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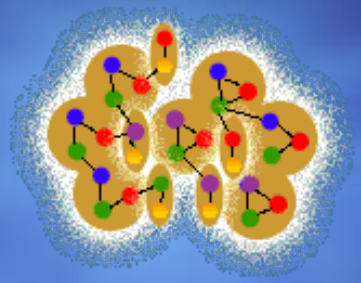

The exploration of strongly interacting matter

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Academia Europaea 19 88 The Academy of Europe

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Academia Europaea – 3 September 2017

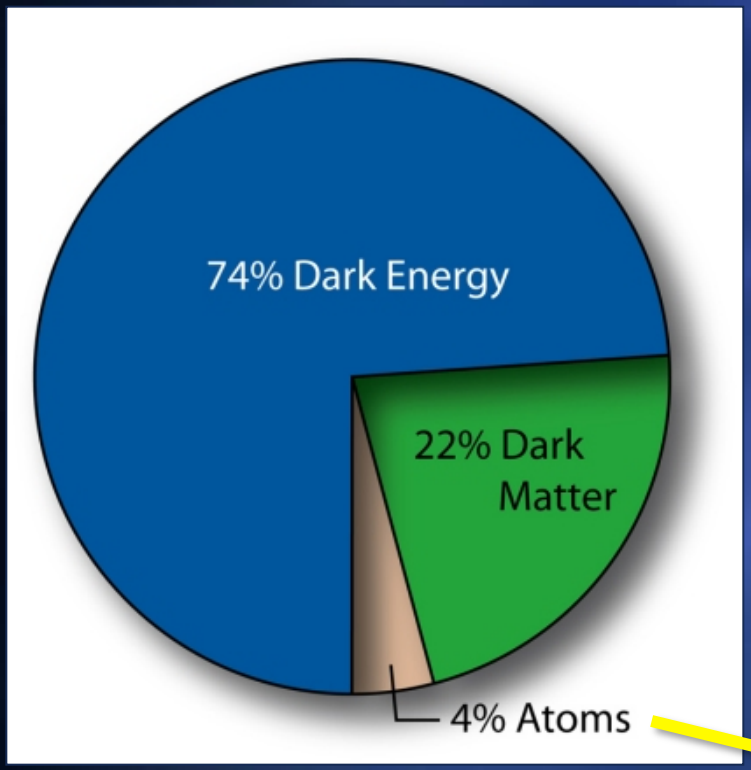
Outline

- About myself
- Structure of matter
- The quark-gluon plasma
- The measuring apparatus
- Heavy-quarks as a sensitive probe
- Exciting future

A few words about myself

- Associate Professor of Physics at Utrecht University, the Netherlands
- PhD at Goethe-University of Frankfurt, Germany
- Studies in Physics and Mathematics at Philipps-University of Marburg, Germany
- Married, one child
- Founding chair, Young Academy of Europe
- My specific research area: dynamical properties of the quark-gluon plasma
- Deputy team leader, Dutch research group in the ALICE Collaboration

What is matter?



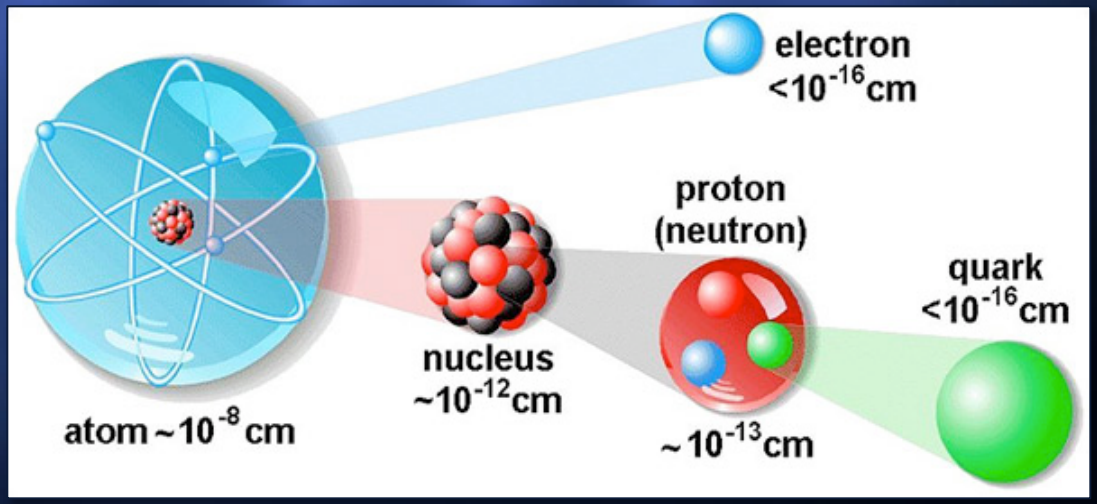
Constituents of the universe

Visible universe (for us)

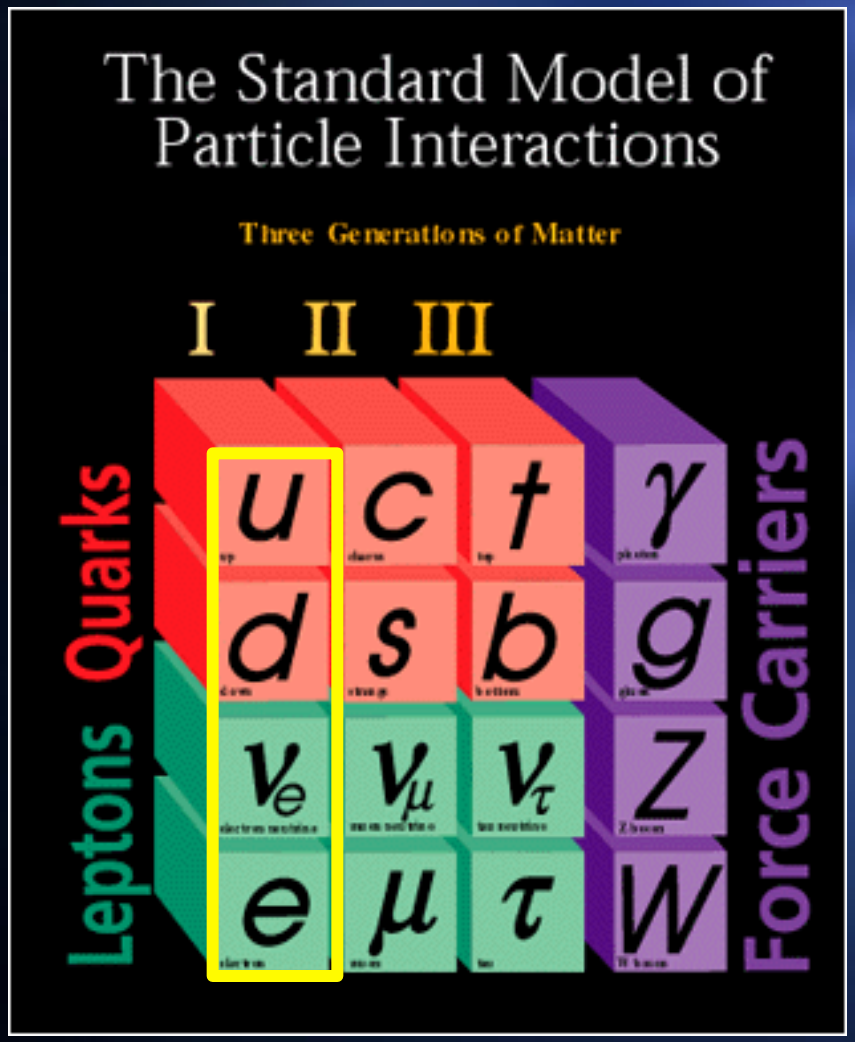
Structure of ("visible") matter

Particle physics: search for the smallest (fundamental) constituents

- Atoms
- Atomic nuclei
- Protons and neutrons
- Quarks and gluons



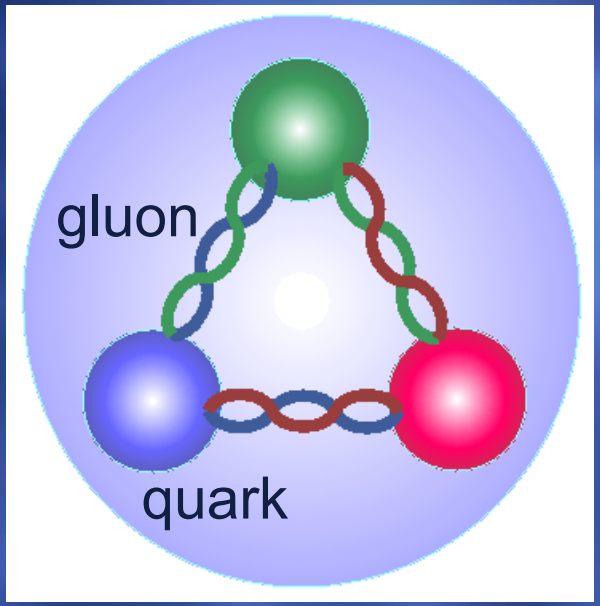
The Standard Model



- Basis of particle physics
  - Elementary particles
  - Fundamental interactions
  - Generation of mass: Higgs Mechanism (Nobel Prize 2013)
- Gravity is not described by the Standard Model
- Still open questions
  - **Strong interaction** has a couple of properties that are not well understood.

Quark confinement

- Strong interaction described by Quantum-Chromodynamics
- Quarks
  - have **colour charge**
  - are **confined** (hadrons)
- Asymptotic freedom



Protons and neutrons are colour neutral states.

$$V(r) = -\frac{4}{3}\frac{\alpha_s(r)}{r} + kr$$

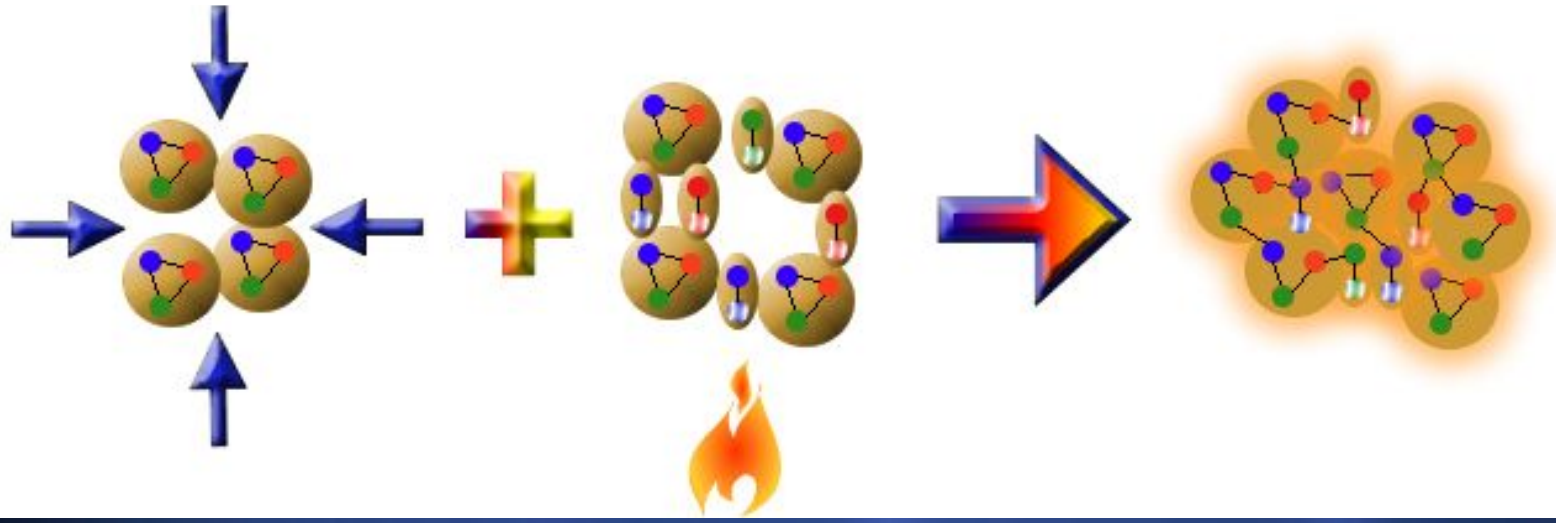
$$k = 1 \text{ GeV/fm}$$

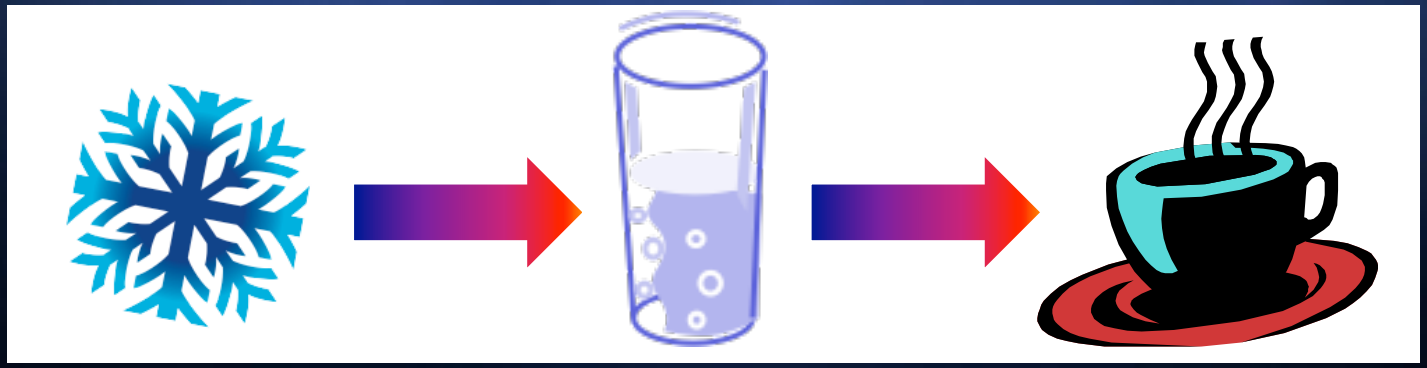
How can we liberate quarks?

Create a Quark-Gluon Plasma

Different phases of matter

Pressure + Heat → Quark Gluon Plasma

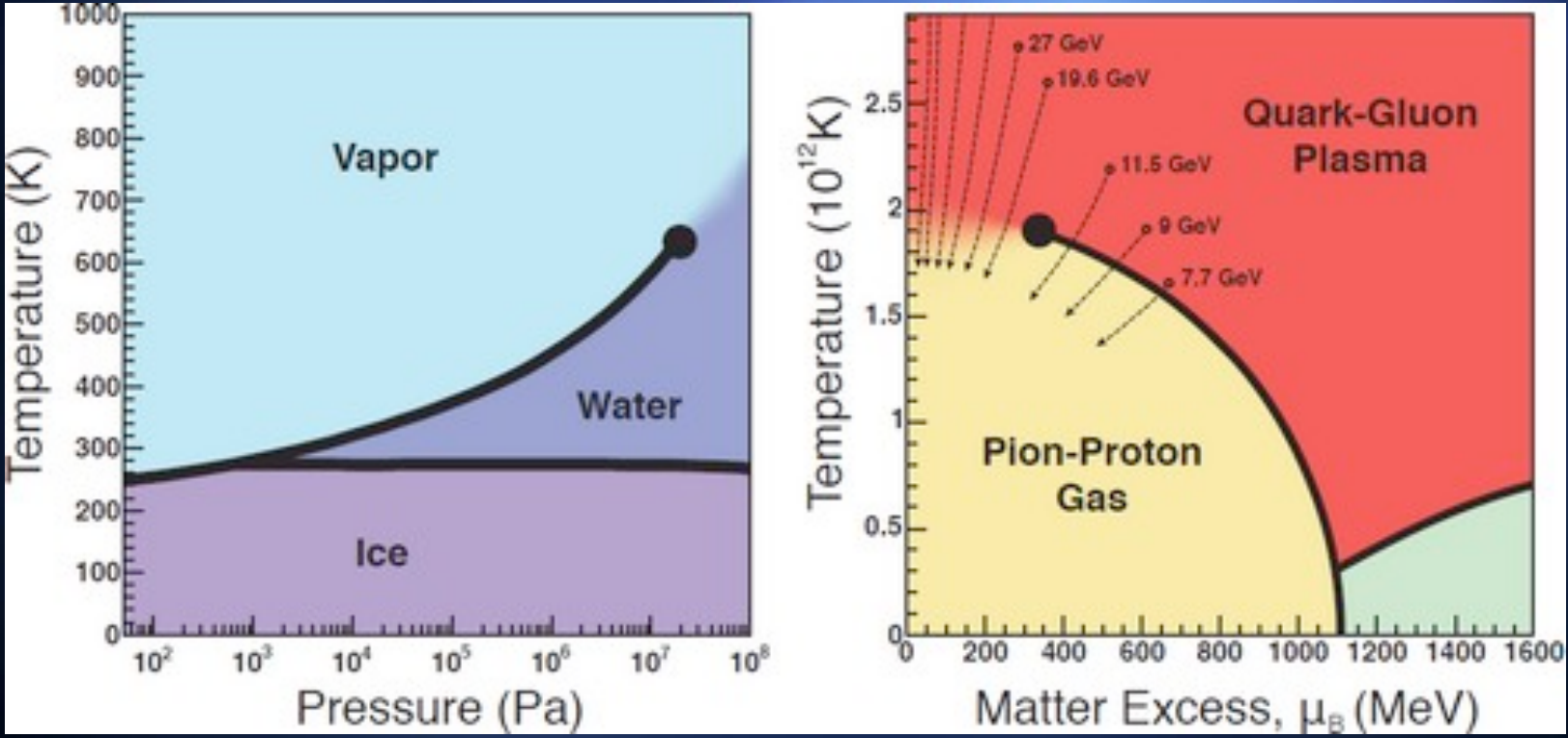




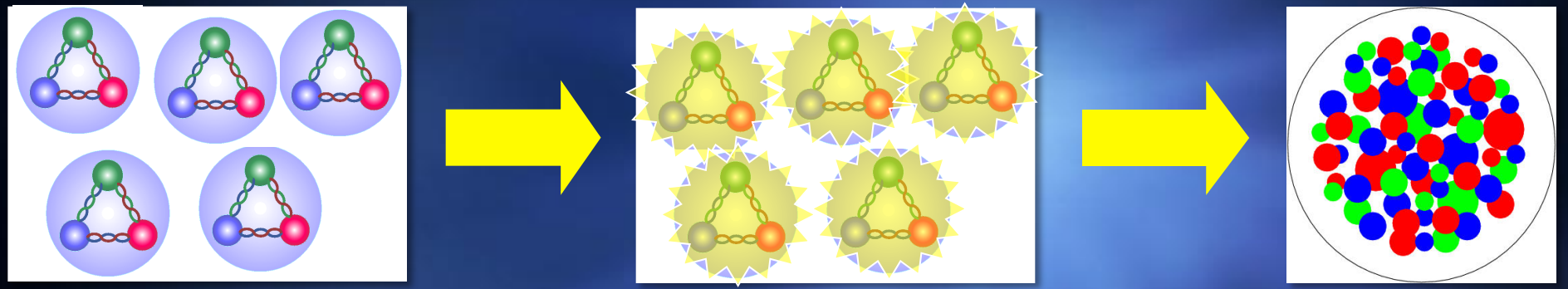
Phase diagram

Water

Subatomic matter



The Quark-Gluon Plasma (QGP)

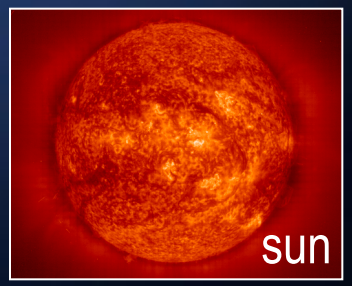


Heat and pressure

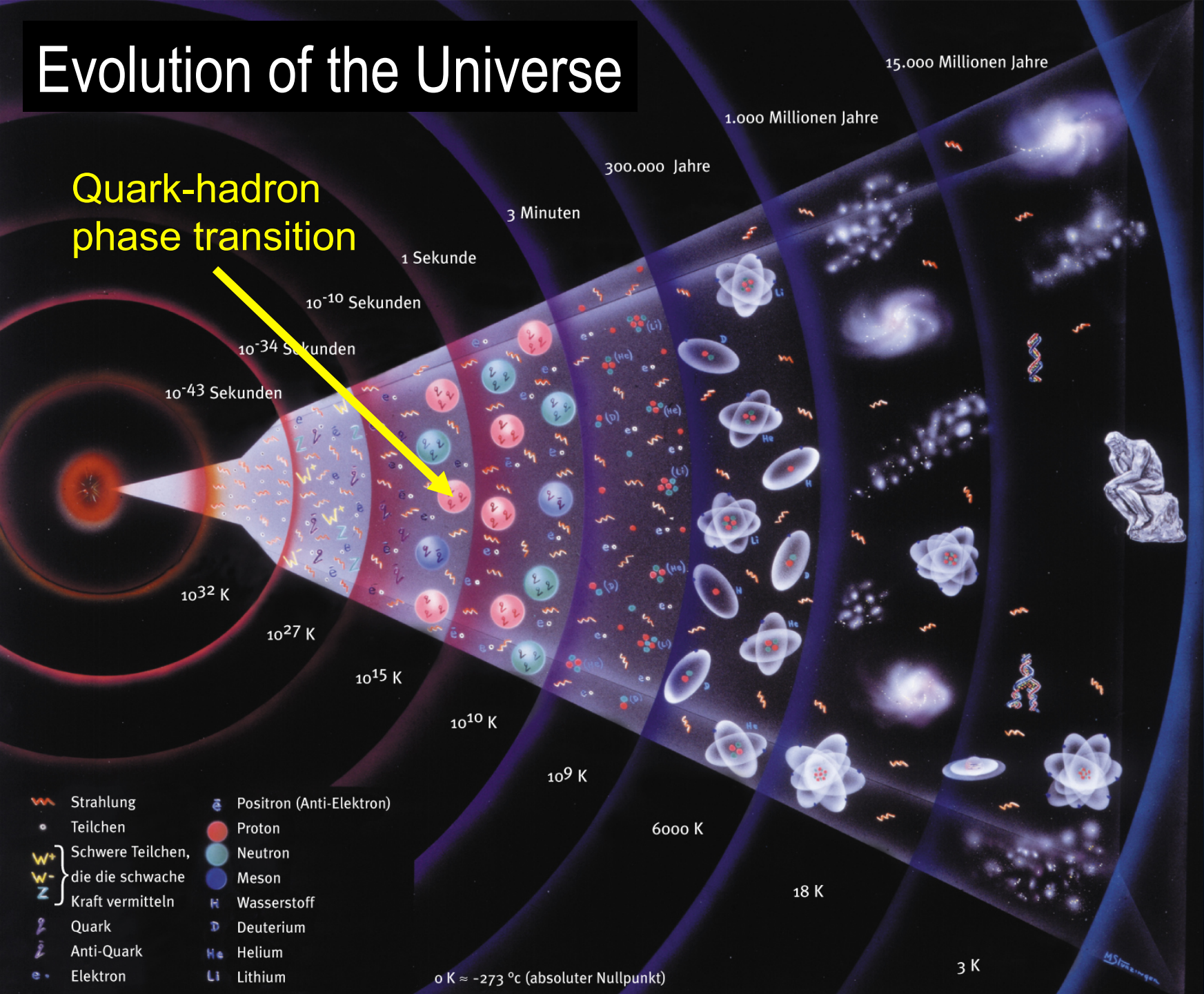
Phase transition to QGP
$T \approx 10^{12}$ K $\approx 10^{5}$x sun's core

- Novel state of matter: quarks and gluons are liberated (deconfinement)
- The hottest man-made matter
- Evolution of the early universe

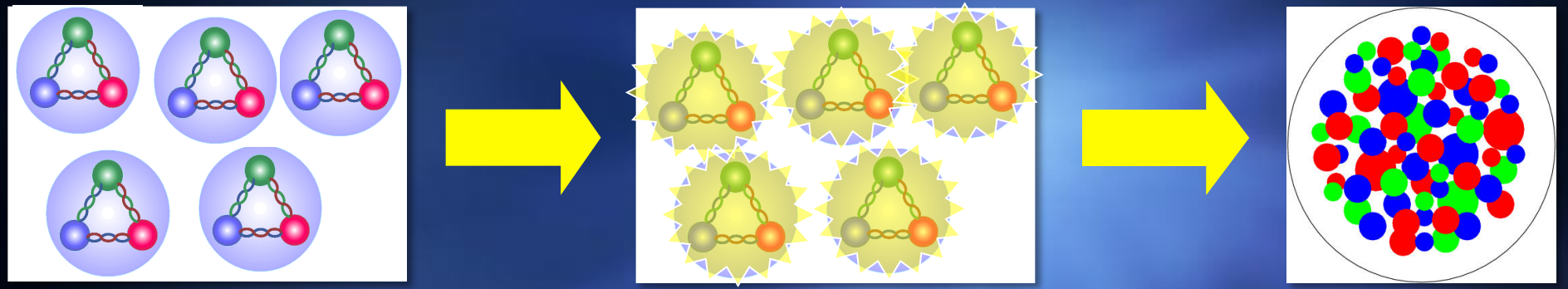
- QGP may still exist in neutron stars



Evolution of the Universe



The Quark-Gluon Plasma (QGP)



Heat and pressure

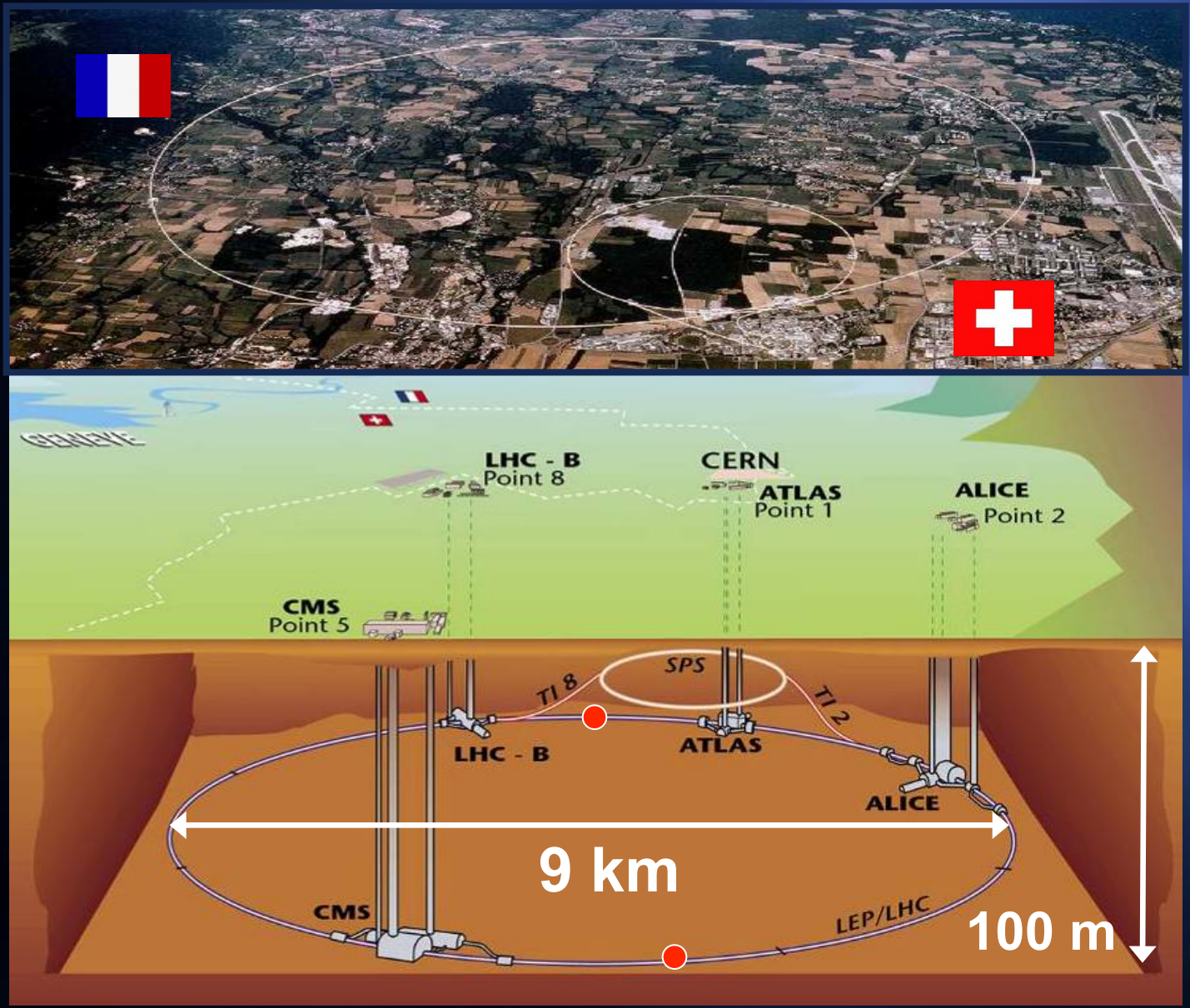
Phase transition to QGP
$T \approx 10^{12}$ K $\approx 10^{5}$x sun's core

- Produce and study the QGP in the laboratory
  - sufficient large reaction volume
  - high density and temperature

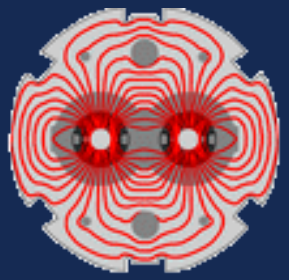
→ Collisions of heavy atomic nuclei (lead or gold)

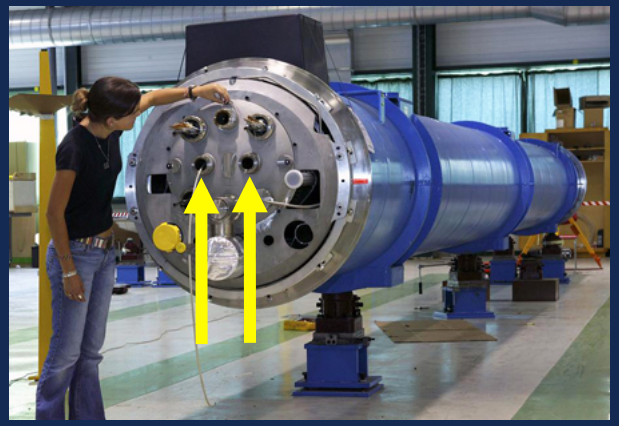
- Large Hadron Collider at CERN: exploration of the plasma properties

Research center CERN in Genève



- Most powerful particle accelerator in the world
- Working at cutting edge of science, technology and computing

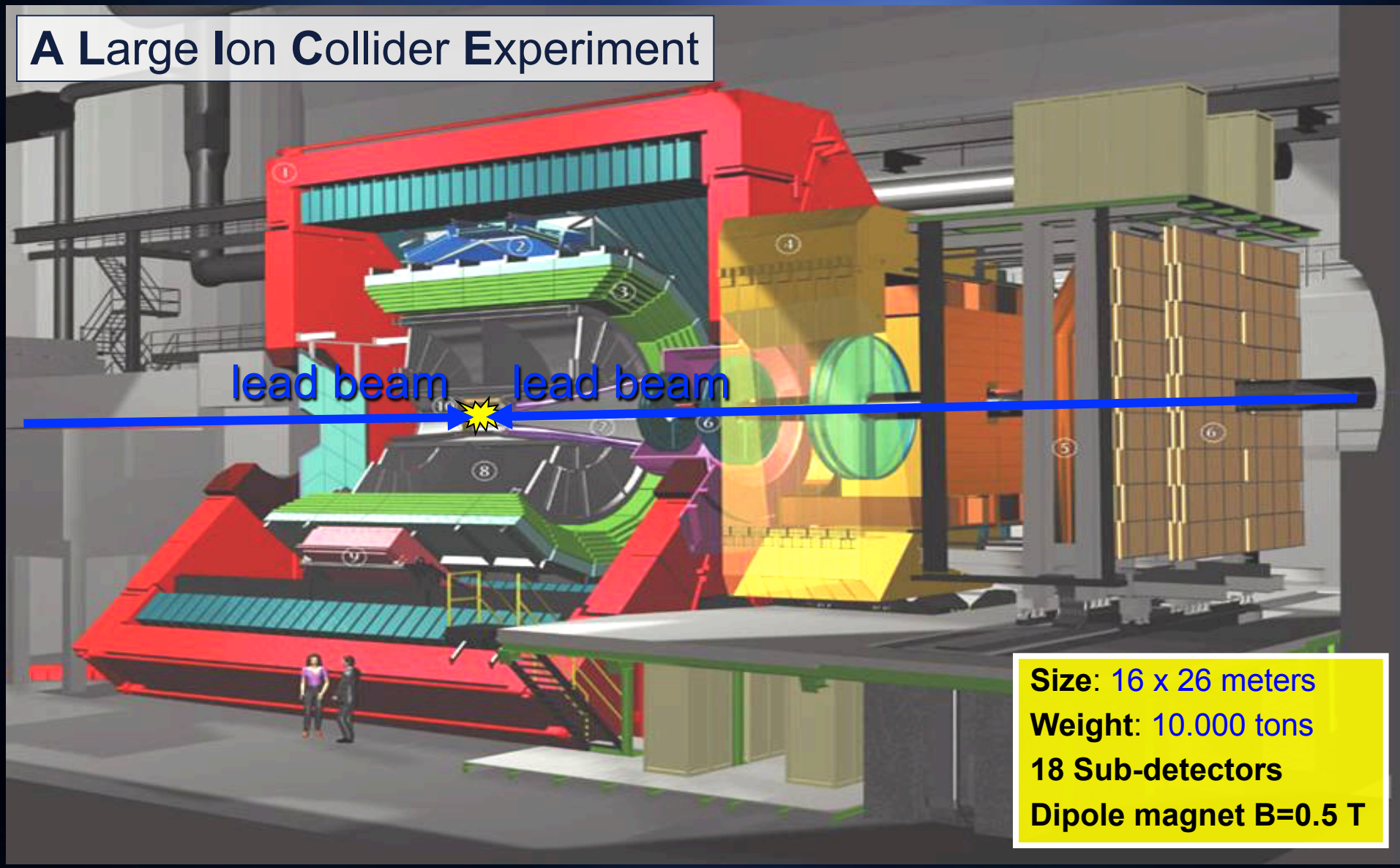


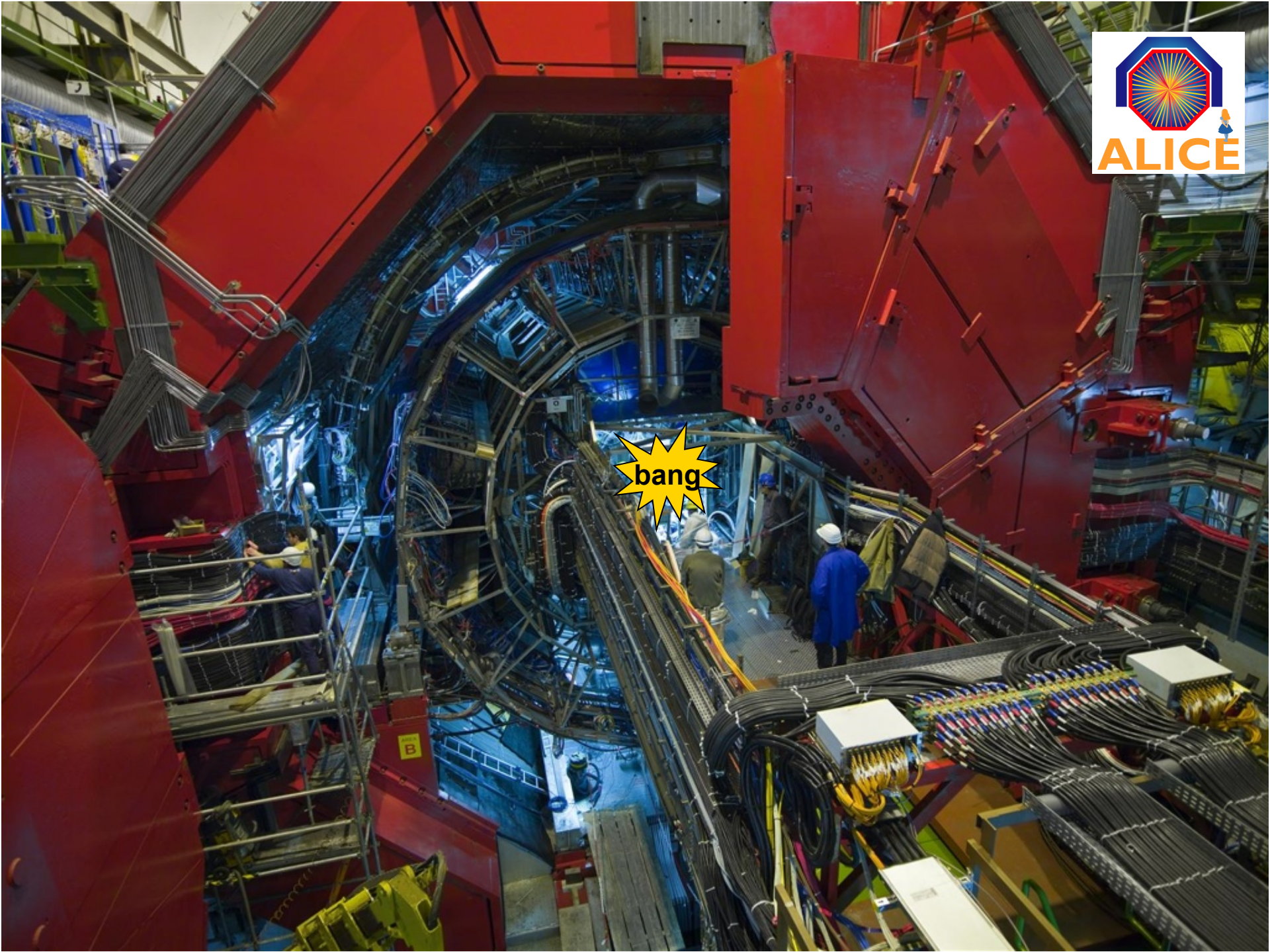


- 1232 dipole magnets
- Two counter-rotating beams
- Operation with superfluid helium at 1.9K (~120 tons)
- 8 Tesla bending field
- 14 TeV proton-proton and 5.5 TeV lead-lead collisions

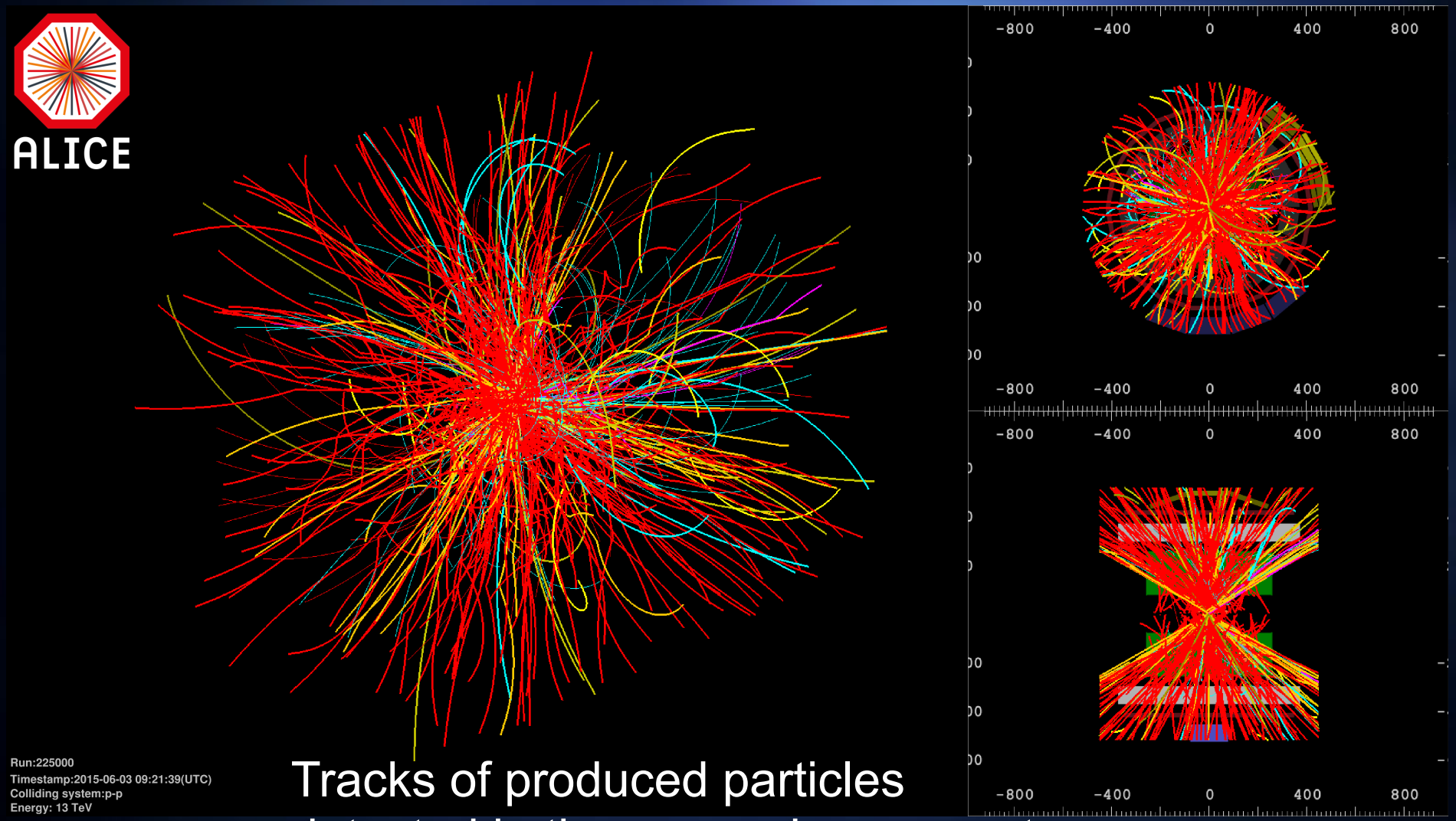
27 km circumference

The ALICE detector




bang
ALICE

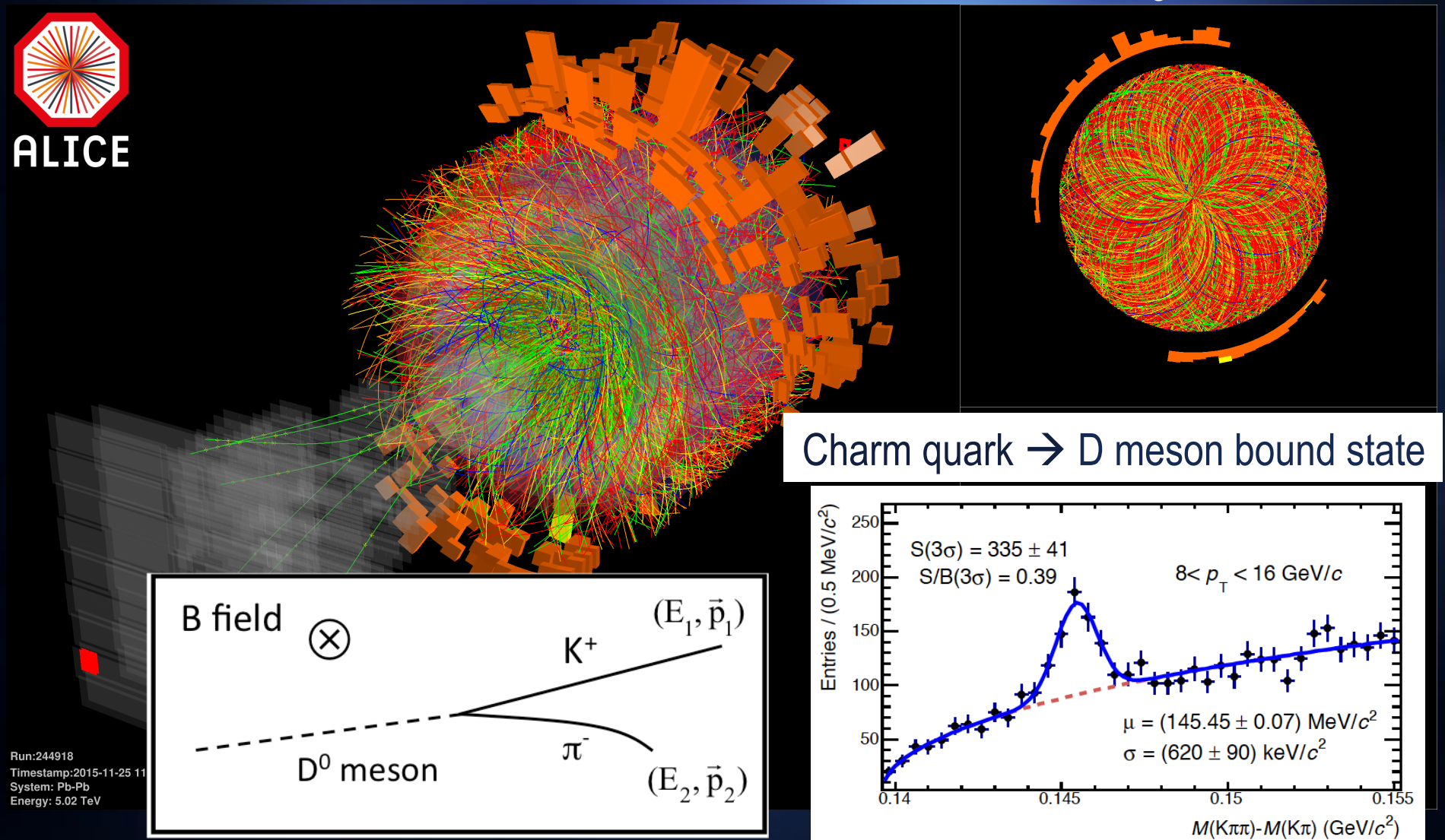
Proton-proton collision at 13 TeV



Tracks of produced particles detected in the measuring apparatus

Lead-lead collision at 5.02 TeV

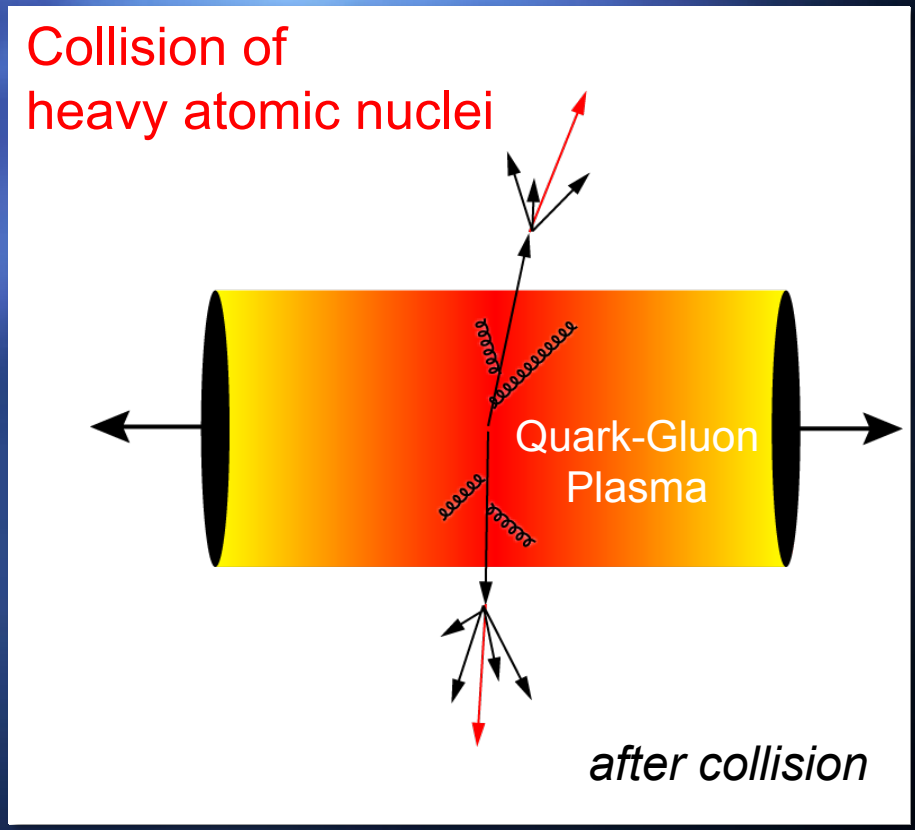
"Run-2 data taking" from 2015-2018



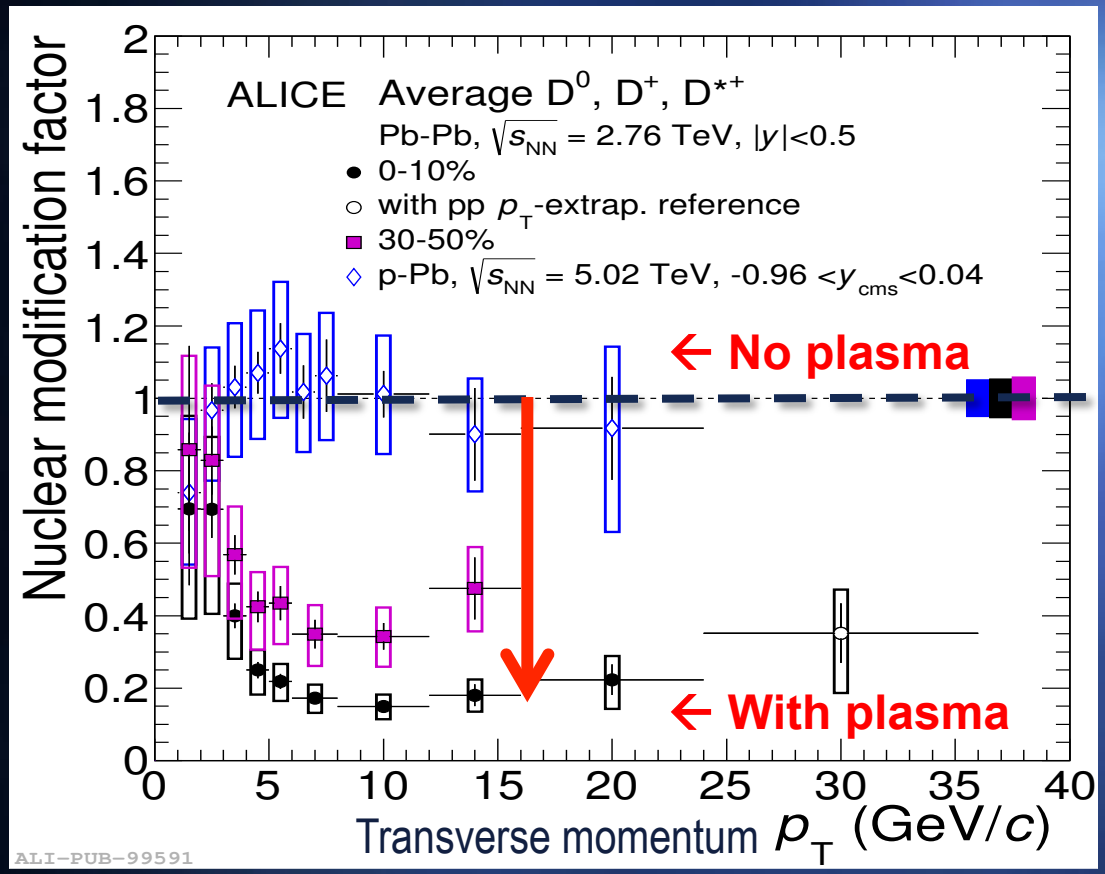
Charm quark → D meson bound state

Probing strongly interacting matter

- Heavy quarks
  - are produced in pairs
  - two types: **charm** and **beauty**
  - well-calibrated probes
- Interaction with the plasma → **energy loss**



D measurements in lead-lead collisions



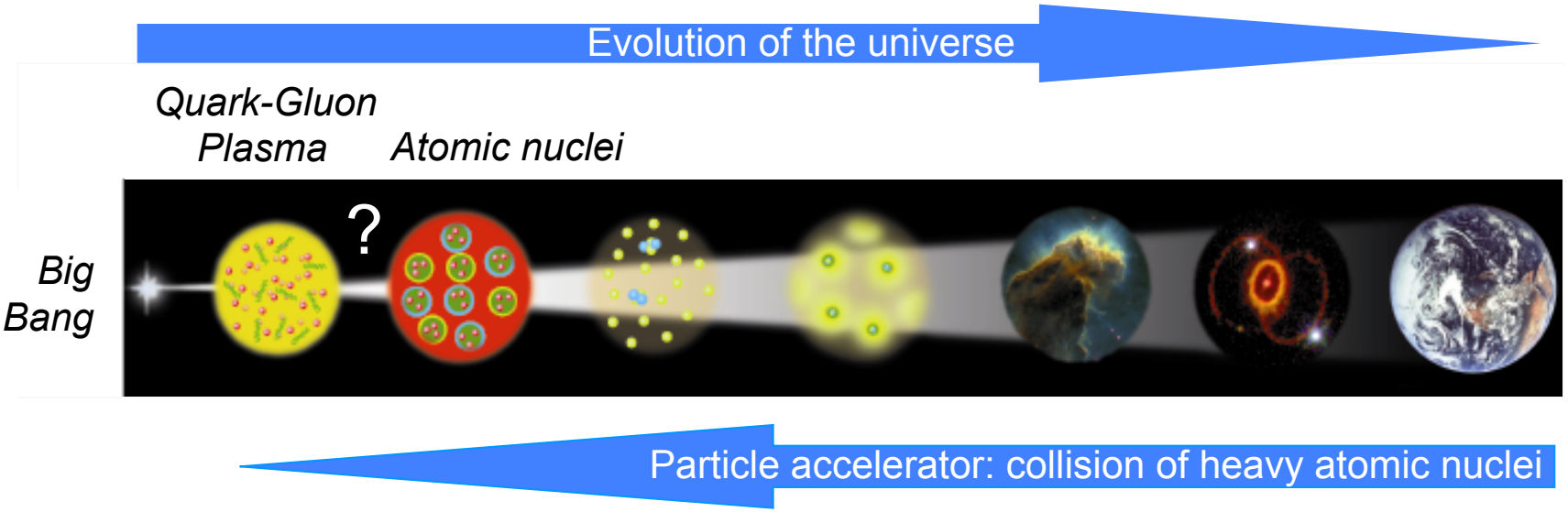
Nuclear modification factor

$$R_{AA}(p_T) = \frac{\text{Yield}_{AA}(p_T)}{\langle N_{bin} \rangle_{AA} \, \text{Yield}_{pp}(p_T)}$$

- In lead-lead collisions: strong suppression of the yield when compared to “simple scaling” from proton-proton interaction
- Still have to learn from theory about medium properties

Summary

Quark-Gluon-Plasma is a new form of strongly interacting matter



- What are the properties of the interaction between quarks and gluons in the plasma phase?
- Outlook: quantitative understanding of the energy loss and dissipation in the plasma

One of the central questions in the NuPECC LRP report

Thank you