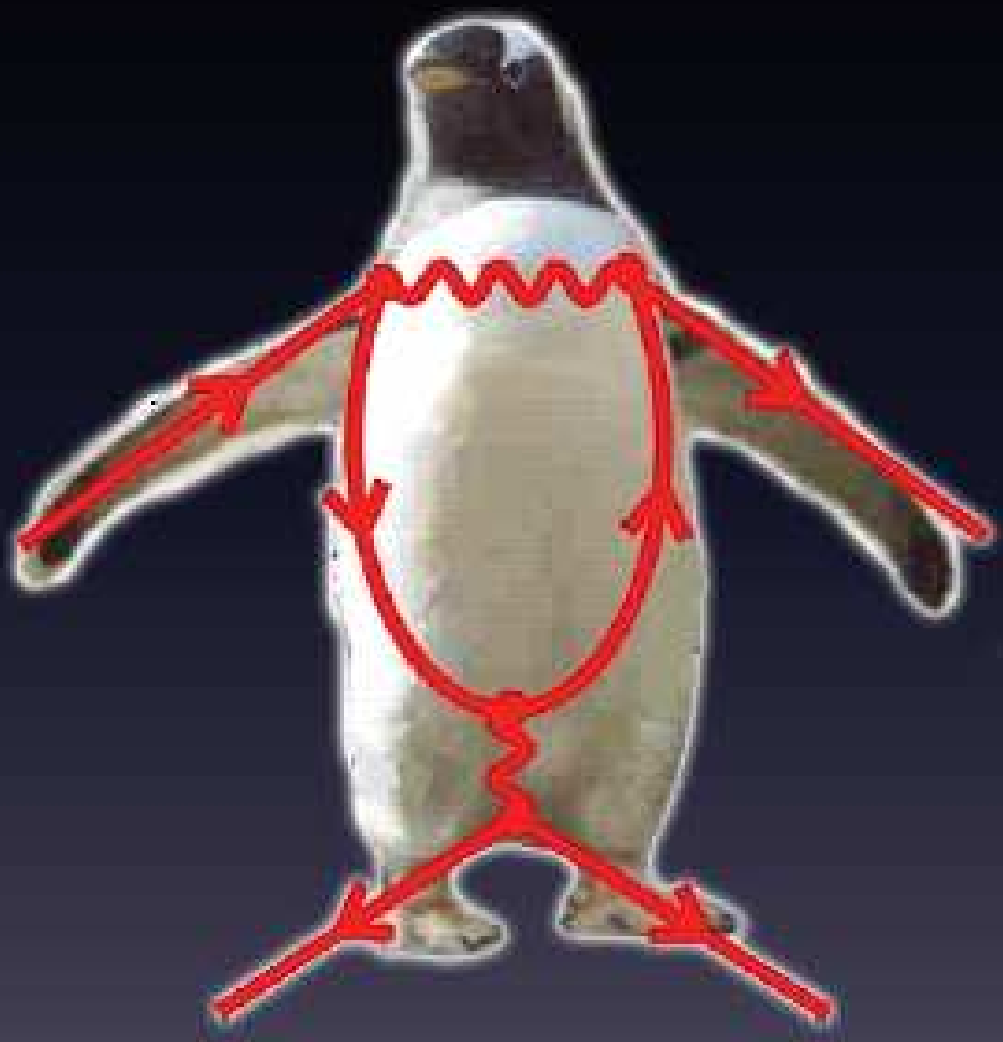
The Birds and the Bs





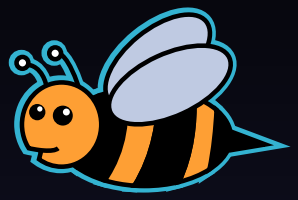
Penguin diagrams: flavour-changing quantum processes that reveal the flavour ($\mathcal{CP}$) structure of nature.

... they kind of look like penguins



... named by an Englishman (John Ellis, CERN)

Birds and Bs: The B meson



Meson	Mass	Mean lifetime
B_d^0	5.28 GeV	1.53×10^{-12}s
B_s^0	5.37 GeV	1.44×10^{-12}s

B meson: easy to detect, penguin-mode decay is dominant.

B-mesons are bound states of quarks and b antiquarks. Their decays shed light on the $\mathcal{CP}$ structure of nature.

The LHCb experiment

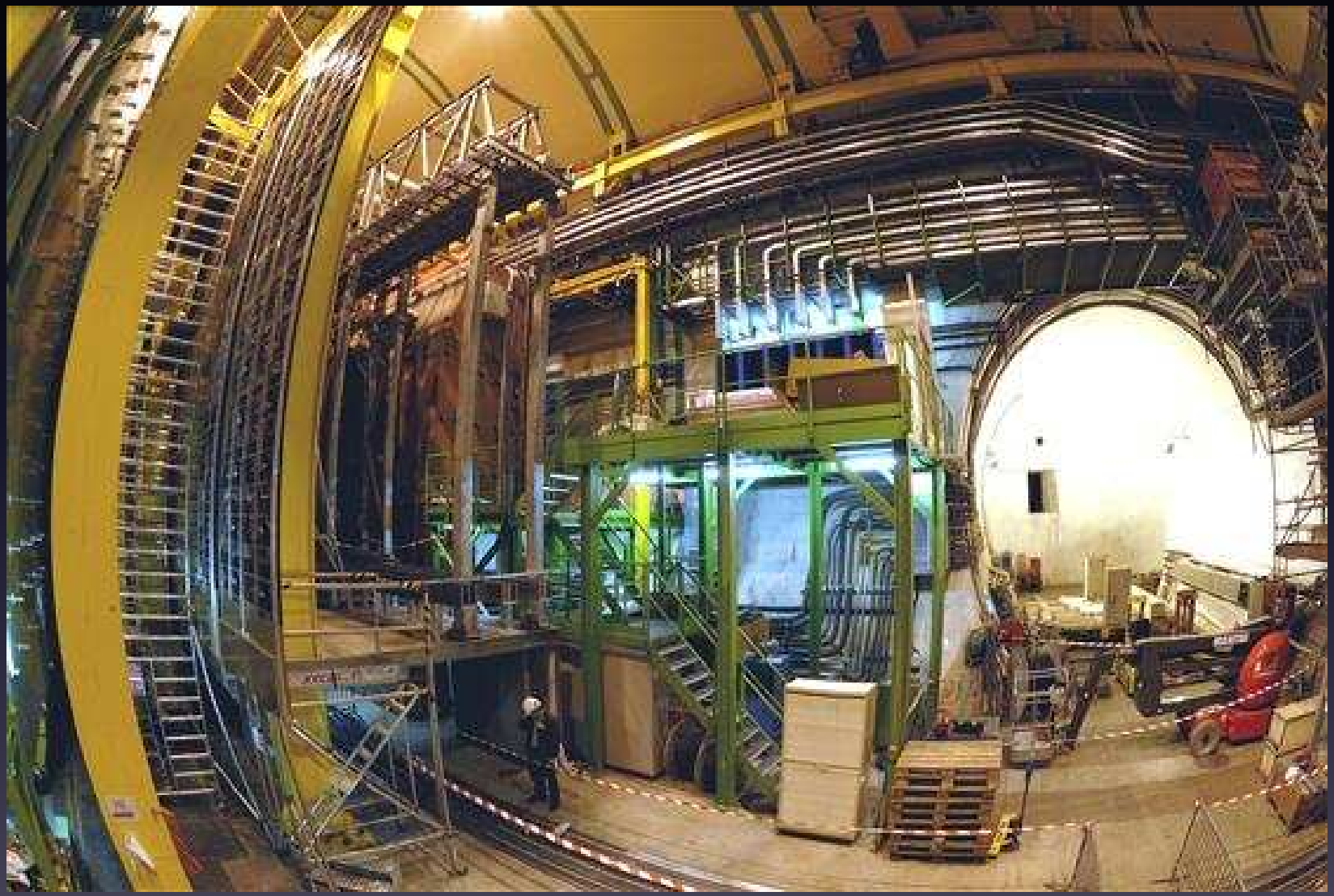
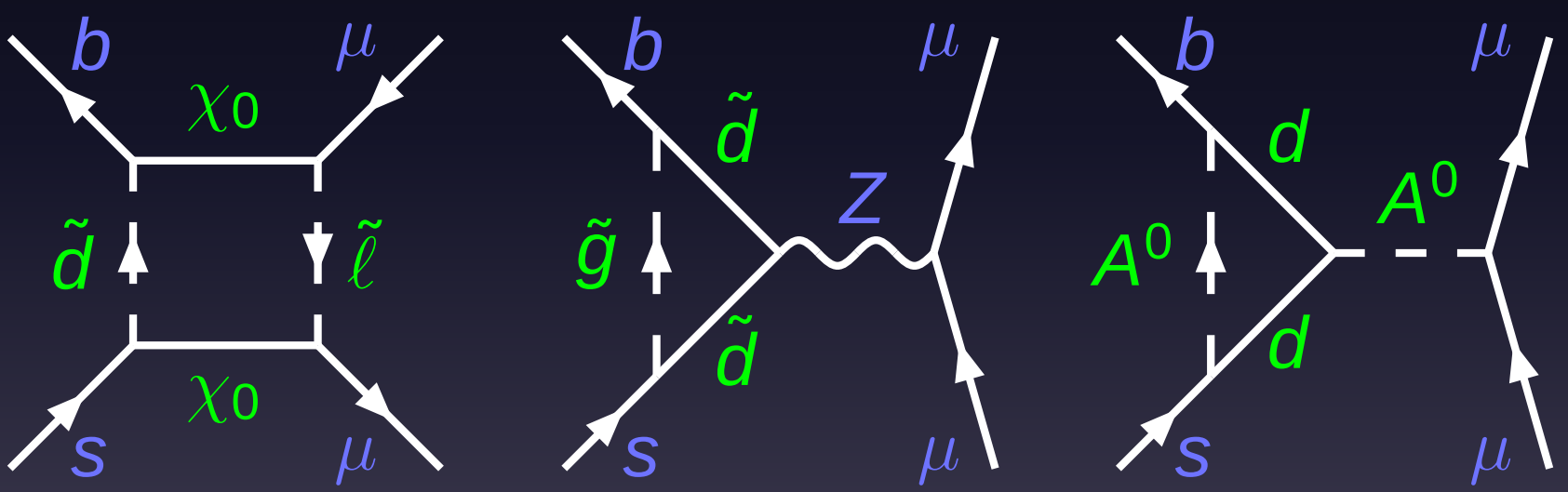


Image courtesy of the CERN Document Server

Theoretical Considerations

The ‘Standard Model’ does *not* contain enough $\mathcal{CP}$ violation to account for the observed matter-antimatter asymmetry!

This means that there must be new physics waiting to be discovered!



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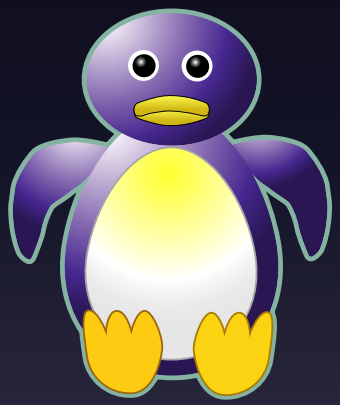

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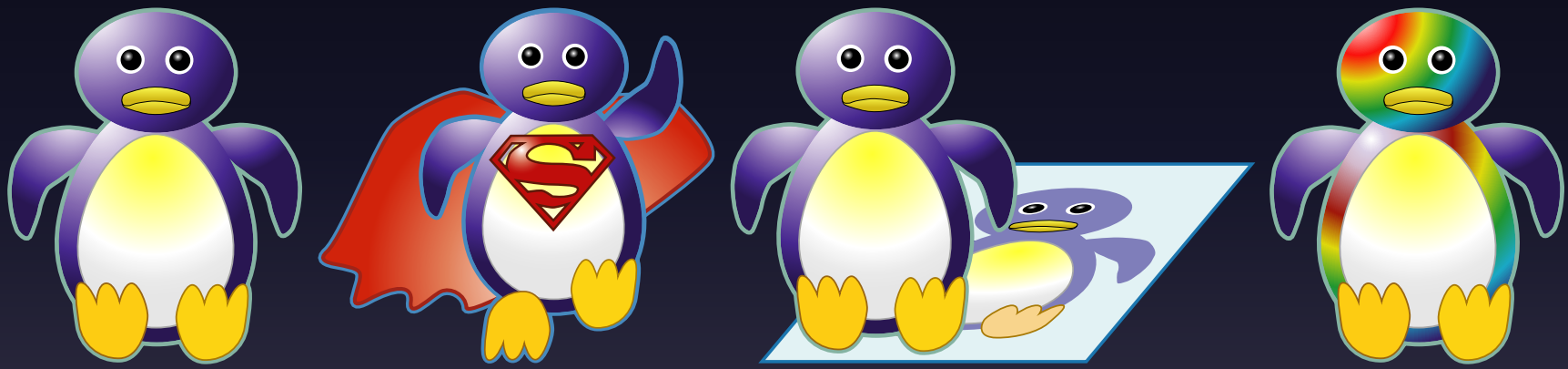

Standard Model, Supersymmetry, Extra Dimensions, Technicolour

Theoretical Considerations

These ideas have deep connections to other ‘big questions’ in physics:

- What is the nature of space and time?
- Do all of the forces unify?
- What is the origin of mass?
- What is dark matter/dark energy?

The physics of antimatter is part of a larger puzzle to understand nature at its most fundamental level.

UK Leadership

Experimental groups in the LHCb collaboration:

- University of Bristol
- Cambridge University
- Rutherford Appleton Laboratory
- University of Edinburgh
- University of Glasgow
- University of Liverpool
- Imperial College
- Oxford University

Theoretical groups doing related research:

- Durham University IPPP
- University of Southampton
- (Cambridge, Edinburgh, Oxford, ...)

Durham University IPPP

Institute for Particle Physics Phenomenology

- Established 2000
- Supported by STFC and private philanthropy
- Unique group focusing on the intersection between theory and experiment
- Hub for UK particle physics community
- Hub for international collaborations

Conclusions

- This is an exciting time for physics when we can probe fundamental questions about matter and antimatter.
- Expect a lot of experimental and theoretical progress
- The UK plays a leading role in this research

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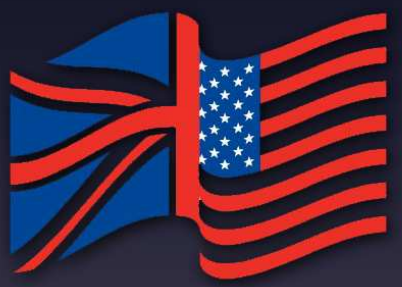
Thanks to the Marshall Commission and the IPPP!



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