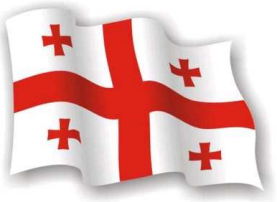
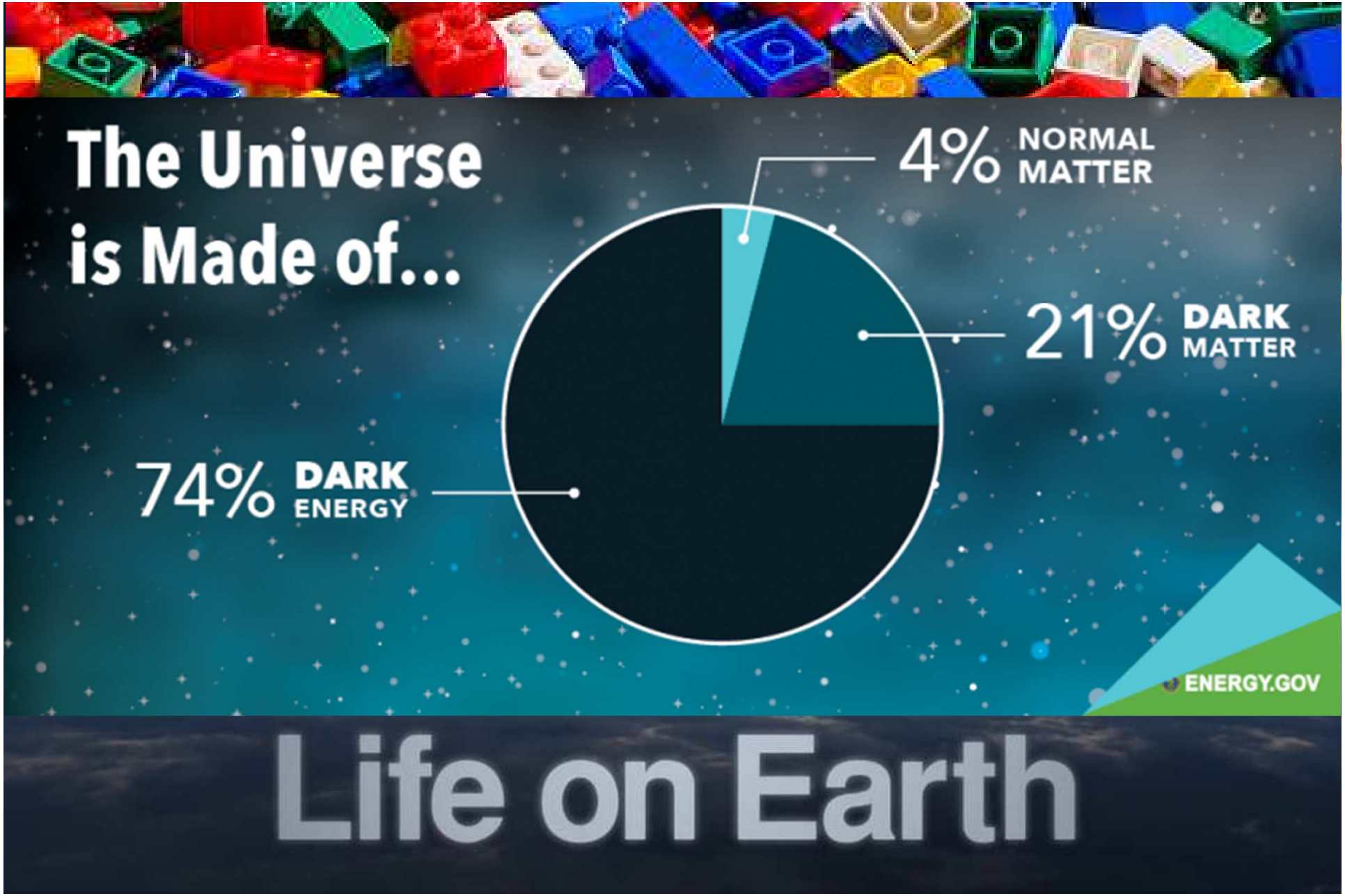


1st QUALI-Start-up Science Lectures at Forschungszentrum Jülich, September 9-17, 2017

Fate of the Antimatter: Why Do We Exist?

Hans Ströher|Forschungszentrum Jülich

Answer (I)

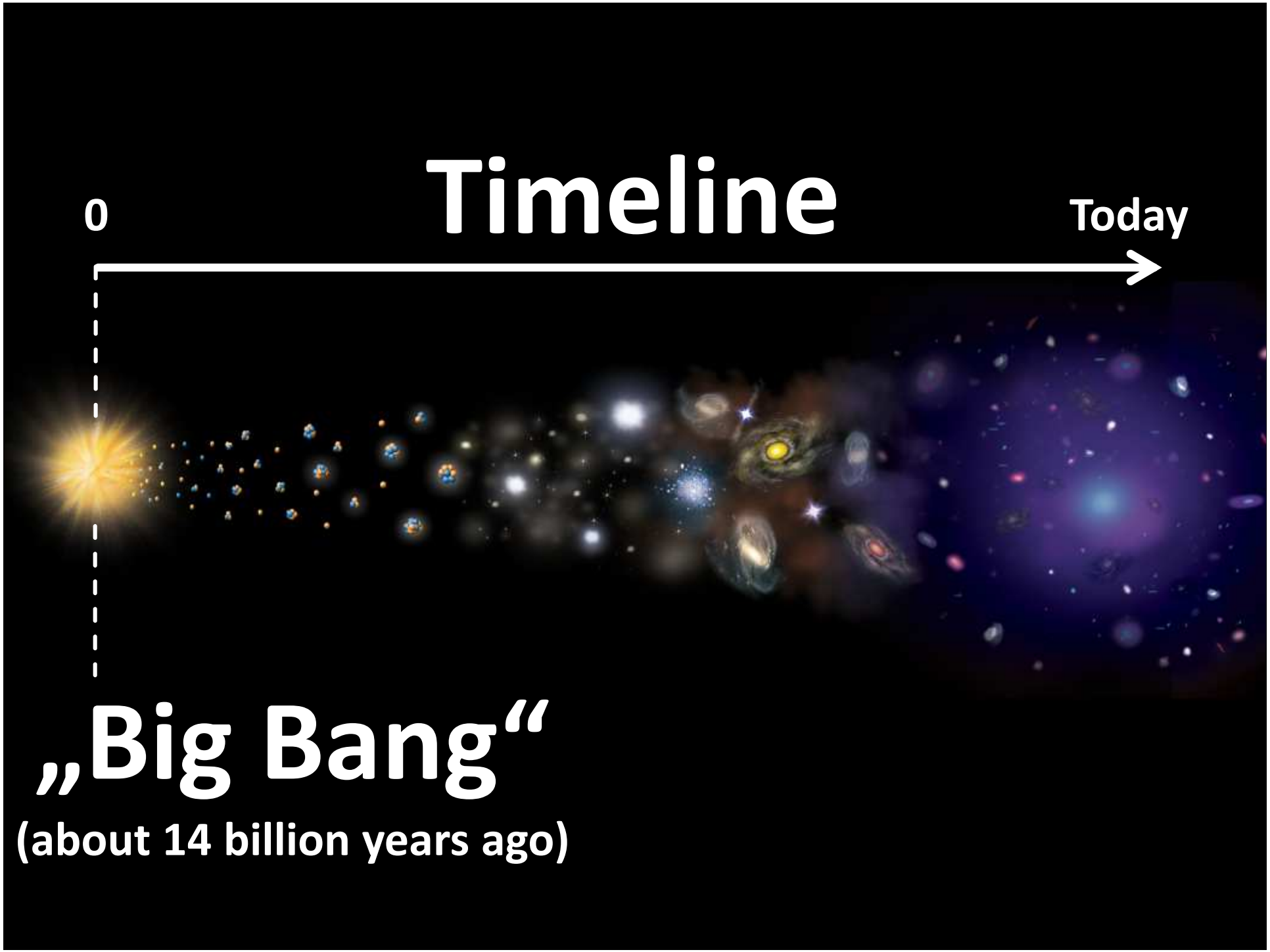

The Universe is Made of...
4% NORMAL MATTER
21% DARK MATTER
74% DARK ENERGY
ENERGY.GOV
Life on Earth

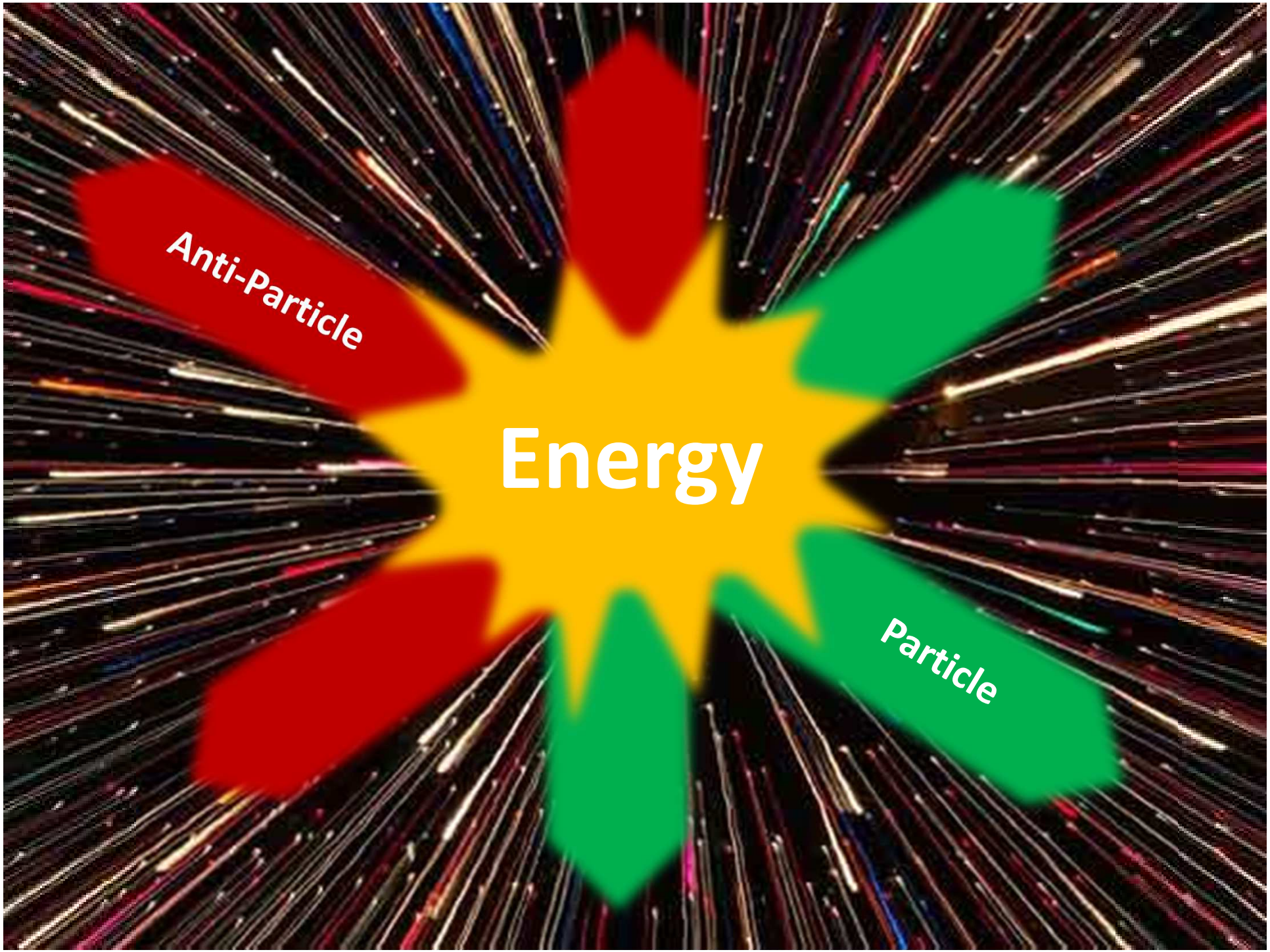
Answer (II)

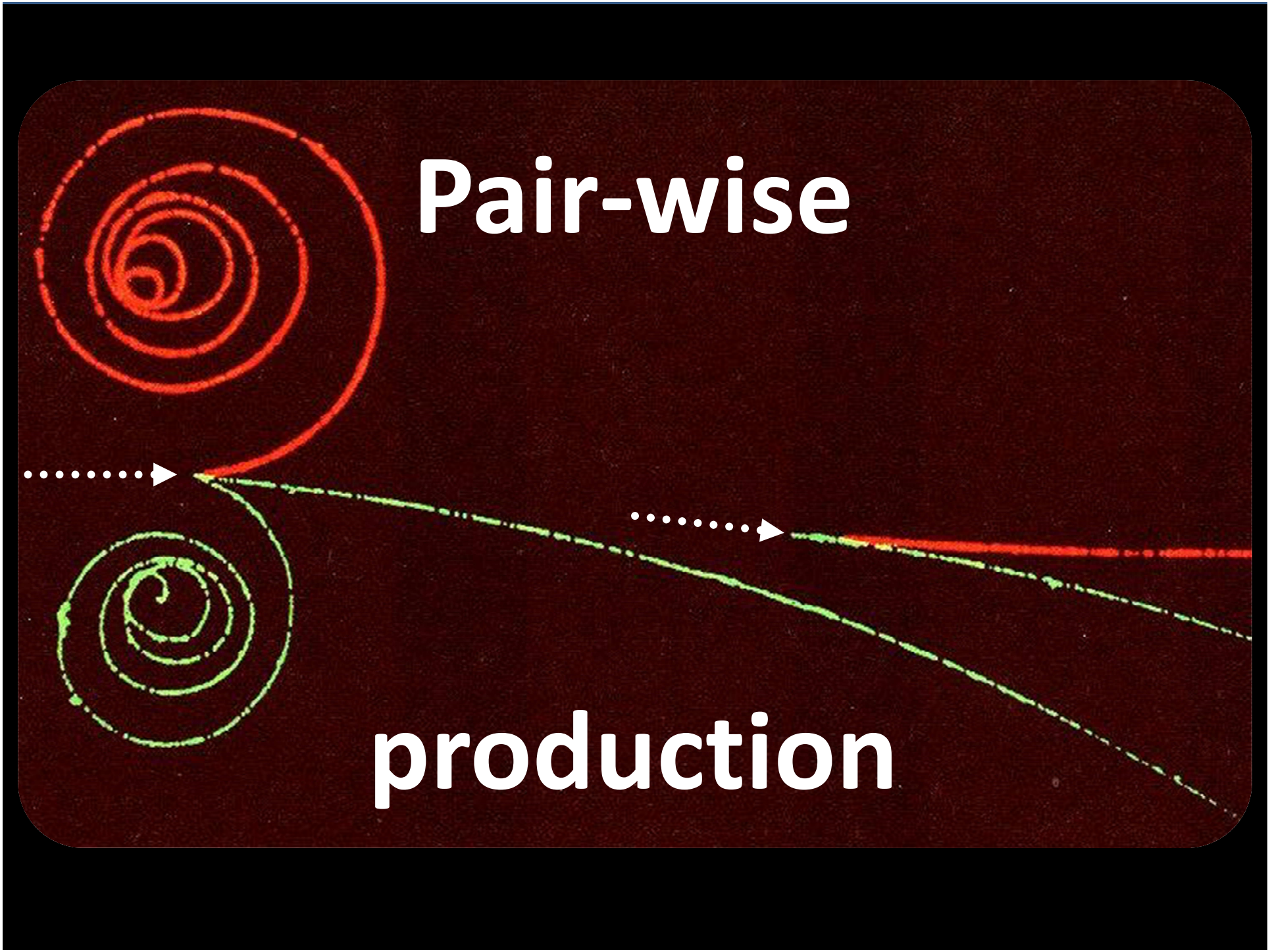

BANG!
The Big Bang ...
Matter meets antimatter
The fight begins.
The winner is matter

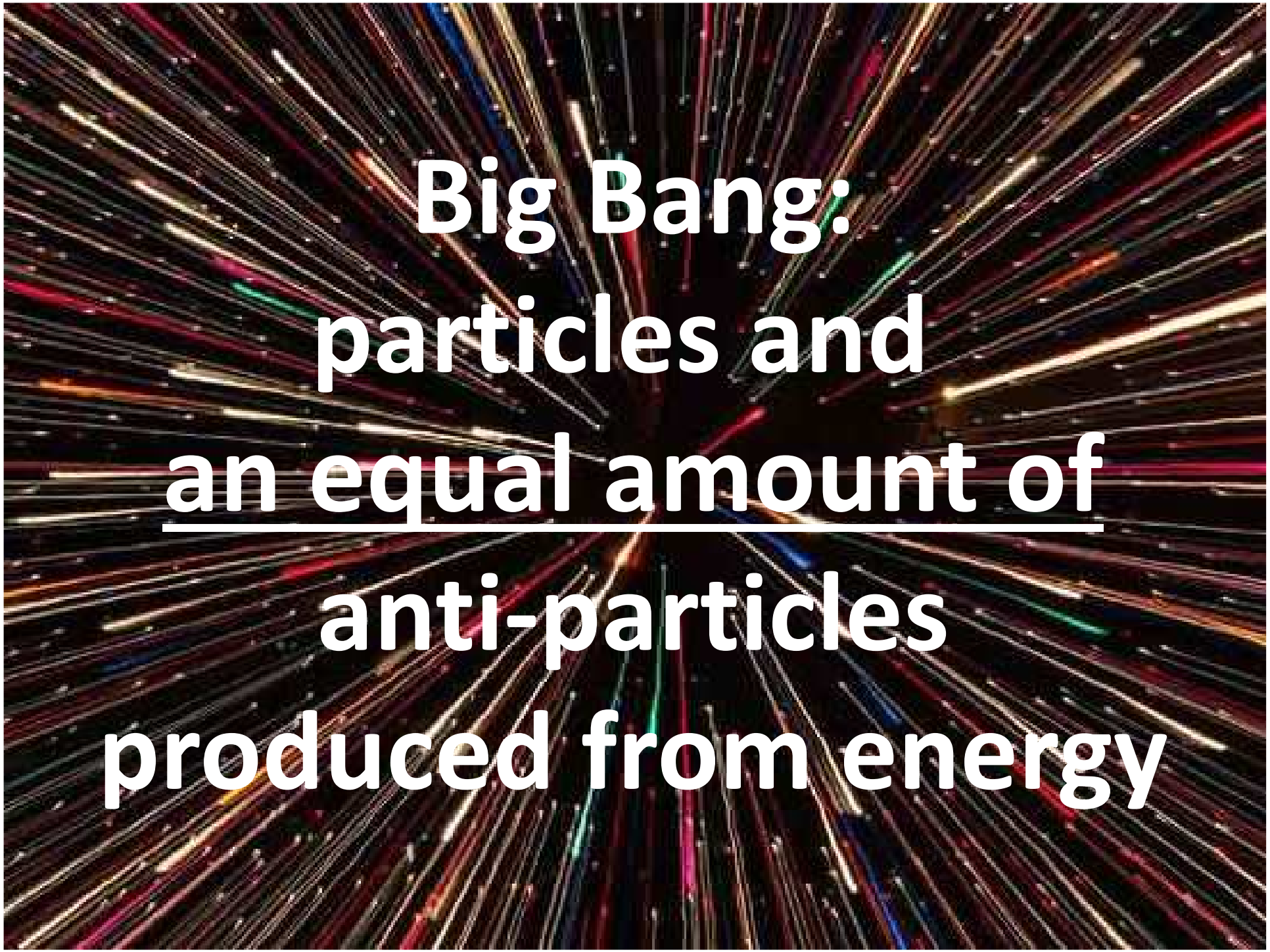
Introduction:

The Puzzle of the Matter-Universe

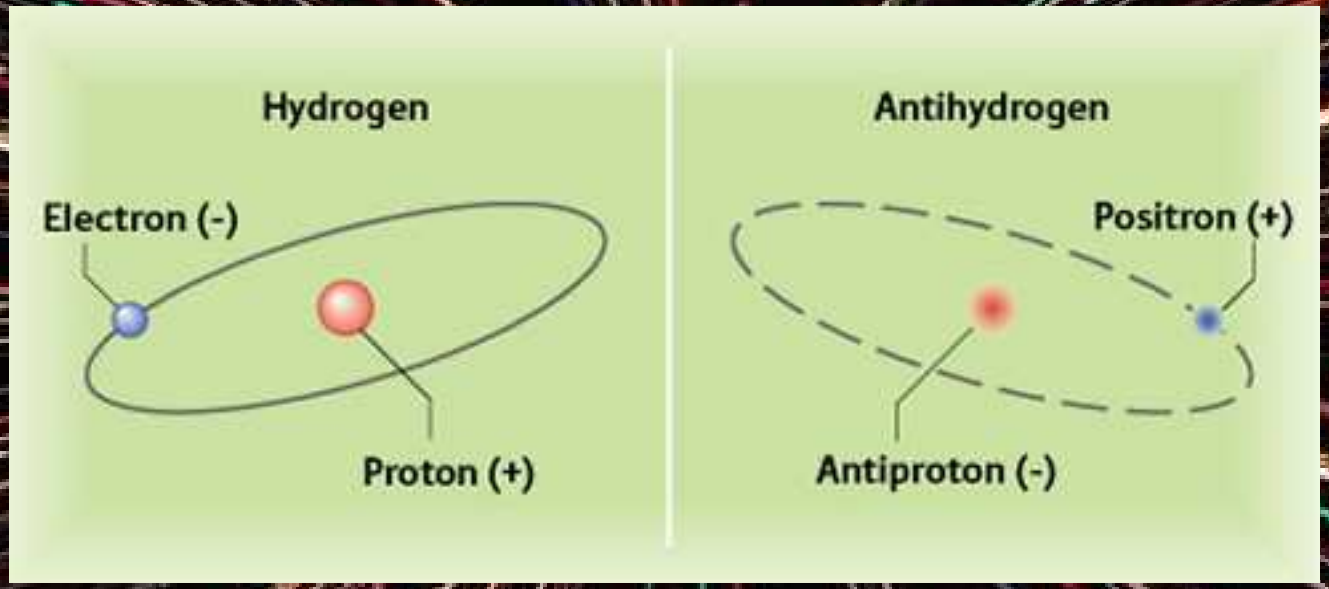

Timeline
0
Today
„Big Bang“
(about 14 billion years ago)


Anti-Particle
Energy
Particle


Pair-wise
production

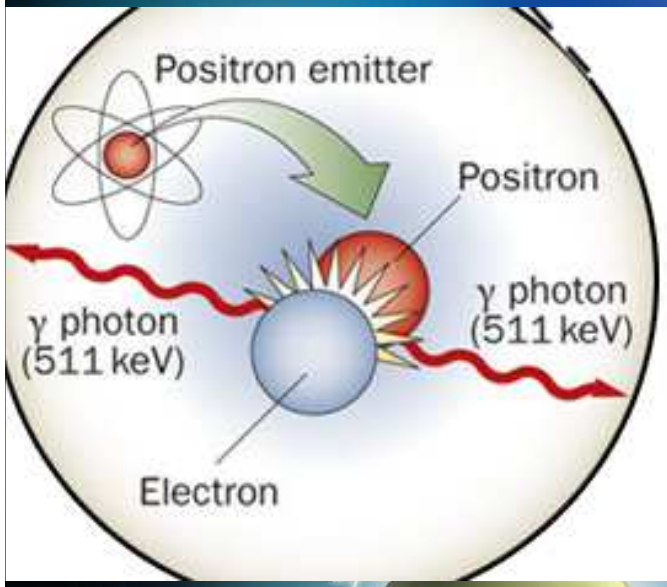

Big Bang:
particles and
an equal amount of
anti-particles
produced from energy

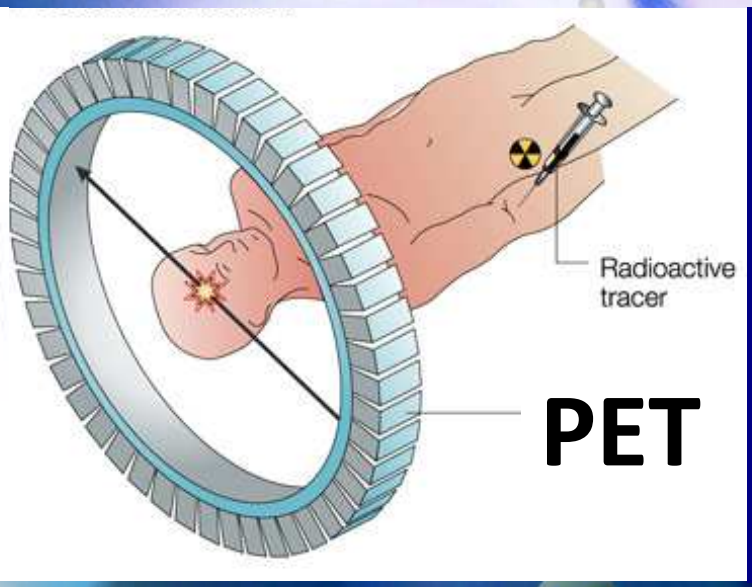
… leading to matter

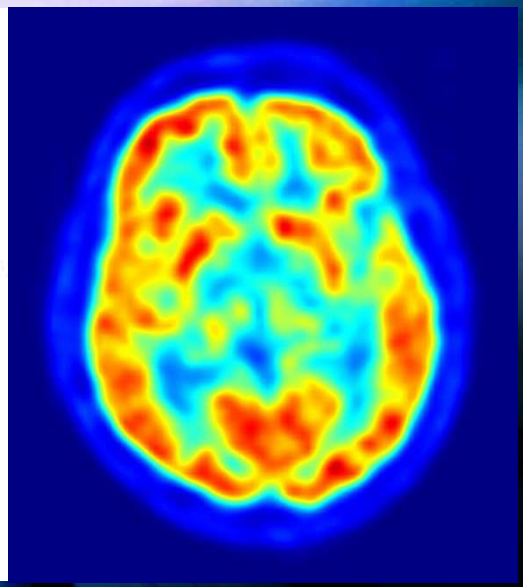


and anti-matter

Pair-wise annihilation







$\bar{p}$ into light


Why isn't there nothing?
Researchers hope to solve one of the greatest mysteries
http://www.fz-juelich.de/SharedDocs/Meldungen/PORTAL/DE/2015/15-04-02effzett.html

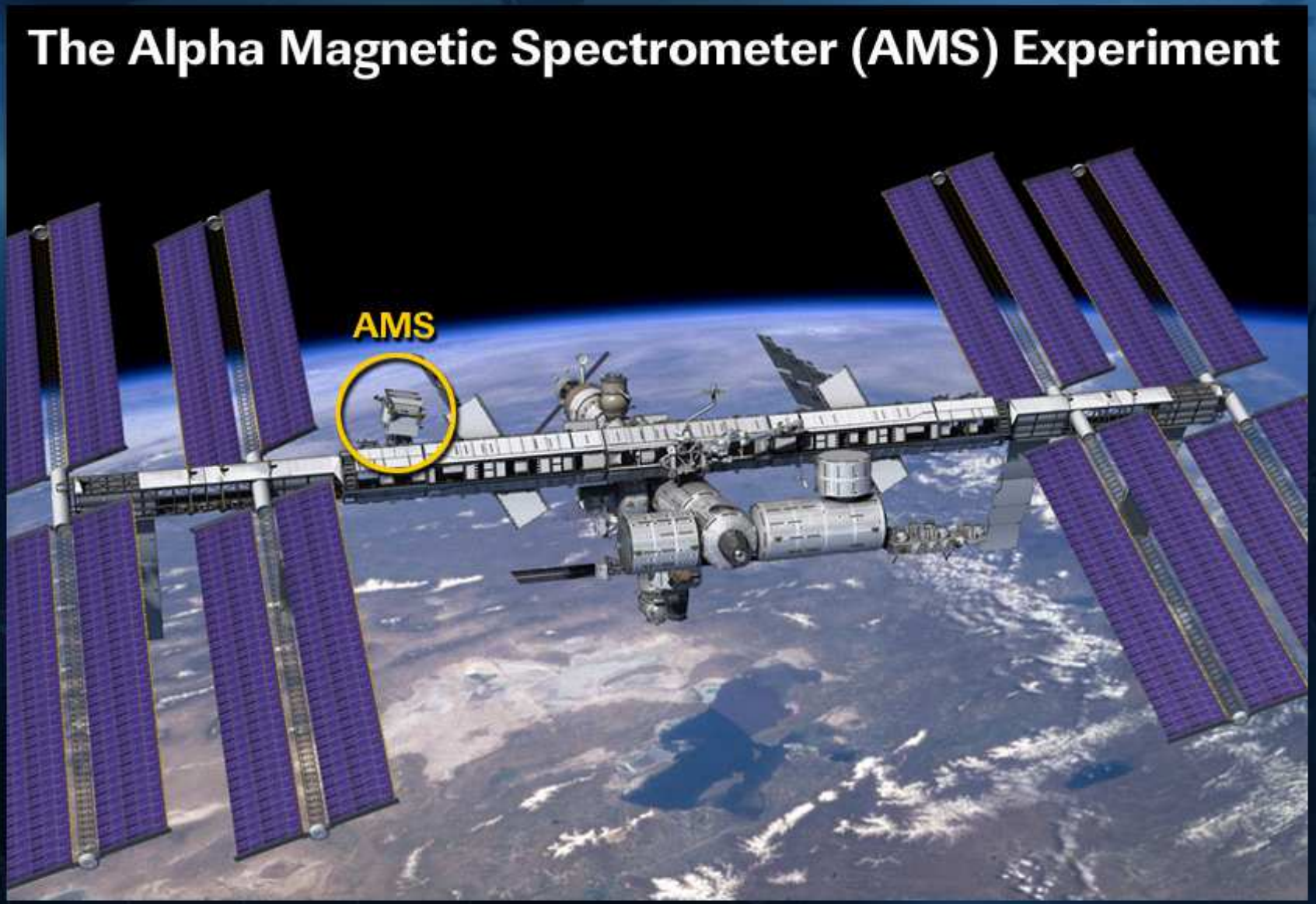
Why is there matter?

Puzzle of our existence!

Local or

global asymmetry?

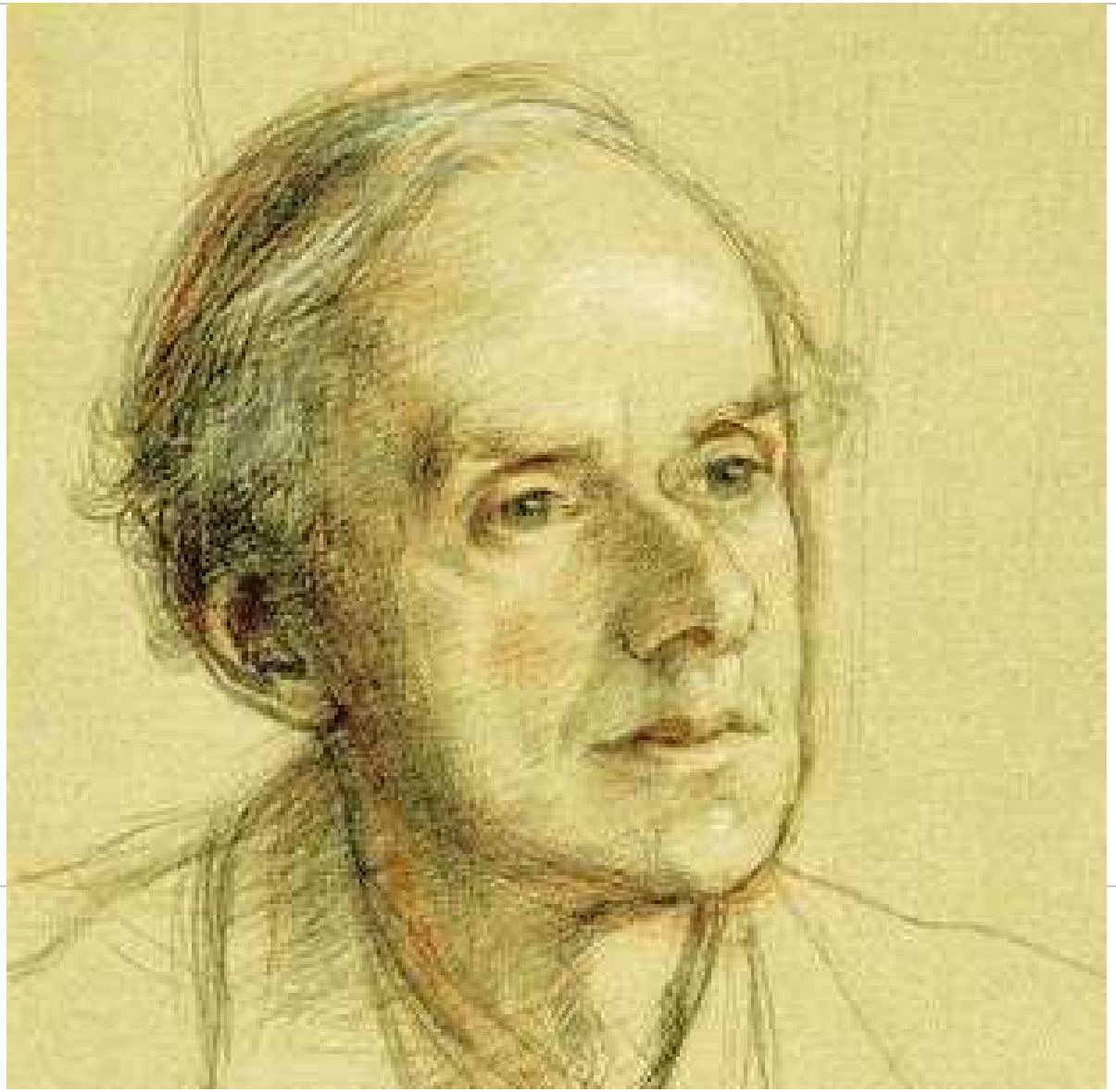
The Alpha Magnetic Spectrometer (AMS) Experiment



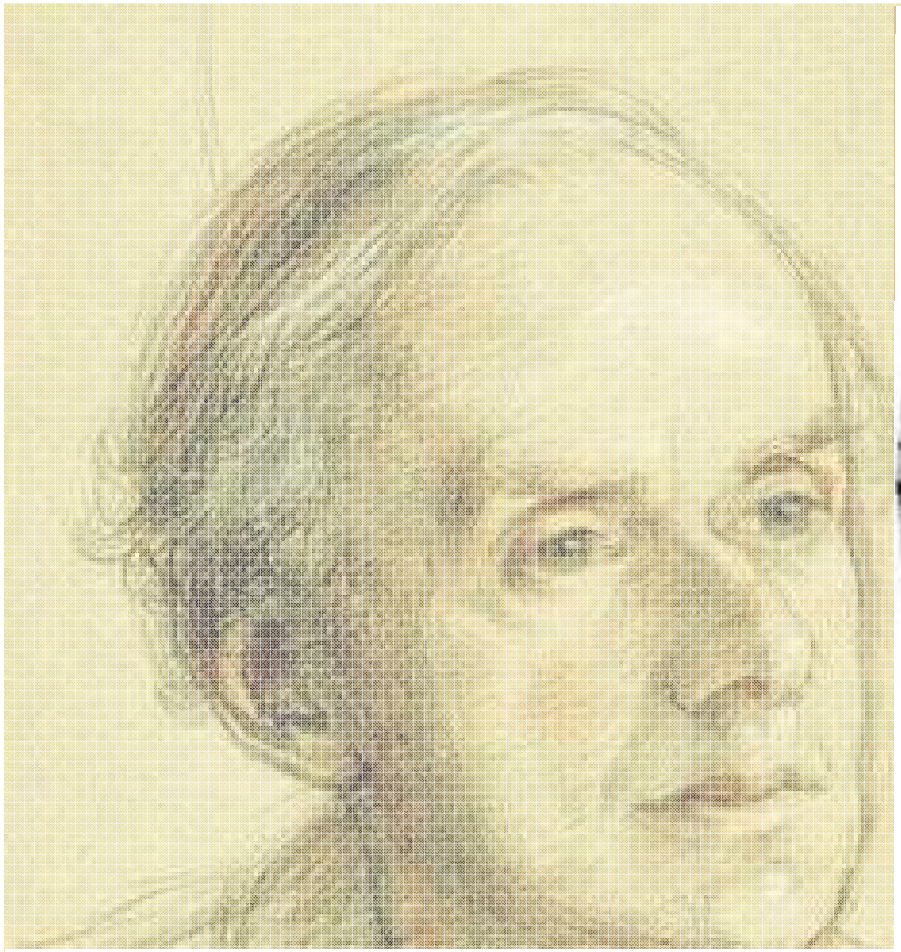
Background:

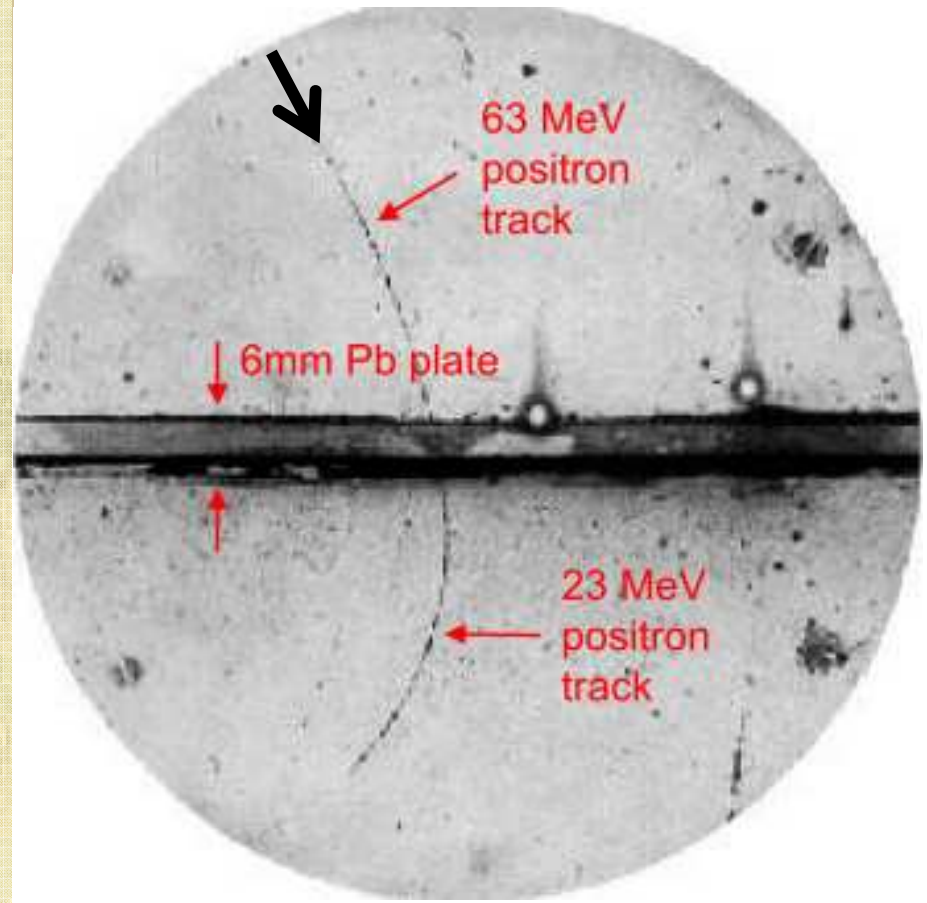
Anti-Particle/-Matter

Paul A.M. Dirac



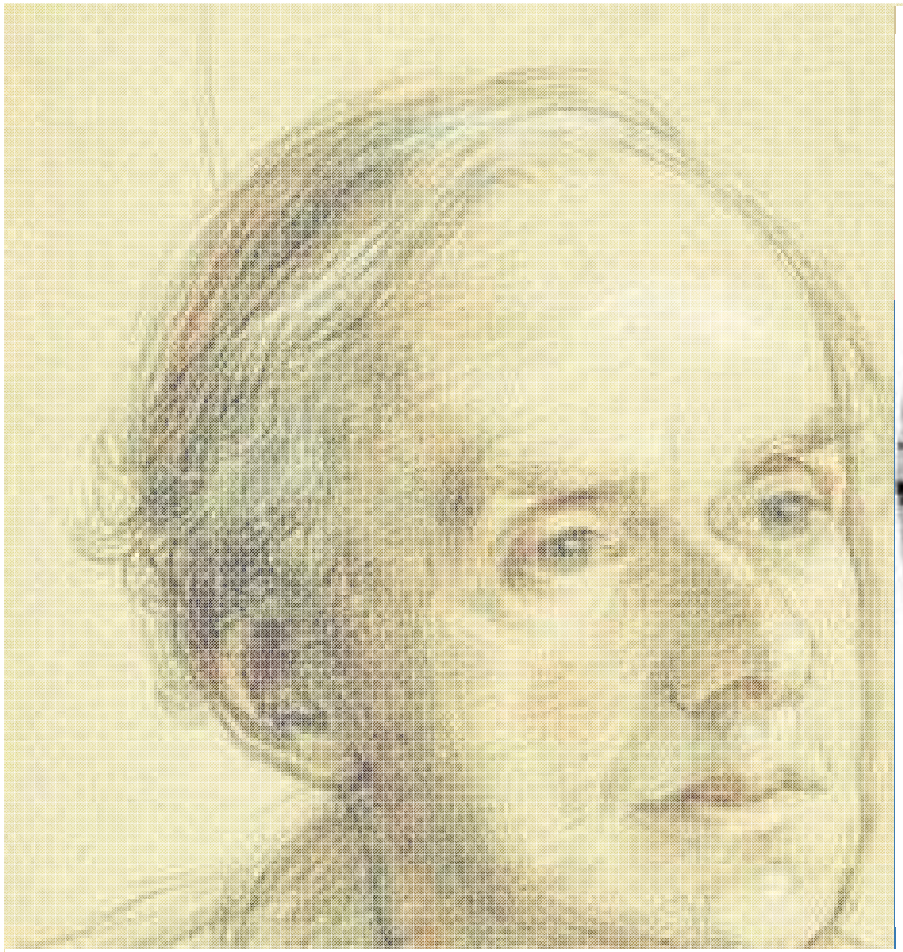
Paul A.M. Dirac

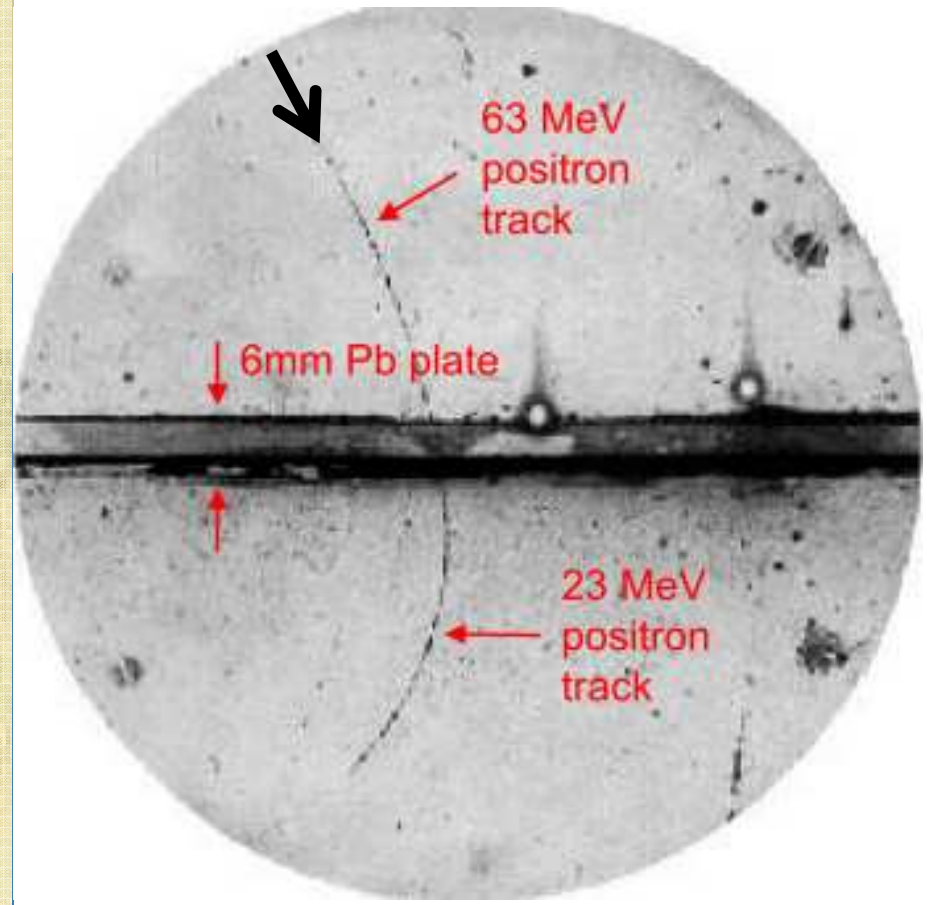




Inventor of Antimatter

Paul A.M. Dirac





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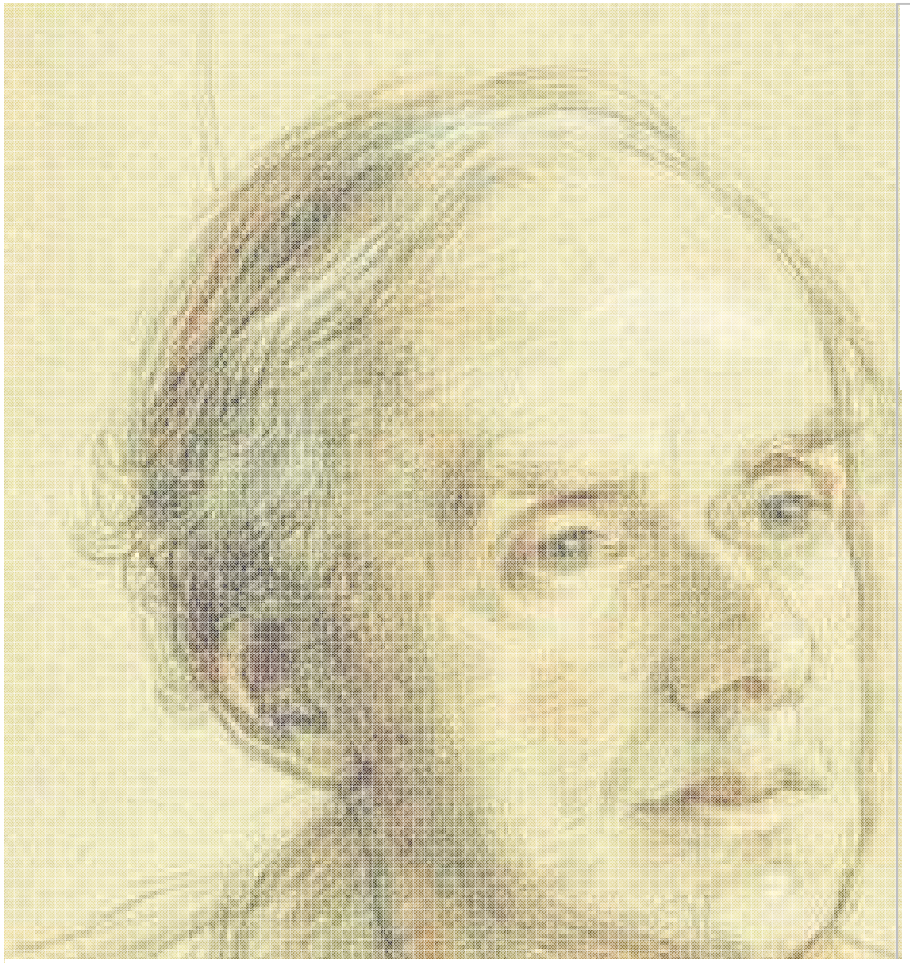


PAUL A. M. DIRAC

Theory of electrons and positrons

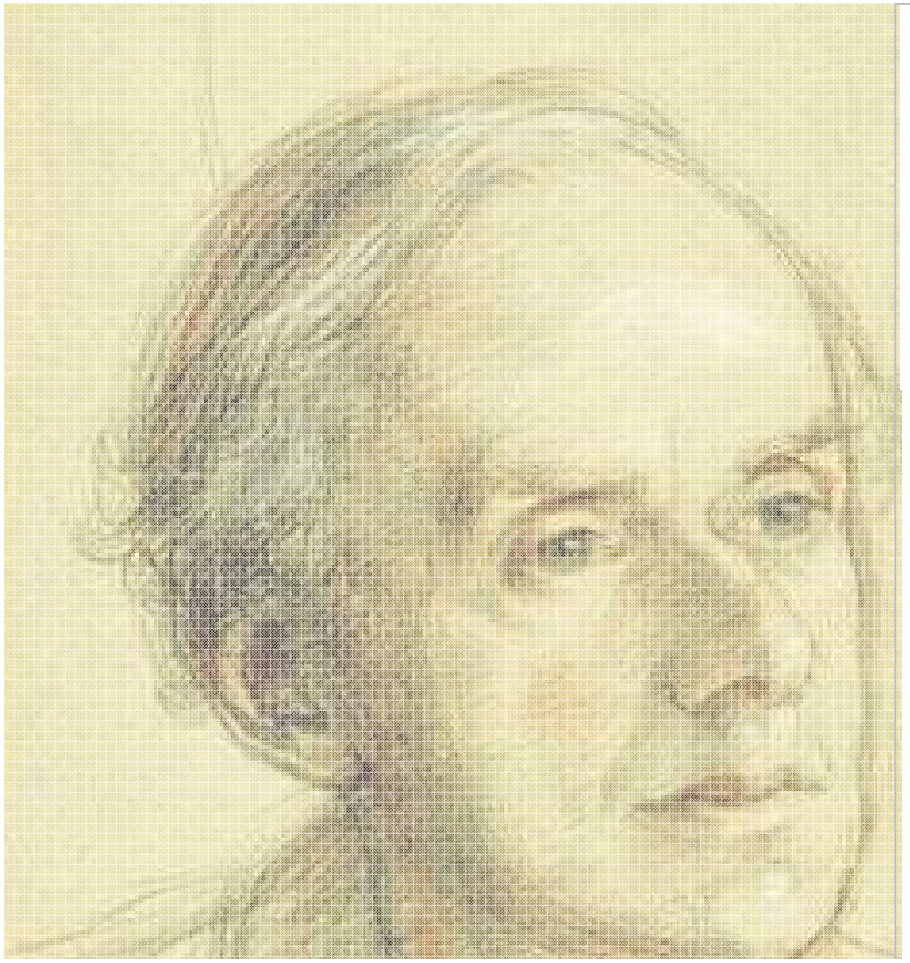
Nobel Lecture, December 12, 1933

“

…, we must regard it rather as an accident that the Earth (and presumably the whole solar system), contains a preponderance of negative electrons and positive protons.

Matter

Paul A.M. Dirac



PAUL A. M. DIRAC

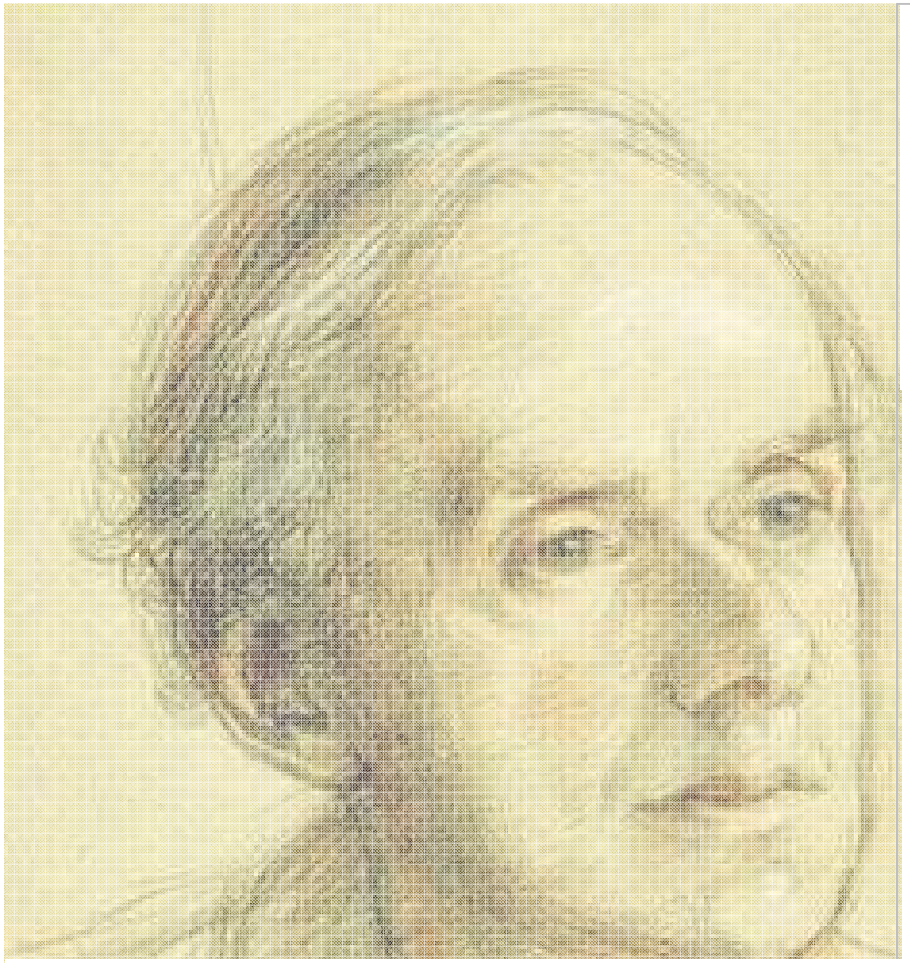
Theory of electrons and positrons

Nobel Lecture, December 12, 1933

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.”

Anti-Matter

Paul A.M. Dirac



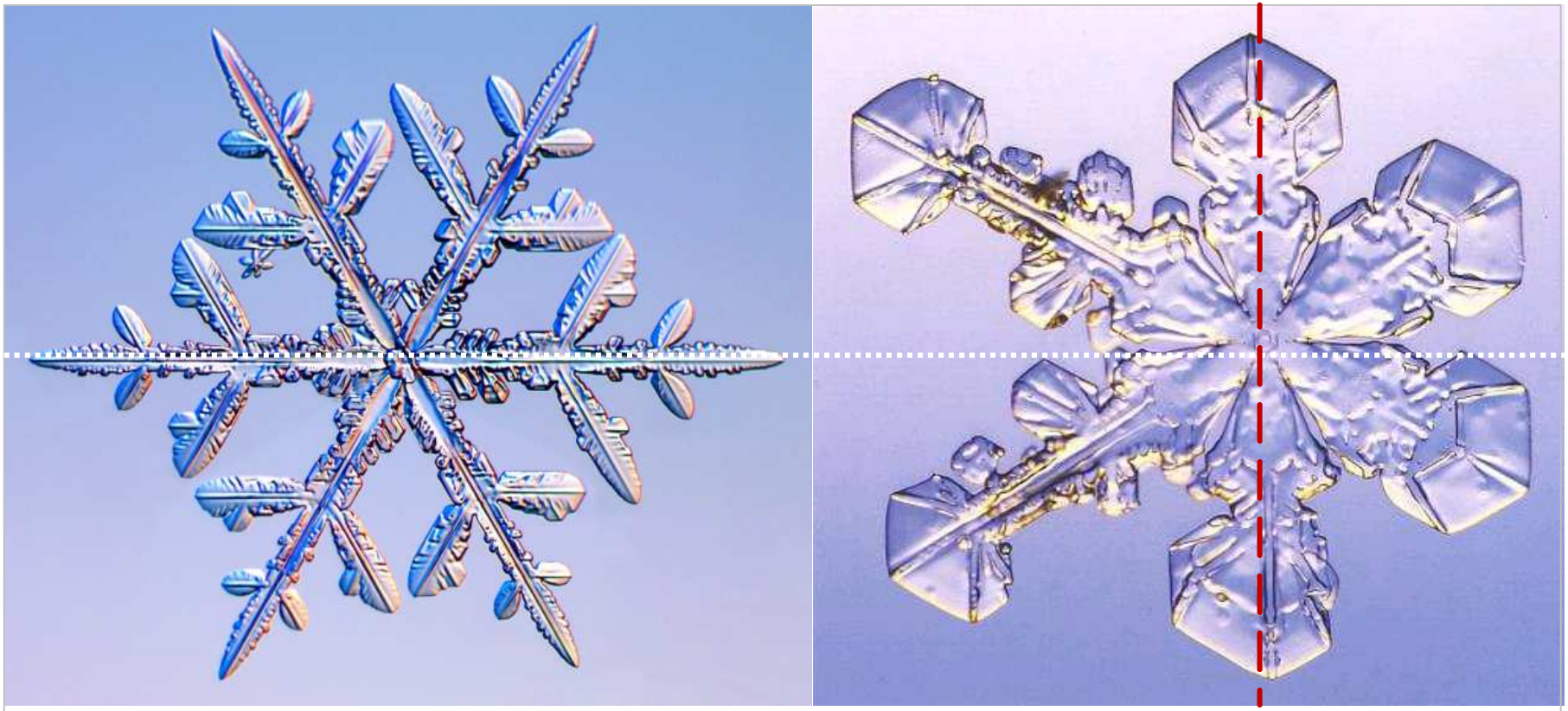
PAUL A. M. DIRAC

Theory of electrons and positrons

Nobel Lecture, December 12, 1933

“If we accept the view of complete symmetry between positive and negative electric charge as far as concerns the fundamental laws of Nature, ...”

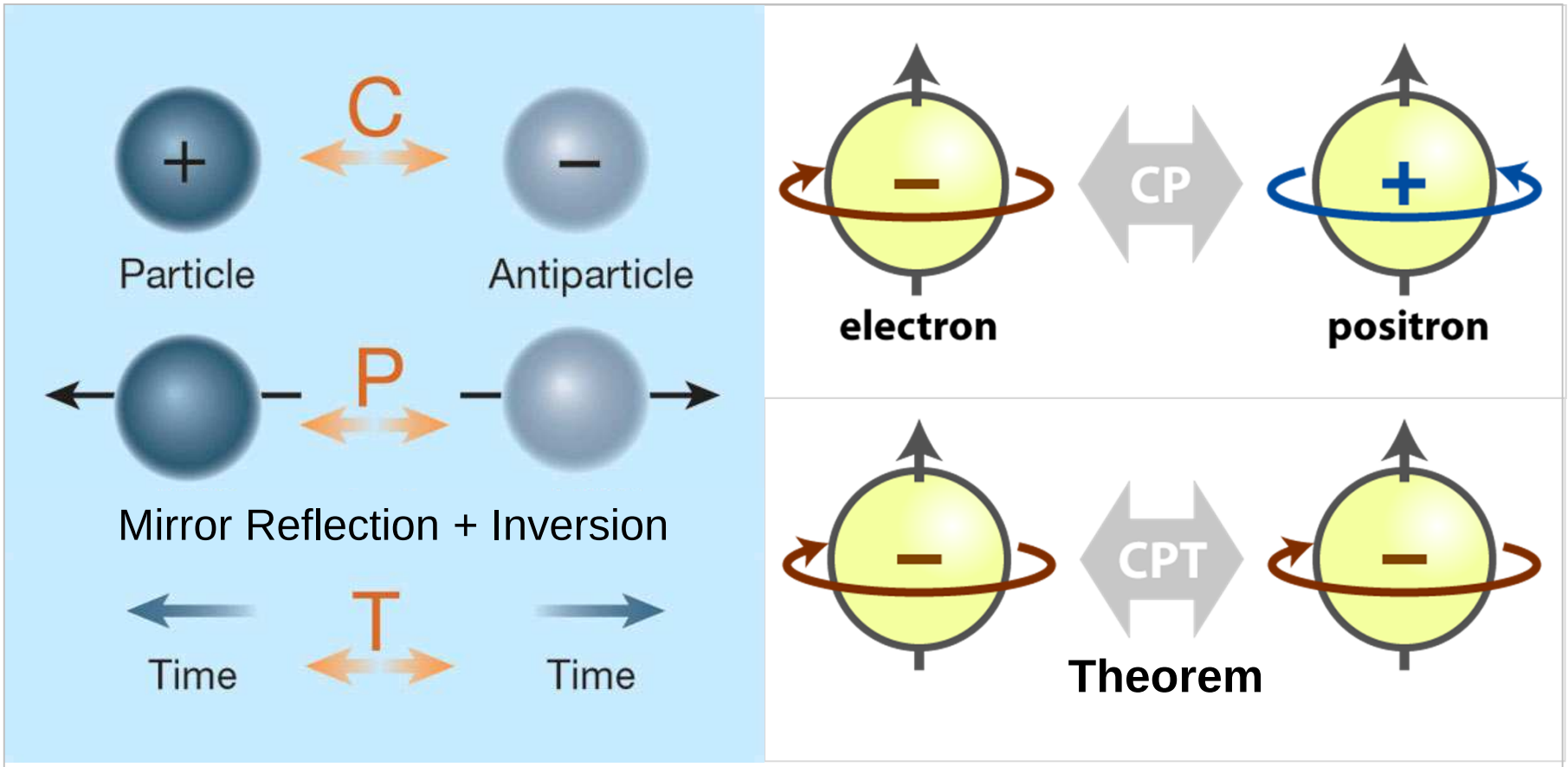
Symmetries



– Snow flakes –

Symmetrical Objects

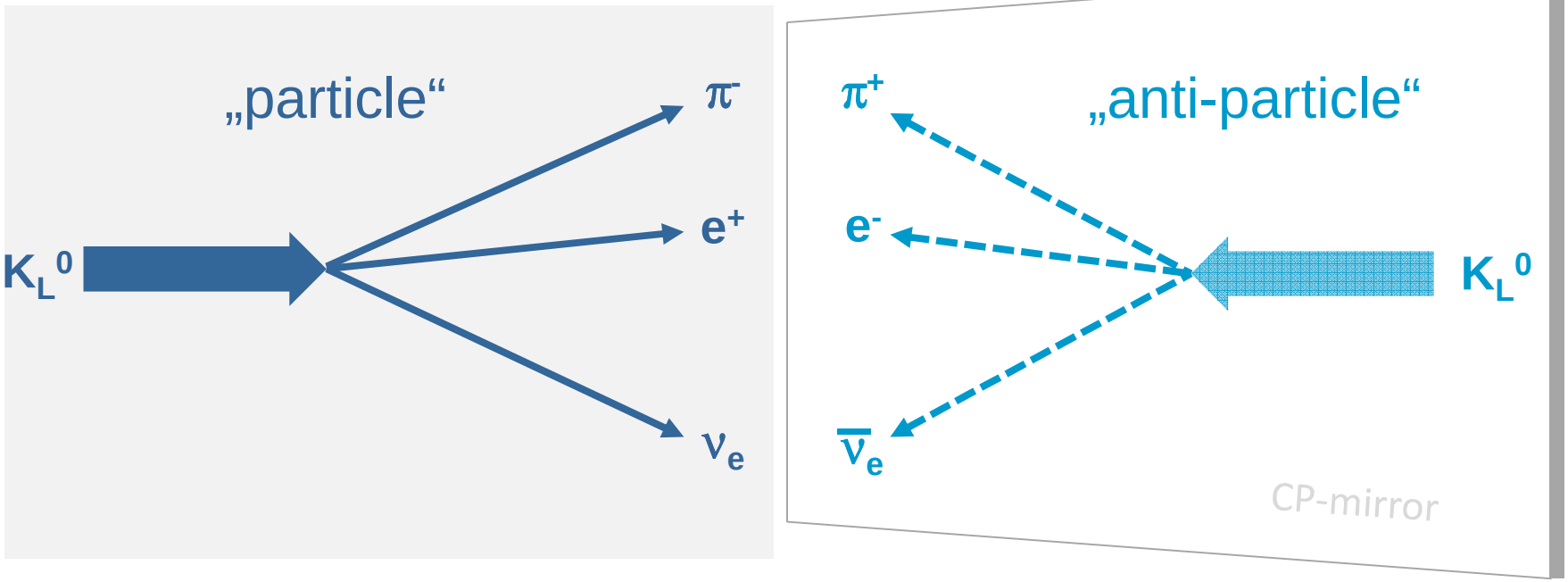
Why symmetries are important



CP is the **particle-antiparticle** symmetry

Discrete Symmetries

Why symmetries are important



Left decay happens more often!! (about 0.3%)

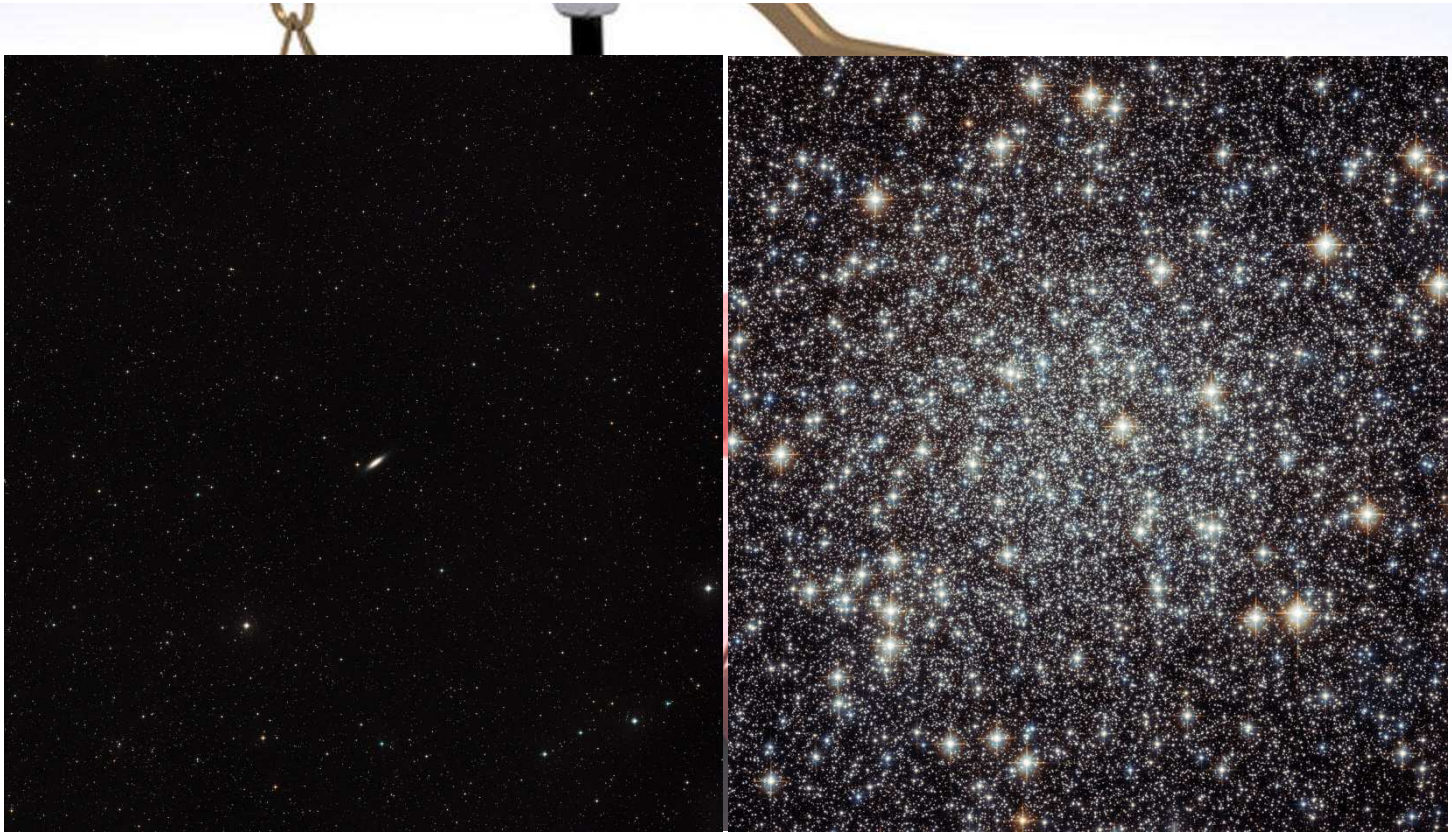
→ CP-Symmetry **is** „violated“

Asymmetry in Nature

Side remark: the question to ask an alien

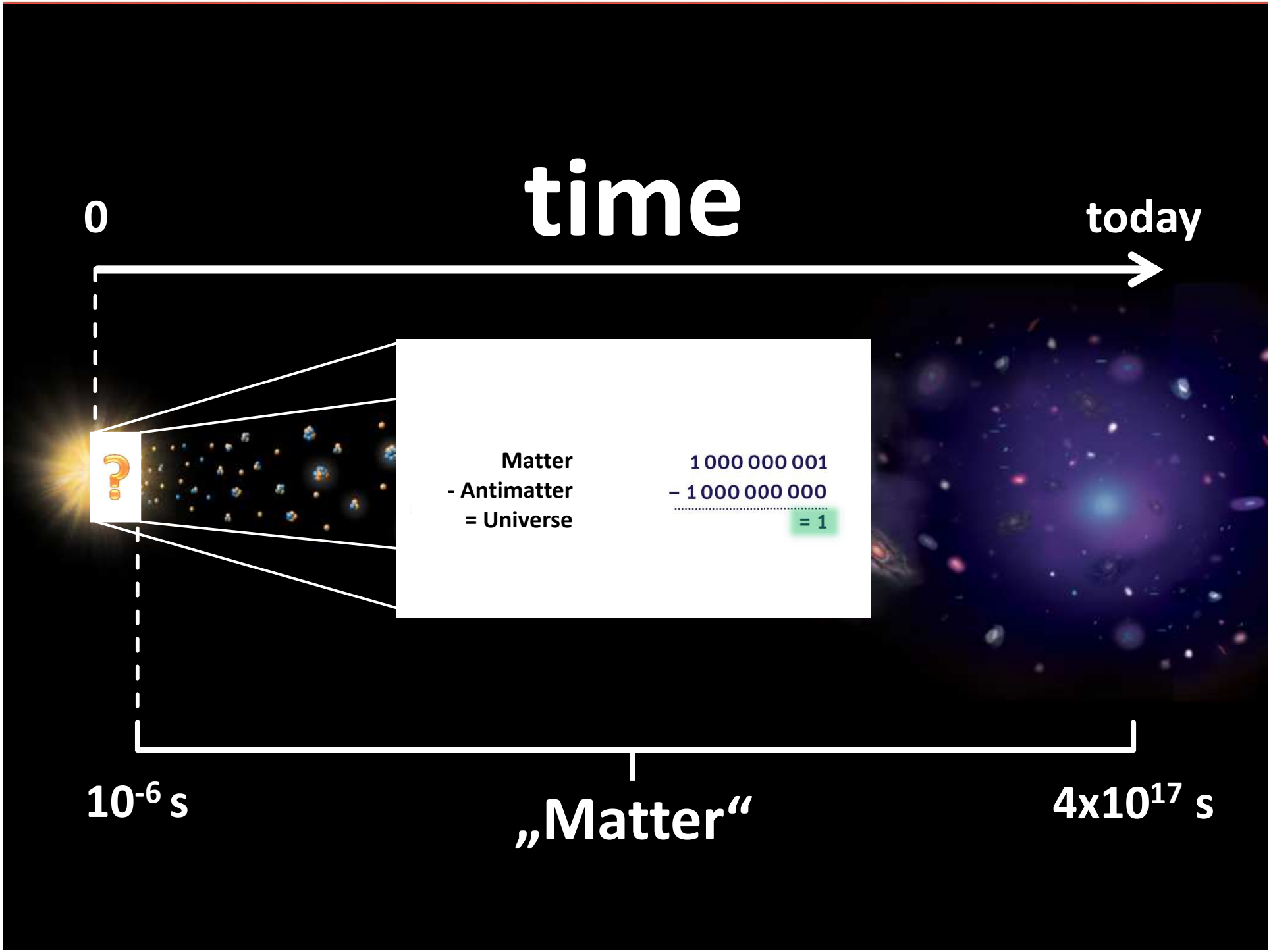
Atoms with e^+ or e^-

Matter-antimatter asymmetry

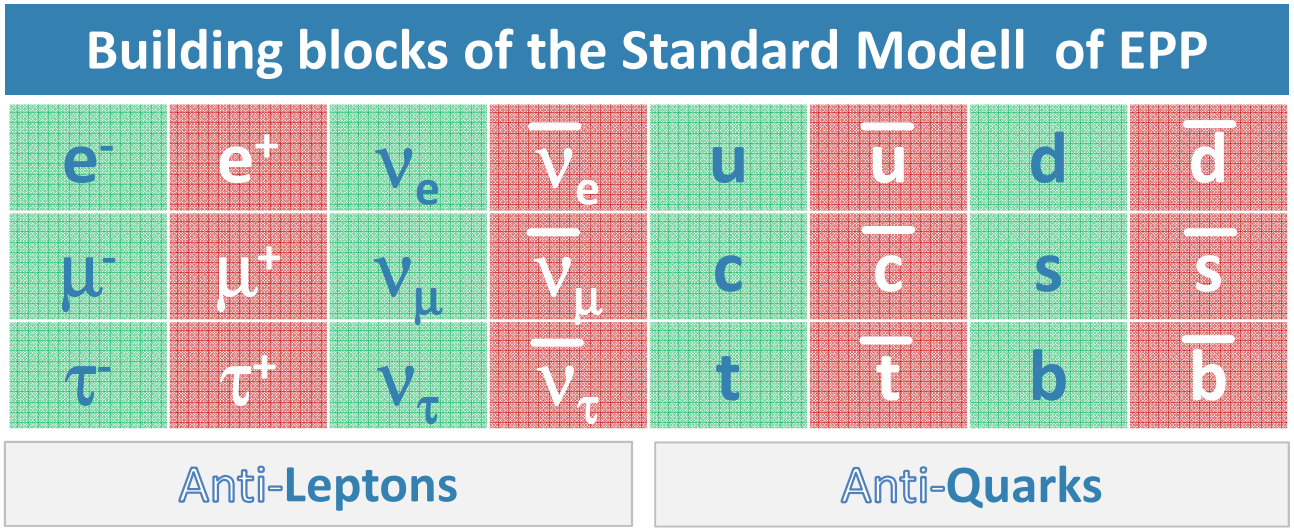


Problem: Standard Modell (SM) **CP-violation much too small**!

New Physics - beyond SM


time
0
today
?
Matter
- Antimatter
= Universe
1 000 000 001
– 1 000 000 000
= 1
10-6 s
„Matter“
4x1017 s

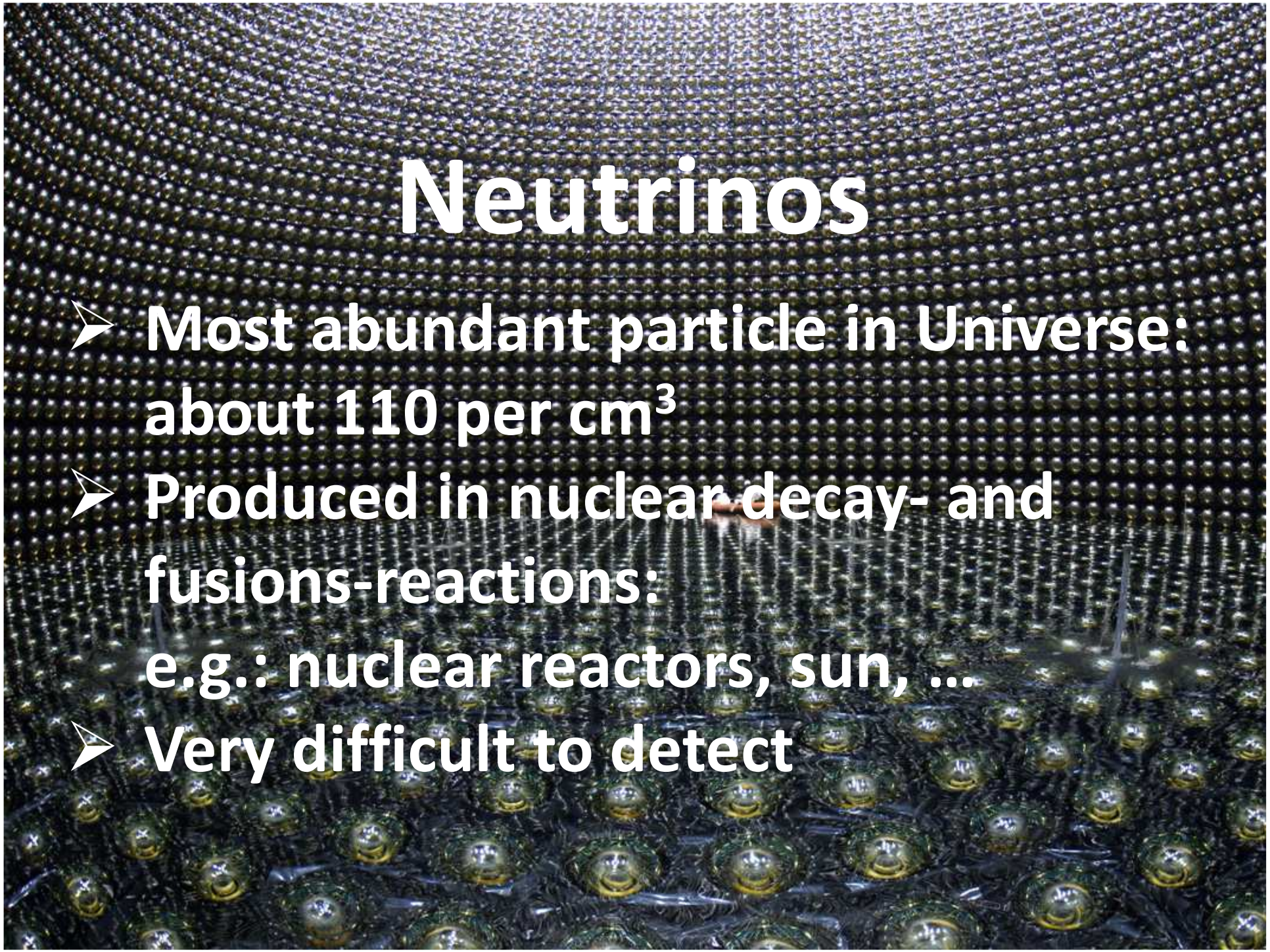
The Fate of Antimatter



Search for new CPV – with Leptons; Quarks

Leptonic Sector:

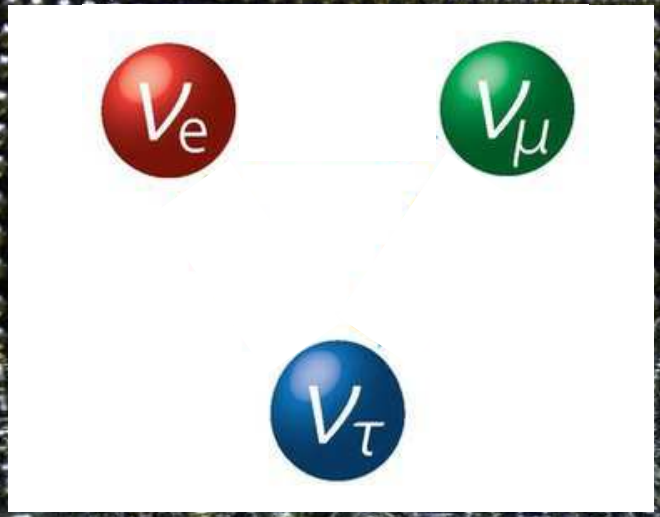
„Lepto-genesis“

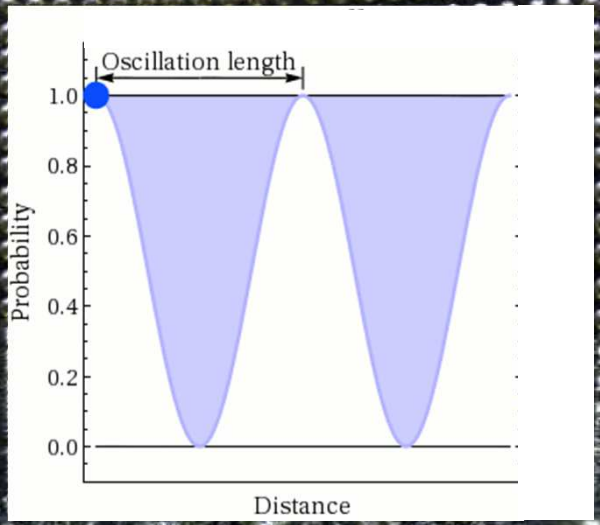


Neutrinos

- Most abundant particle in Universe: about 110 per cm^3
- Produced in nuclear decay- and fusions-reactions:
  e.g.: nuclear reactors, sun, …
- Very difficult to detect

Neutrinos

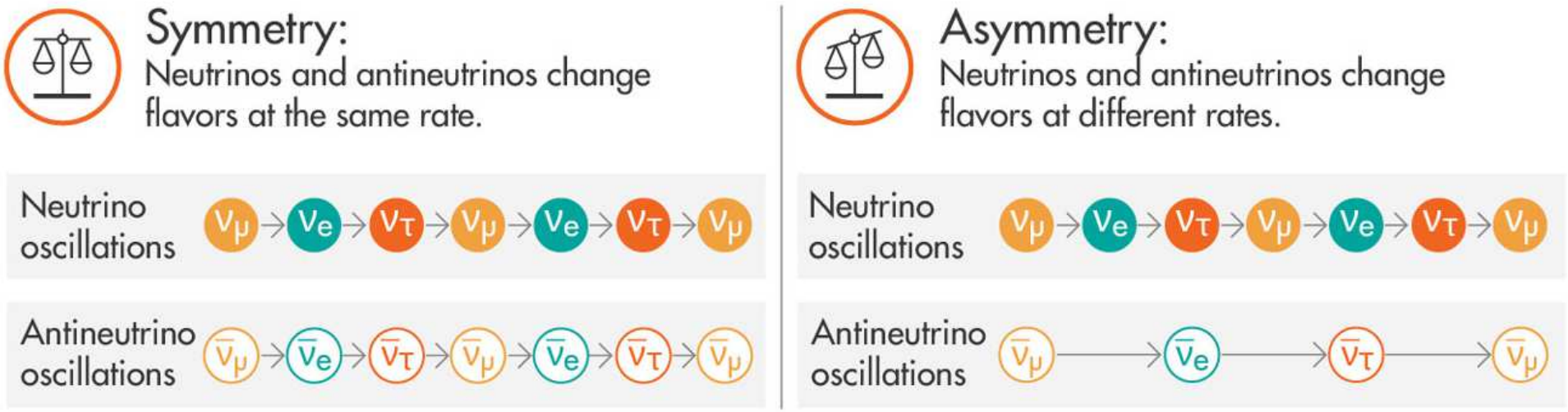




Flavor-Oscillations

Leptonic Sector

$\nu_\alpha \rightarrow \nu_\beta$ CP $\bar{\nu}_\alpha \rightarrow \bar{\nu}_\beta$



Comparison of **neutrino-** und **anti-neutrino** – oscillations

CP-Violation?

Leptonic Sector

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

after about 2 µs

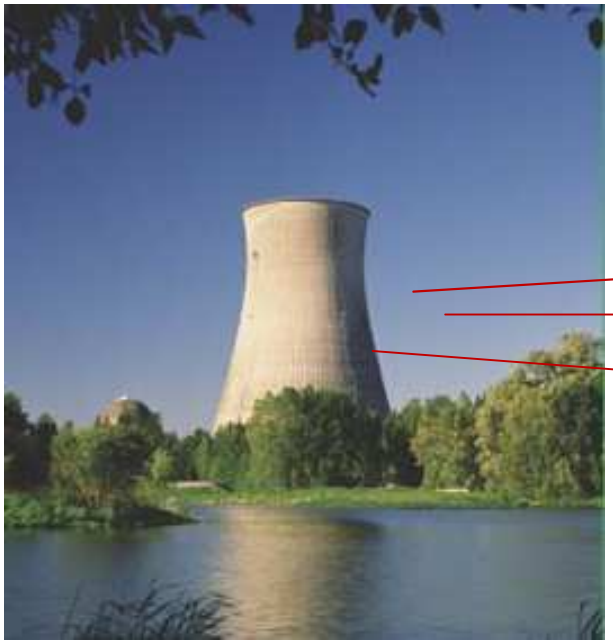
$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

(… similar for π^+ …)

Difference between **neutrino-** und **anti-neutrino** – oscillations

Set-up of Experiments

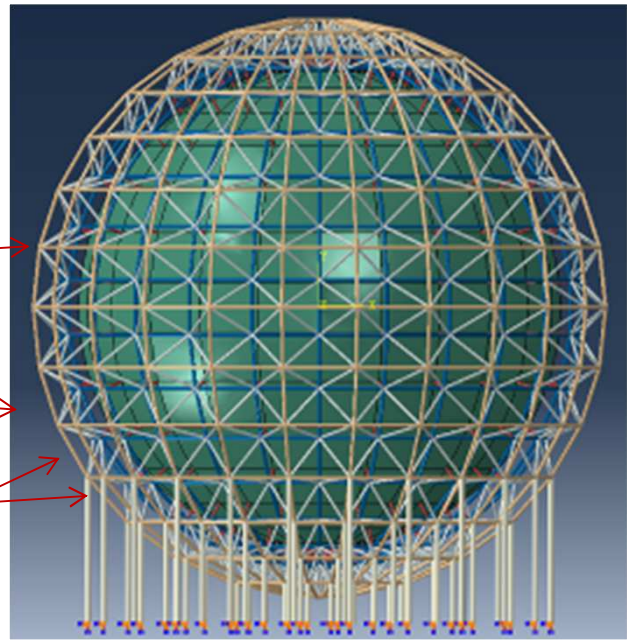
Leptonic Sector



Neutrinos

from nuclear reactors
distance ~53 km

and from Universe



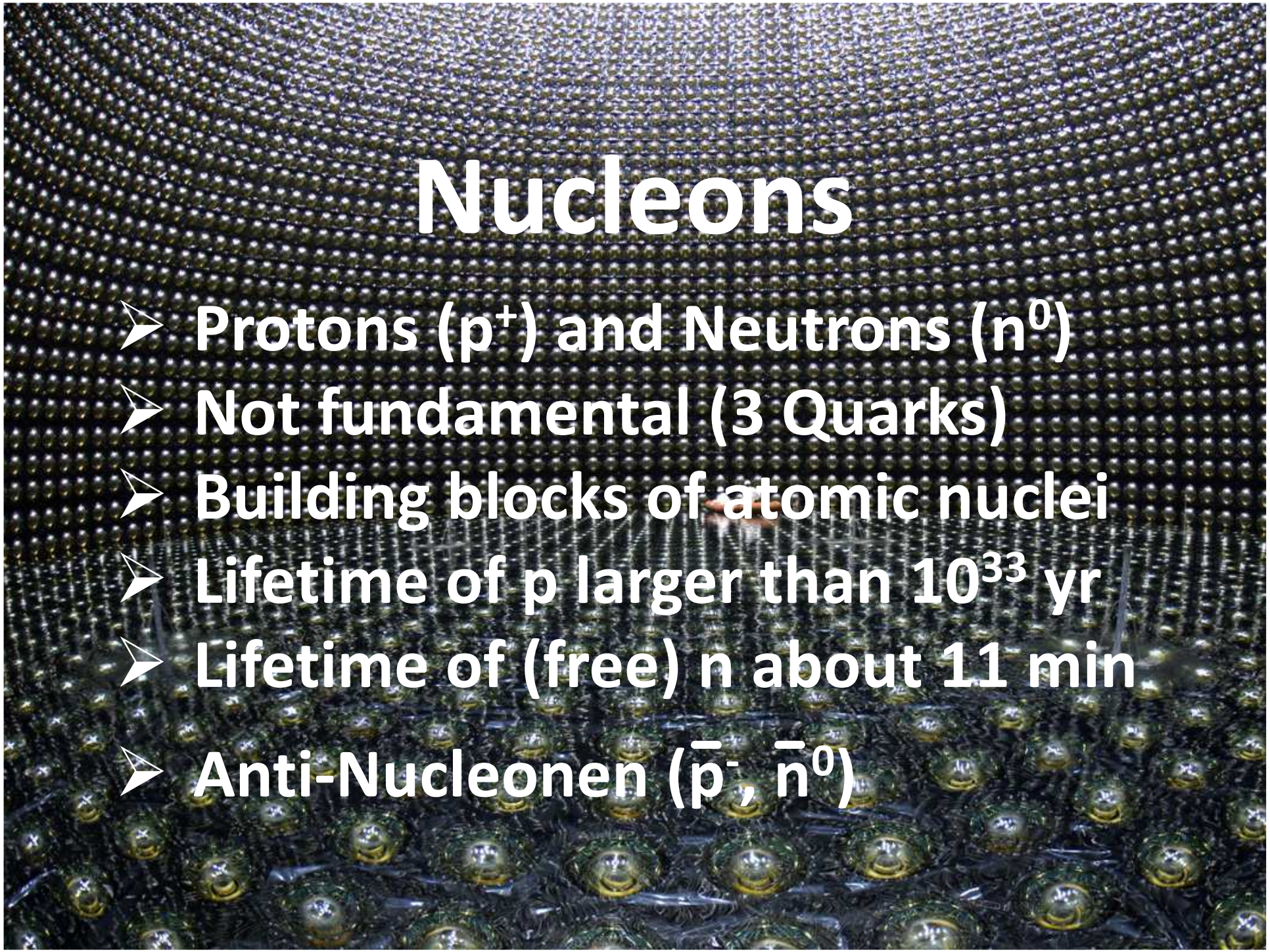
Jiangmen Underground Neutrino Observatory (JUNO), China

20.000 t liquid scintillator
15.000 photomultiplier
700 m below ground
construction 2015 – 2019

One Example

Hadronic Sector:

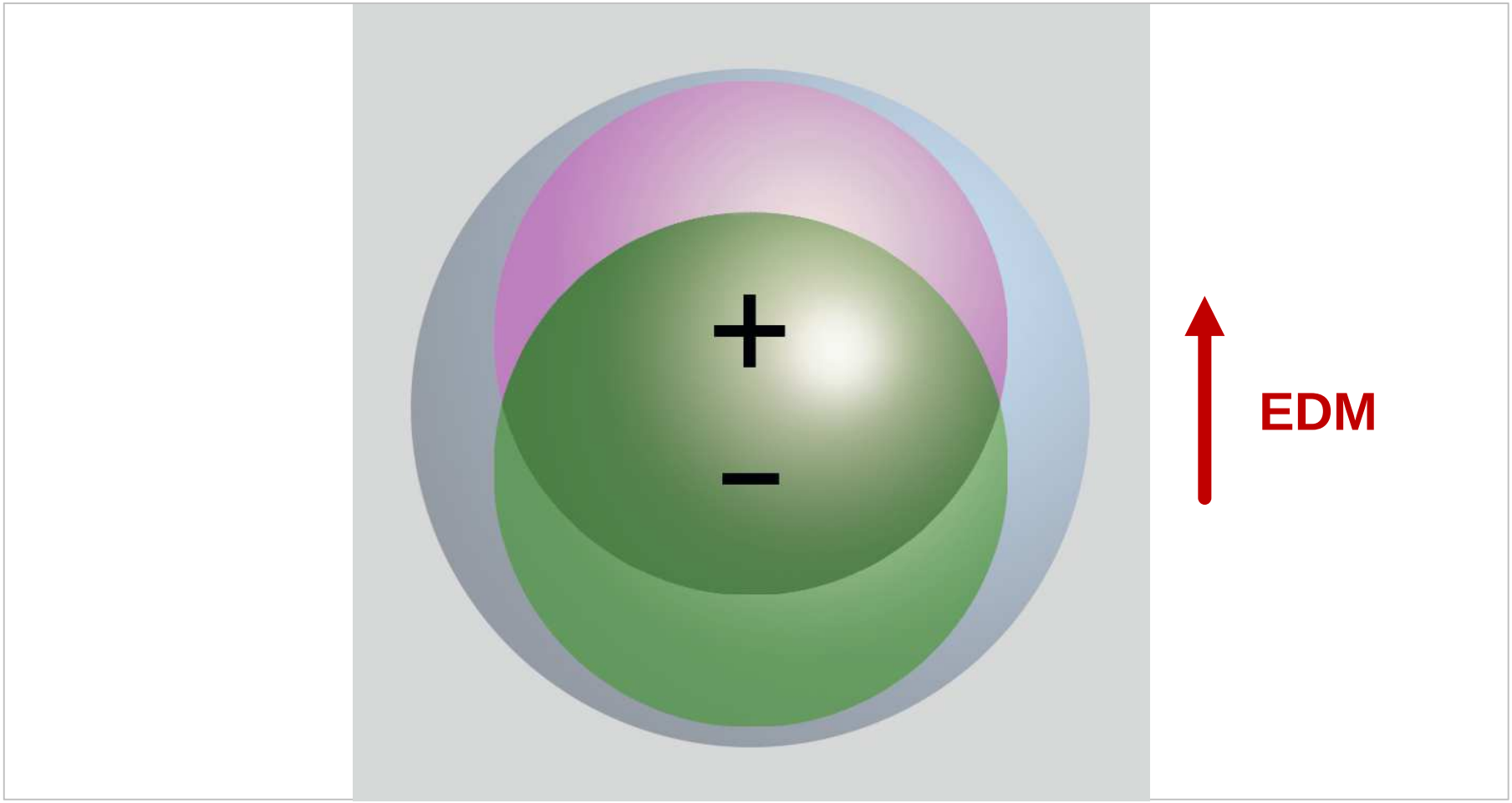
„Baryo-genesis“



Nucleons

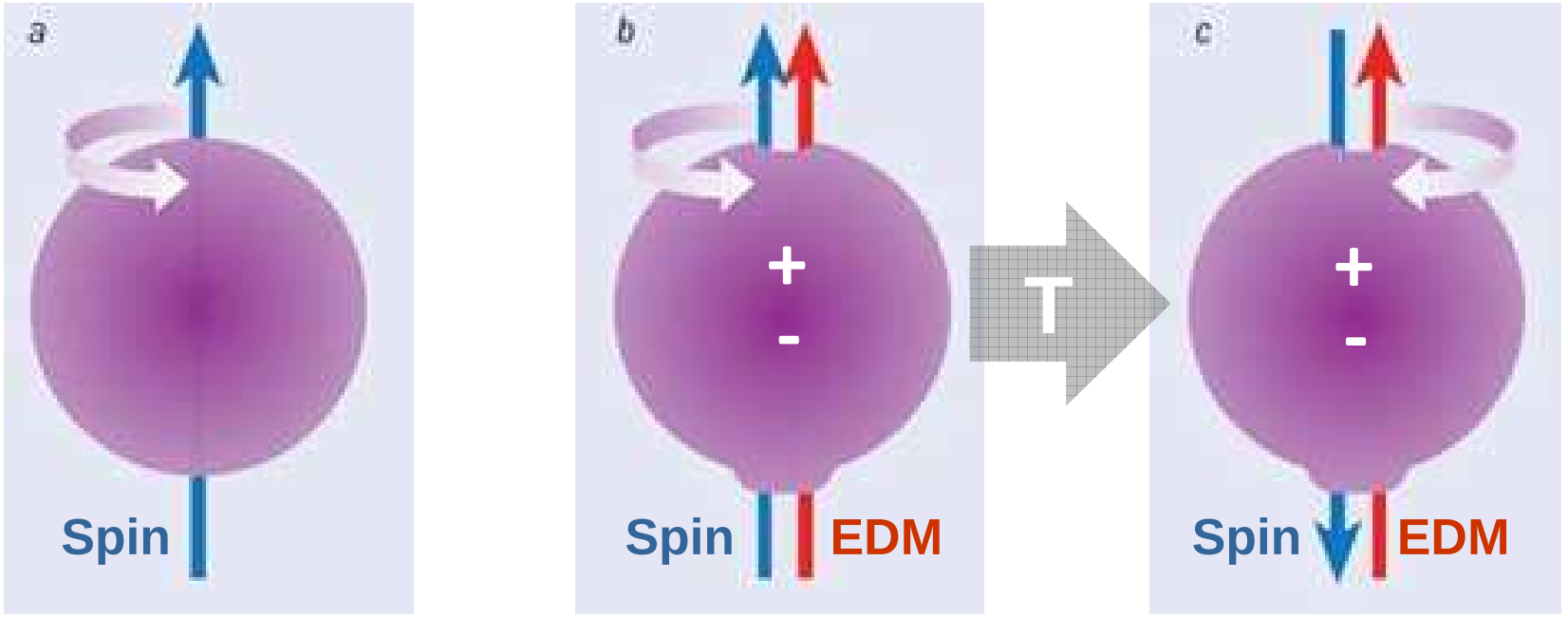
- Protons (p^+) and Neutrons (n^0)
- Not fundamental (3 Quarks)
- Building blocks of atomic nuclei
- Lifetime of p larger than 10^{33} yr
- Lifetime of (free) n about 11 min
- Anti-Nucleonen ($\bar{p}^-$, $\bar{n}^0$)

Hadronic Sector



Electric Dipole Moment

Hadronic Sector



„Sphere“:
No EDM

Different
states

EDM violates T (CP)

Hadronic Sector

Neutron

1 fm

10^{22} fm

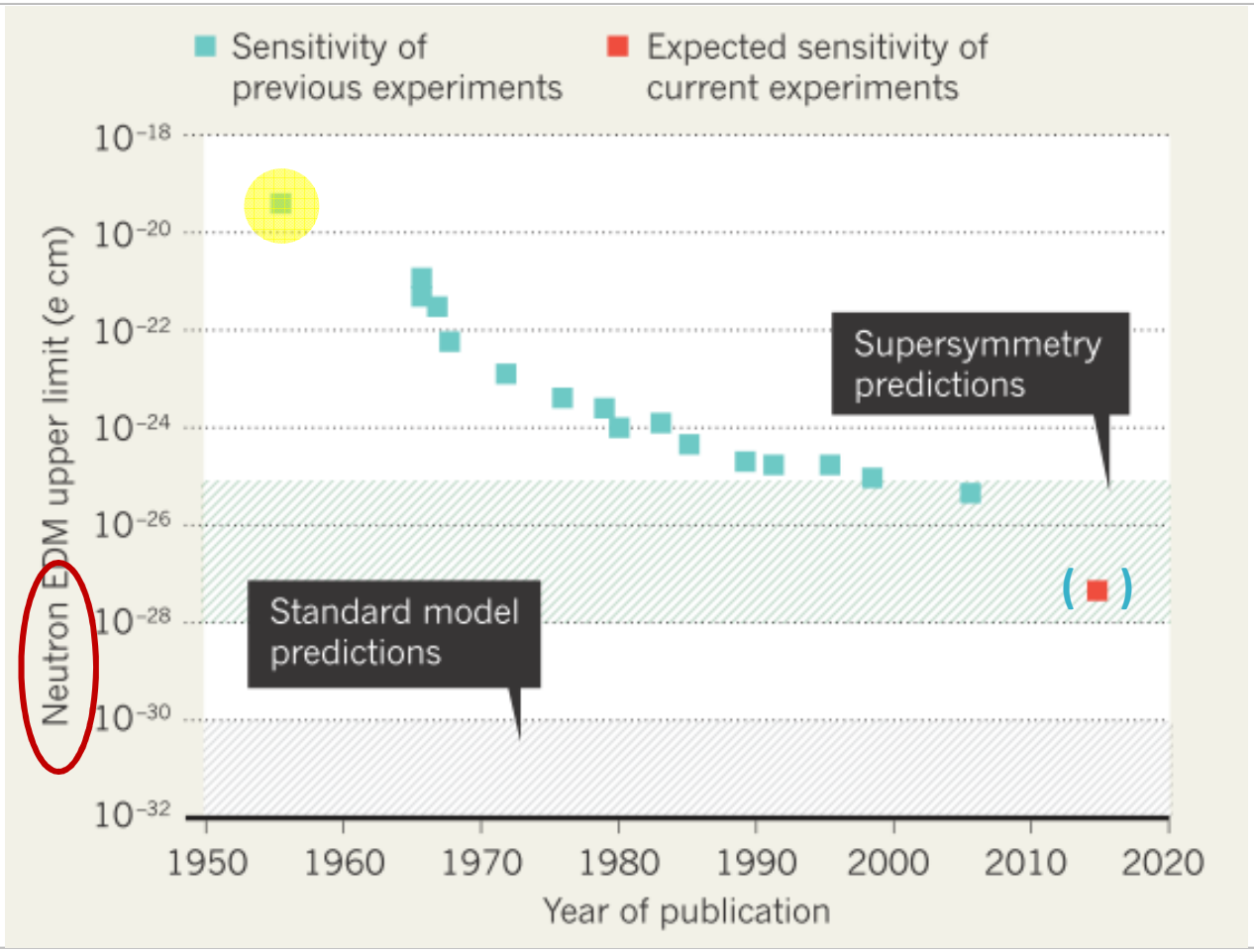
+

<10 µm

-

Precision Experiment!

Hadronic Sector

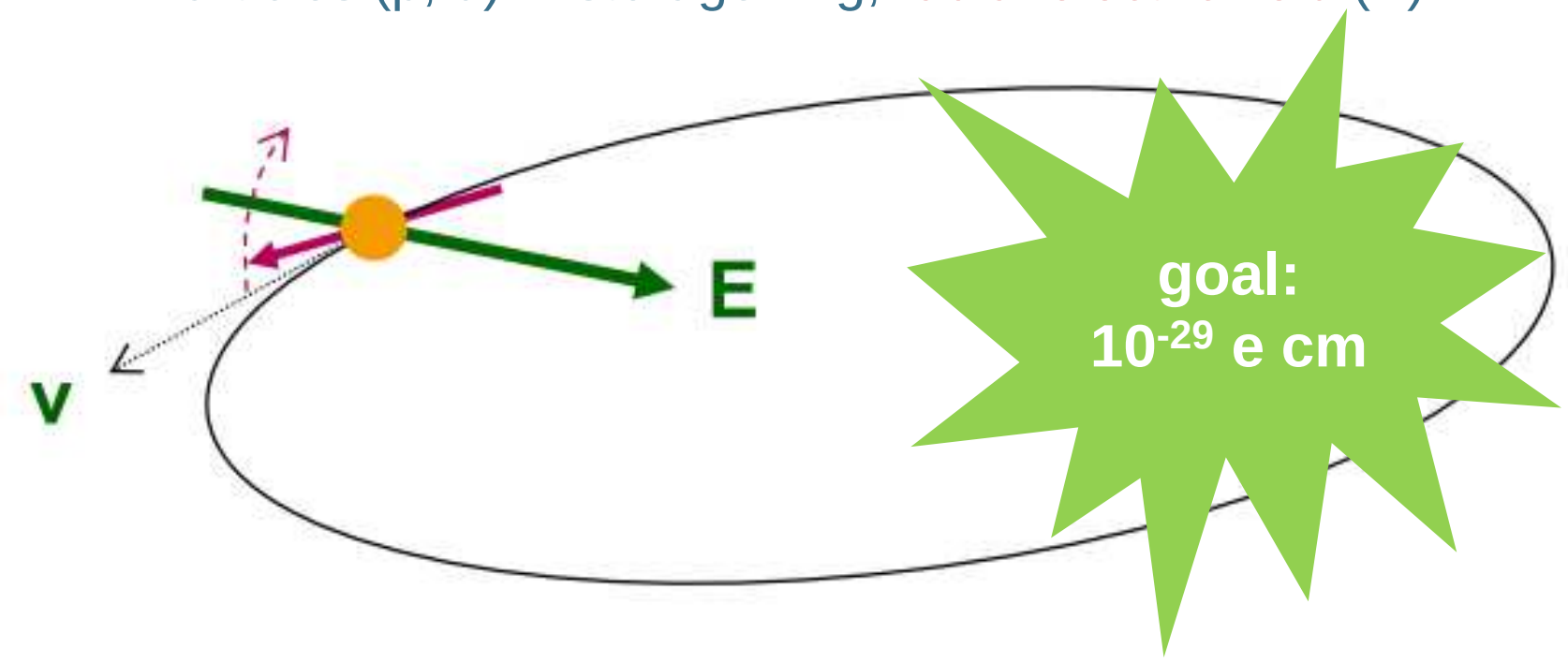


After *Nature*, Vol 482 (2012)

To date: only upper limits

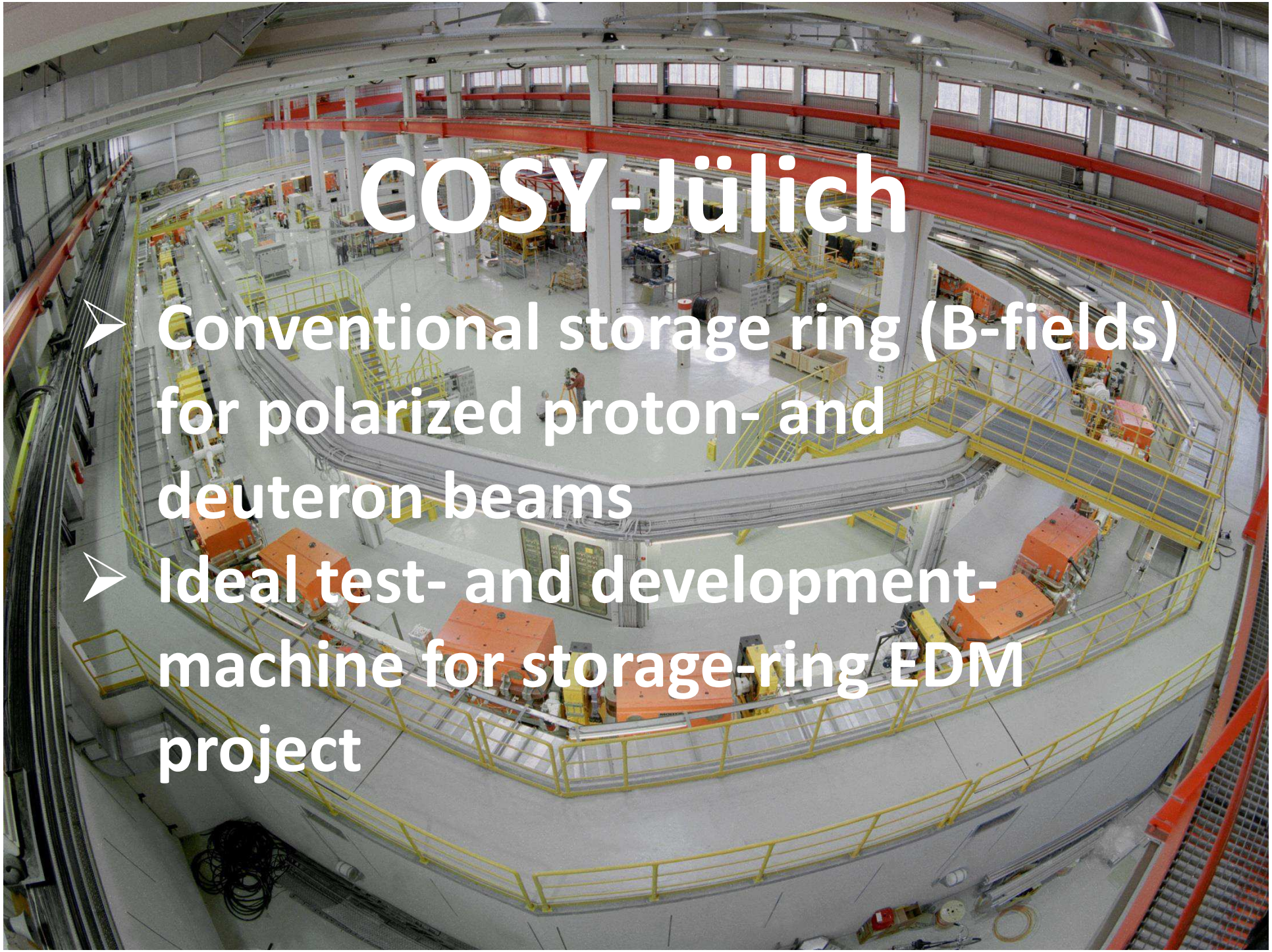
Hadronic Sector

Particles (p, d) in storage ring; radial electric field (E):

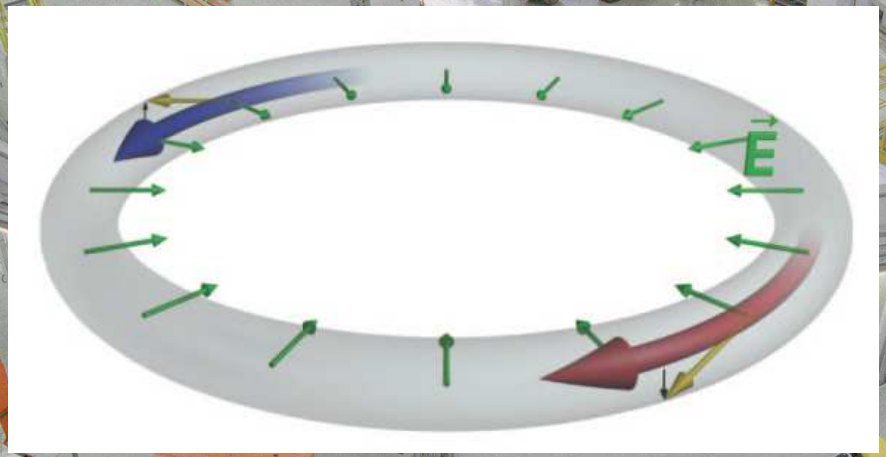


If EDM ≠ 0: torque: $\vec{\tau} \sim \vec{d} \times \vec{E}$ → spin rotates out of plane

New: charged particles

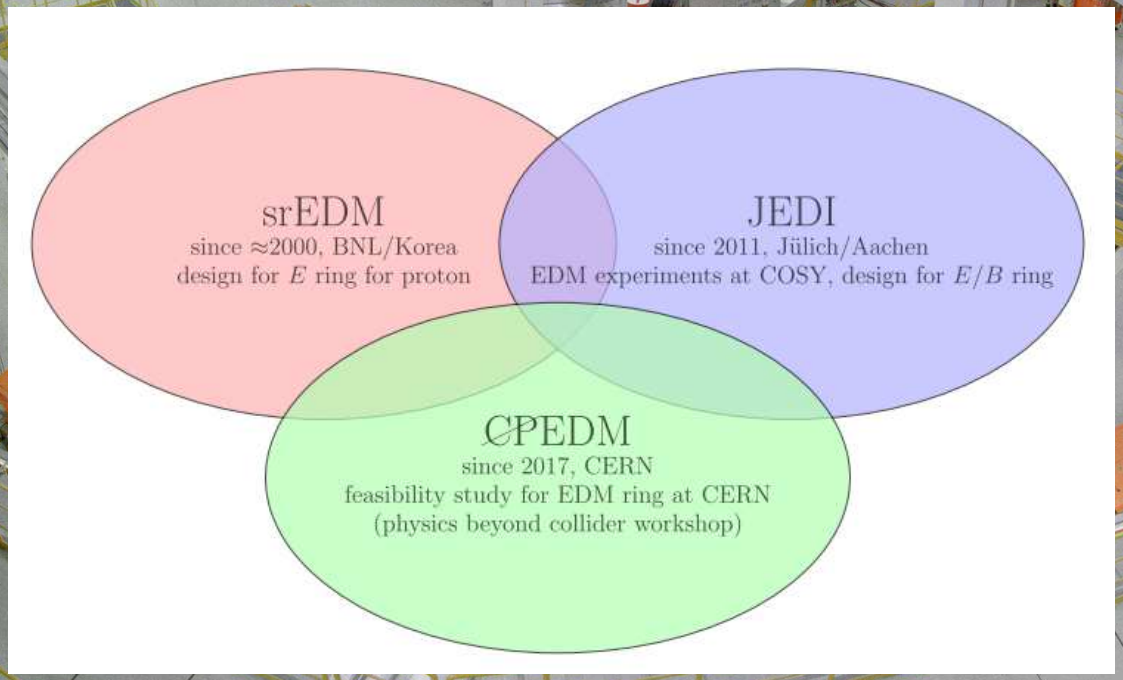

COSY-Jülich
Conventional storage ring (B-fields) for polarized proton- and deuteron beams
Ideal test- and development-machine for storage-ring EDM project

Precision storage ring

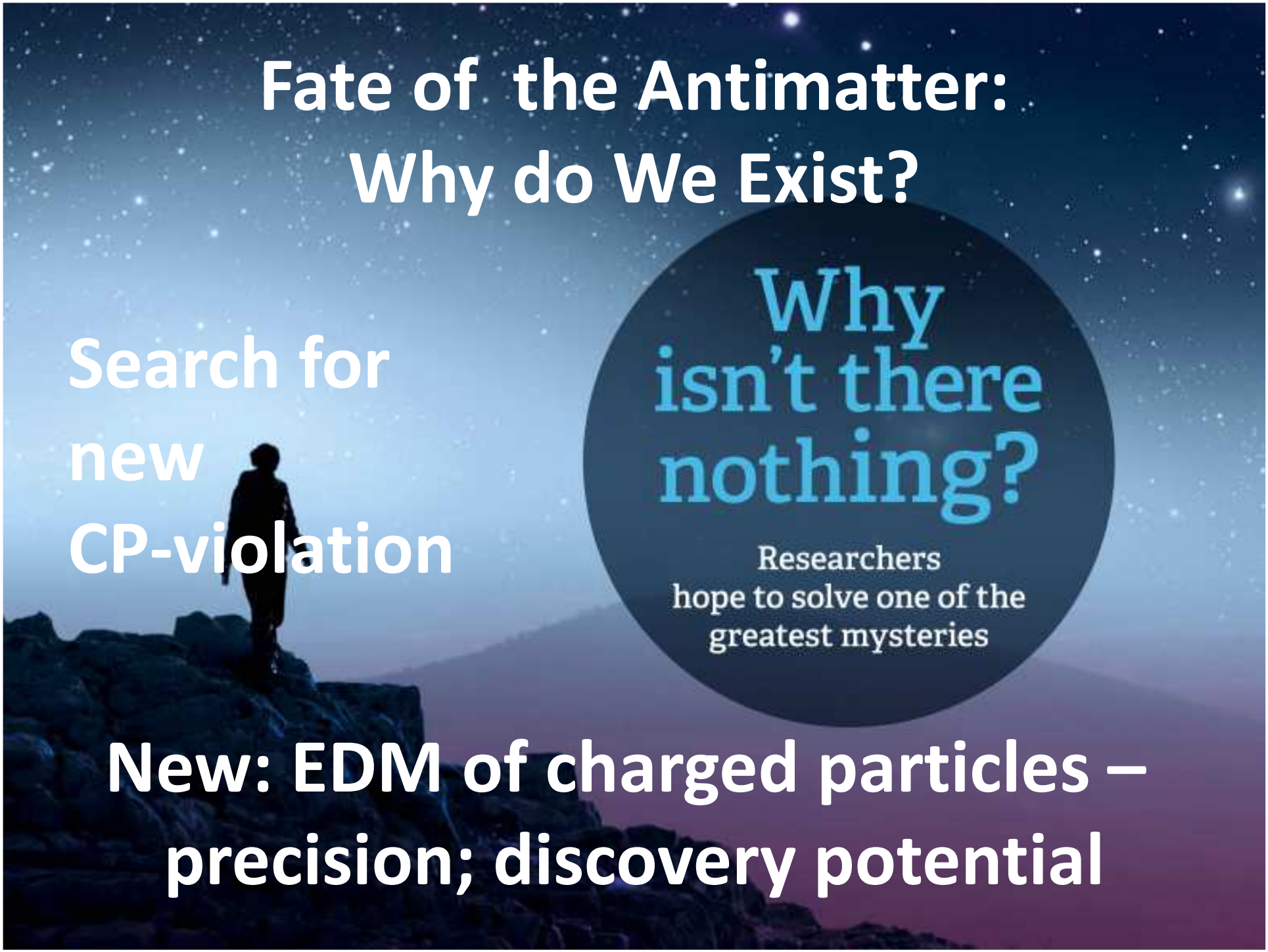


- Challenges of utmost level –
  an international project → CERN
  (PBC: *P*hysics *B*eyond *C*olliders)

Collaborations



Fate of the Antimatter: Why do We Exist?



Search for new CP-violation

New: EDM of charged particles – precision; discovery potential

Thank you very much!

Hans Ströher|Forschungszentrum Jülich