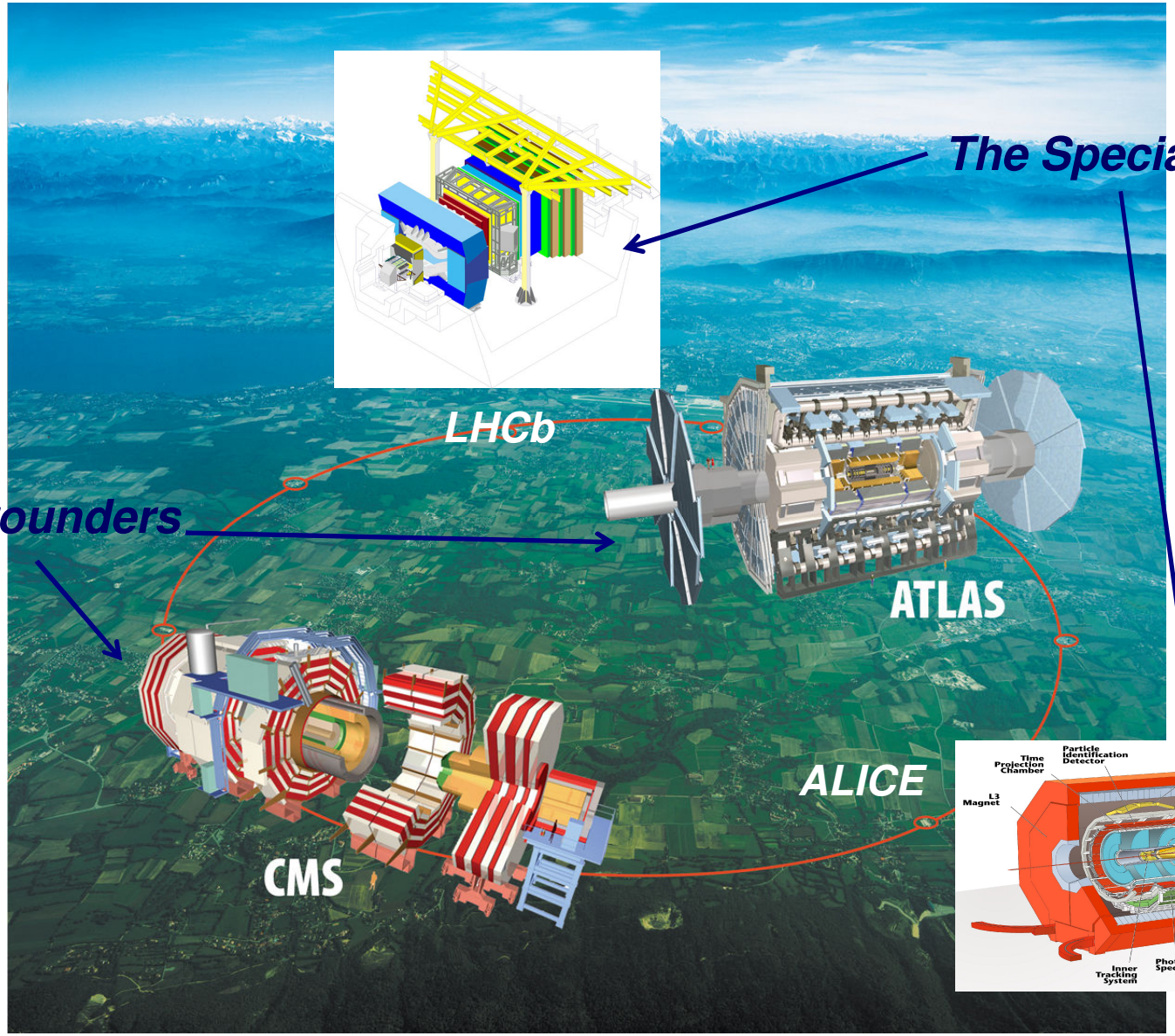
Experiments at the LHC

EIROforum Teacher School
November 17 2009

Christoph Rembser (CERN)

The 4 LHC Experiments



High Energy Physics Experiments

- **Goal: understand "rules" of nature:**
  - → How do particles interact
  - → How are particles produced, how they decay…

Somewhat similar:
Understand "rules" for football by analysing photos
- ***good camera allows to see details***
  - ***when taking many pictures, rare "events" can be stud***

The LHC "Experiments"

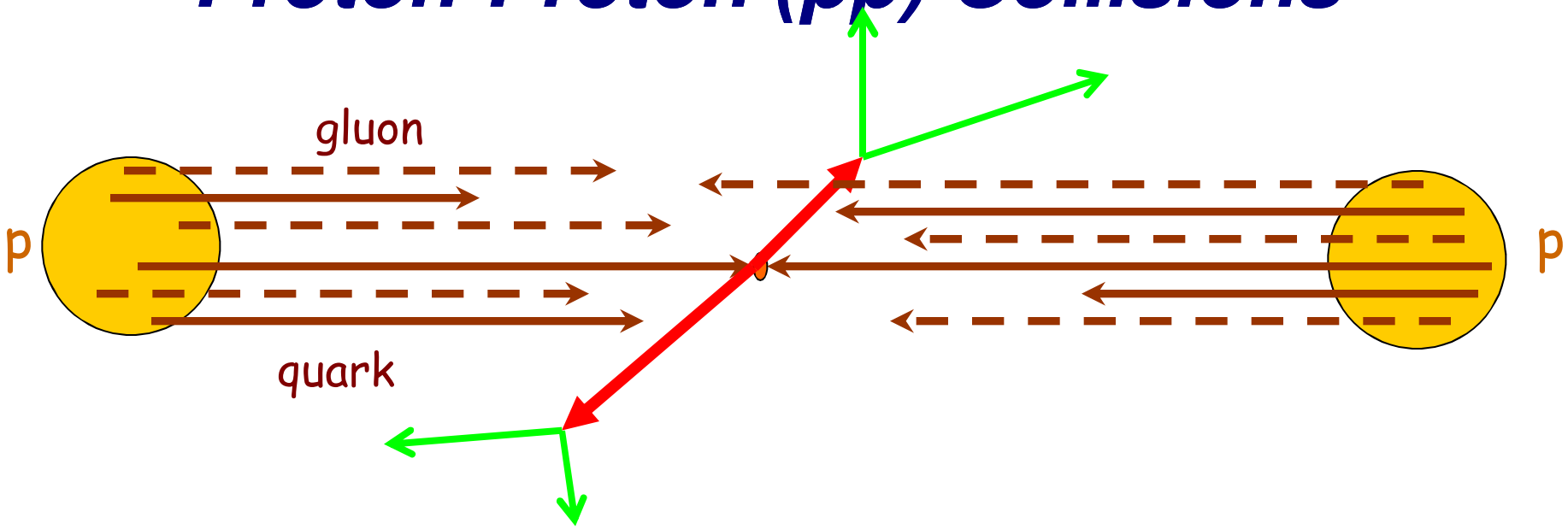
Better: the LHC experiment, consisting of

- **The Large Hadron Collider (see talk by D.Brandt)**
  → Provides particle (Proton) beams which collide at four interaction points

- **The four cameras taking pictures of the collisions**
  → Around the four interaction points, four cameras are installed, the **LHC detectors**
    - ALICE, LHCb, CMS and ATLAS
    - Huge permanent installations, taking photos 24h/7d for >10 years

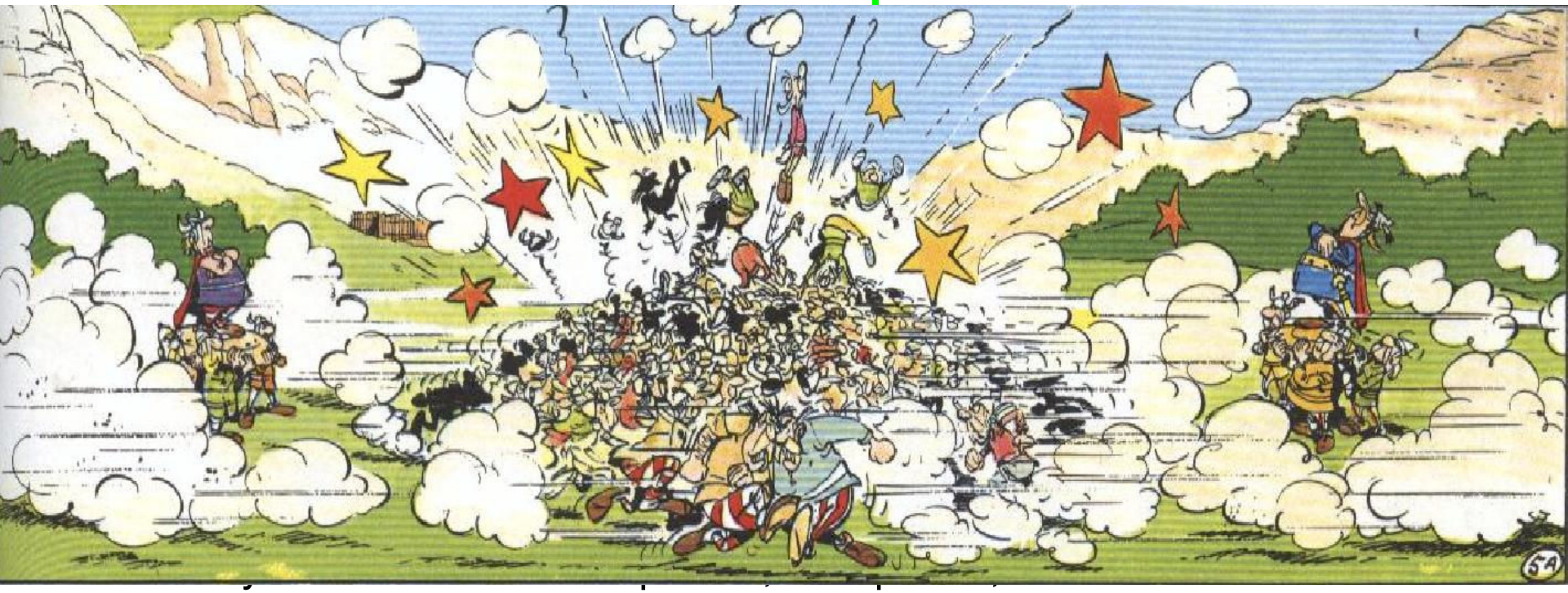
- **This talk (a personally biased selection)**
  → Overview on LHC detector(s)
  → Highlights of physics analyses

Proton-Proton (pp) Collisions



- **At interaction point, collision of one (sometimes more) protons**
  - → Only constituents of the proton, the quarks, collide!
  - → E=mc2 : "new" particles can be produced!
  - → Produced particles or their decay products fly away from the interaction point
- **Cameras (the detectors) take a photo of this event**
  - → 30 million pictures per second!

Proton-Proton (pp) Collisions



→ E=mc2 : “new” particles can be produced!

→ Produced particles or their decay products fly away from the interaction point

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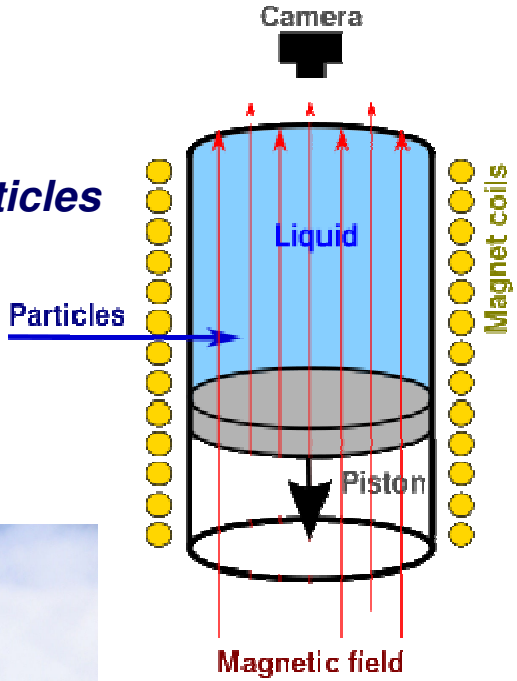
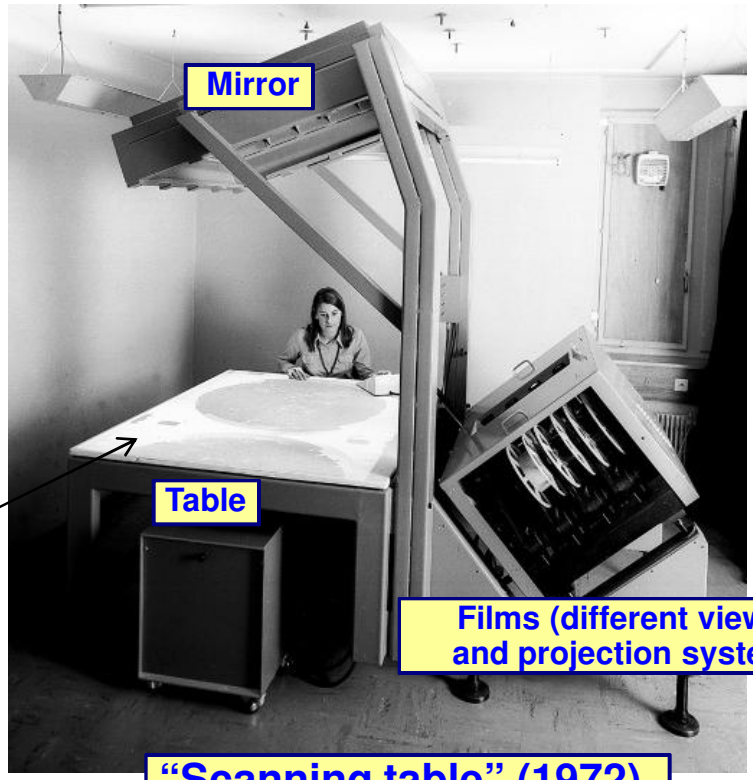
"Old" Detectors: Bubble Chambers

Vessel filled with superheated transparent liquid. Electrically charged particles leave "traces, like condensation trails by airplanes. Beautiful pictures!



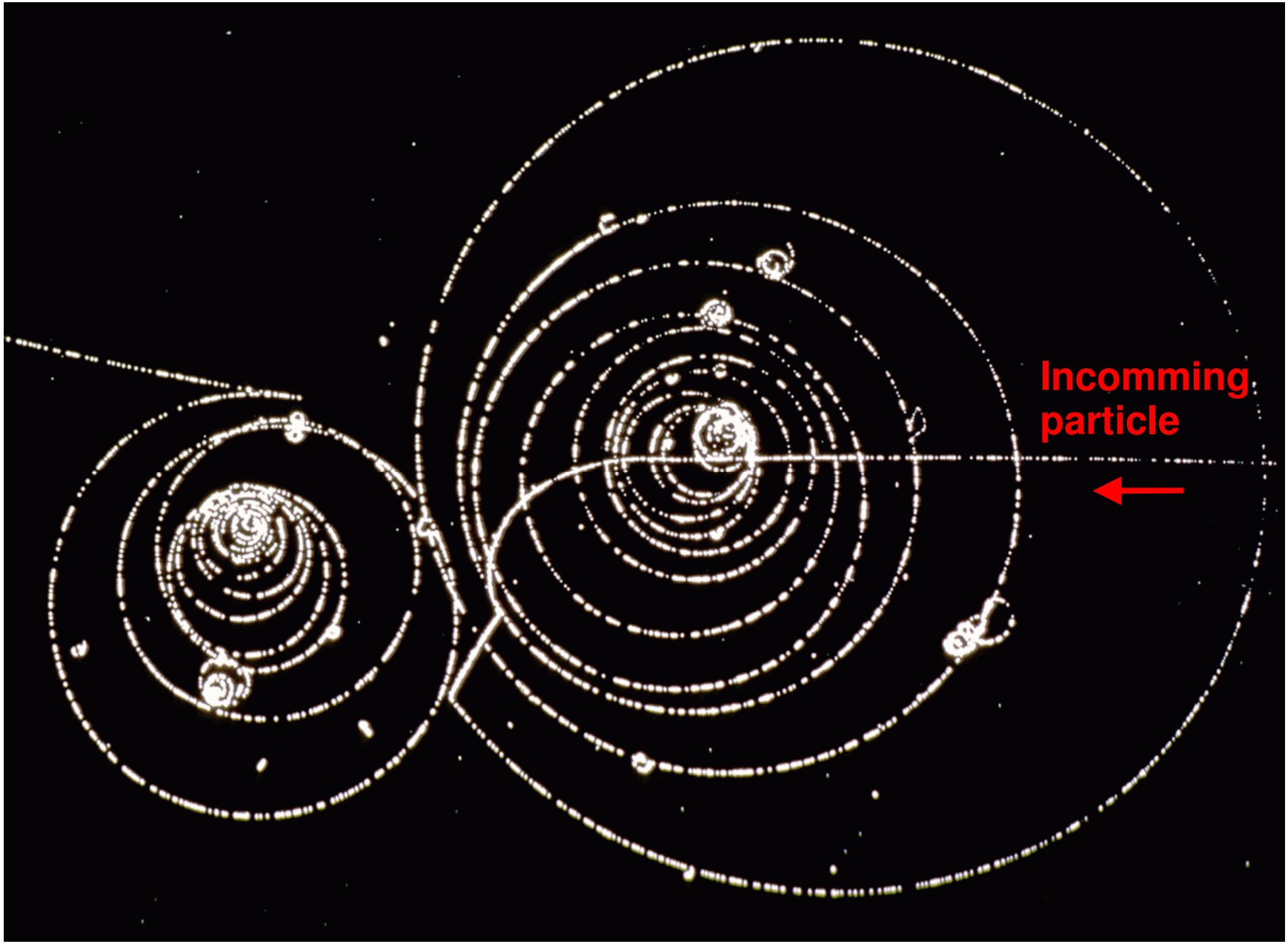
A bubble chamber

"Scanning girl" analysing bubble chamber photos.

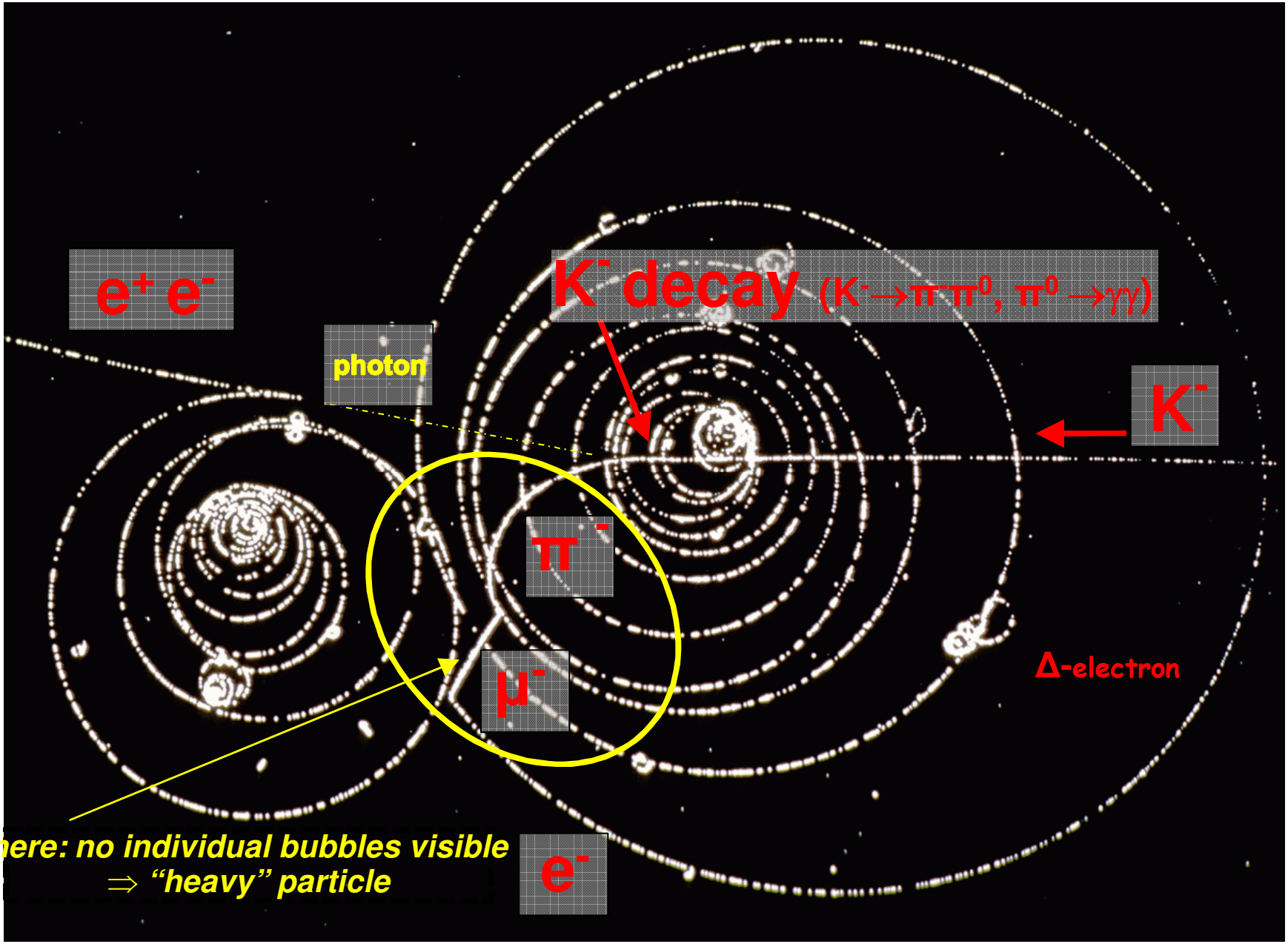


"Scanning table" (1972)

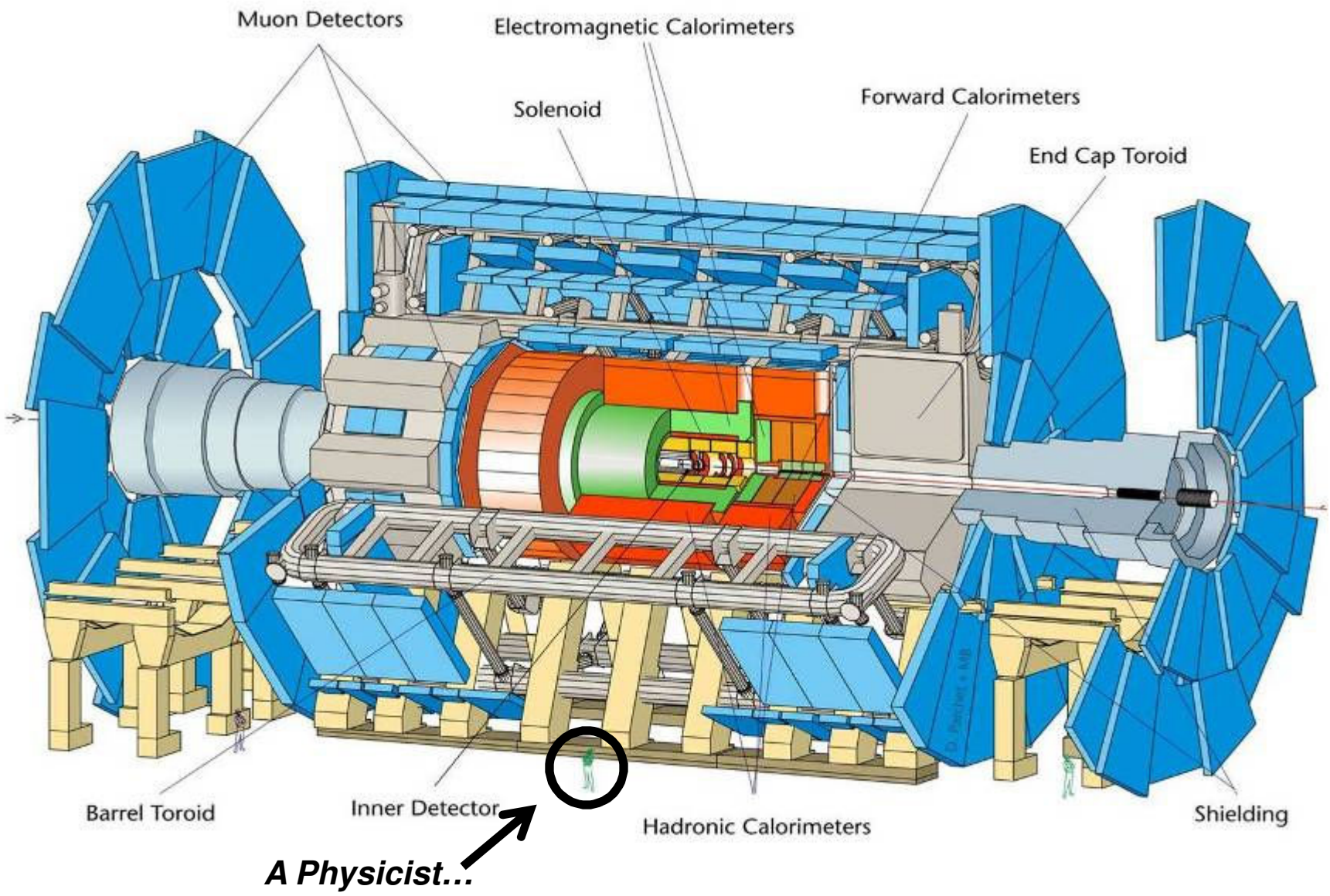
Bubble Chamber Pictures



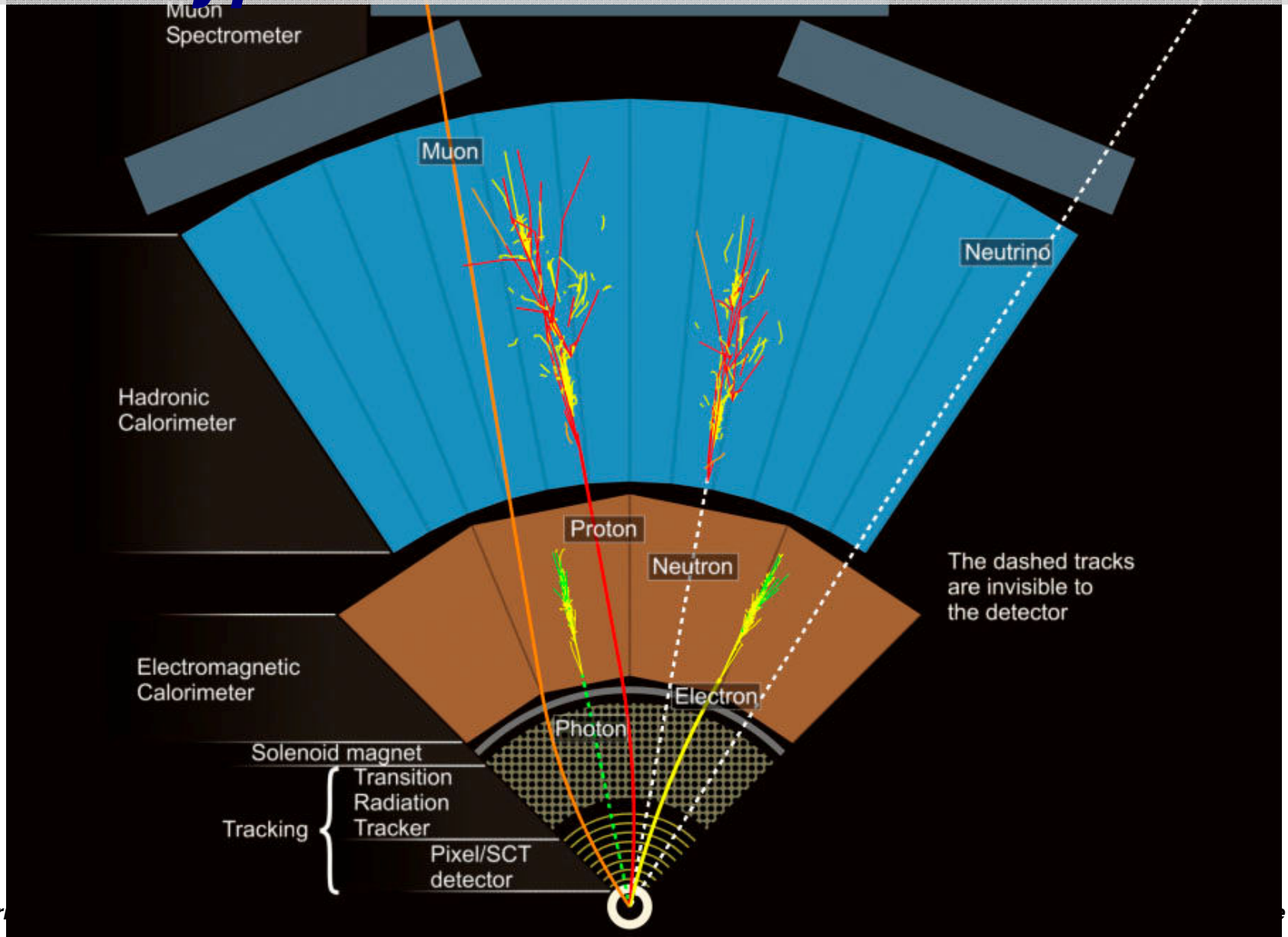
Bubble Chamber Pictures



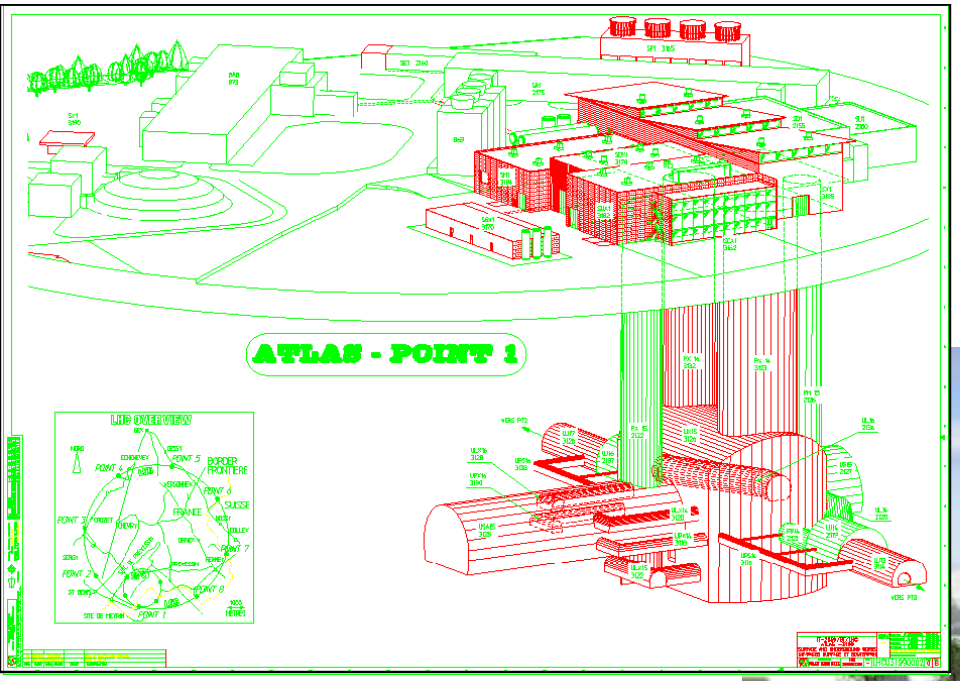
An LHC Detector (ATLAS)



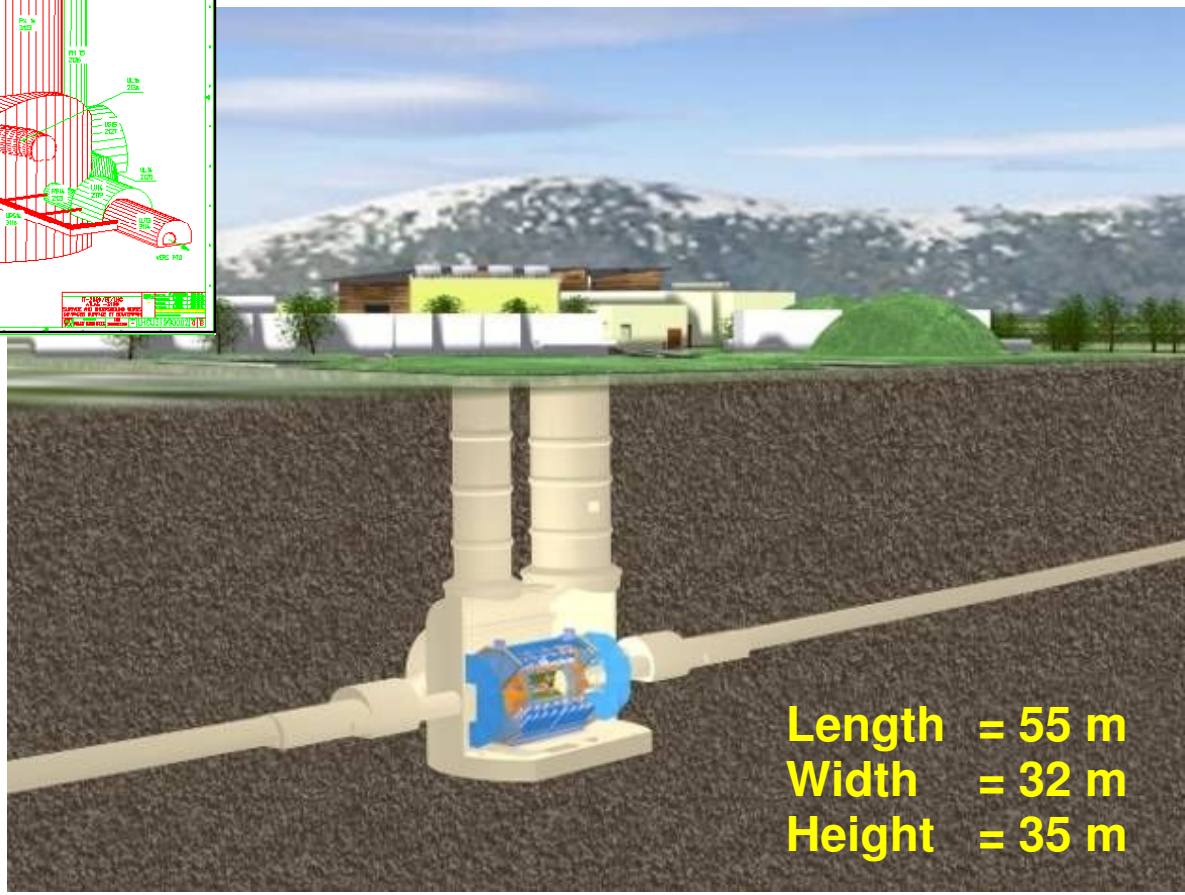
Detector Layers – Different "Camera Types for different Particles

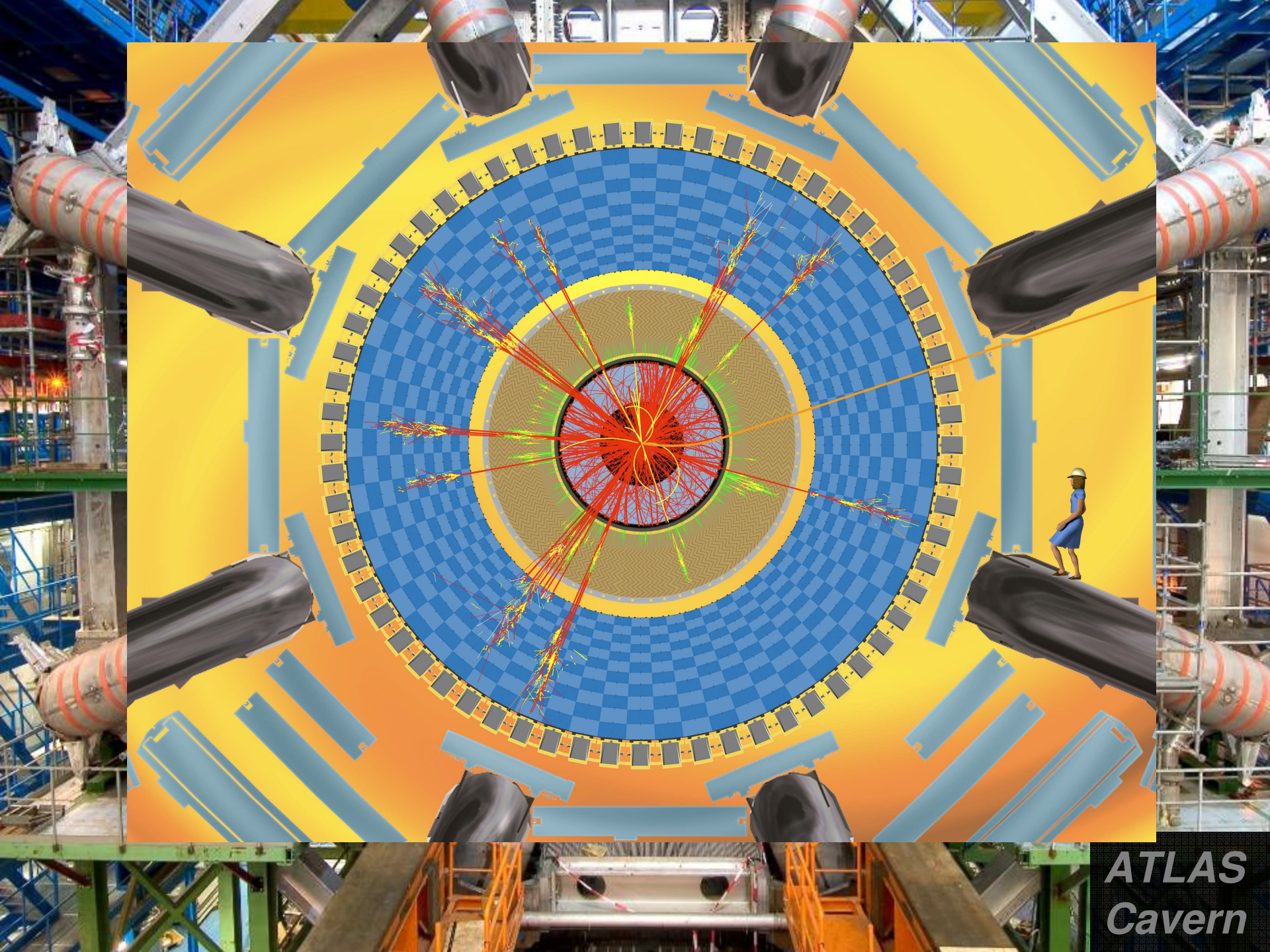


Detectors are huge!!!!



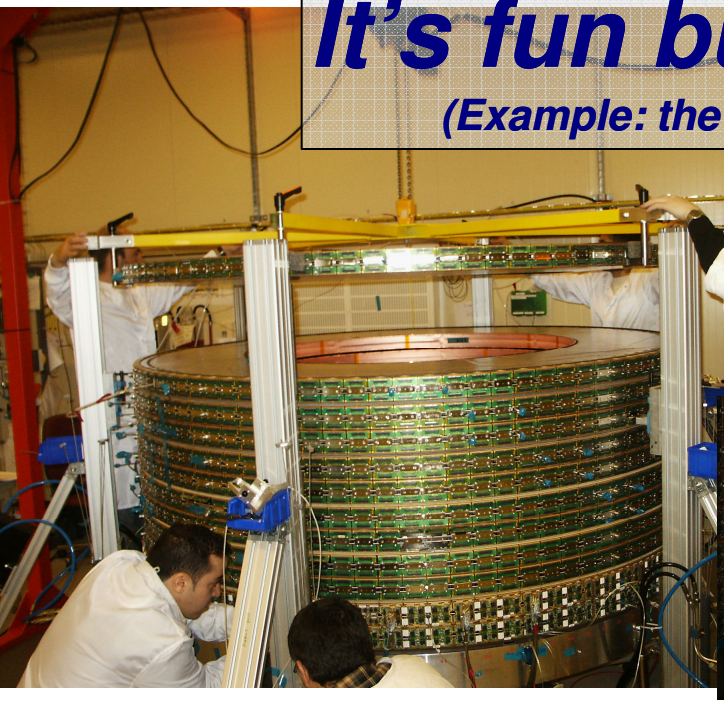
Huge underground hall +
many buildings on surface
2 access shafts18m + 12m Ø,
2 smaller shafts for elevator and stair

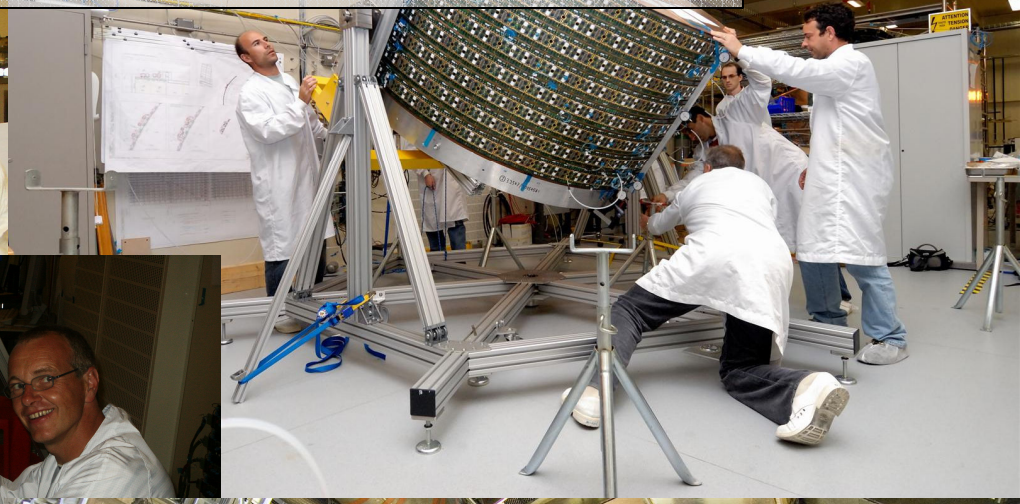


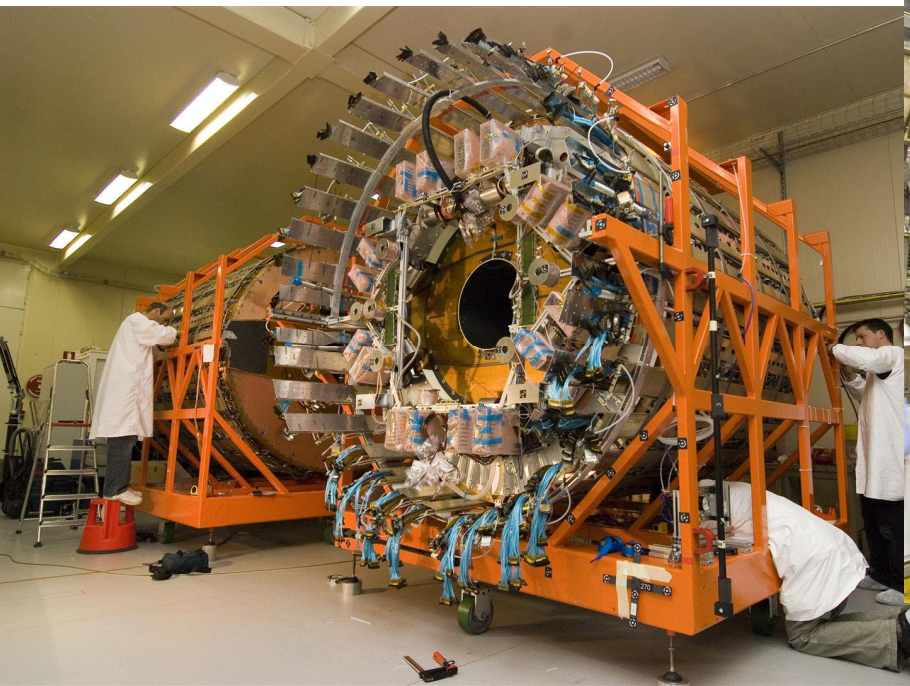

ATLAS
Cavern

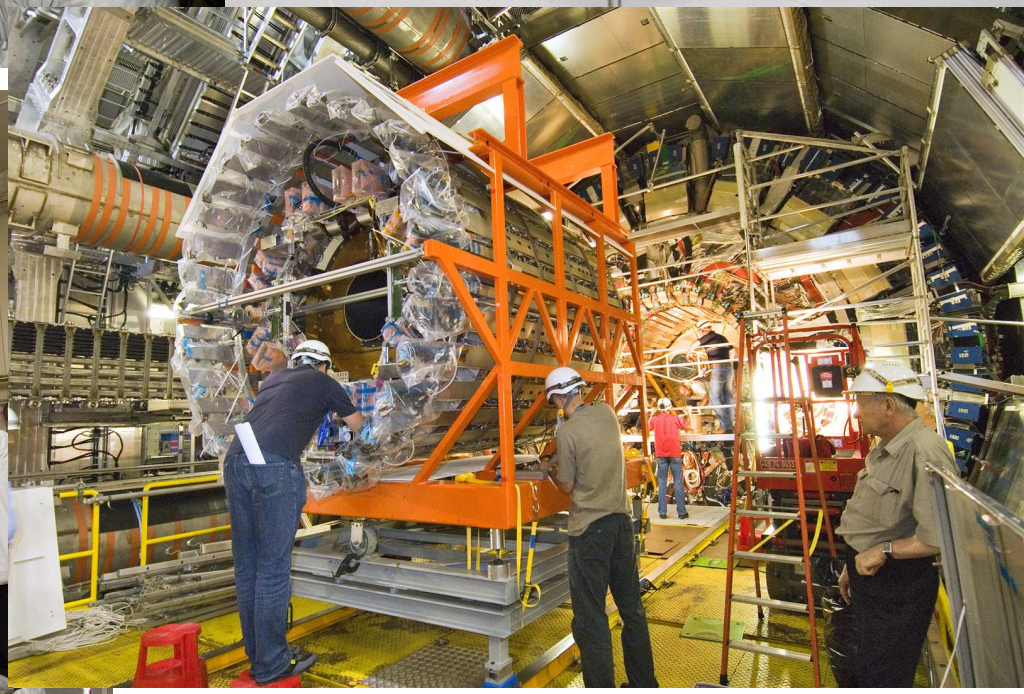
It's fun building detectors!!!!

(Example: the ATLAS Transition Radiation Tracker)

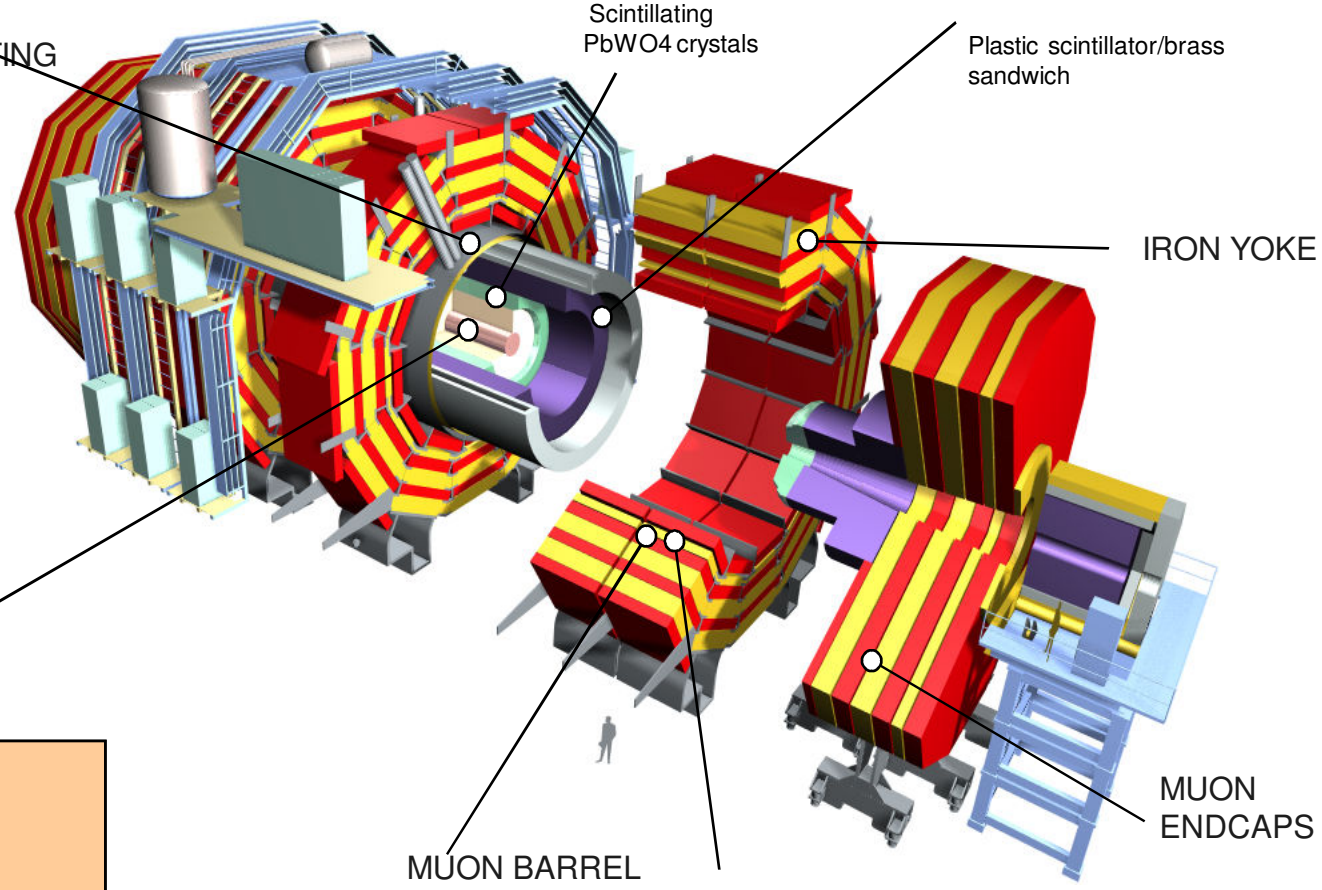






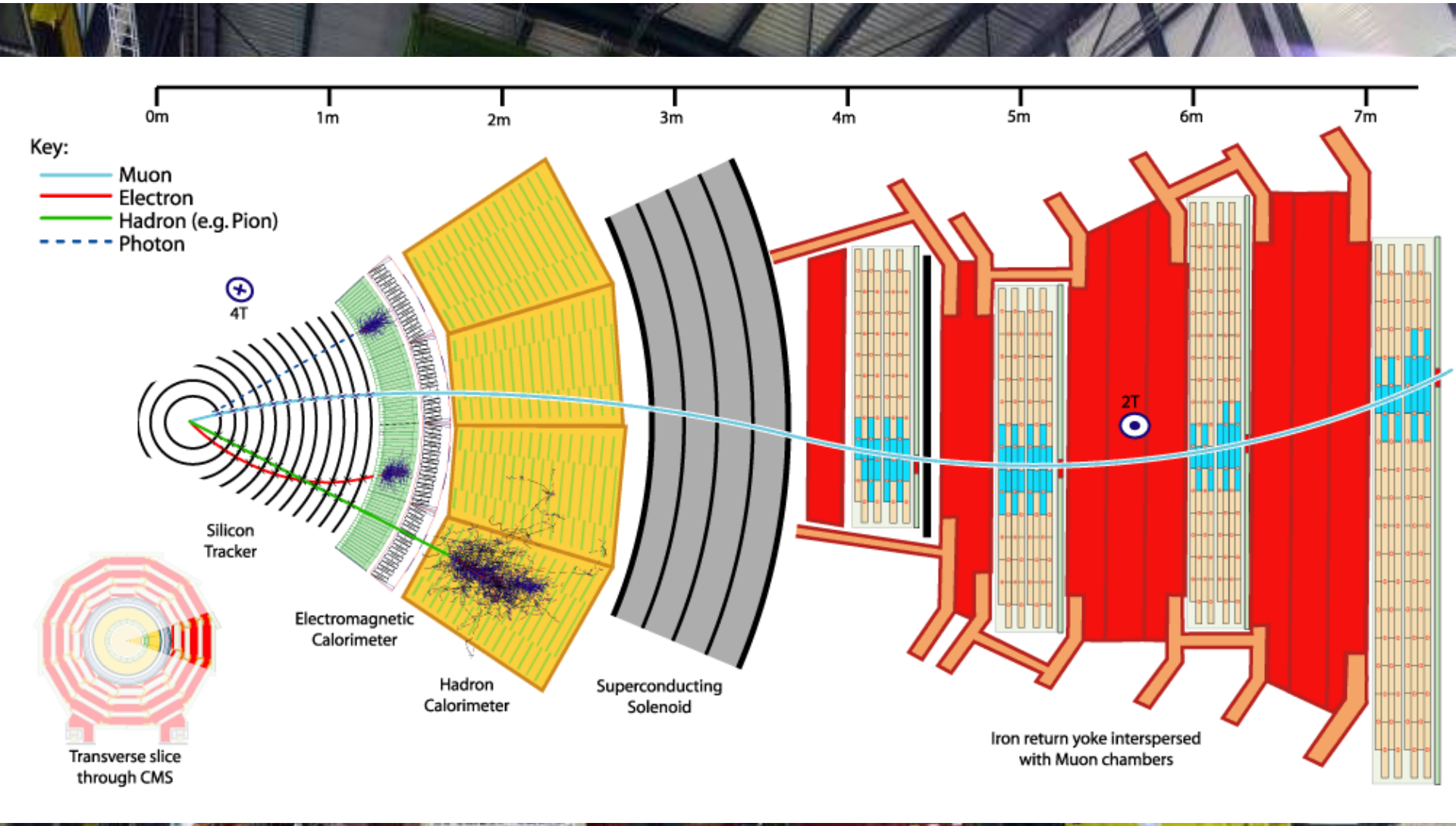


The CMS Detector



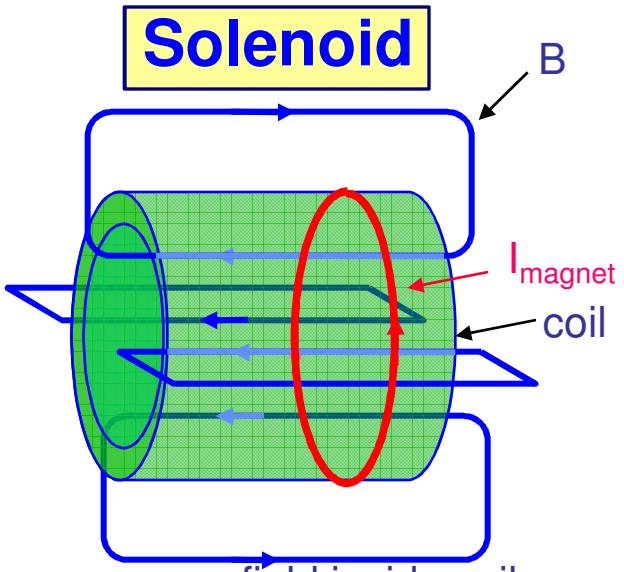
Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

CMS


0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Hadron (e.g. Pion)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS

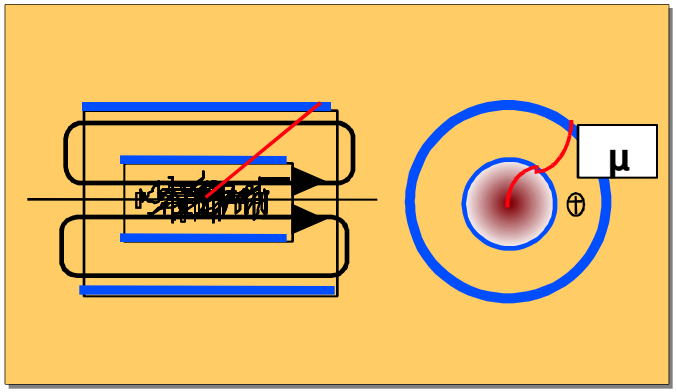
Different Magnet Concept of LHC Detectors

Solenoid

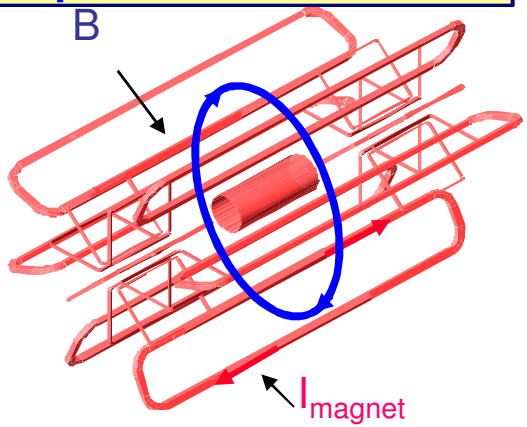


+ high homogenous field inside coil, excellent momentum resolution
- expensive
- Thick coils, lot of material influences particles going from trackers to calorimeters

CMS, ALICE, LEP Detektoren

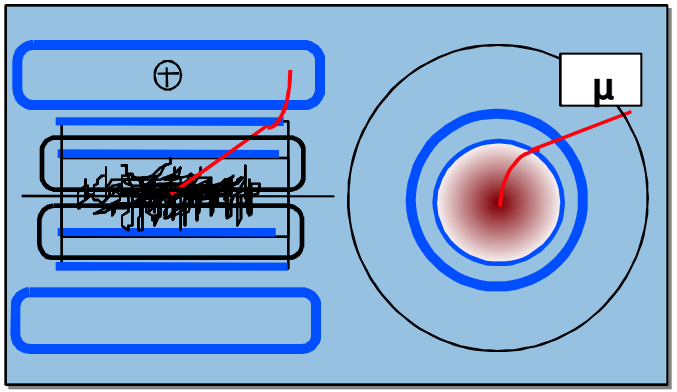


(Air coil)-Toroids plus Solenoid



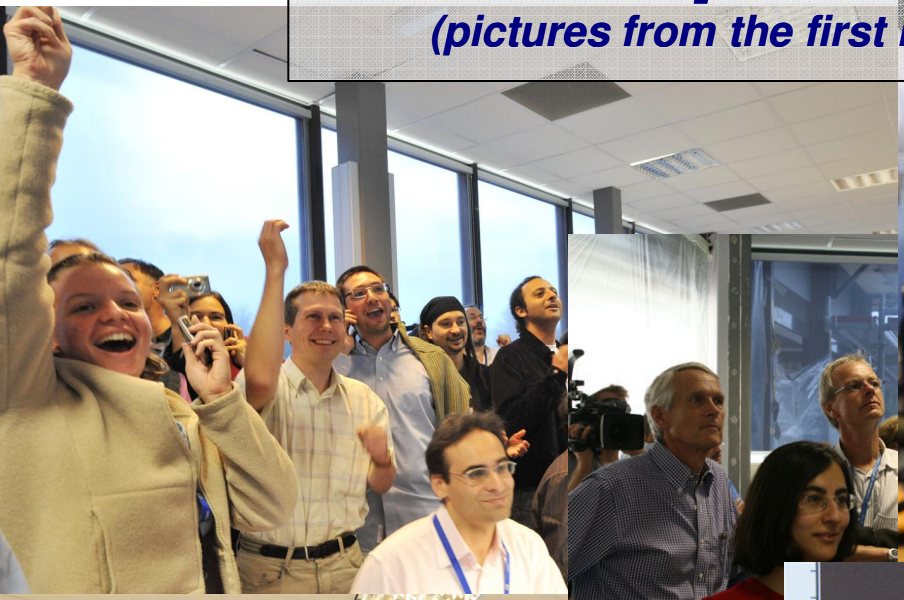
+ covers large volume
+ air coil, not a lot of material
- Requires additional
- Field less uniform
- Complex strukture

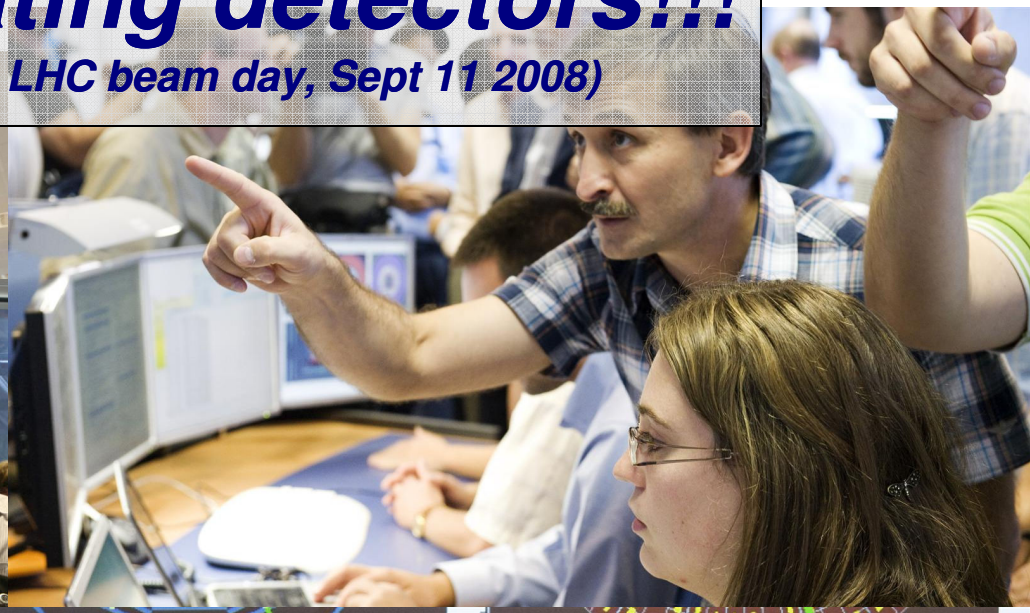
ATLAS

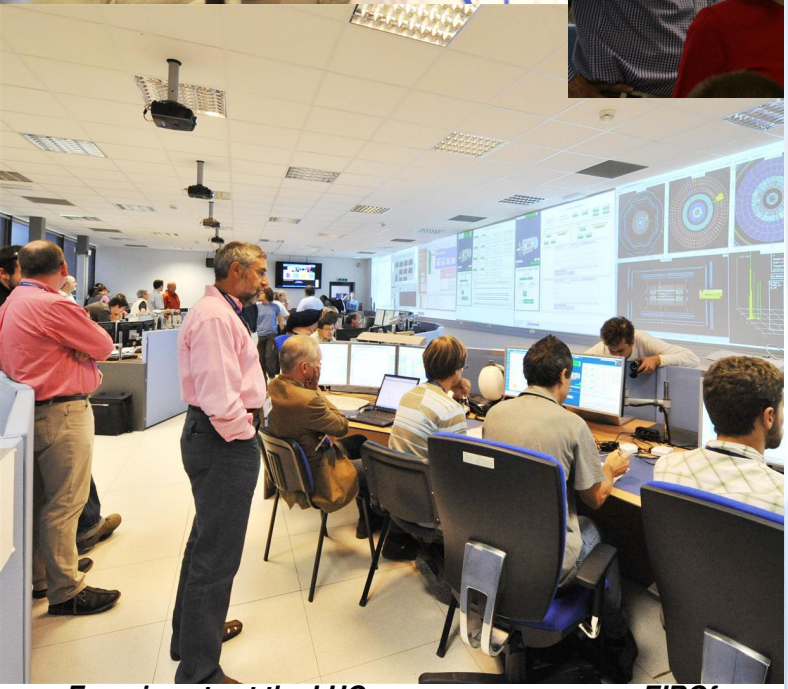


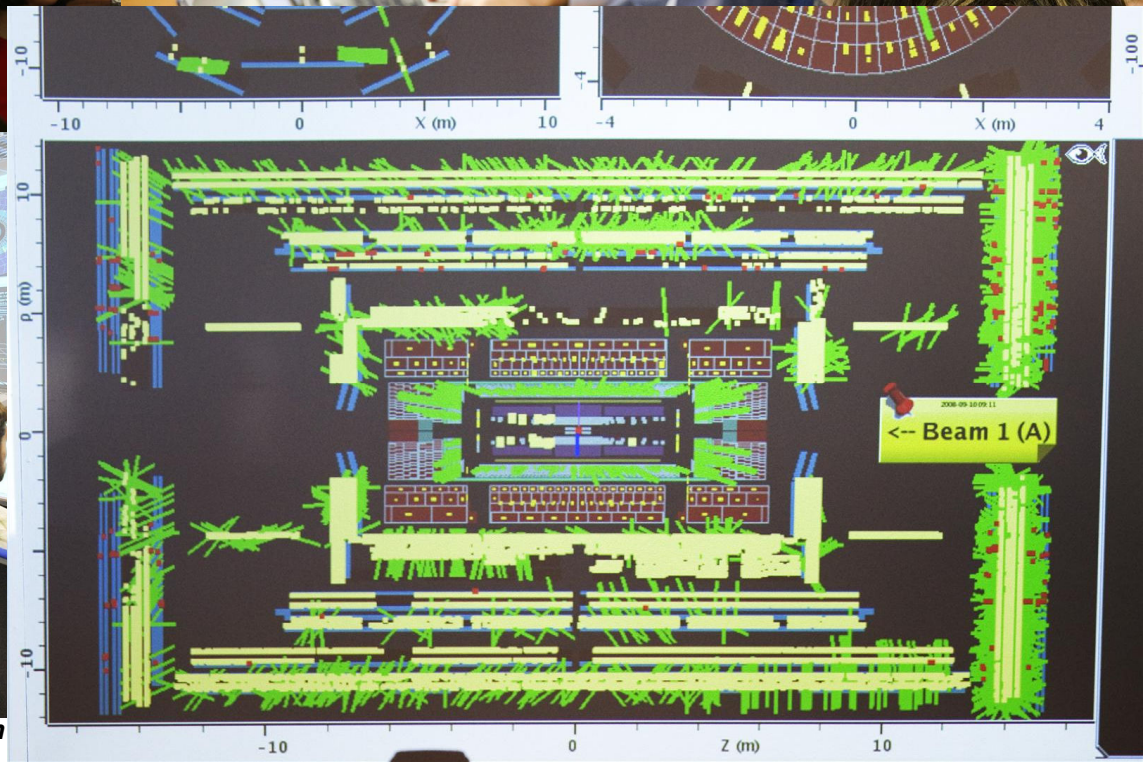
It's fun operating detectors!!!

(pictures from the first LHC beam day, Sept 11 2008)

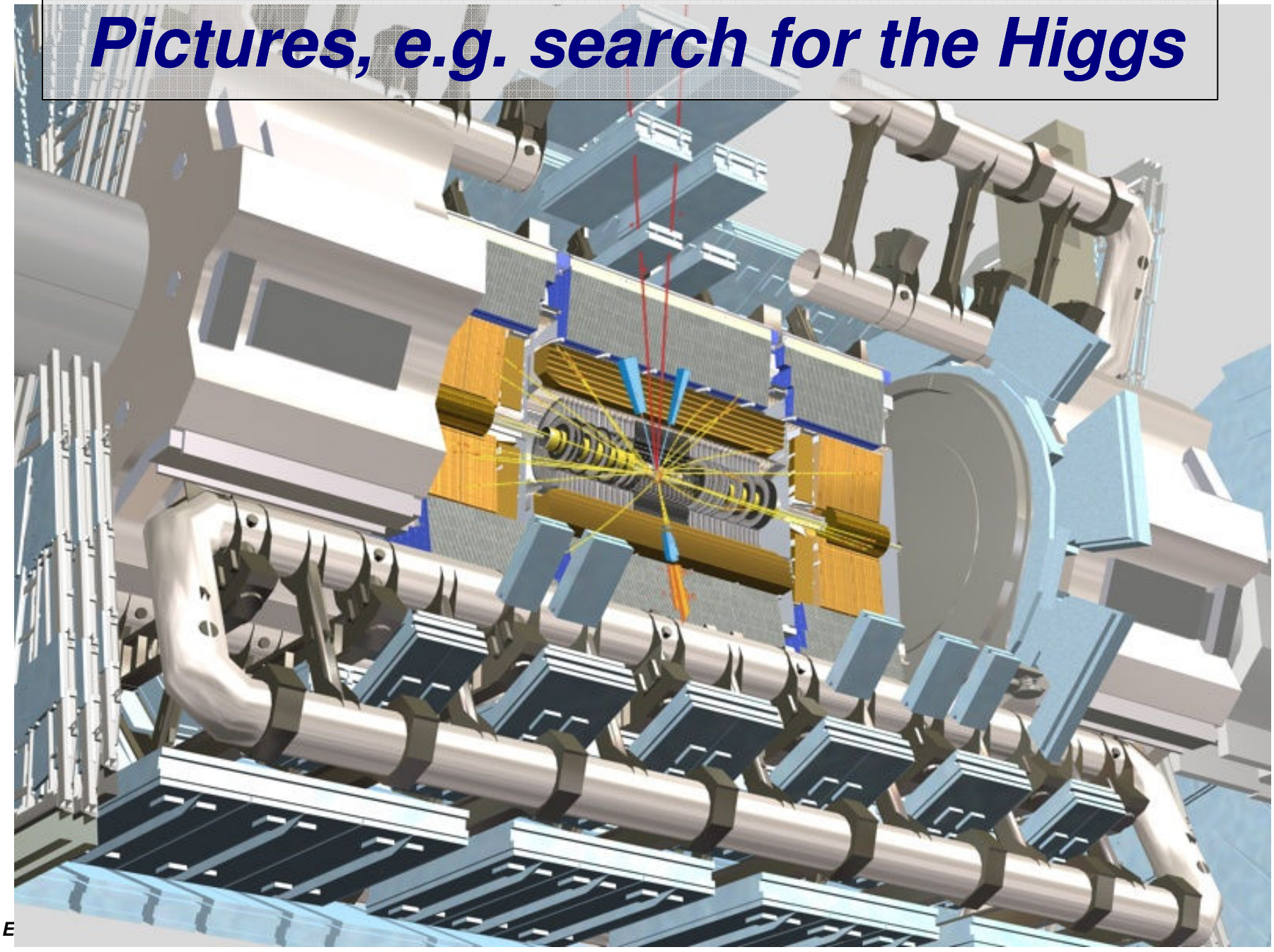








…and more fun: analysing Physics Pictures, e.g. search for the Higgs



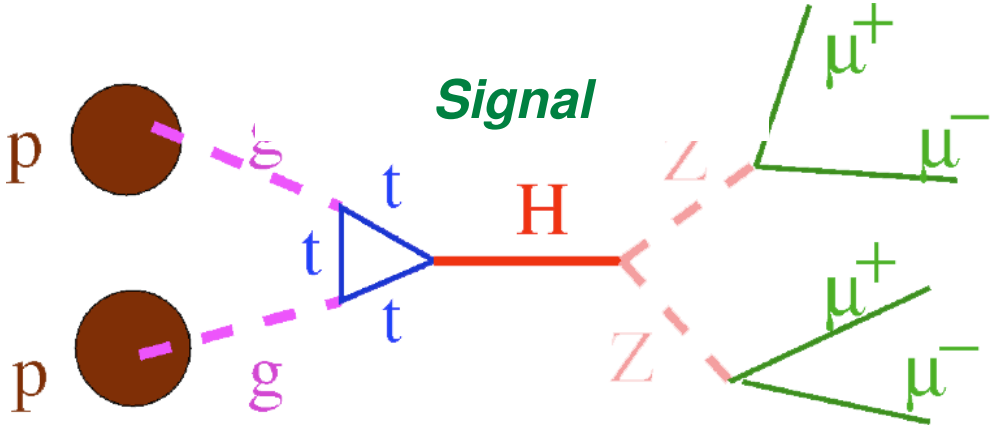
...and more fun: analysing Physics Pictures, e.g. search for the Higgs

Keep in mind:
The nice event pictures are simulations!!!
(simulations are important tools for high energy physics experiments, simulations give predictions from what we already know and extrapolate the knowledge to the collisions at higher energies! Deviations from the measurements w.r.t. the simulations are exciting!!!)

We are looking forward to have real collisions, thus real photos soon!!!

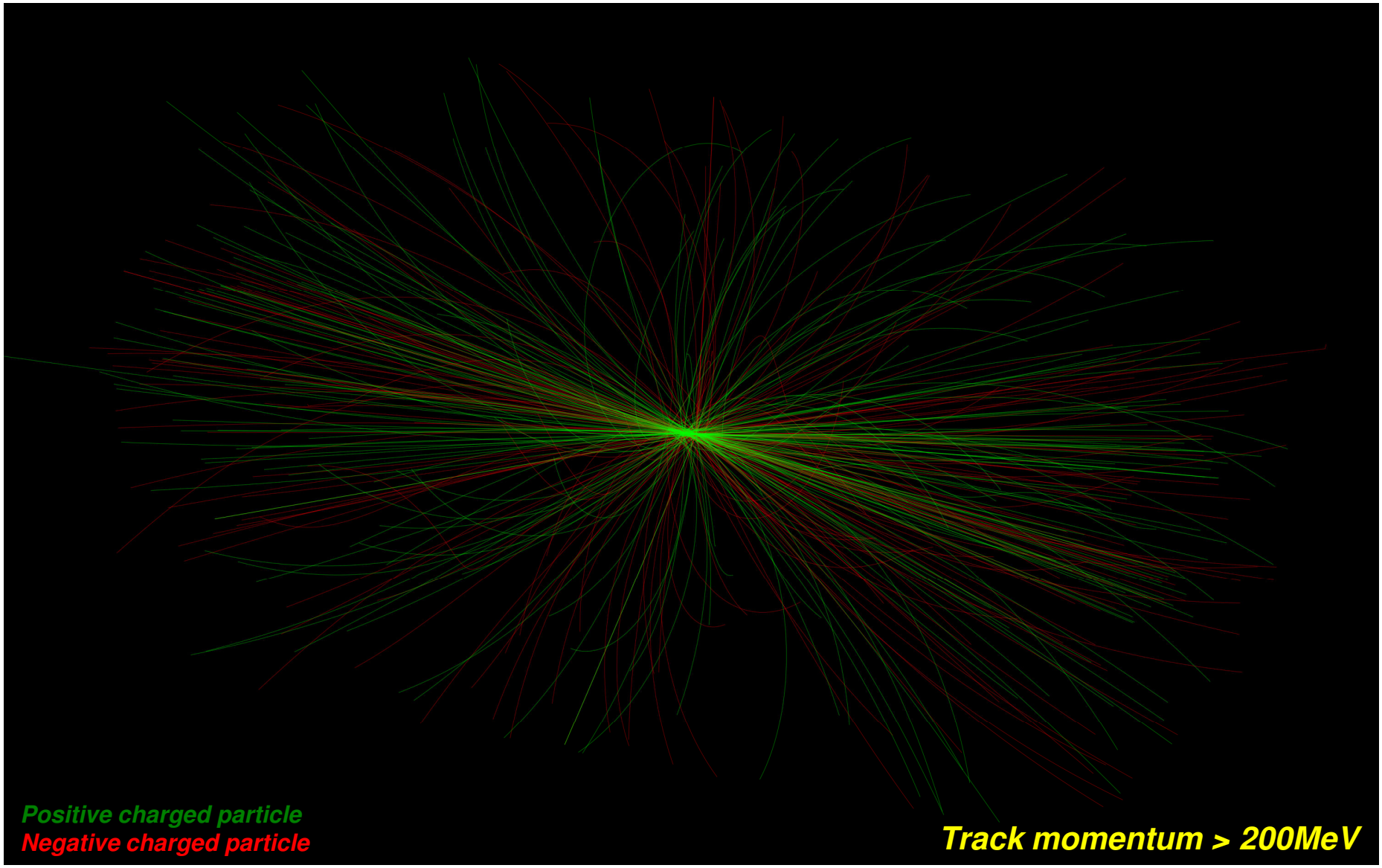
Search for the Higgs Boson

- **One way we expect the Higgs to be produced and to decay (Signal):**



- **… how to find "photos" of this process?**

Simulated Event, tracks only



Simulated Event, tracks only

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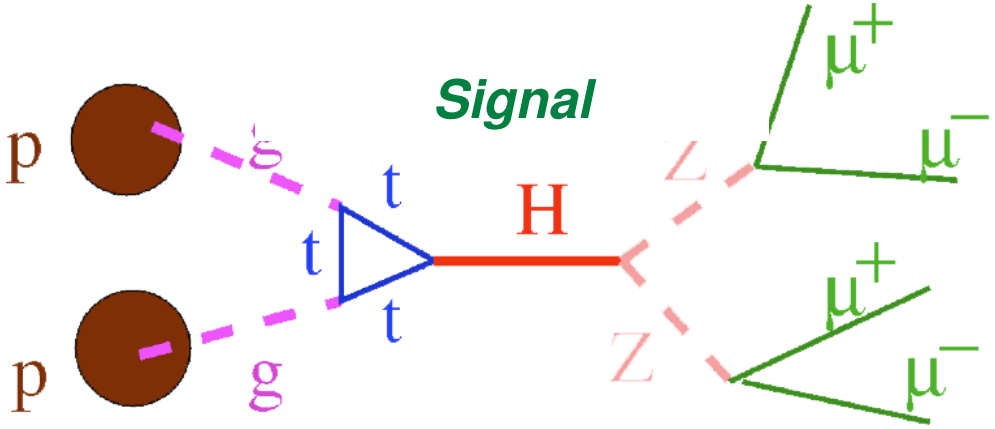
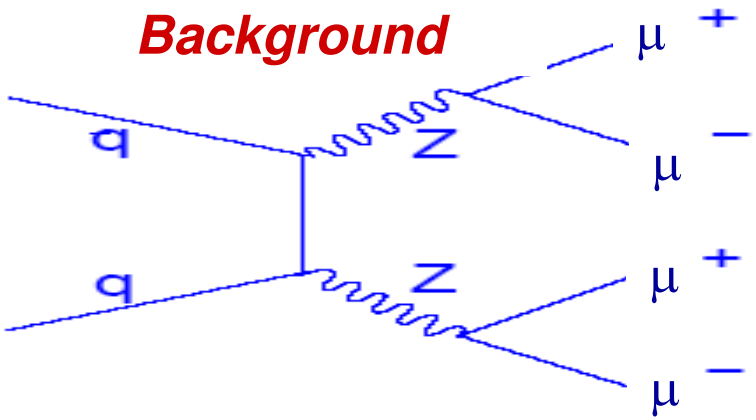


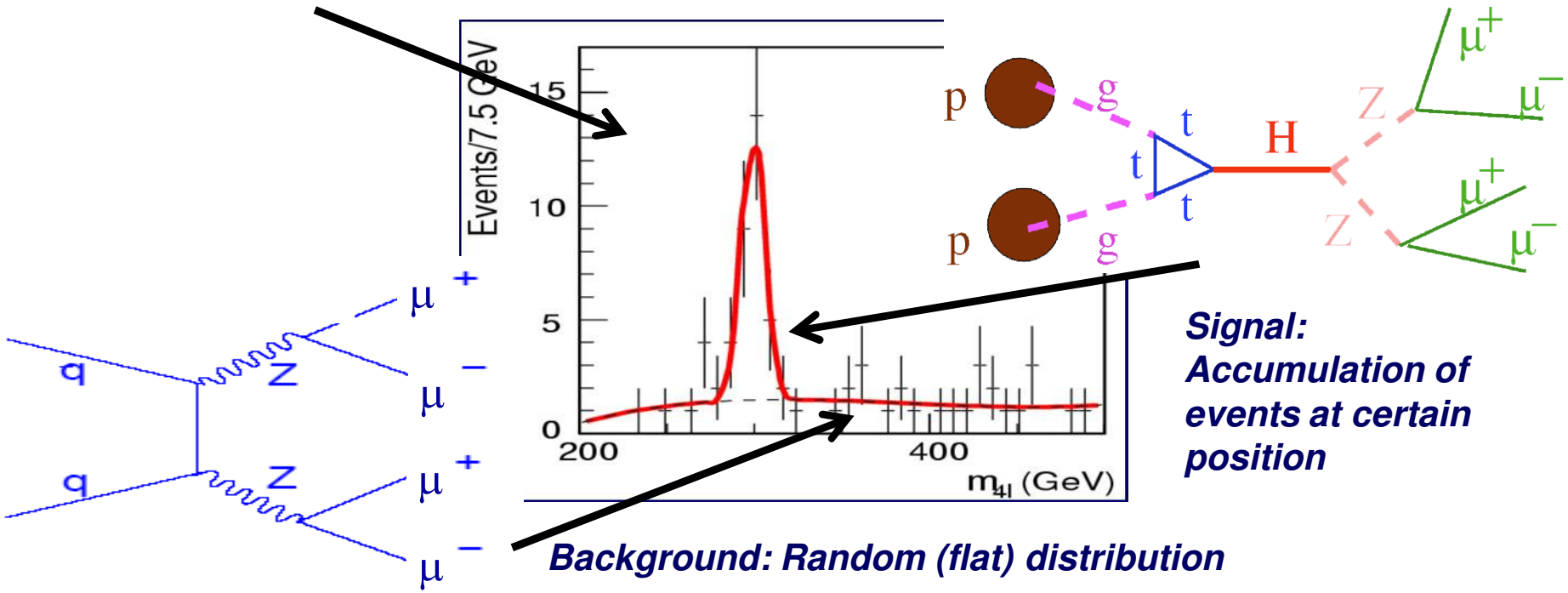
- **…but 4 muons could be also produced by the following process (background)**



Search for the Higgs Boson

- **Trick: "combine" one positive charged track and one negative charge track and calculate the momentum and energy of the "mother" particle, the Z**

  → Using momentum conservation, energy conservation
- **"combine" the 2 Z particles and calculate mass of the "mother" particle, possibly the Higgs**
- **Plot the results for the possible Higgs mass**



Signal: Accumulation of events at certain position

Background: Random (flat) distribution

Search for the Higgs Boson

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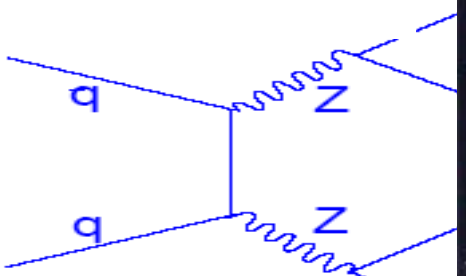
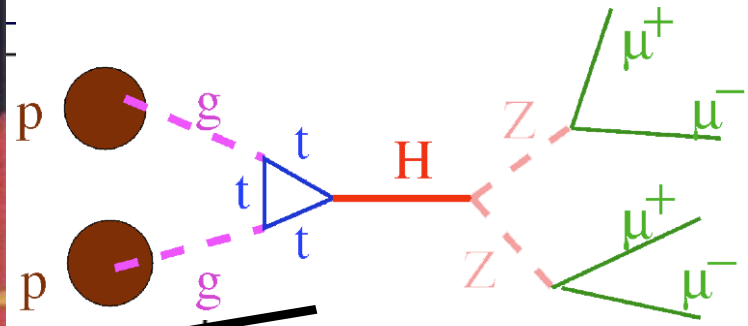
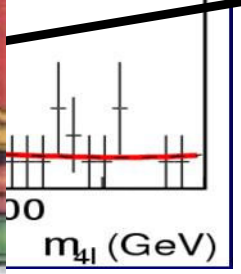




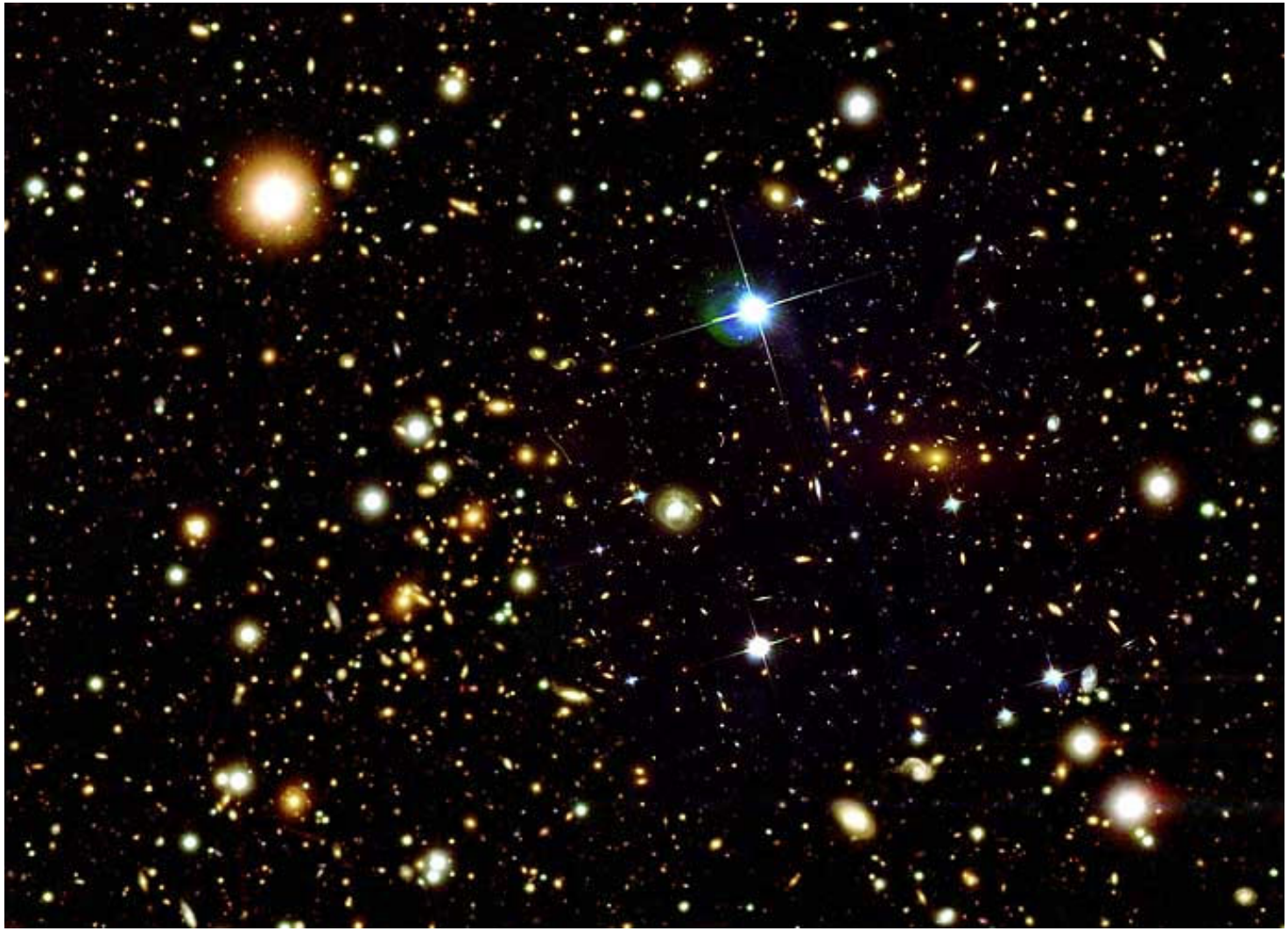


Signal: Accumulation of events at certain position

(flat) distribution

Search for Dark Matter – Motivation

(personal motivation)



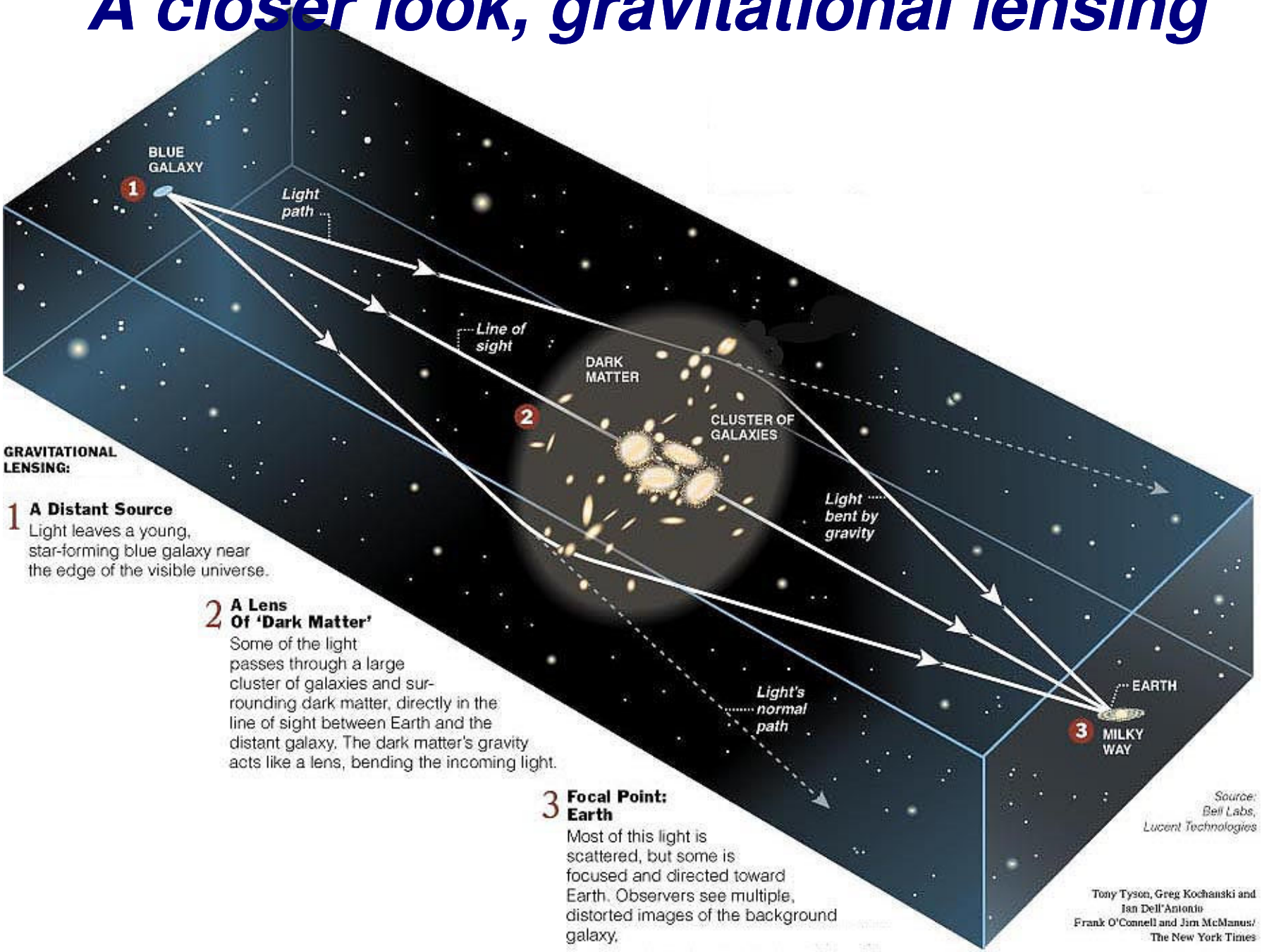
Search for Dark Matter – Motivation

(personal motivation)

Have another view, same region of the sky, infra red…

⇒ two galaxies just collided!
(galaxy cluster 1E 0657-56)

A closer look, gravitational lensing



Search for Dark Matter – Motivation

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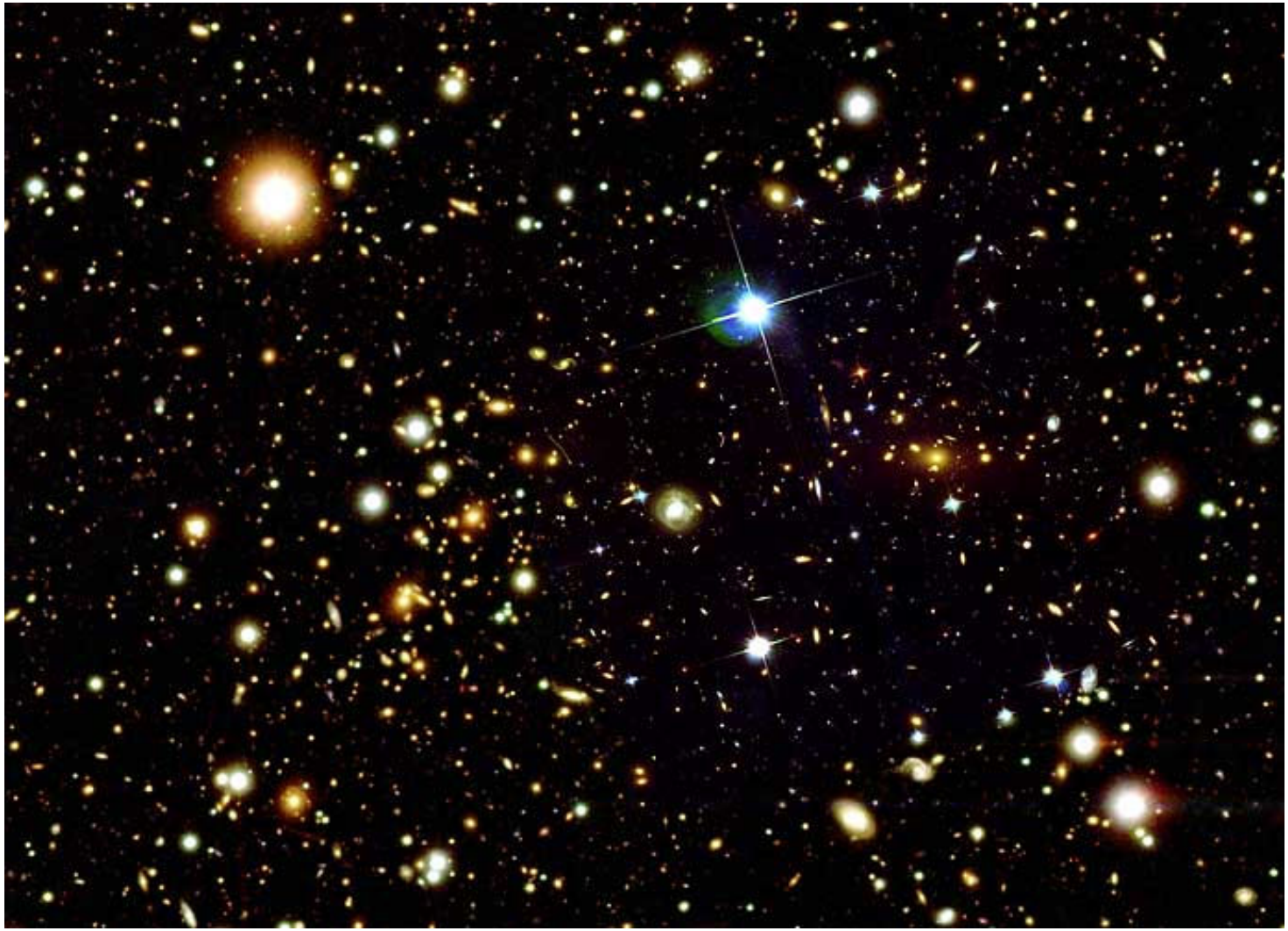
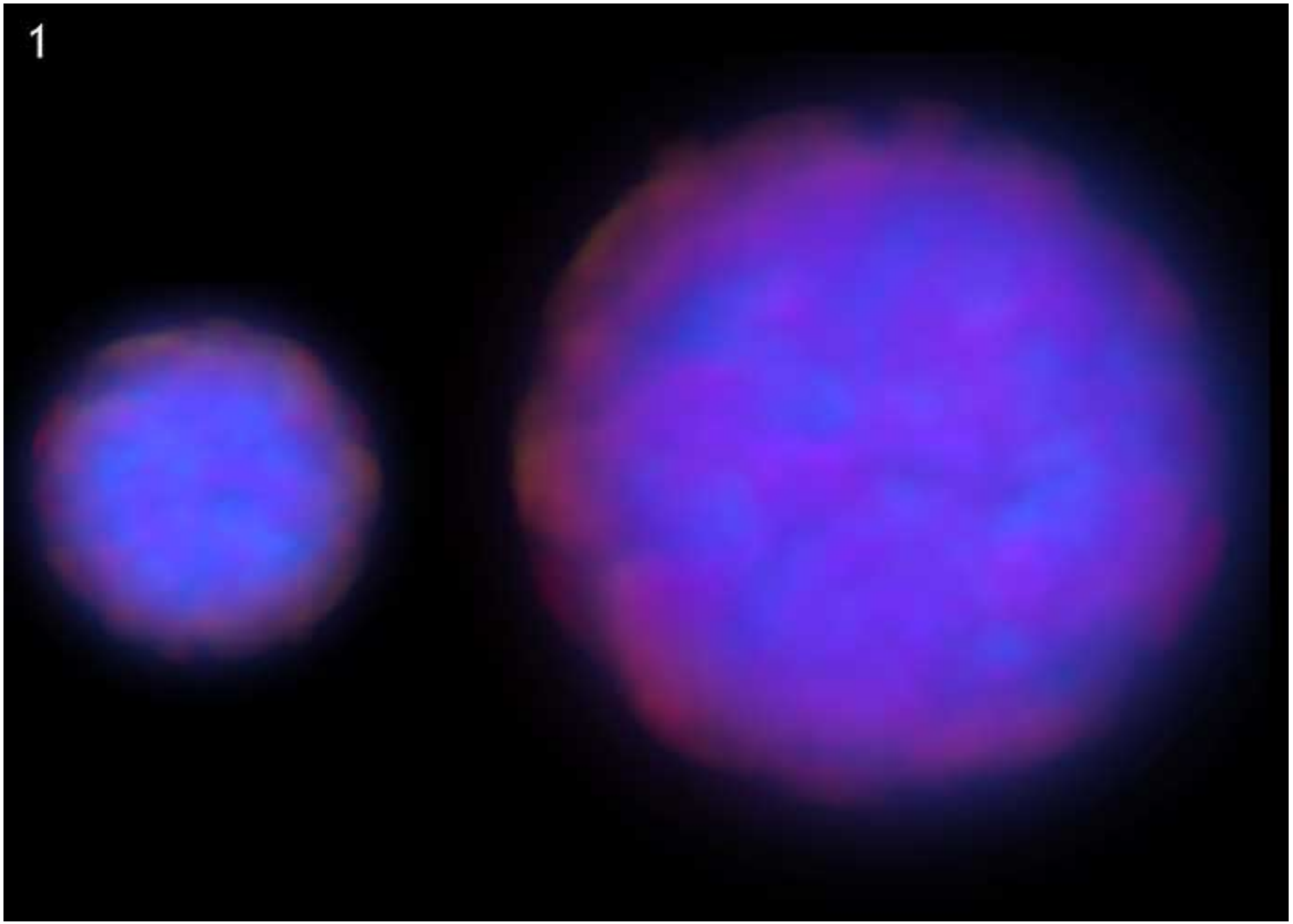


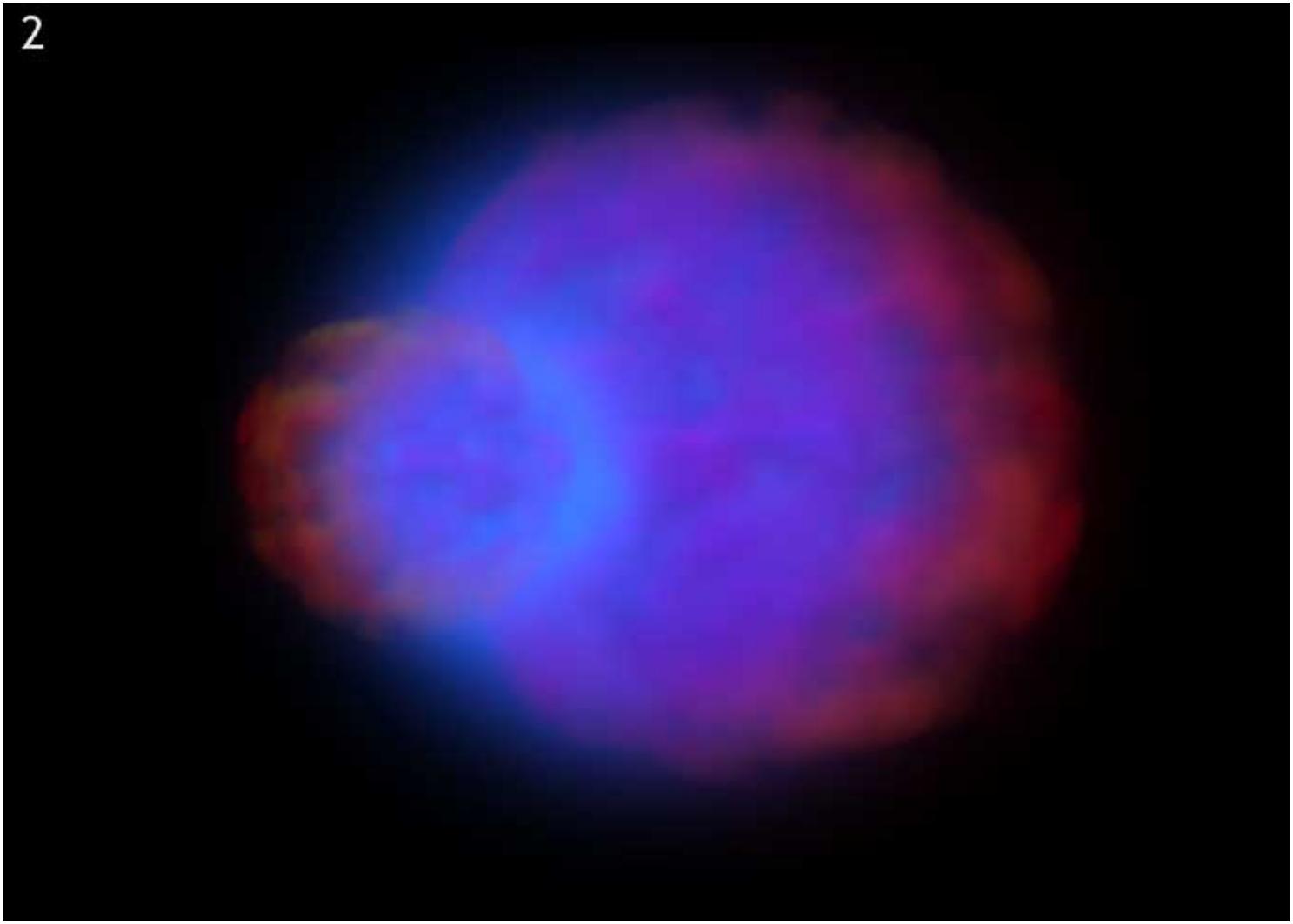
Analysing Photos: Search for Dark Matter - Motivation

Superposition of all 3 observations:
2 different regions (red, blue) are visible…
How to interpret these???

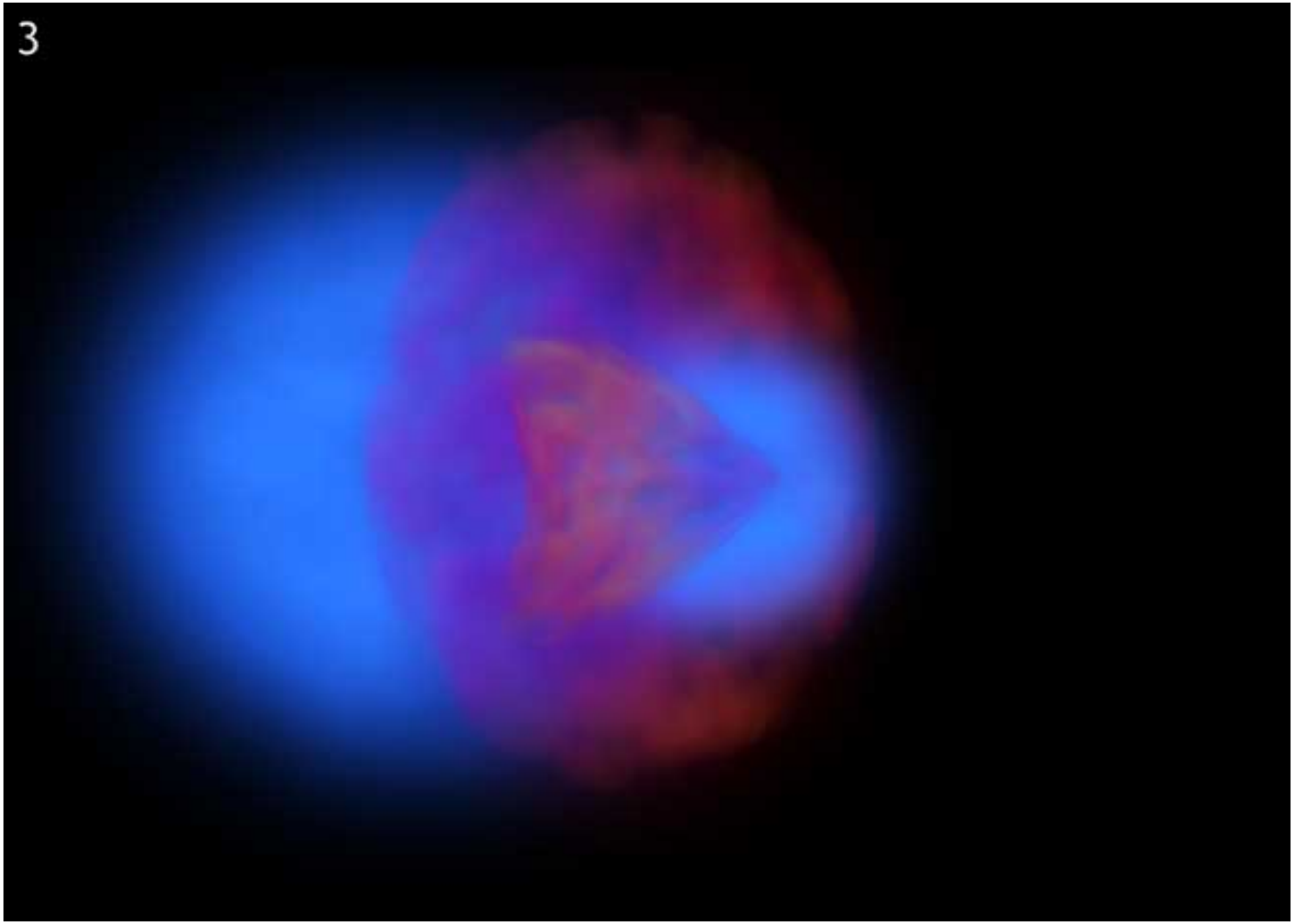
A Simulation: red – "normal matter", blue – dark matter (1)



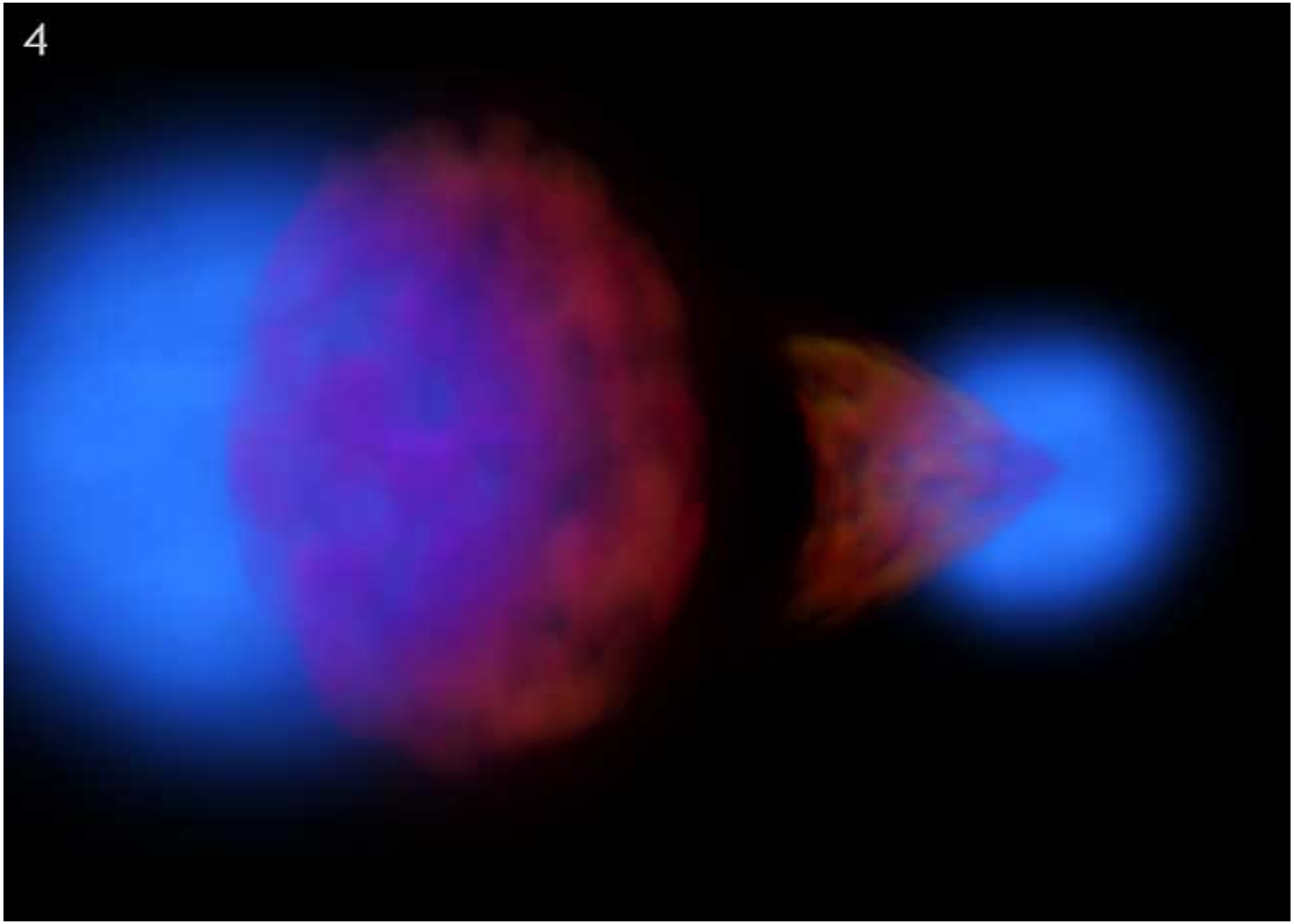
A Simulation: red – "normal matter", blue – dark matter (2)



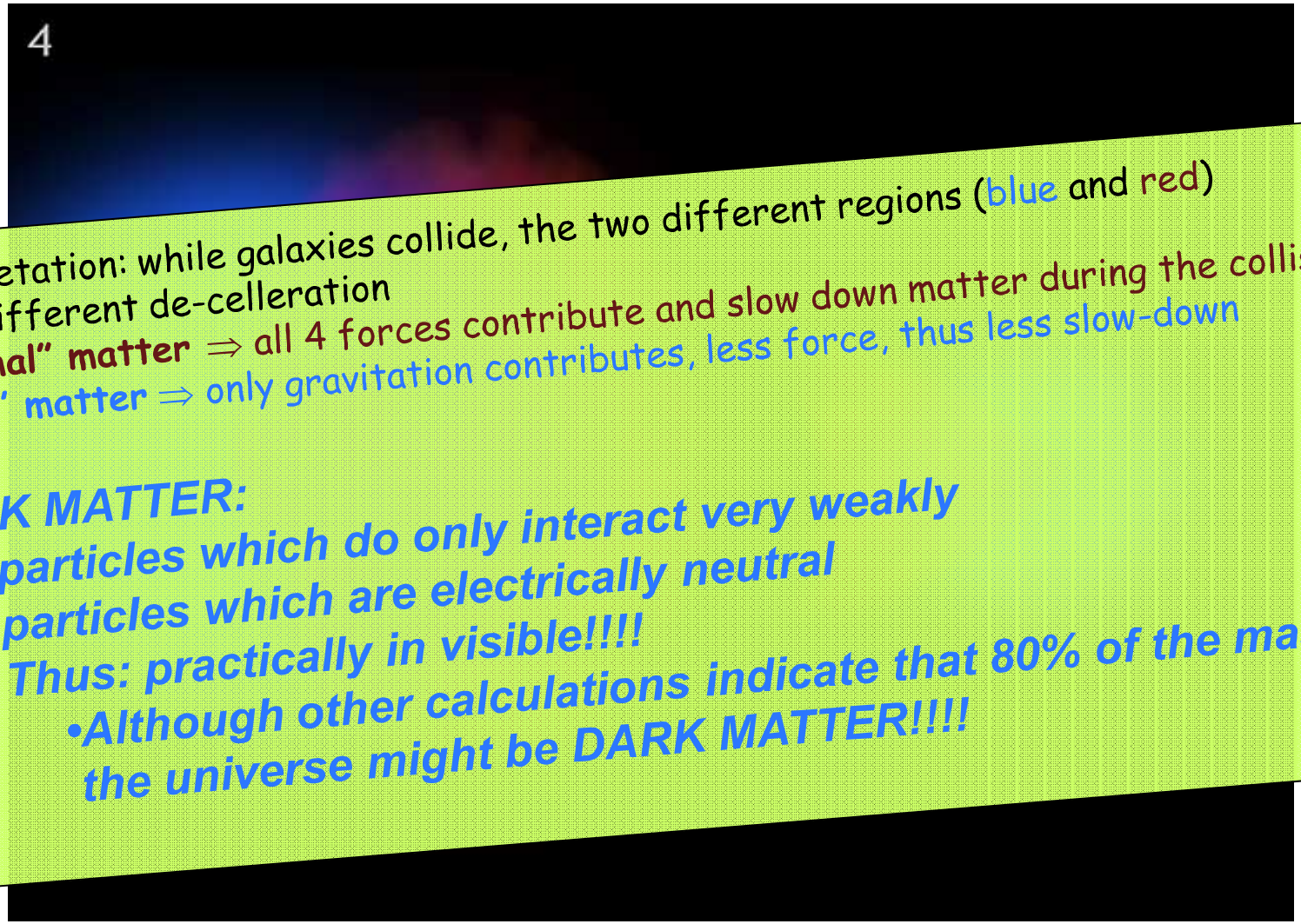
A Simulation: red – “normal matter”, blue – dark matter (3)



A Simulation: red – “normal matter”, blue – dark matter (4)



A Simulation: red – "normal matter", blue – dark matter (4)

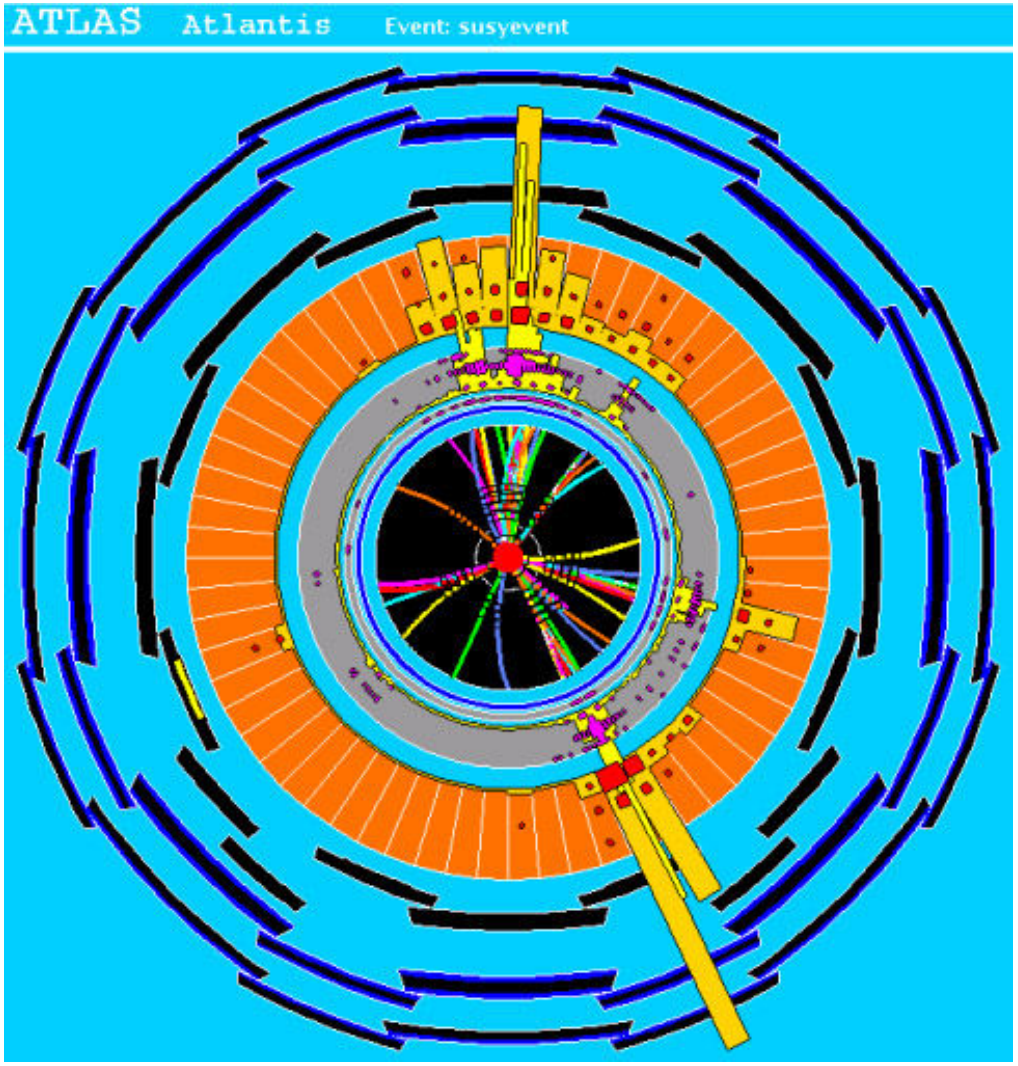


Interpretation: while galaxies collide, the two different regions (blue and red) "feel" different de-celleration

- **"normal" matter** ⇒ all 4 forces contribute and slow down matter during the collision
- "dark" matter ⇒ only gravitation contributes, less force, thus less slow-down

- ***DARK MATTER:***
  - ***particles which do only interact very weakly***
  - ***particles which are electrically neutral***
  - ***Thus: practically in visible!!!!***
    - ***Although other calculations indicate that 80% of the mass of the universe might be DARK MATTER!!!!***

Search for the "Invisible": Missing Energy Signal



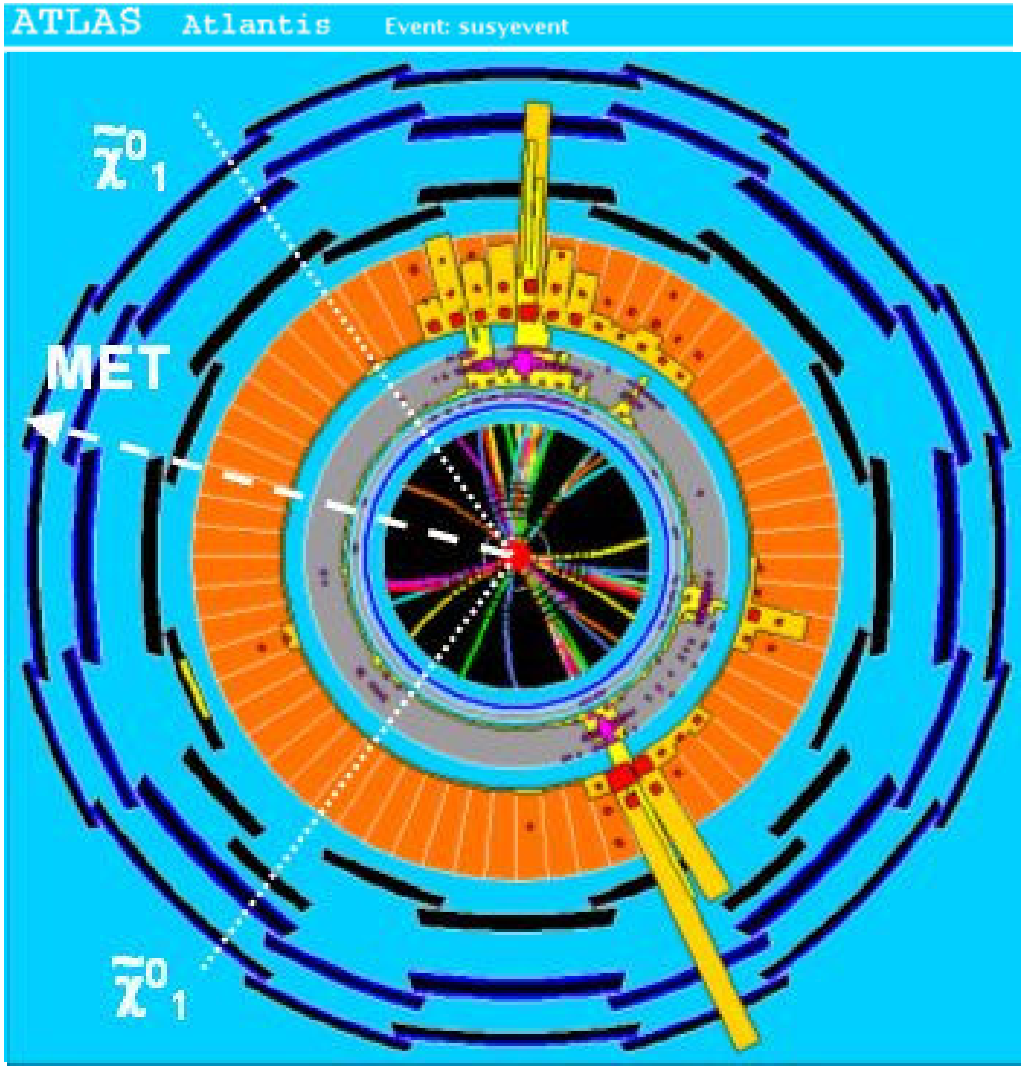
- Again simulation: an event in which a "dark matter particle" is produced…
- What is special in this picture, a cross section of the detector perpendicular (transverse) to the beam axis?

⇒ **Event is not "balanced": energy distribution is not symmetric!**

⇒ **But events SHOULD be balanced as incoming beam has no momentum component in this plane!**

⇒ **Indication for DARK MATTER!!!!**

Search for the "Invisible": Missing Energy Signal



- **MET = missing transverse momentum…**
- **Origin could be two dark matter particles, e.g. in supersymmetric models the neutralinos (X^0_1)**
- ***(… SUSY???***
  - ➔ ***Would need an extra talk…)***

Looking forward!!!!

Designed by my 1998 Summer Student

- The LHC accelerator and detectors provide a great opportunity to search for answers to fundamental questions!
- It was exciting to build and commission the experiments…
- …and now it is time to look at the data!!!!

It will be phantastic!!!!