Physics at the LHC
(a challeging talk)

Christoph Rembser
CERN
23.6.2014

Physics at the LHC - what does thins mean?

- Introduction

(LHC, detector performance)

- Test of perturbative QCD

(Jet production, W/Z production, tt production)

- Electroweak parameters

(mW, mt, gauge couplings, ..)

- The search for the Higgs Boson
- Search for Physics Beyond the Standard Model

(Supersymmetry, the unexpected...)

A challenge!

The role of the LHC

- Explore the TeV mass scale
  - ★ What is the origin of the electroweak symmetry breaking ?
  - ★ Does the Higgs boson exist?
  - ★ Search for physics Beyond the Standard Model (Low energy supersymmetry, other scenarios...,)
  - ★ Look for the “expected”, but we need to be open for surprises
  - ★ perform as many searches (inclusive, exclusive...) for as many final states as possible
- Precise tests of the Standard Model
  - ★ There is much sensitivity to physics beyond the Standard Model in the precision area (loop-induced effects, probe energy scales far beyond direct reach)
  - ★ precise measurements, search for rare processes

➡ Guidance to theory and Future Experiments

There are many physics models on the market!

What is it about?

1897 : Paul Gauguin

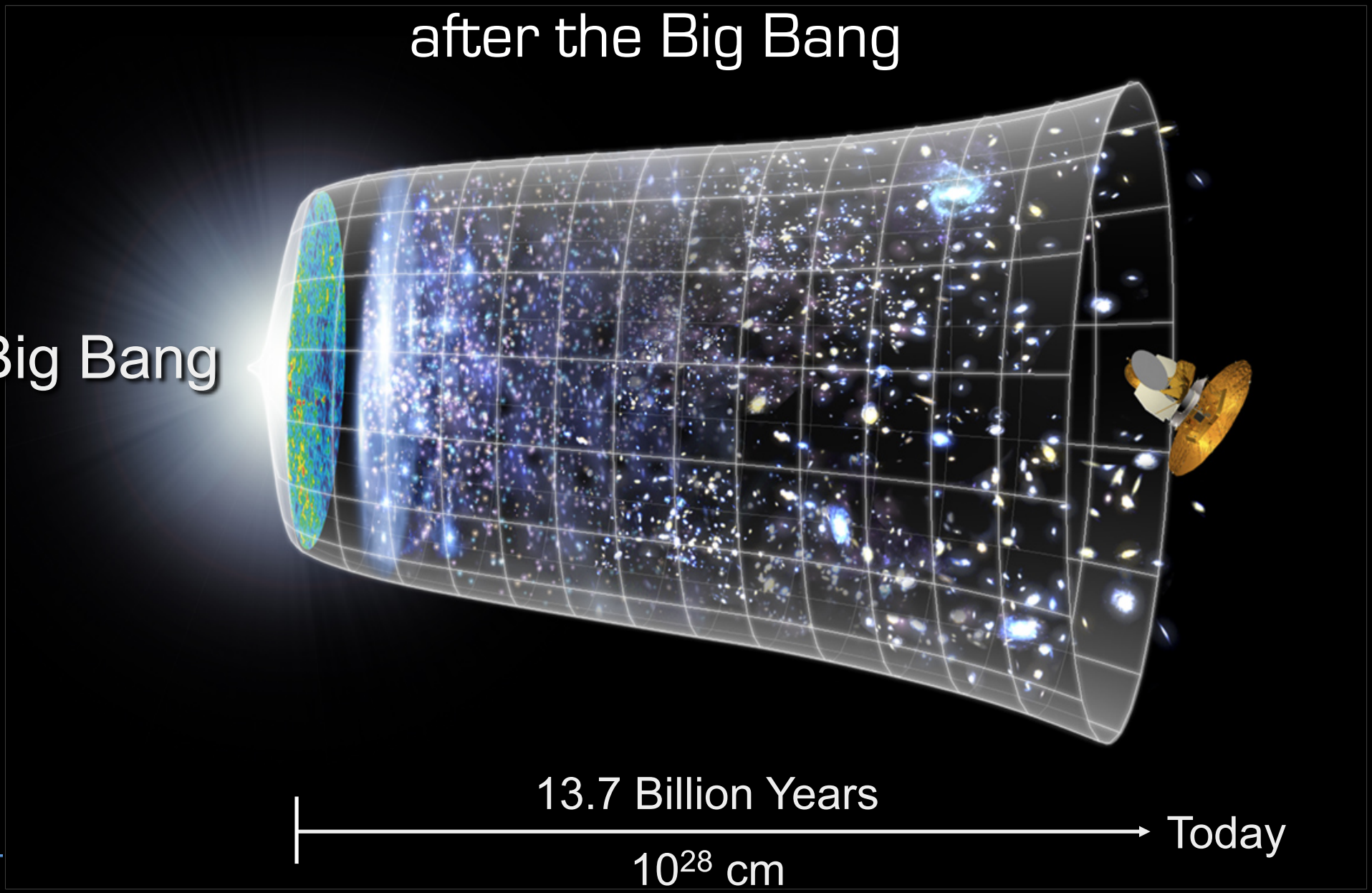
D'où venons-nous?

Que sommes-nous?

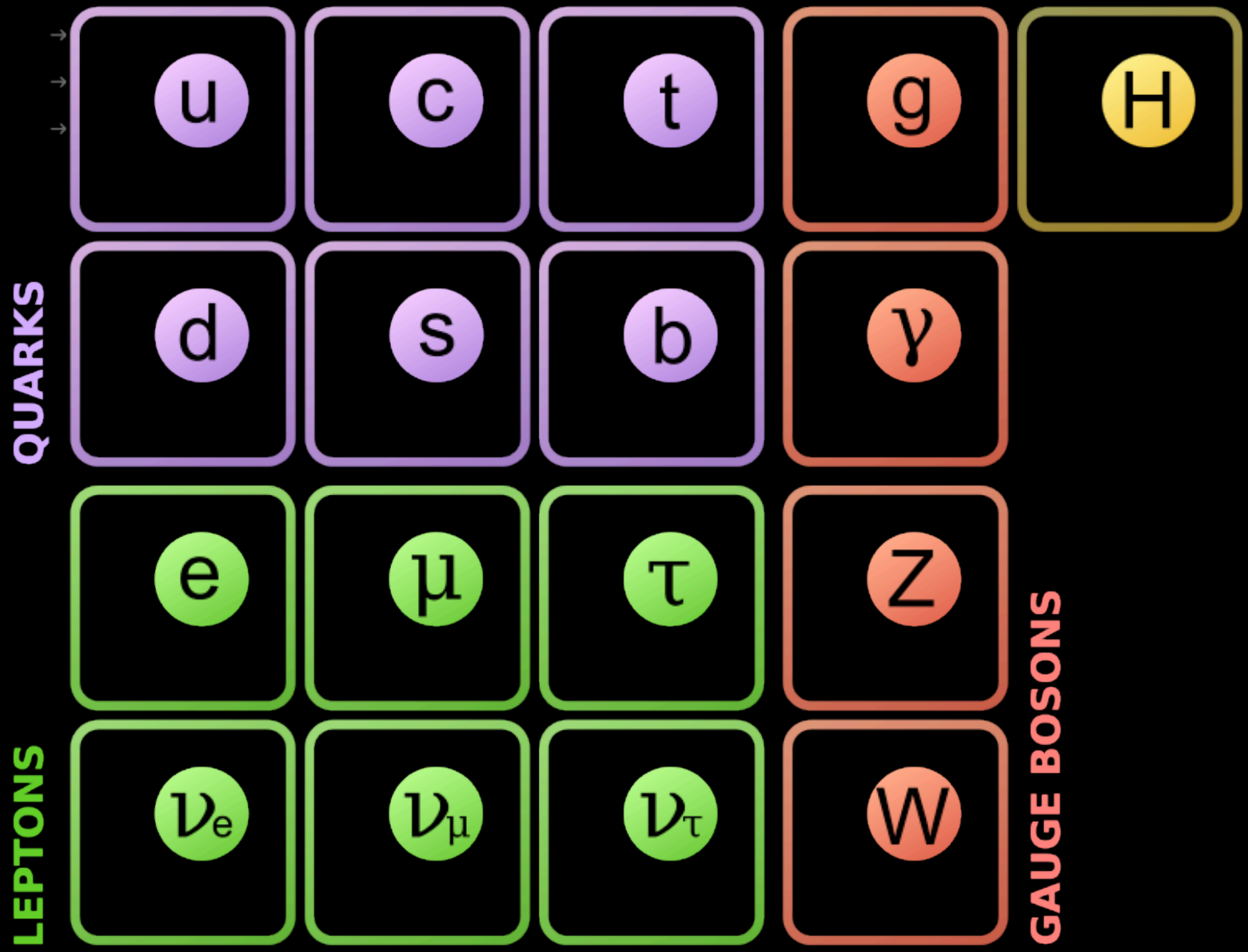
Où allons-nous?

Scientific Challenge

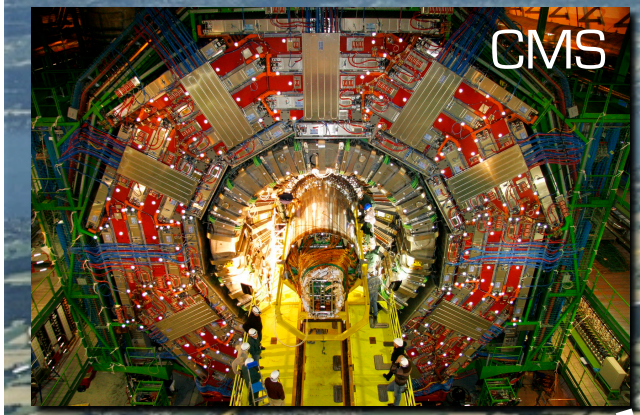
understand the very first moments of our universe after the Big Bang

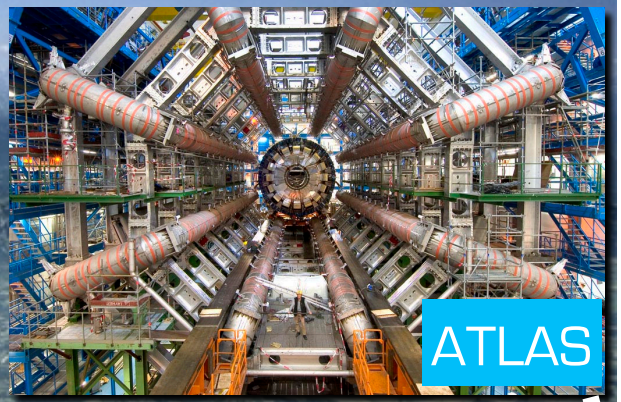


Standard Model of elementary particles

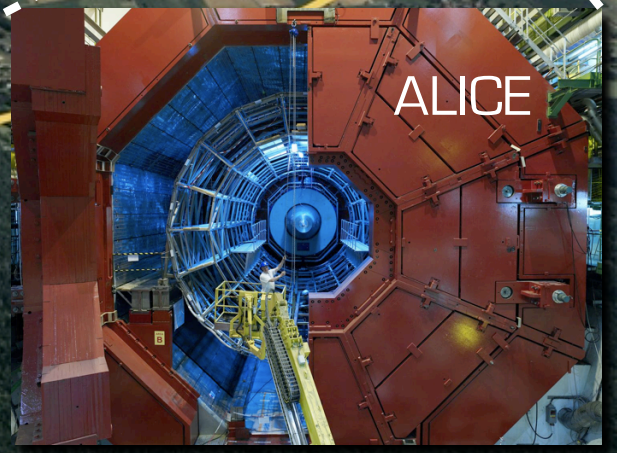


CERN: entering a new era in fundamental research with the LHC



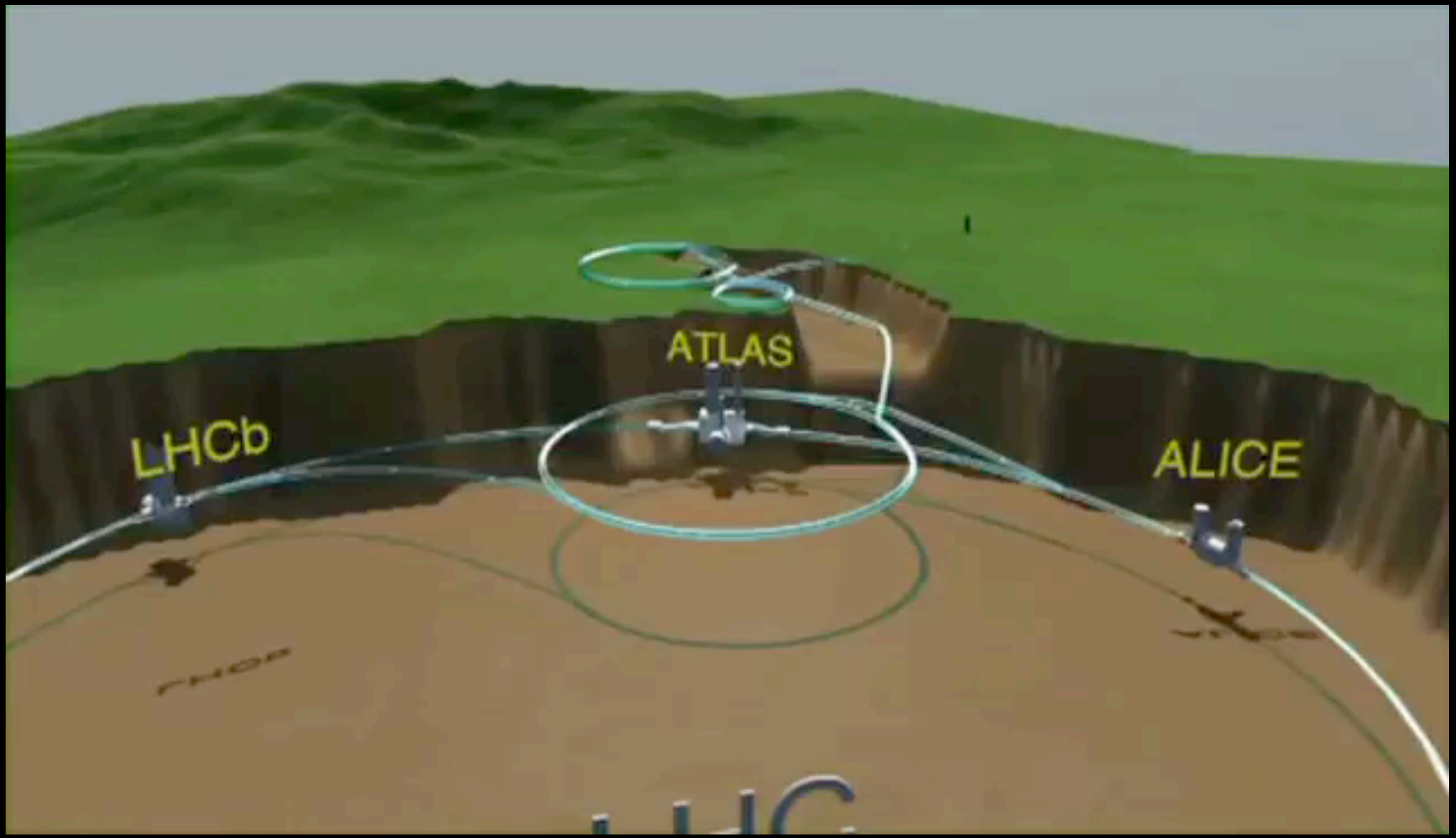


Since March 2010 exploration of a new energy frontier
in proton-proton collisions, e.g. searching for the Higgs boson

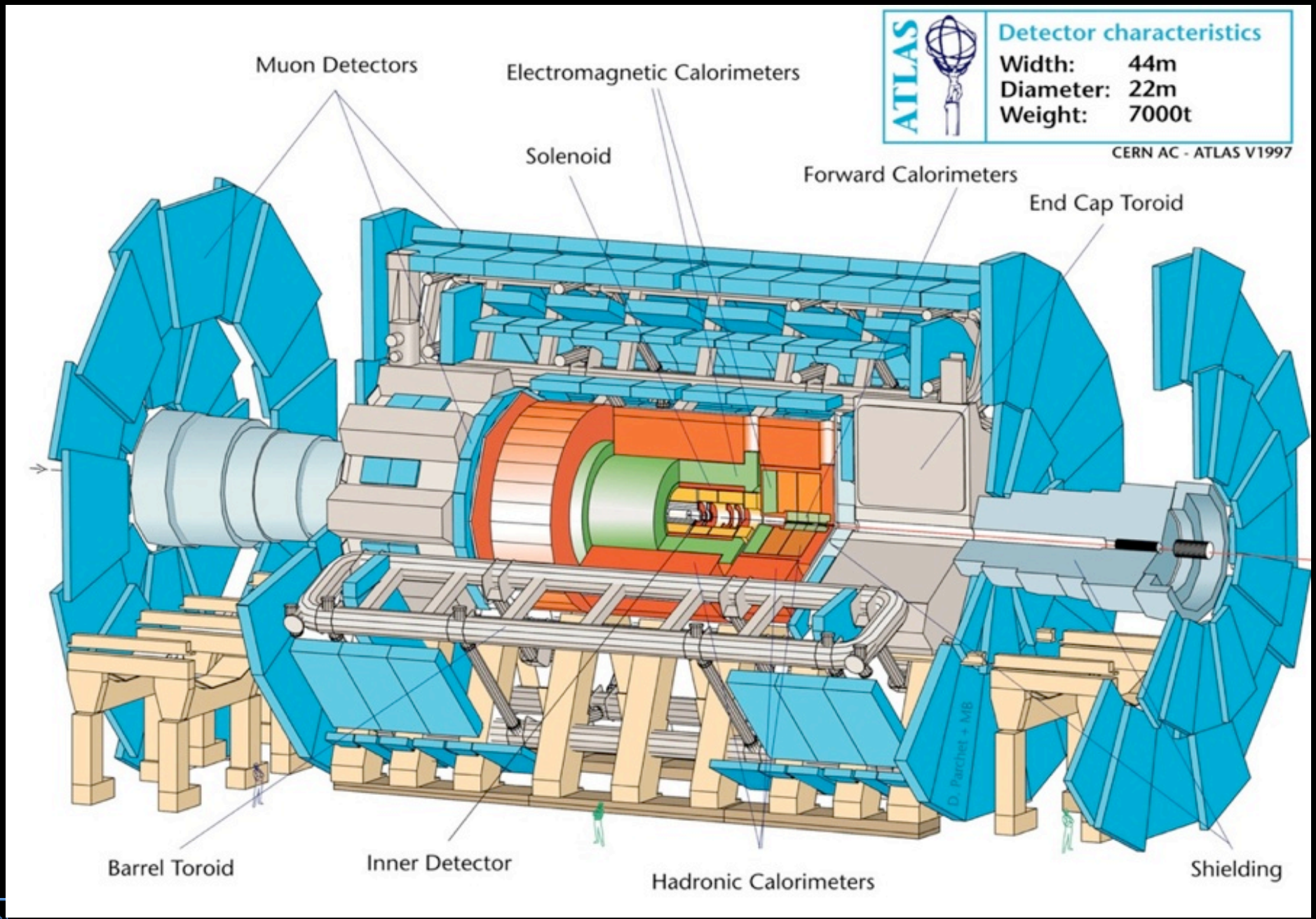


The Large Hadron Collider

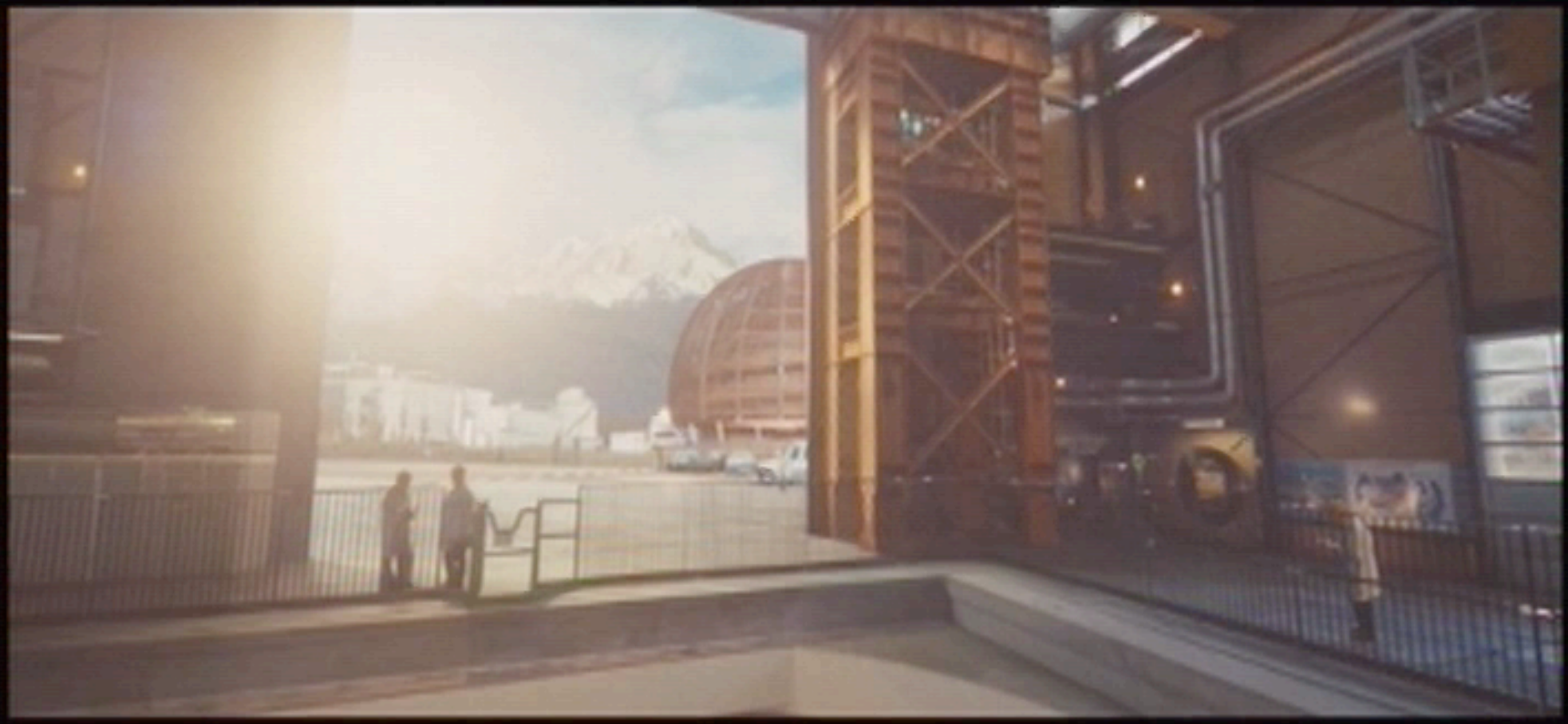
Collisions in the LHC



An example of an LHC particle detector: ATLAS

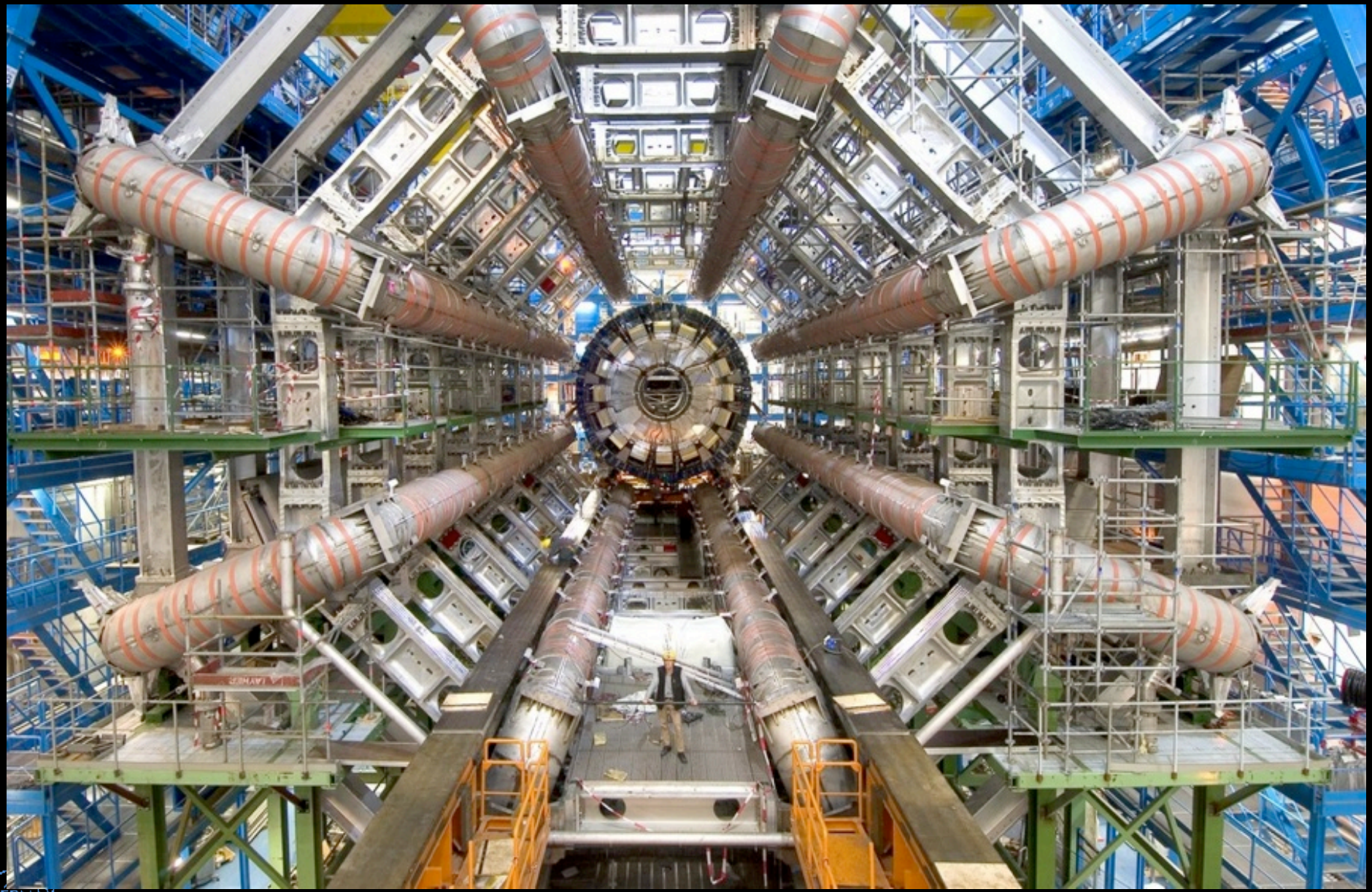


CERN and the Large Hadron Collider (in the movie “Angels & Demons”)

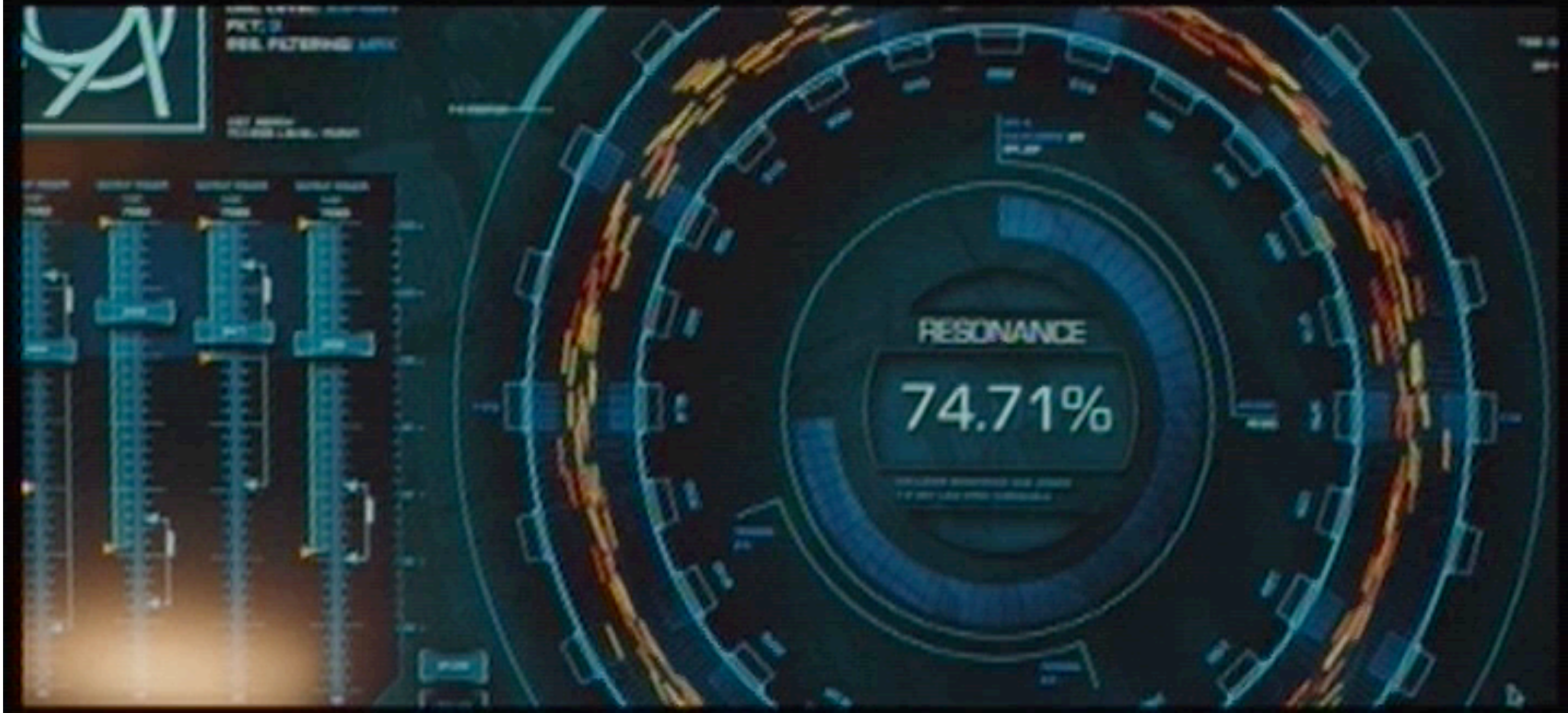


Particle detectors are built by large international collaborations

(e.g. ATLAS has more than 3000 members)

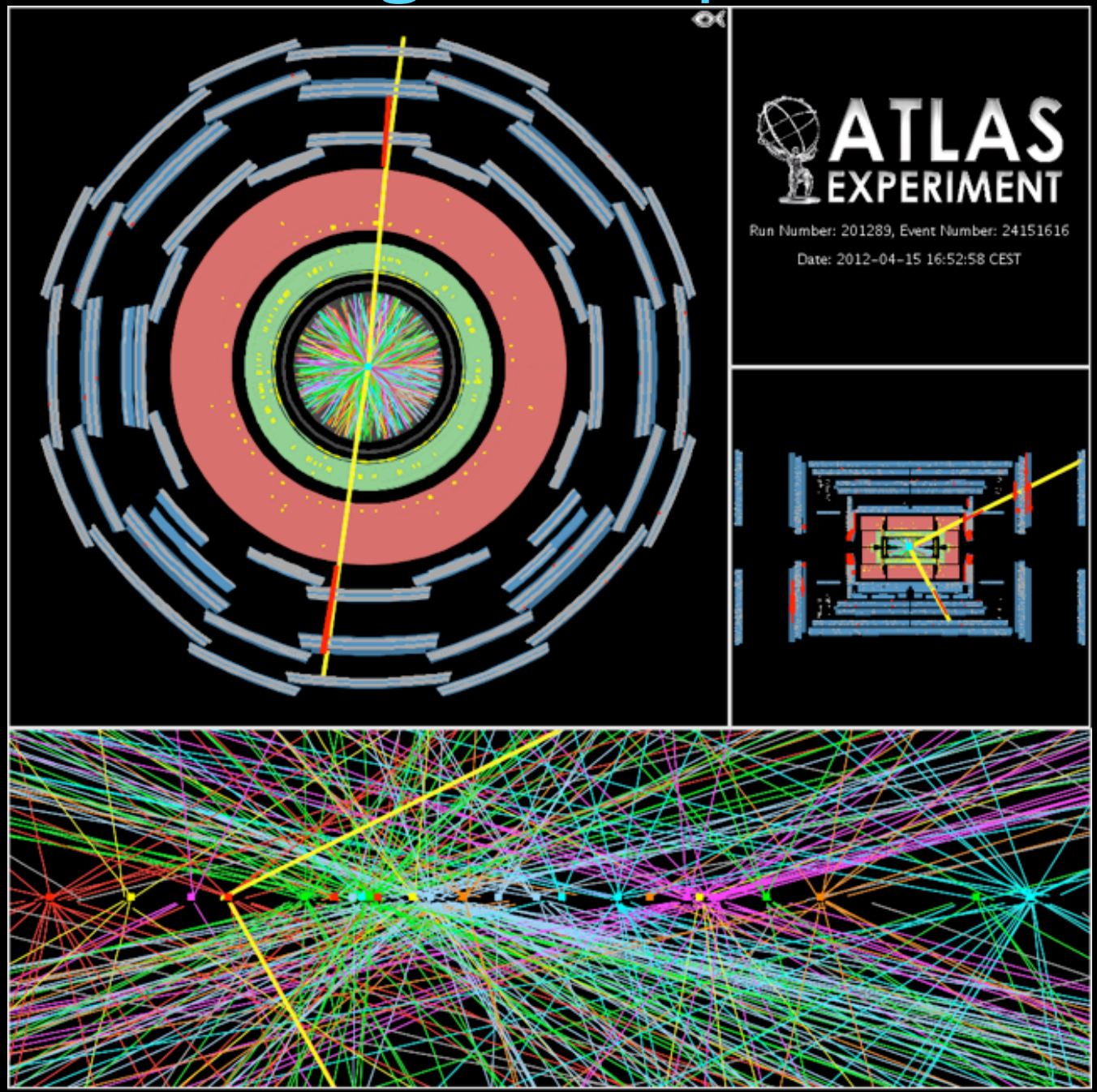


CERN and the ATLAS Detector (in the movie “Angels & Demons”)



Capture should begin at any moment.

Learning from pictures



The LHC success: one sentence summarises it all

We present updated results on SM Higgs searches based on the data recorded in 2011 at $\sqrt{s}$=7 TeV (~4.9 fb^{-1}) and 2012 at $\sqrt{s}$=8 TeV (~5.9 fb^{-1})

Results are preliminary:
- 2012 data recorded until 2 weeks ago
- [illegible] conditions in 2012 due to [illegible] larger event pile-up
- new, improved analyses deployed for the first time

H → γγ and H→ 4l: high-sensitivity at low-m_H; high mass-resolution; pile-up robust
- analyses improved to increase sensitivity → new results from 2011 data
- all the data recorded so far in 2012 have been analyzed

→ results are presented here for the first time

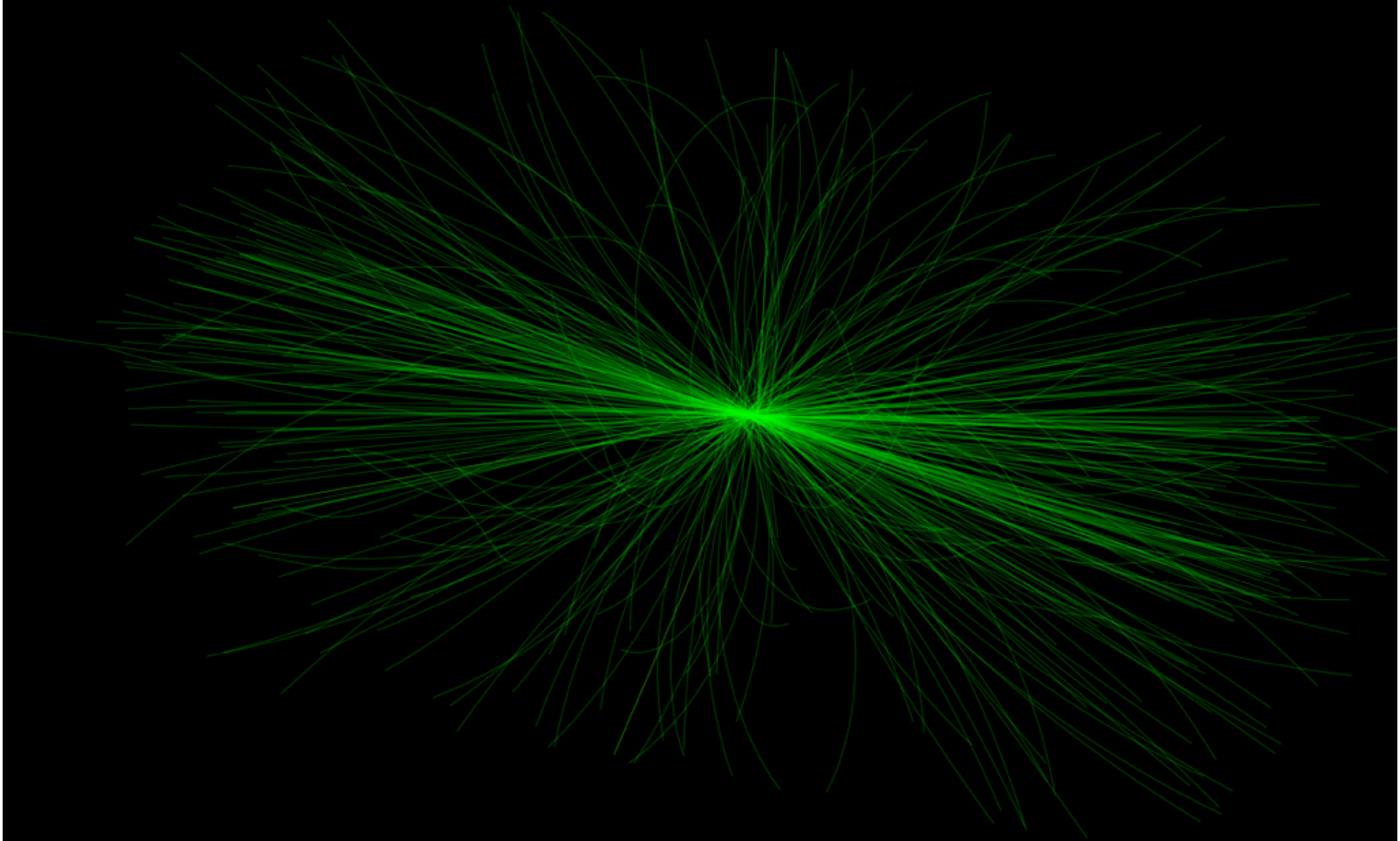
Other low-mass channels: H→ WW$^{(*)}$→ lνlν, H→ ττ, W/ZH
- E_T^{miss} in final state → less robust to pile-up
- worse mass resolution, no signal "peak" in some cases
- complex mixture of backgrounds

→ understanding of the detector performance and backgr advanced, but results not yet mature enough to be pres

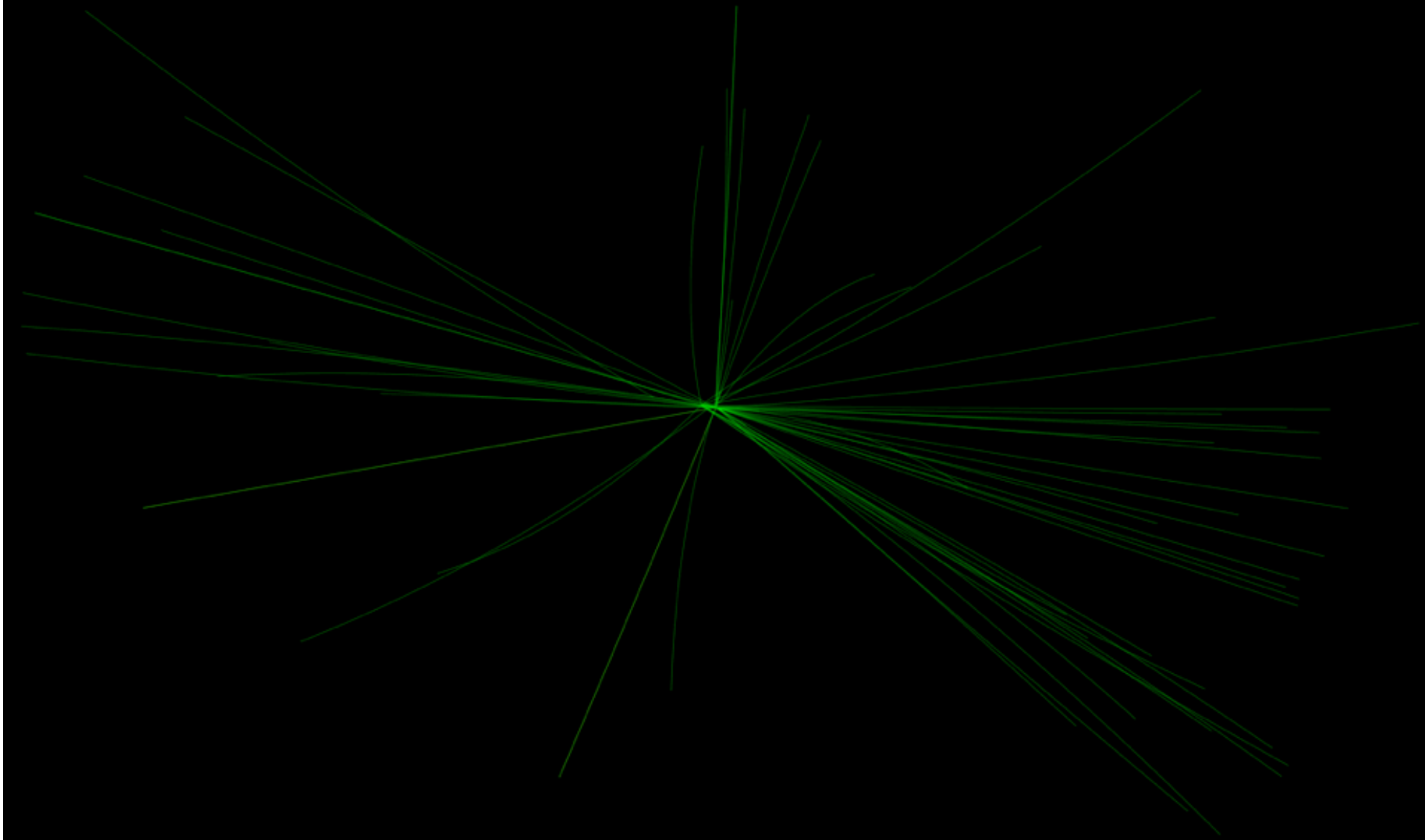
→ 2011 results used here for these channels for the overa

ATLAS: Status of SM Higgs searches, 4/7/2012

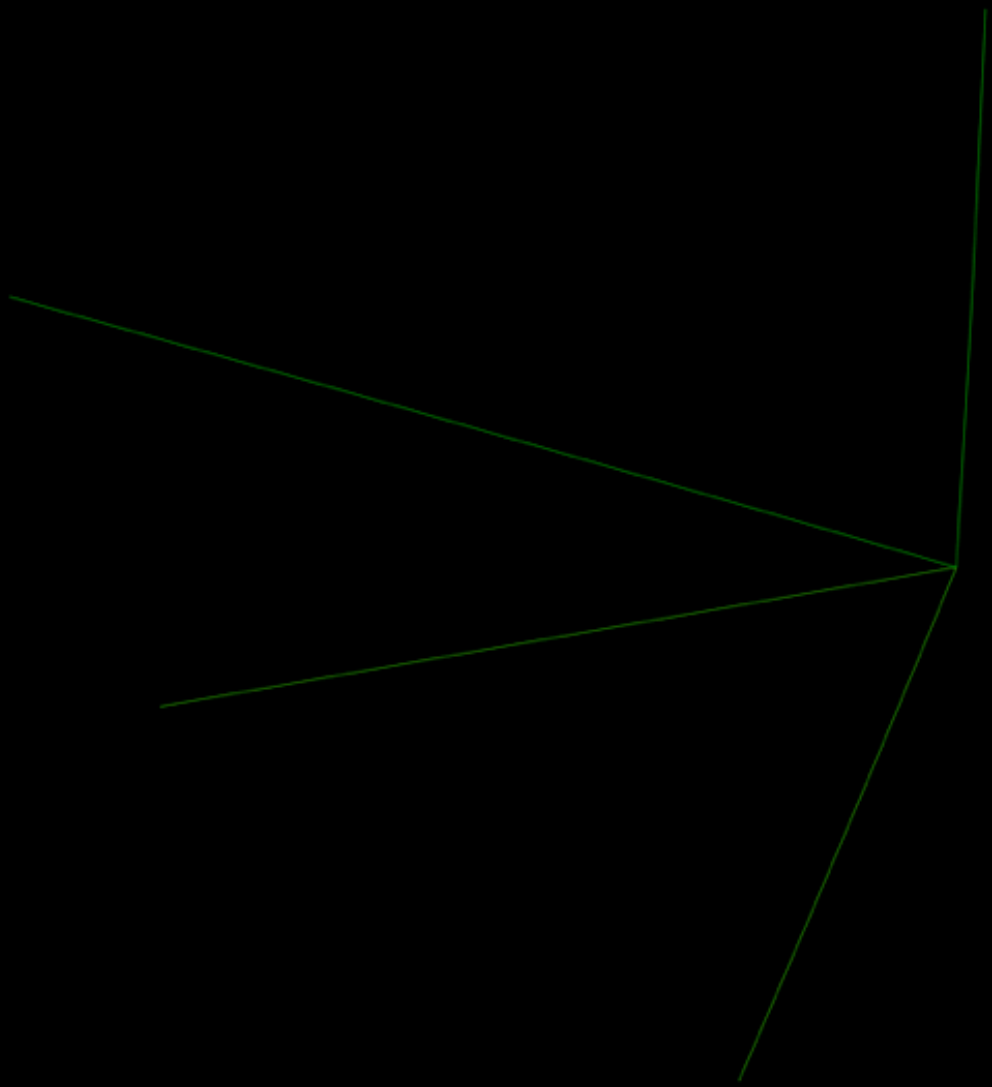
Simulation: Higgs production, H→ZZ→μμμμ



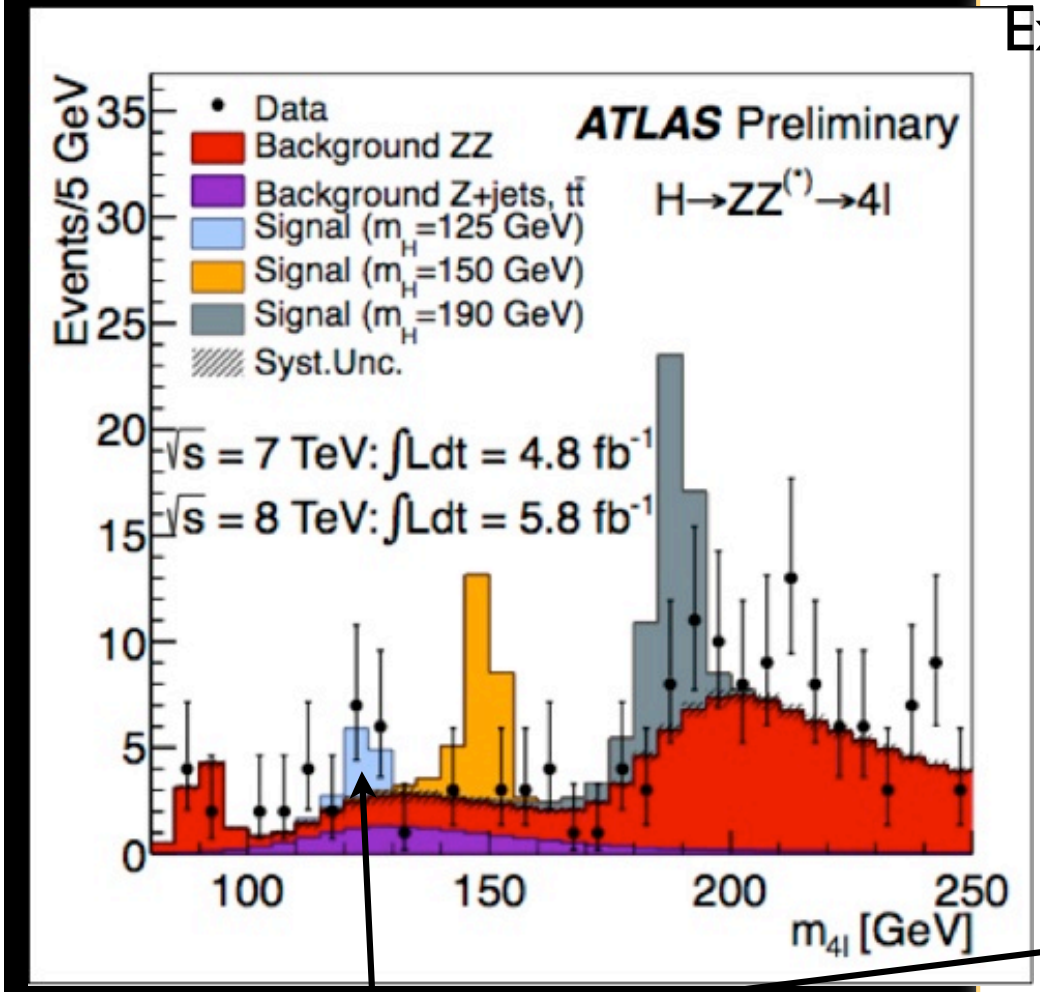
Simulation: Higgs production, H→ZZ→μμμμ



Simulation: Higgs production, H→ZZ→μμμμ

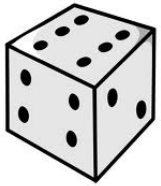


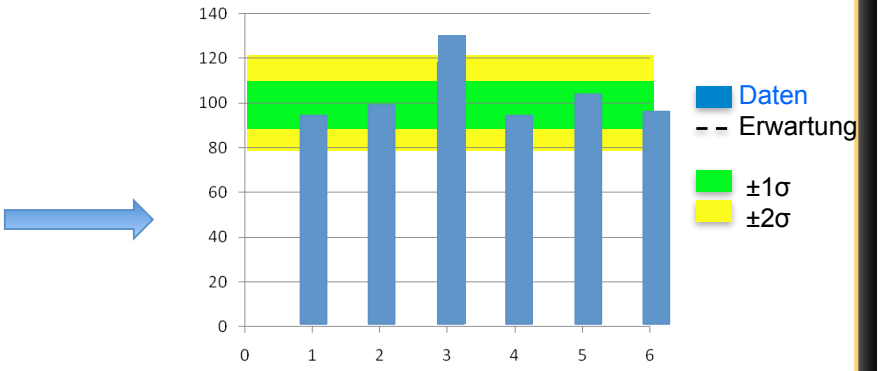
Finding new particles: calculate invariant mass



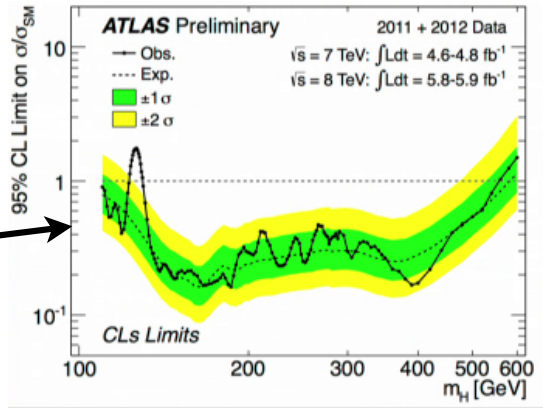
This is the Higgs particle!!!

Example: is the dice marked?

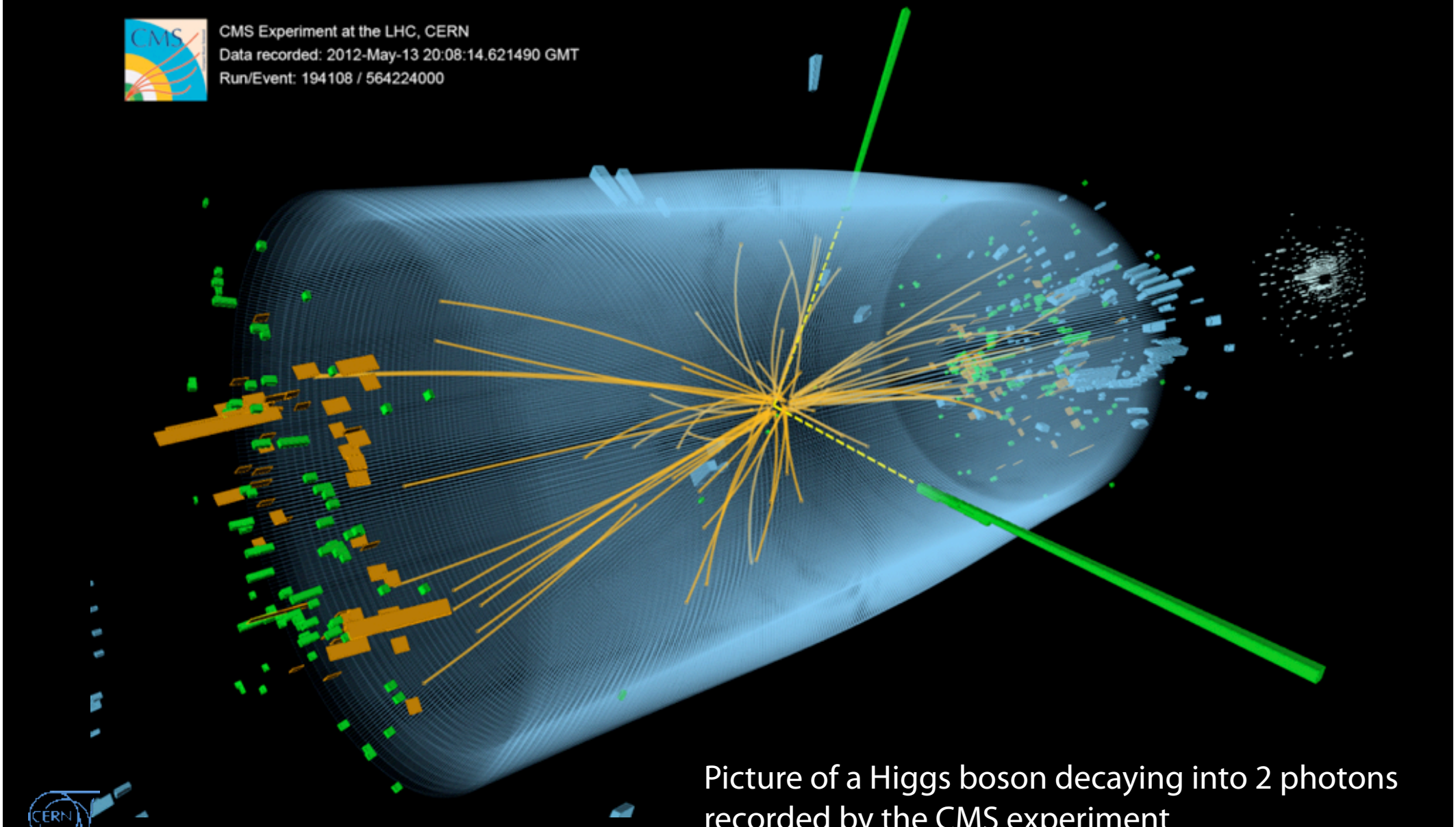




Is there a new particle?

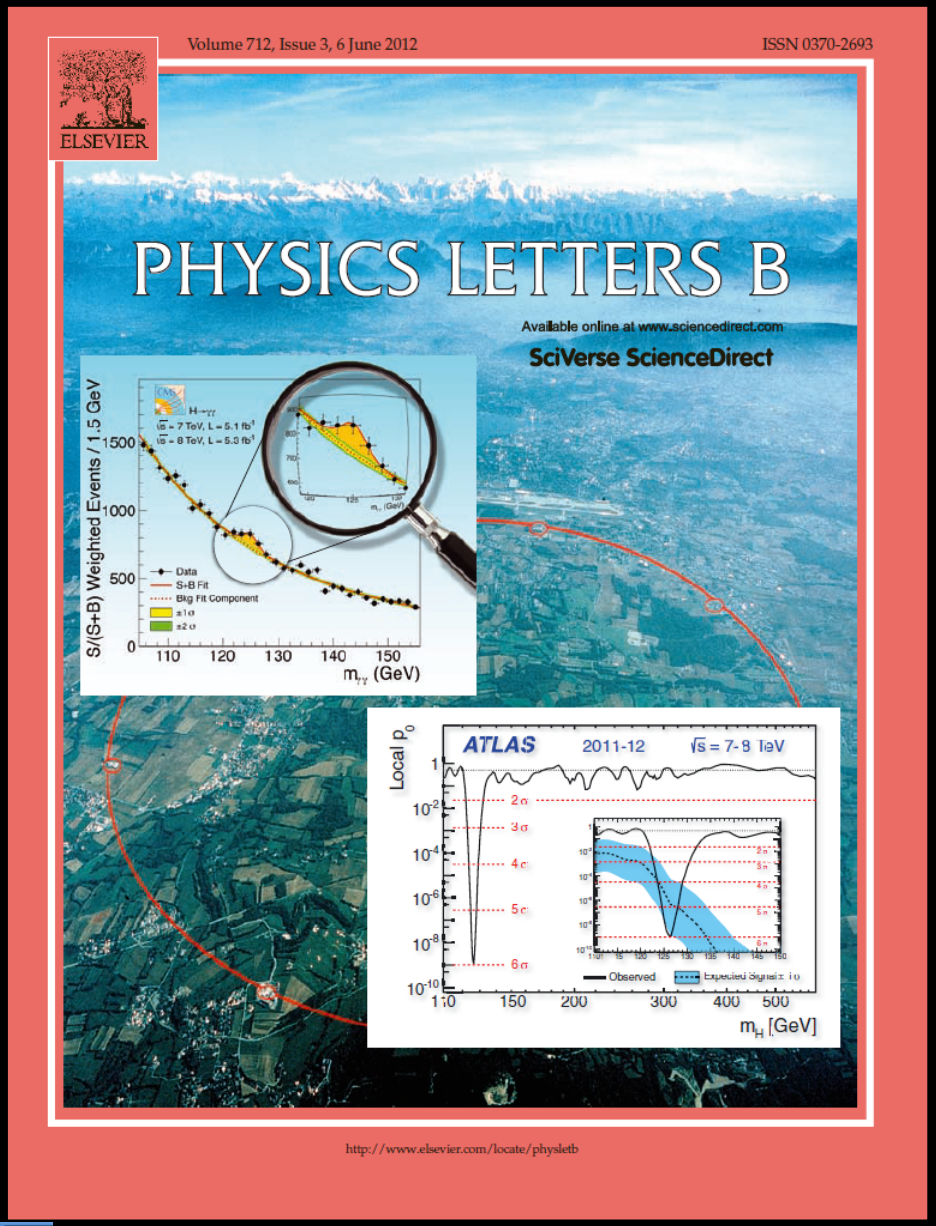


4. July 2012: CERN special seminar
"CERN experiments observe particle consistent with long-sought Higgs boson"



Picture of a Higgs boson decaying into 2 photons recorded by the CMS experiment

The Higgs discovery: a highlight in 2012



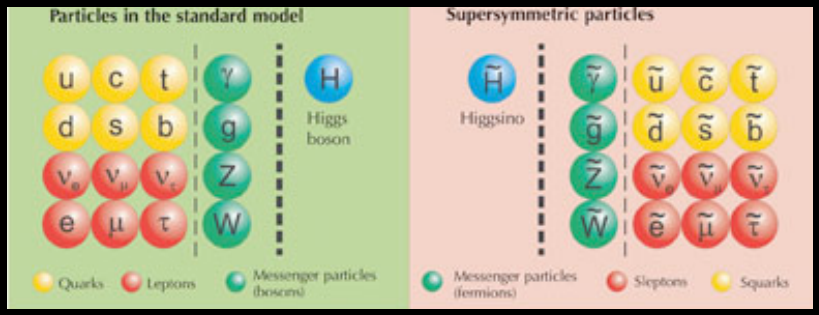
The Nobel Prize in Physics 2013

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

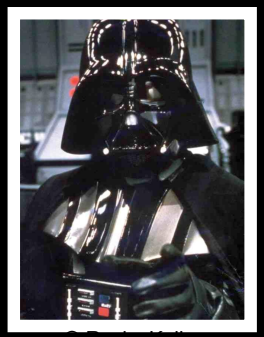
Finding the Higgs particle is just the start...

With the particles of the Standard Model we only know 5% of our universe.

- What is Dark Matter?



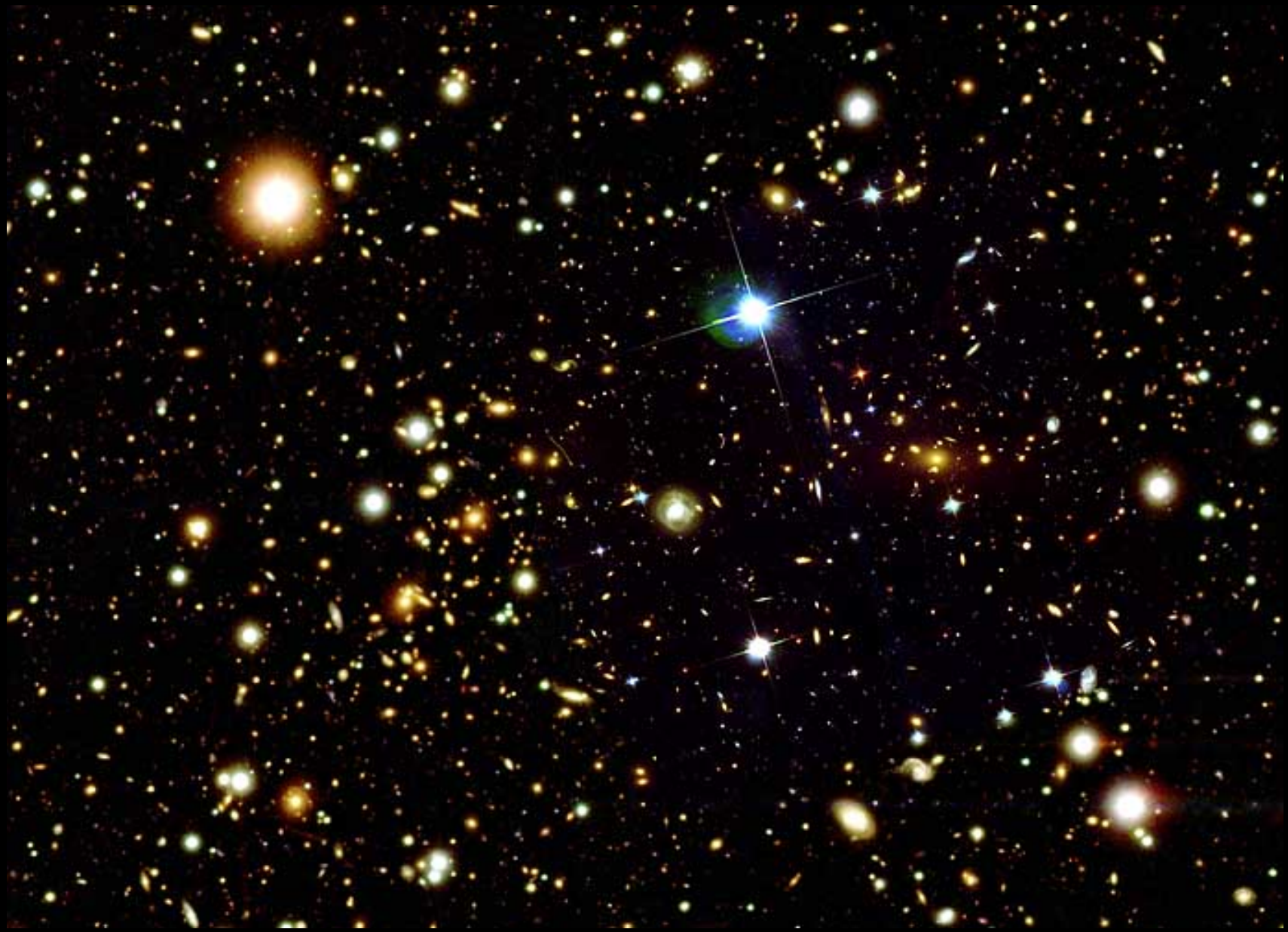
- What is Dark Energy?



- Why did antimatter after Big Bang disappear?

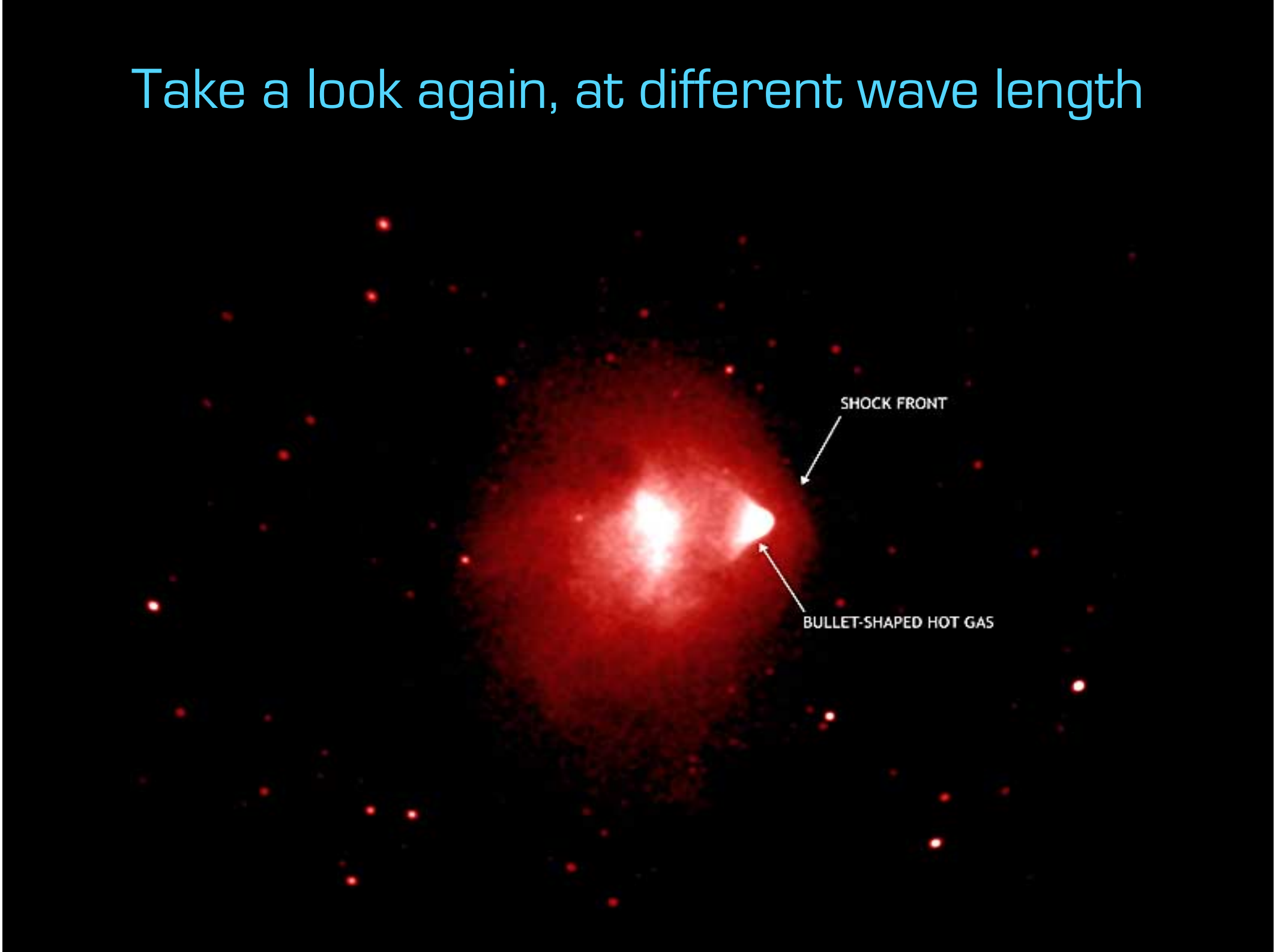
- Are there an unknown unknowns?

My dream at the LHC: find dark matter

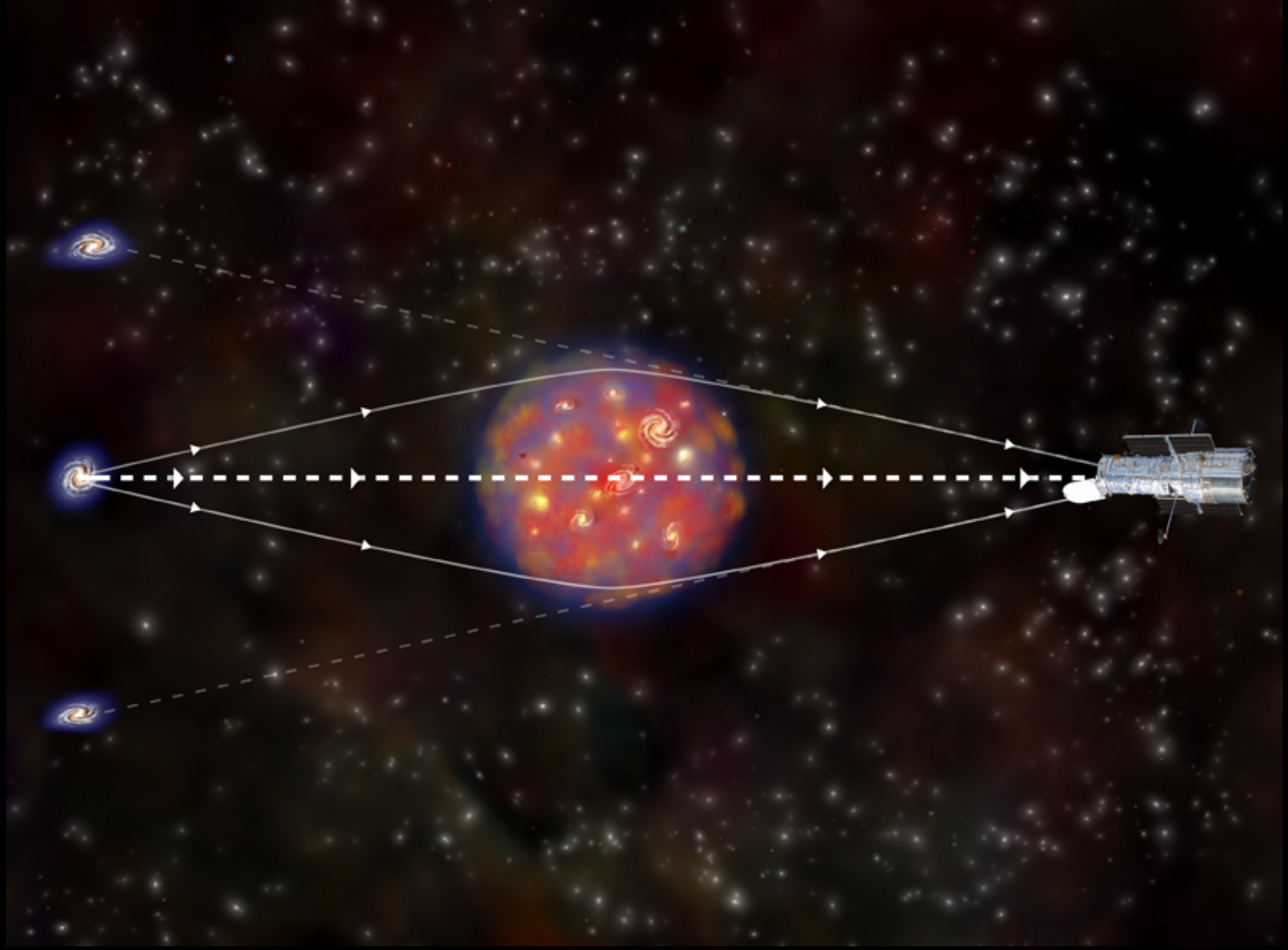


Take a look at the stars, as here, August 2006

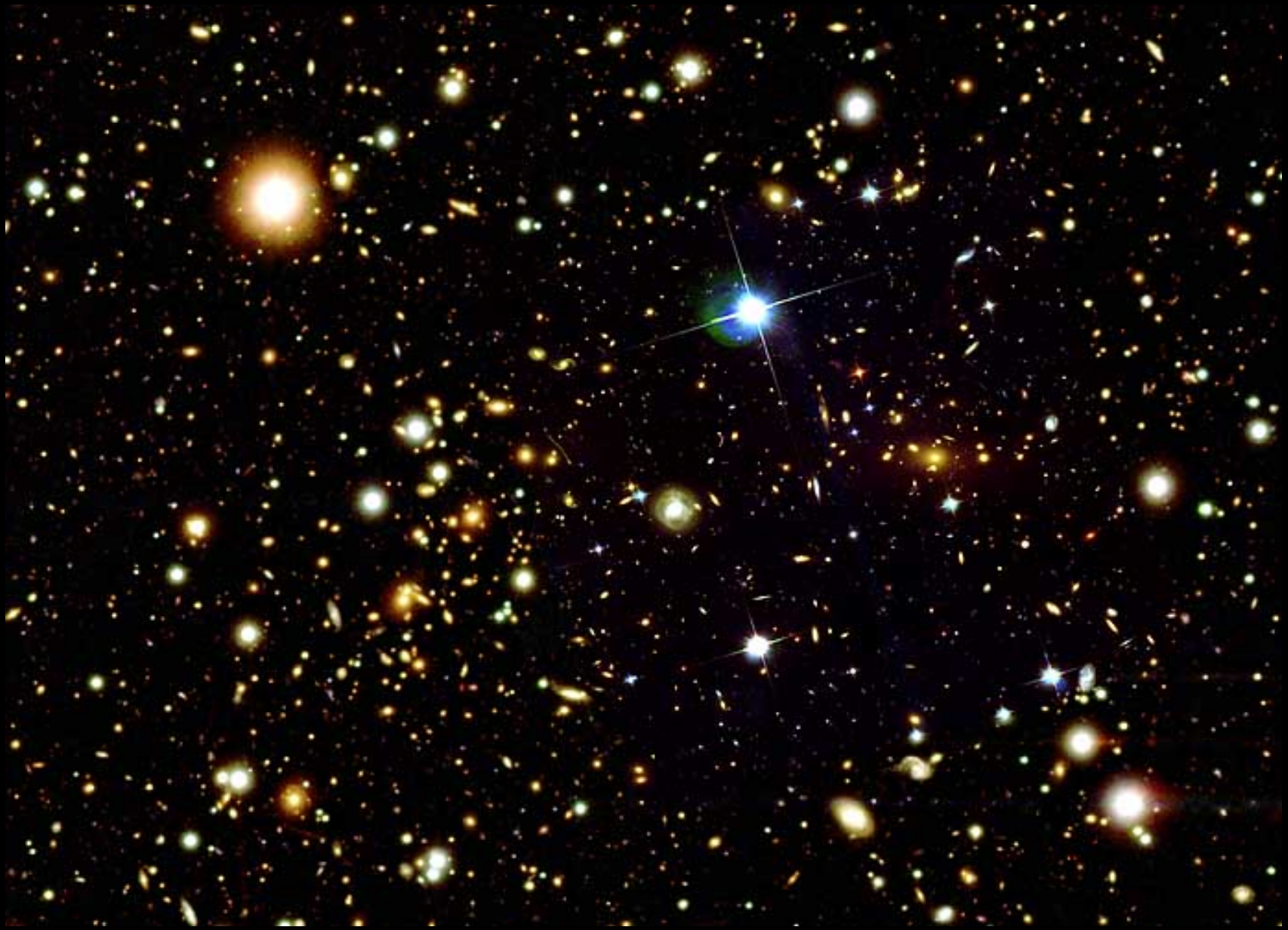
Take a look again, at different wave length



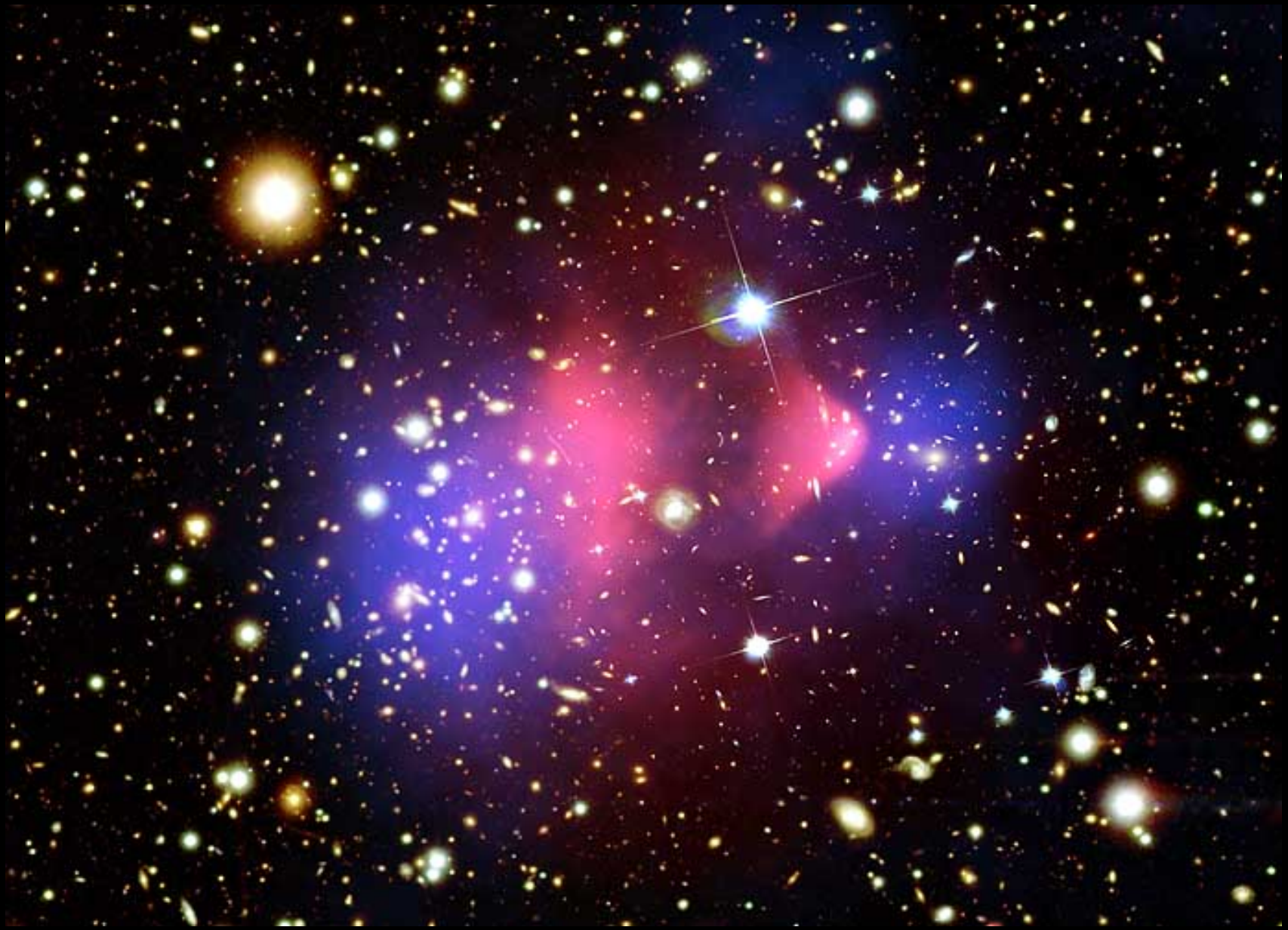
And look again, this time with gravitational lensing



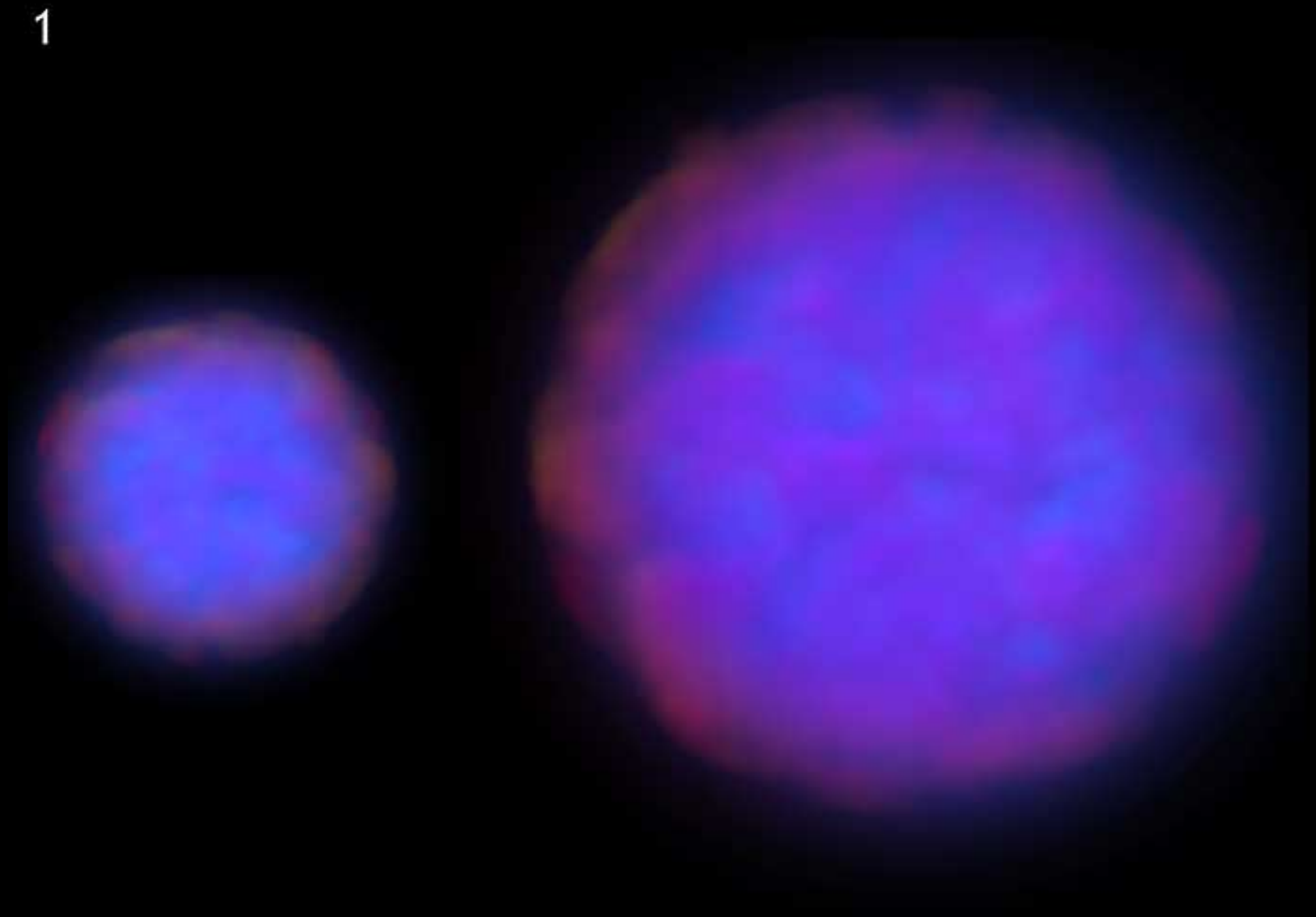
Now overlay all three different pictures



WHOW!

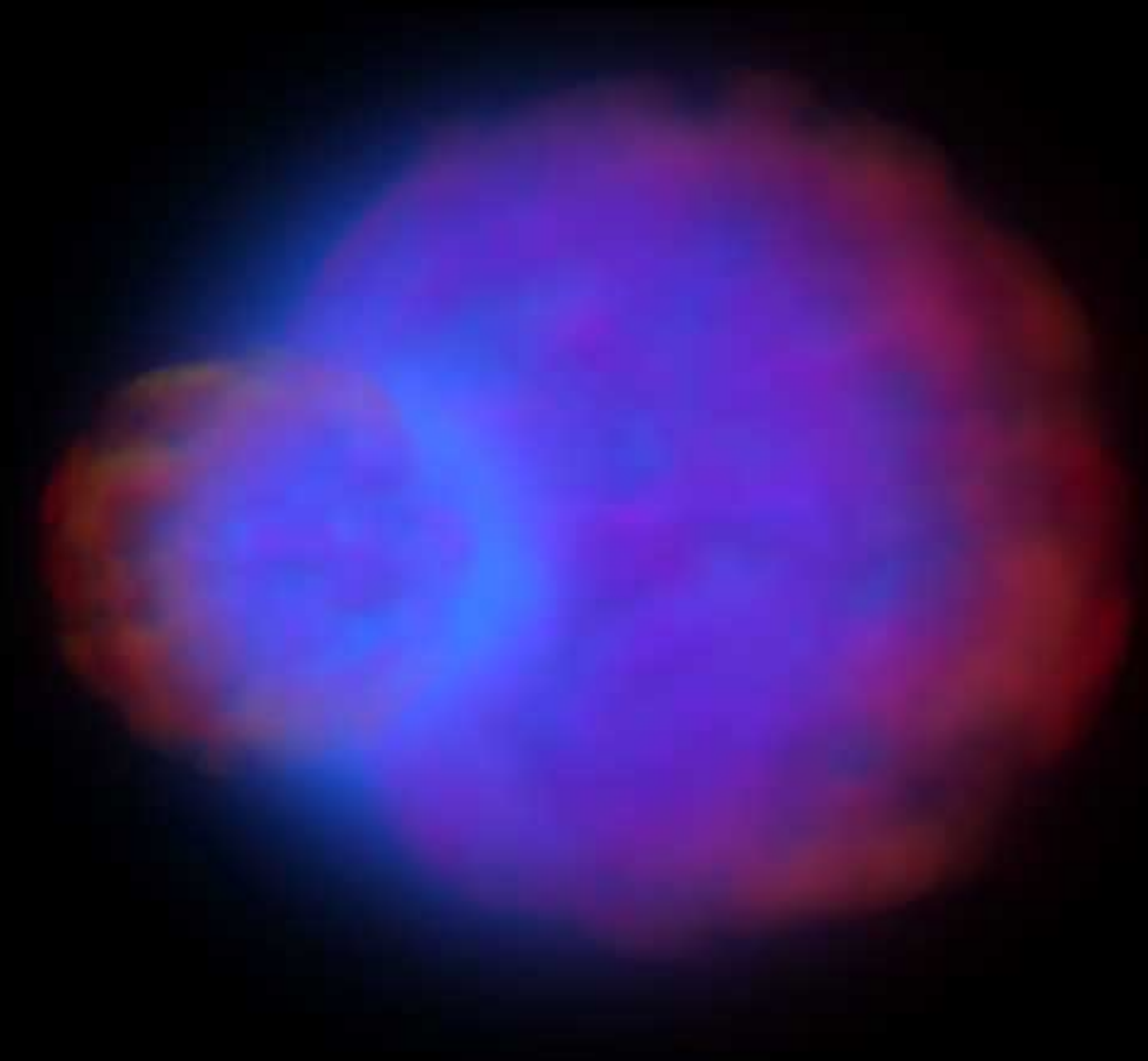


What could this be? A simulation of colliding galaxies



What could this be? A simulation of colliding galaxies

2

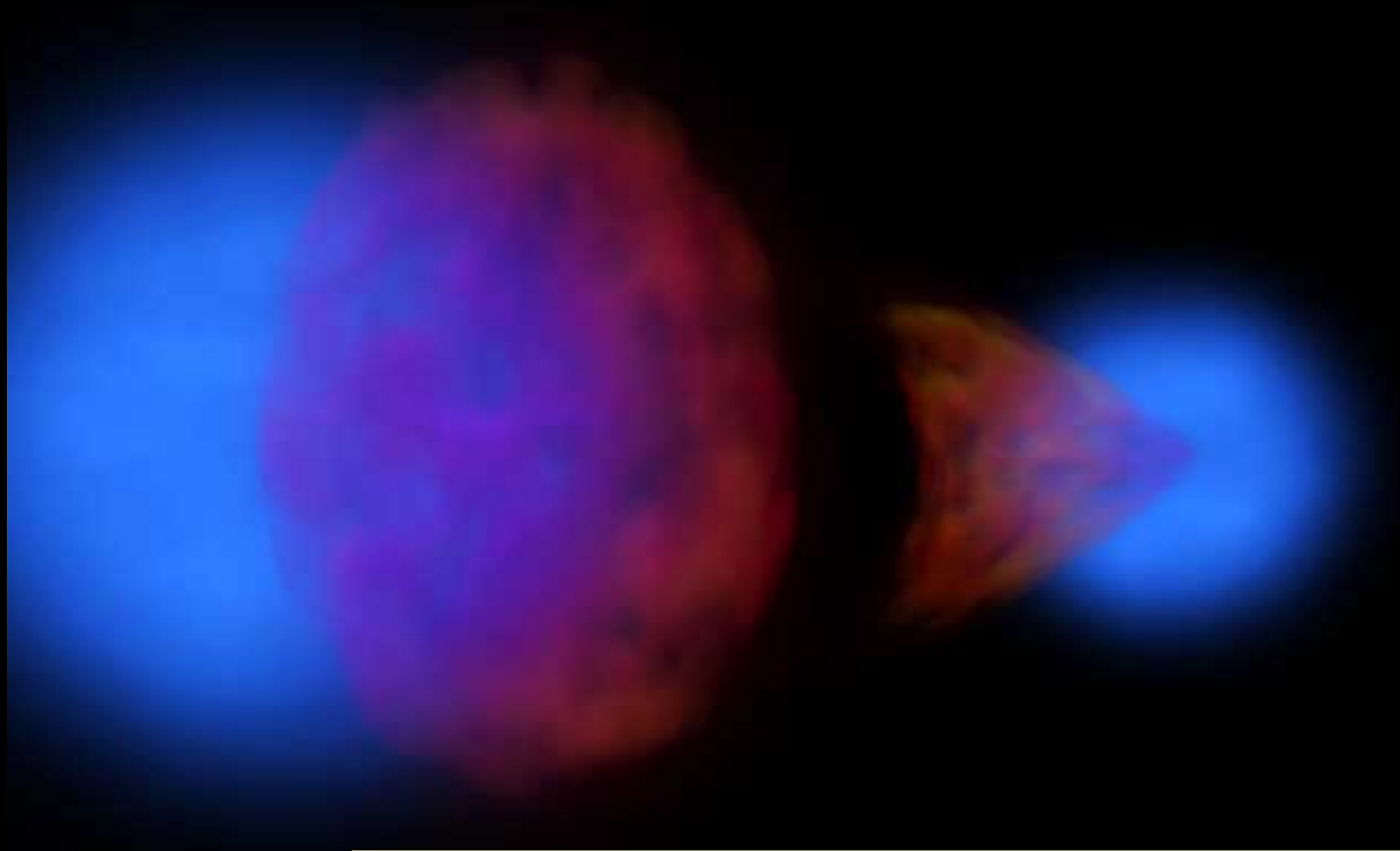


What could this be? A simulation of colliding galaxies

3

What could this be? A simulation of colliding galaxies

What could this be? A simulation of colliding galaxies

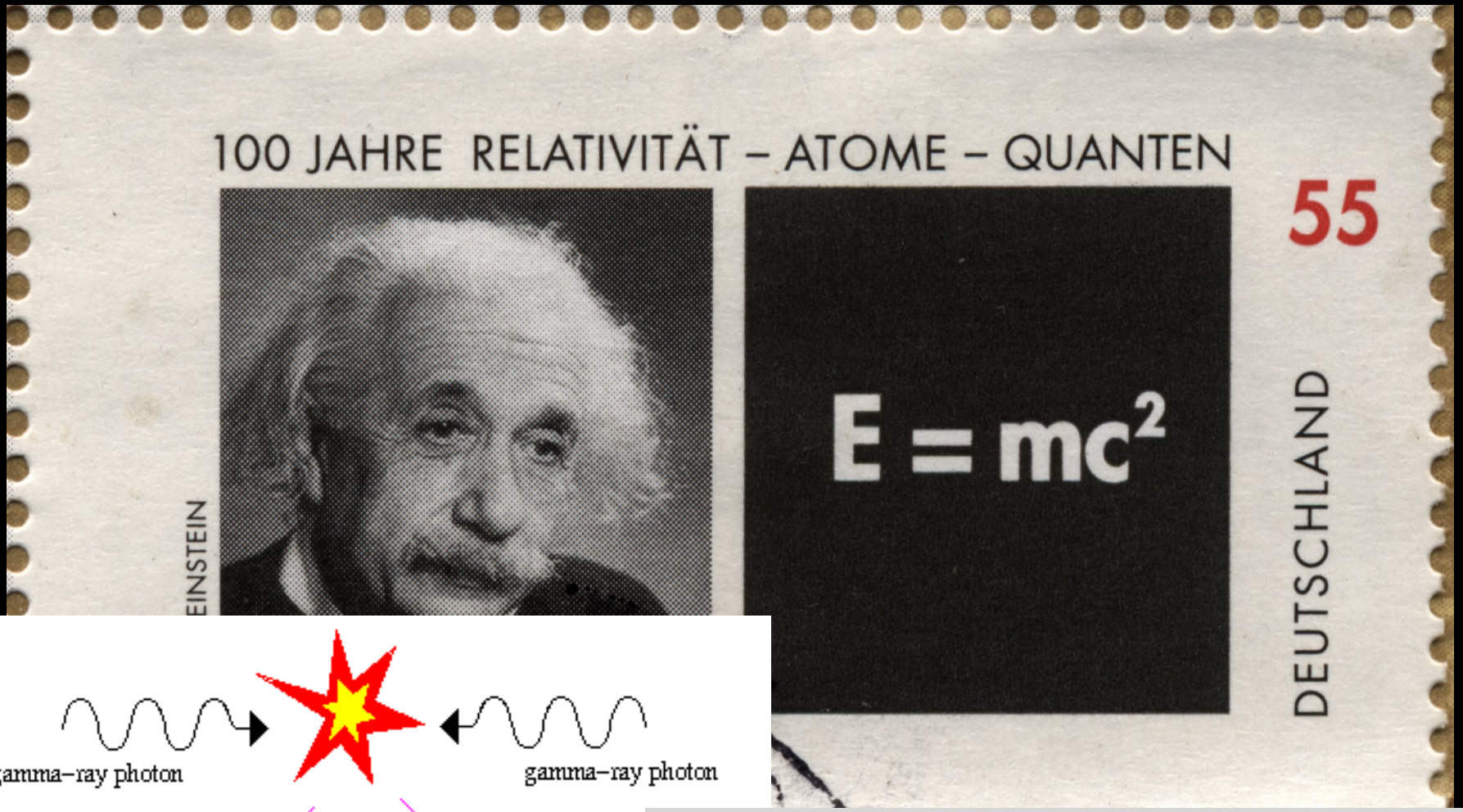


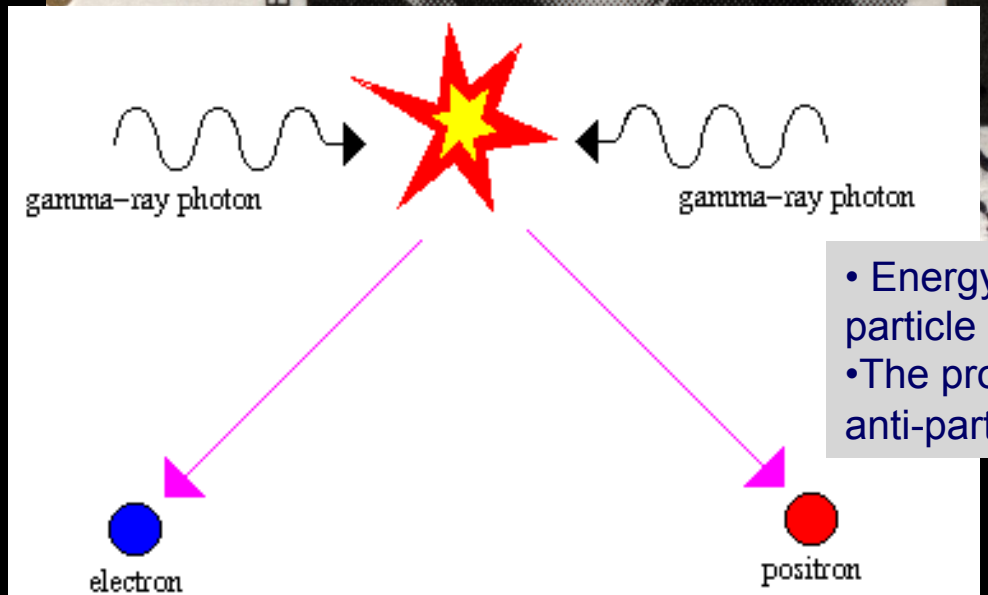
While the two galaxies collide and pass through each other, two areas feel different deceleration

- **"known" matter, more decelerated** ⇒ feels electromagnetic, strong, weak forces and gravitation;
- "unknown matter = **"Dark Matter"** ⇒ just feels gravitation.

(Another hint for Dark Matter: rotation curves of galaxies)

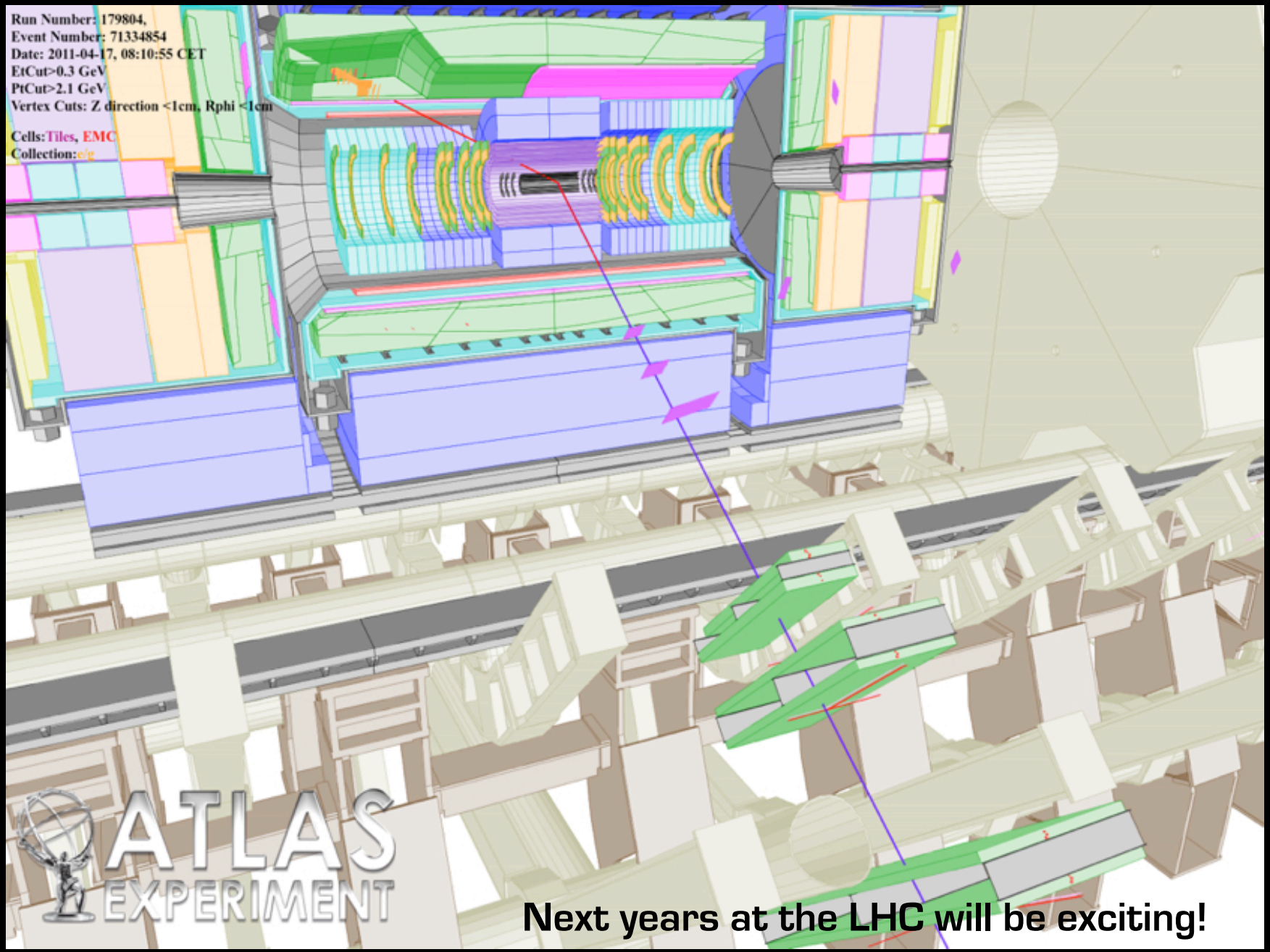
Produce dark matter particles in the LHC



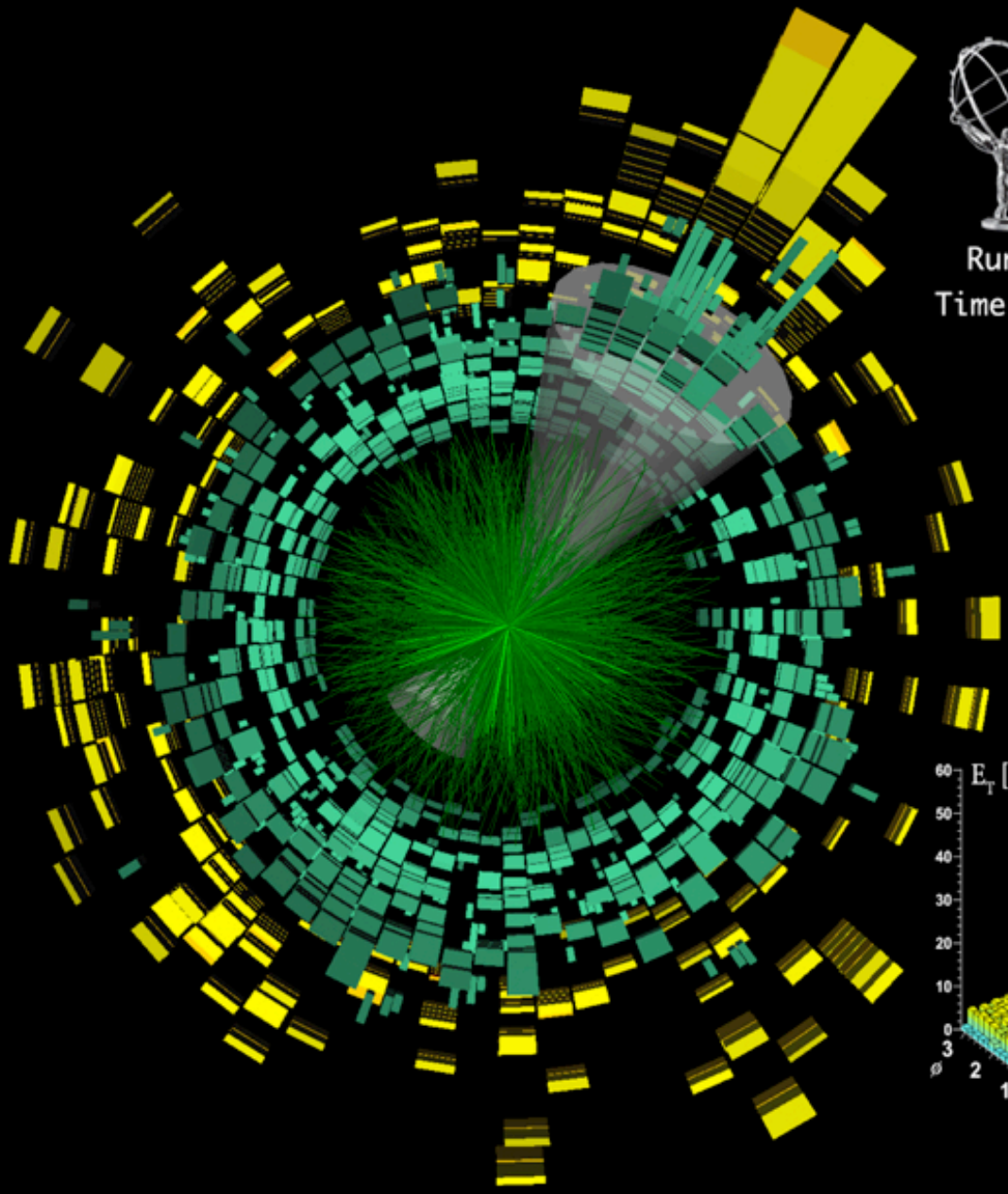


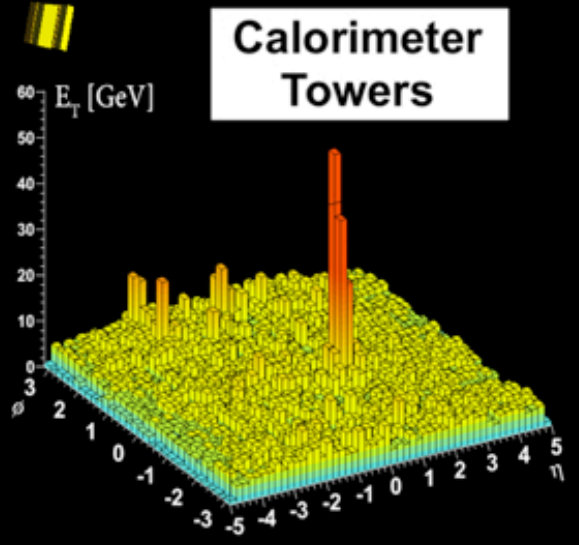
- Energy can only transform in a particle plus an anti-particle
- The process is reversible: when a particle meets an anti-particle, they annihilate to energy

How could it look like? Missing energy!



What else have we learned?





Jet quenching in heavy ion collisions. Exciting!

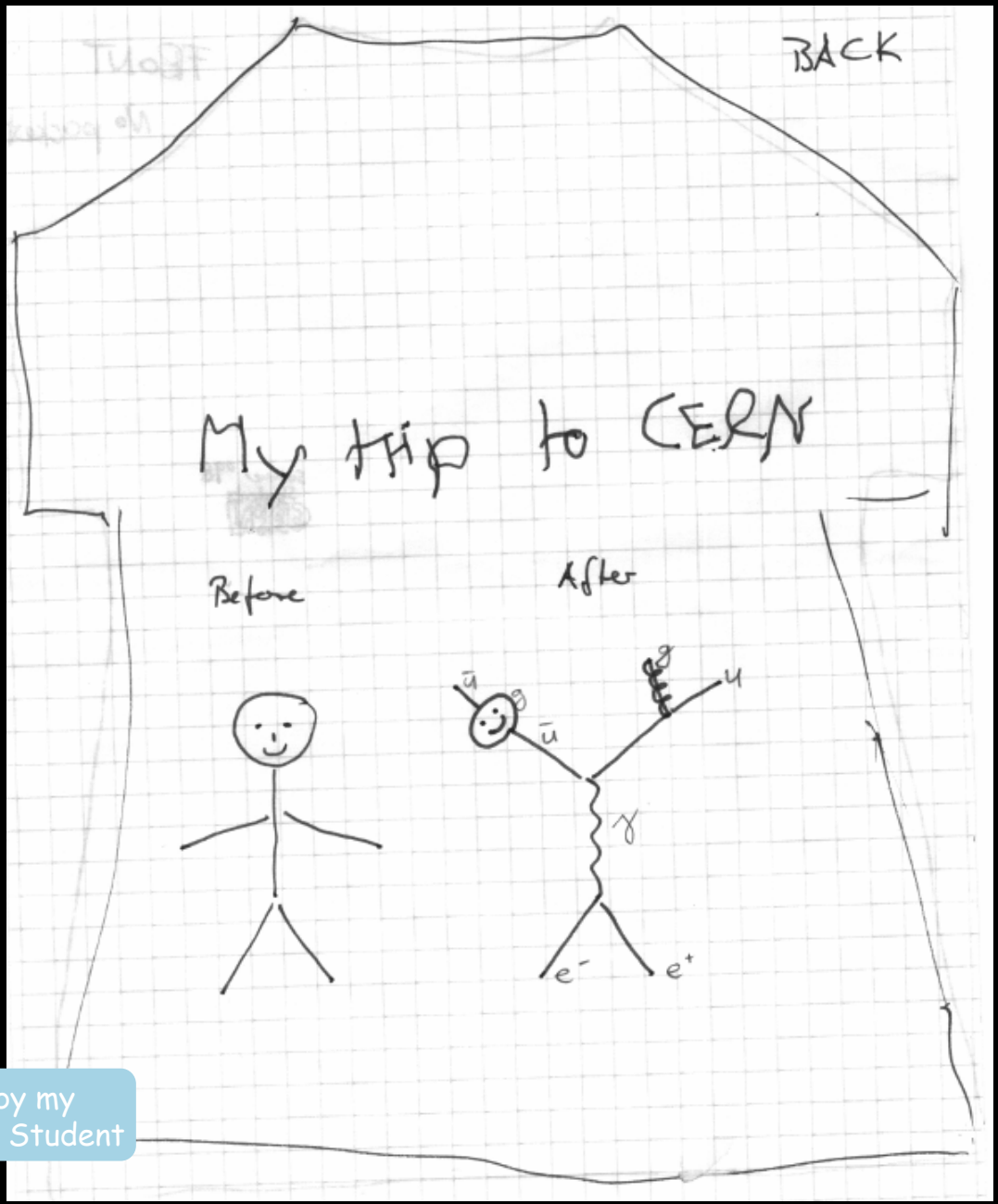
...and we have learned much more

My advise: study particle physics ;o)

Summary

- The discovery of the Higgs particle is a giant leap for science
  - Brout-Englert-Higgs Mechanism explains mass of elementary particles
  - We learn more about us, our universe...
  - ...but it is just a start: there are more open questions.
- Goal could only be reached by long-term strategic planning and international partnership
  - needs excellent people and inspiring environment
  - needs leading edge technology, innovative techniques
  - needs readiness to accept failure i.e. take (some) risk
- CERN is the place in the world to reach such goals
  - 60 years of Science for Peace
  - Synergy between research and innovation; results create opportunities for the future; fundamental science and applied science cannot be separated
  - provides excellent education of young researches, the future generation in science, politics and economy
  - is a beacon of science for the public.

Maybe a better summary



Designed by my
1998 Summer Student

There is still a lot to learn about the world we live in!

Camille Flammarion, 1888

Thank you very much for your attention!