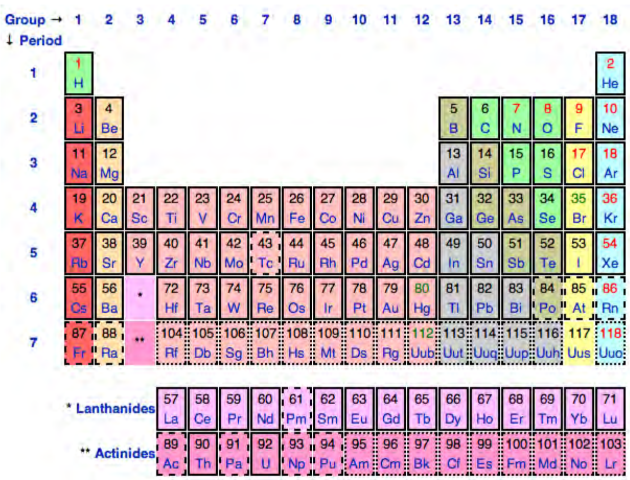
Dark Matter and the ATLAS Experiment at the Large Hadron Collider

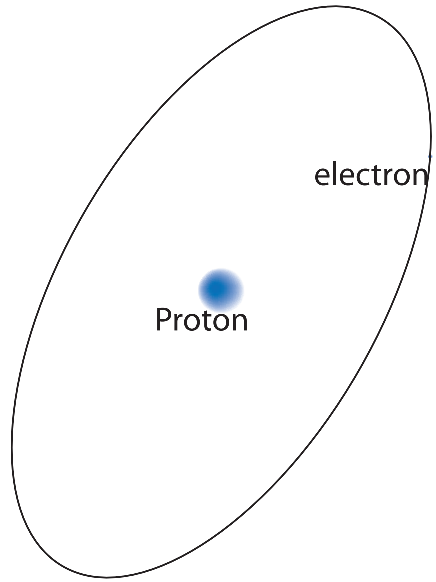
Outline:

1. A little bit of particle physics
2. What particle properties does dark matter have?
3. An example of dark matter model we can test at the LHC.
4. The LHC and the ATLAS detector

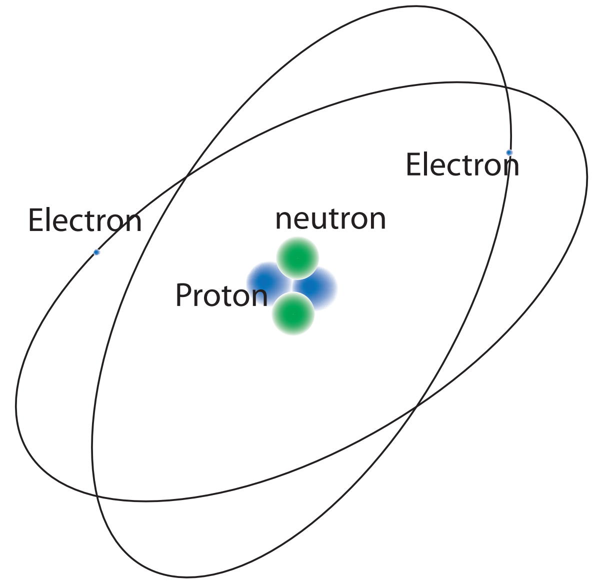
Quick review of matter:



Periodic Table



Hydrogen



Helium

⇒ All elements consist of electrons circulating around a nucleus made of protons and neutrons

All of chemistry from three particles!

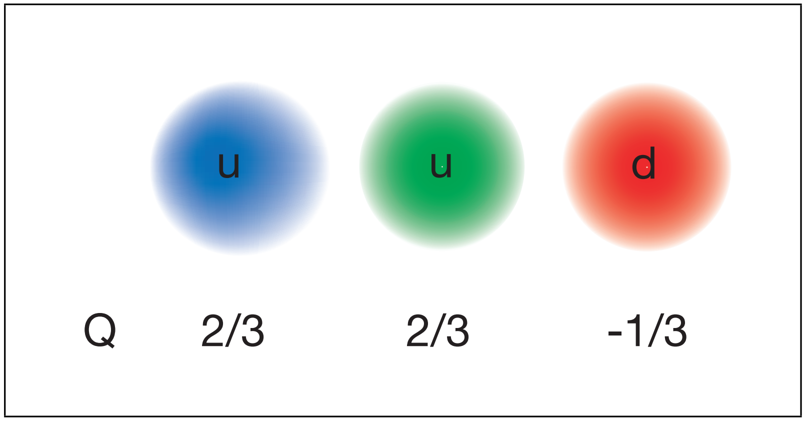
What are the forces that act on these particles:

• **Gravity** – Newton realized that gravity on the Earth and in the heavens are same.

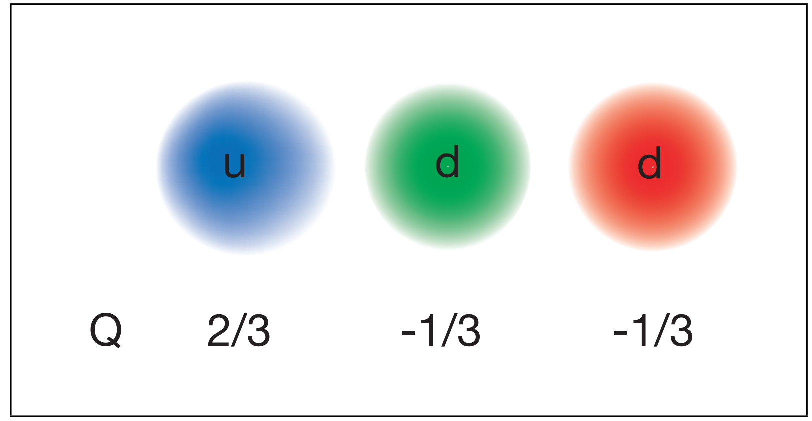
• **Electromagnetism** Faraday, Maxwell and others realized the magnetism and electricity are connected and give rise to radio waves and light .

• **Strong aka QCD** There must be some strong force to hold the protons together in the nucleus!

We now know that protons (and neutrons) are made of three quarks*:



proton



neutron

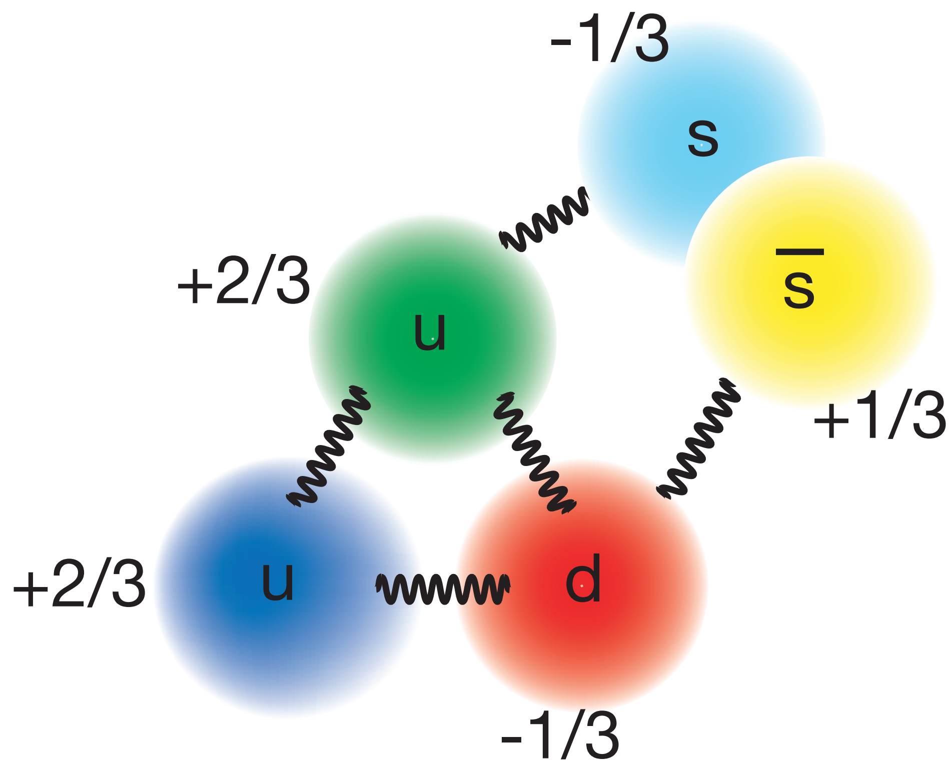
• The quarks interact with each via particles (similar to photons) that are **gluons**.

• These gluons hold the proton together and responsible for the mechanism that binds protons and neutrons.

• The theory that explains strong force is call Quantum ChromoDynamics or QCD.

* Quark model is due to Gell-Mann, name based on fragment of Joyce's Finnegans Wake – "Three quarks for Muster Mark"

Previous particle physics experiments tell us that real protons are more complicated:



In collisions between protons, for example at the LHC, interactions interactions between constituents in the proton are important.

Can we make the Sun shine with just three forces? **No.**

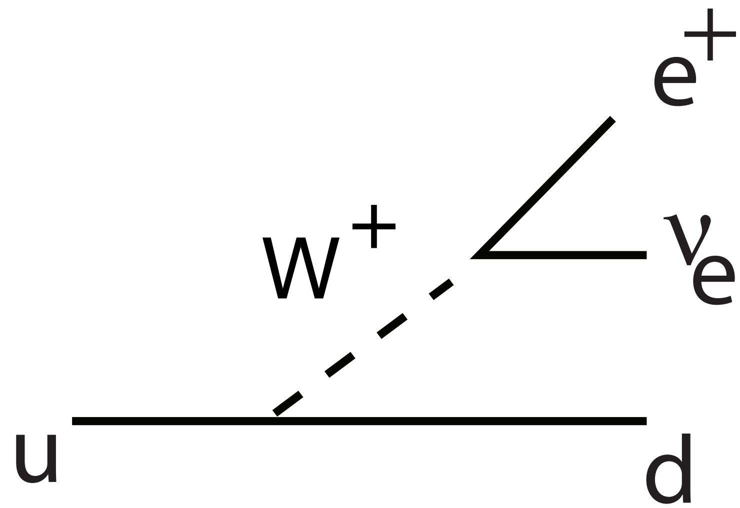
Example

$$p + p \rightarrow pn \; e^{+} \; \nu_e$$

p = proton
n = neutron
e^{+} = postiron
ν_e = electron neutrion
pn = deuteron

Changing the protons into neutrons requires the weak force!

The force that can change the quark flavor is called the weak force:



• The neutrino was introduced by Pauli to save energy conservation in some kinds of radioactive decay and theory was developed by Fermi. Neutrinos were first "seen" in the early 1950s.

• Fermi's original theory had no "W" particle. This was introduce to save the theory and discovered in accelerators in the early 80s.

Matter

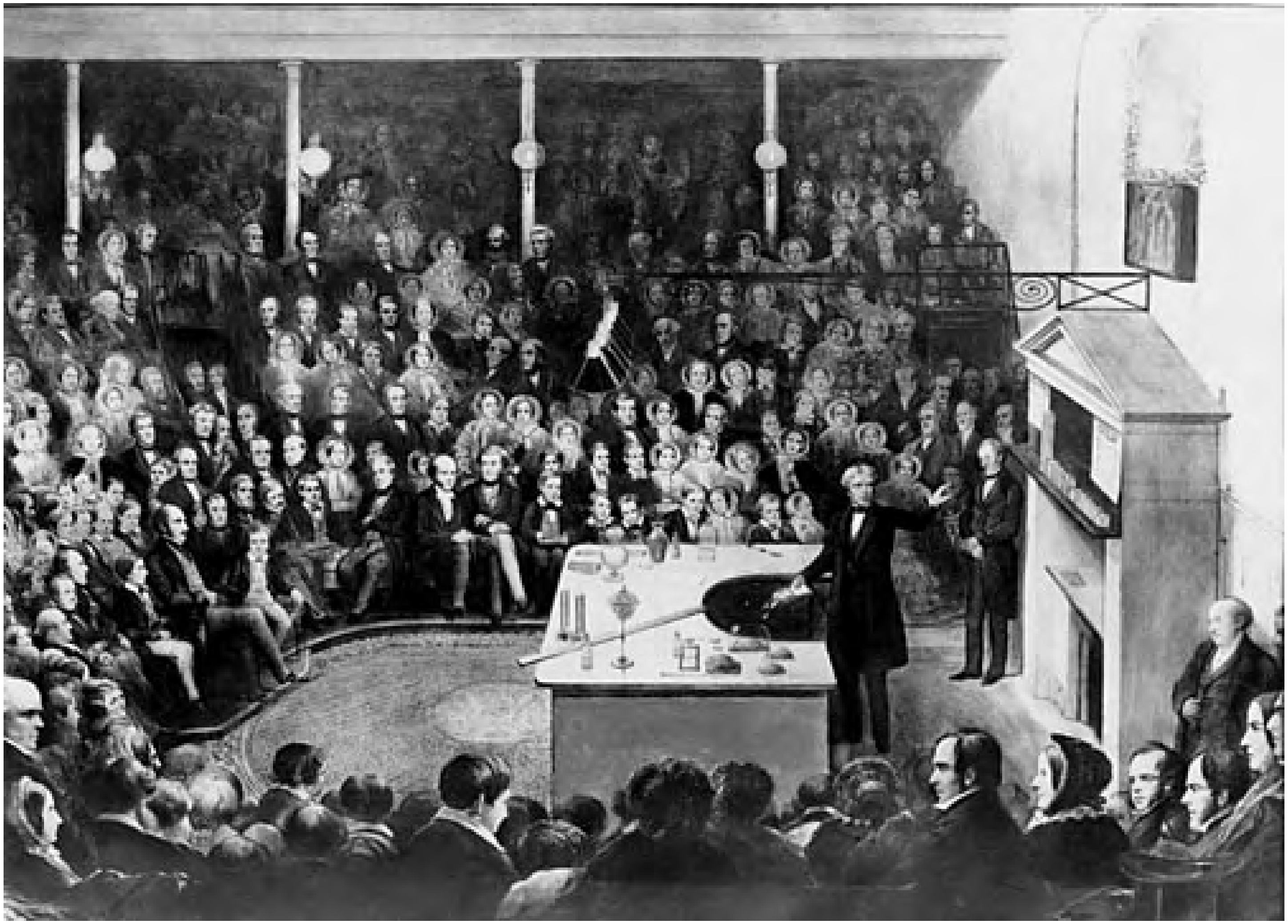
				Charge
Quarks*	**u**	**c**	**t**	2/3
	d	**s**	**b**	-1/3
Leptons	**e**	μ	τ	-1
	ν_e	ν_μ	ν_τ	0

Forces

Gravity	graviton
Weak	$W^{\pm}$,Z^0
Electromagnetic	γ
Strong	gluon

- Particles important in everyday life are shown in blue
- Each of the matter particles has a corresponding **anti-particle**
- There are no "anti-particles" for the Force Carriers

Paradigm of Modern physics started by Michael Faraday



Michael Faraday $\Rightarrow$ Electricity + Magnetism = radio waves?

Gladstone: *What use are your discoveries?*

Faraday: *I do not know, but some day you will tax them.*

There are very few aspects of modern life not touched by the unification of Electricity and Magnetism:

- **Radio-waves**
- **Electric motors**
- **Electric power generation**

Another application of this paradigm is antimatter ....

P.A.M. Dirac

- Dirac combined Einstein's Relativity with Quantum Mechanics to predict anti-mater (1928)

- In 1932 Anderson discovers Positrons (anti-electrons) in cosmic rays

- Today, main use of anti-mater today is for medical diagnostics (PET)

• **Combining** the Weak and Electromagnetic forces forces us to postulate the famous **Higgs** boson – perhaps soon to be discovered at the LHC.

• Trying to combine the the other forces (Weak, Electromagnetism, Strong (and perhaps gravity) leads to theoretical troubles called the **Hierarchy** problem.

Example solutions to this problem:

• **Supersymmetry** (postulates partners for all known particles), e.g.

$$\text{quarks} \rightarrow \text{squarks}$$
$$q \longrightarrow \tilde{q}$$

• **Extra dimensions**

Many variants of these theory have particles that could be the cosmological dark matter

Requirements of dark matter particles:

• Must be very weakly interacting – for example dark matter particles must pass through planets and starts without interacting.

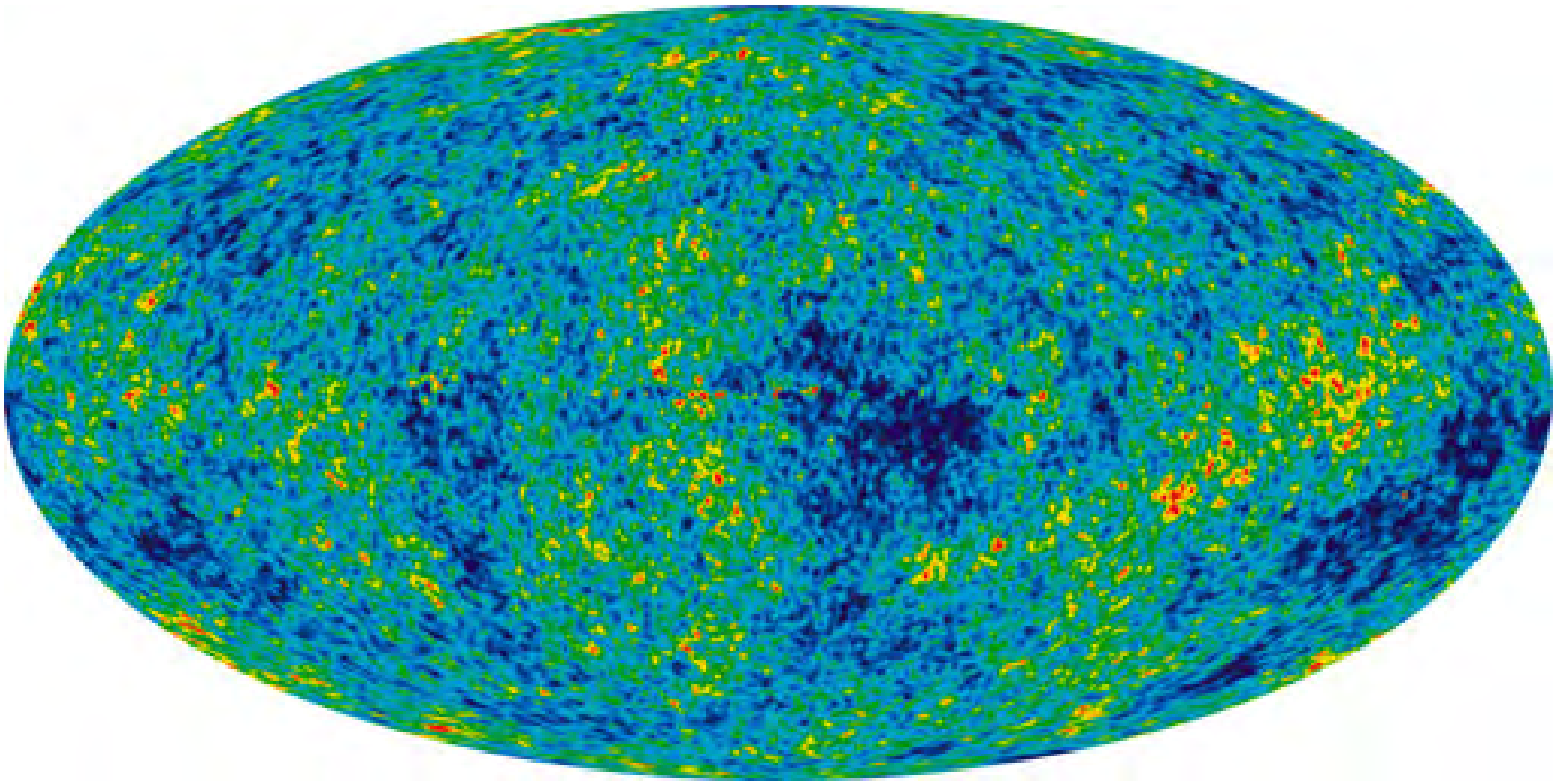
• Dark matter particles must be **stable** on time scales of the age Universe

• Dark matter must have the correct mass and annihilation cross section so that 20% of the closure density of the universe is from dark matter $\Rightarrow$ These cross section are "coincidentally" the same as weak interaction cross section, hence the term :

WIMP = Weakly Interacting Massive Particle

• Must be cold – rules out neutrinos as the dark matter

Results from the Wilkinson Microwave Anisotropy Probe – show fluctuations in the microwave background that can only be explained by cold dark matter:



http://map.gsfc.nasa.gov/

Neutralino Dark Matter

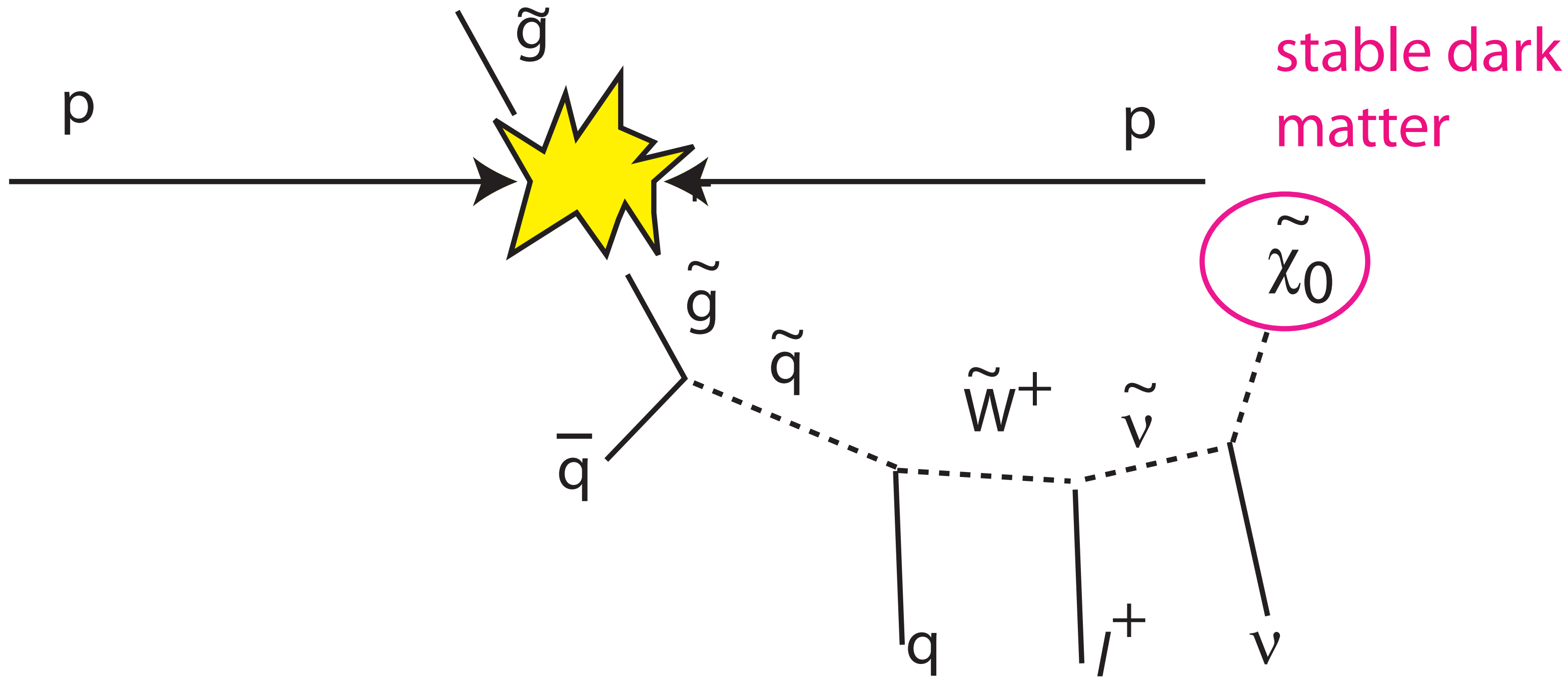
• In SuperSymmetry (SUSY) the concept of R-parity plays a role similar to charge:

$\Rightarrow$ SUSY particles are always produced in pairs (one SUSY particle and one anti-SUSY particle)

$\Rightarrow$ SUSYness is conserved (similar to charge conservation)

$\Rightarrow$ Lightest SUSY particle must be stable!

Possible reaction at the LHC



Signature: multiple leptons, missing energy (χ, ν), jets from quarks (q)

supersymmetric particles have $\sim$

What do we need to observe such events?

• Collisions of very energetic protons (beam with protons of energies 3.5 to 7 TeV each)
i.e. The LHC Accelerator

These collisions have a center-of-mass energy of 7 to 14 TeV.
14 TeV is equivalent of rest mass of 14,000 protons

• Excellent detection of muons and electrons (leptons)

• Good detection of jets from quarks

• Hermetic detectors so that missing energy from invisible dark matter particles can be observed.

The LHC accelerator – near Geneva, Switzerland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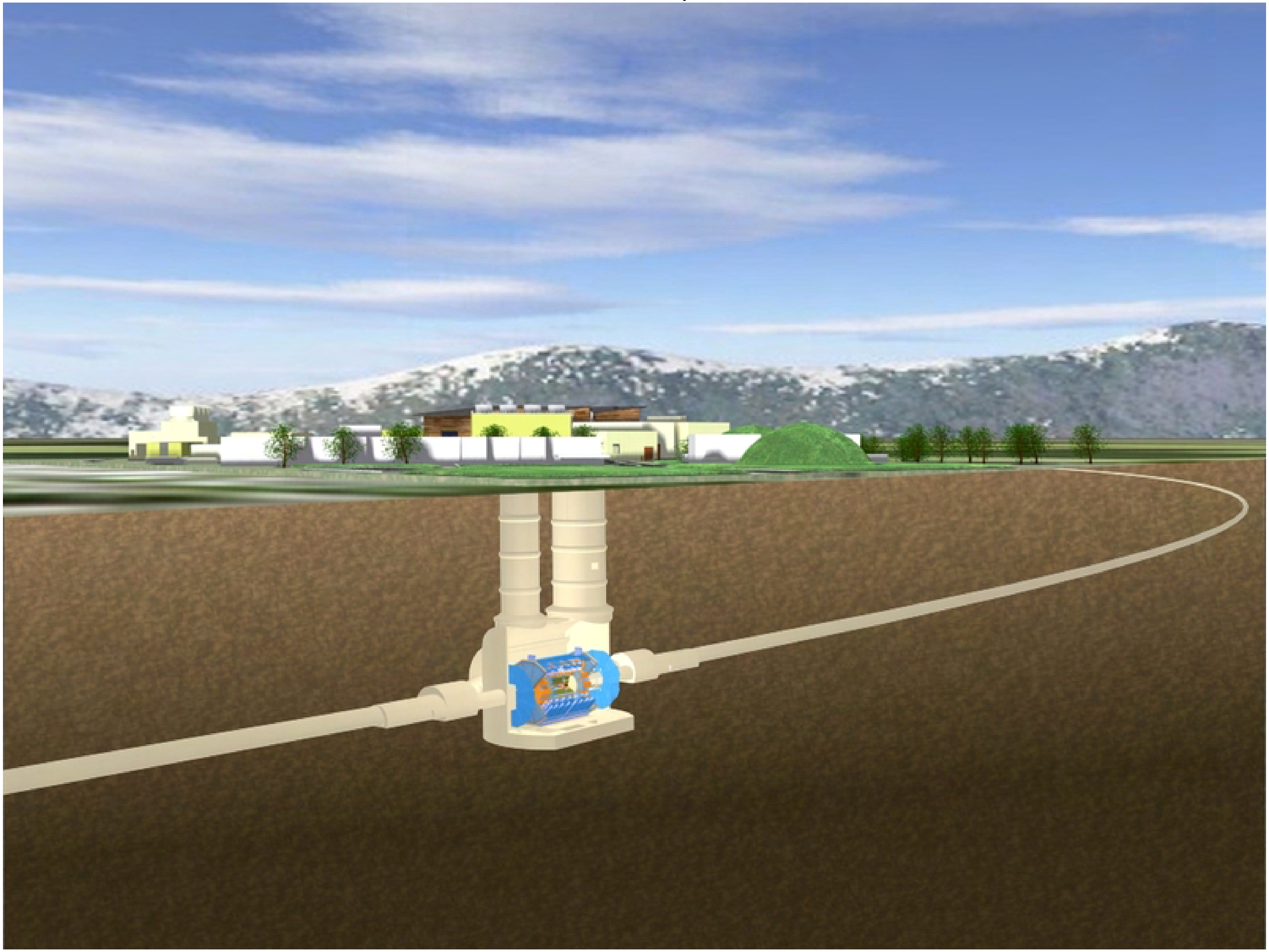
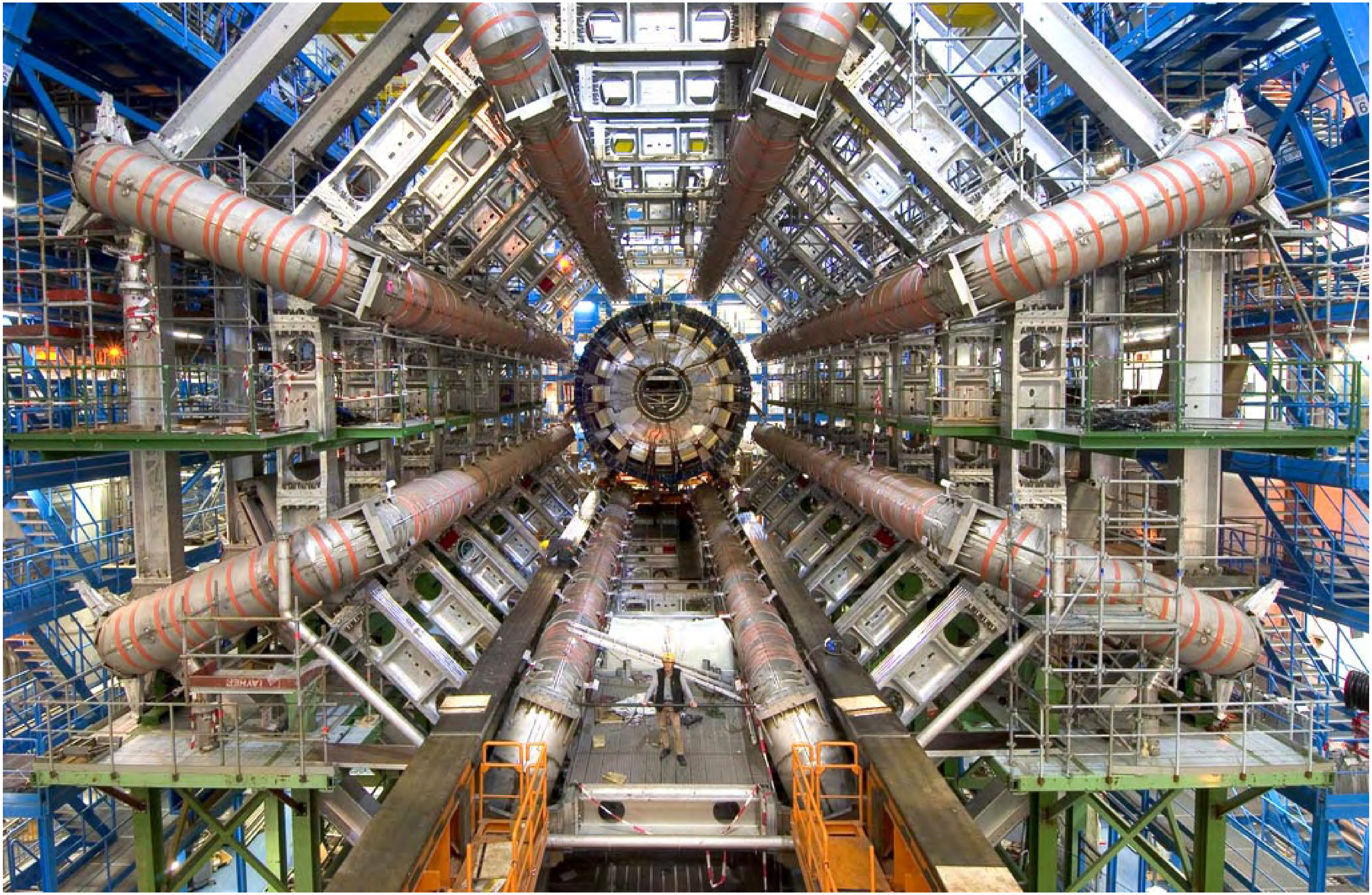
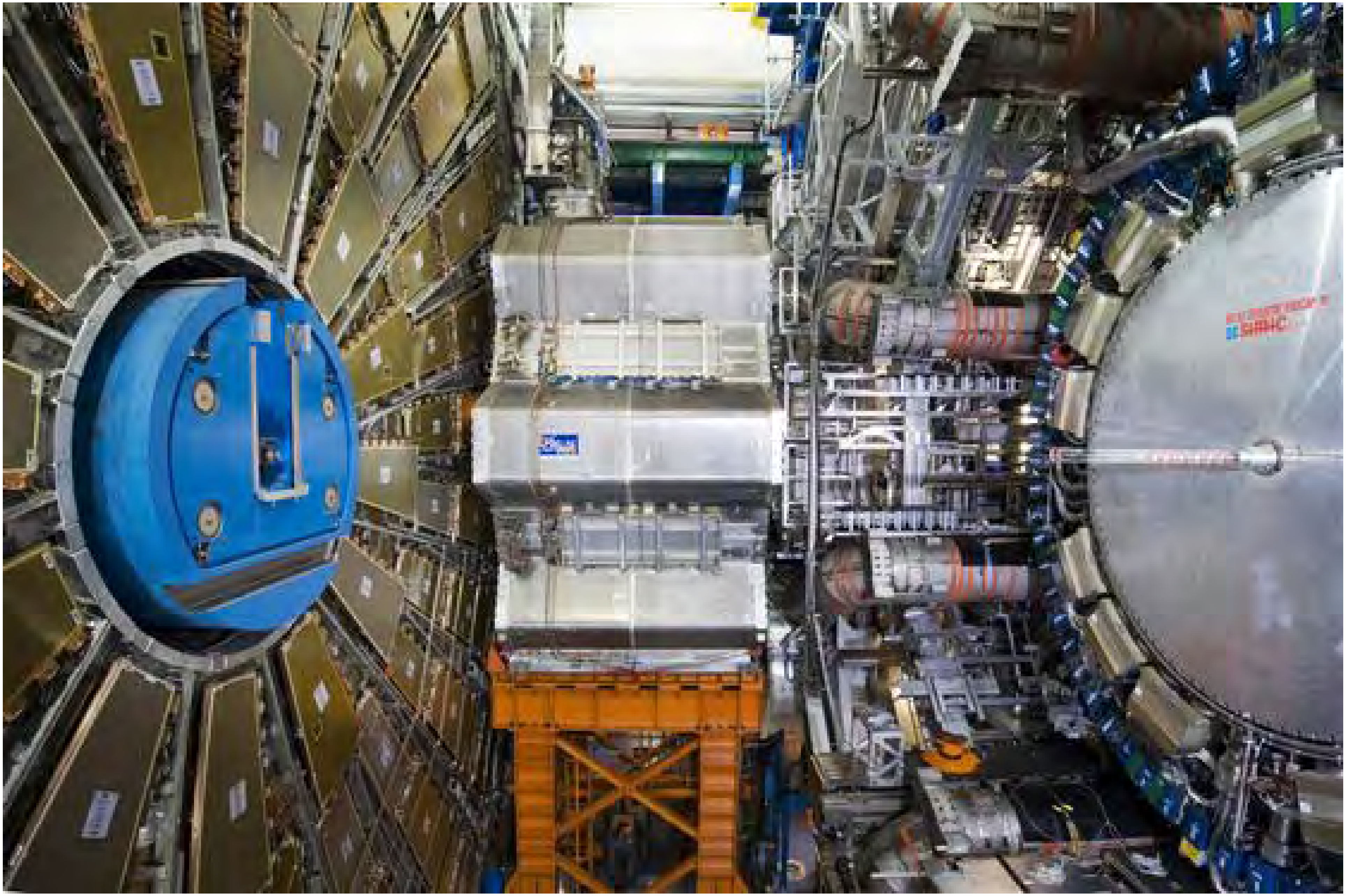
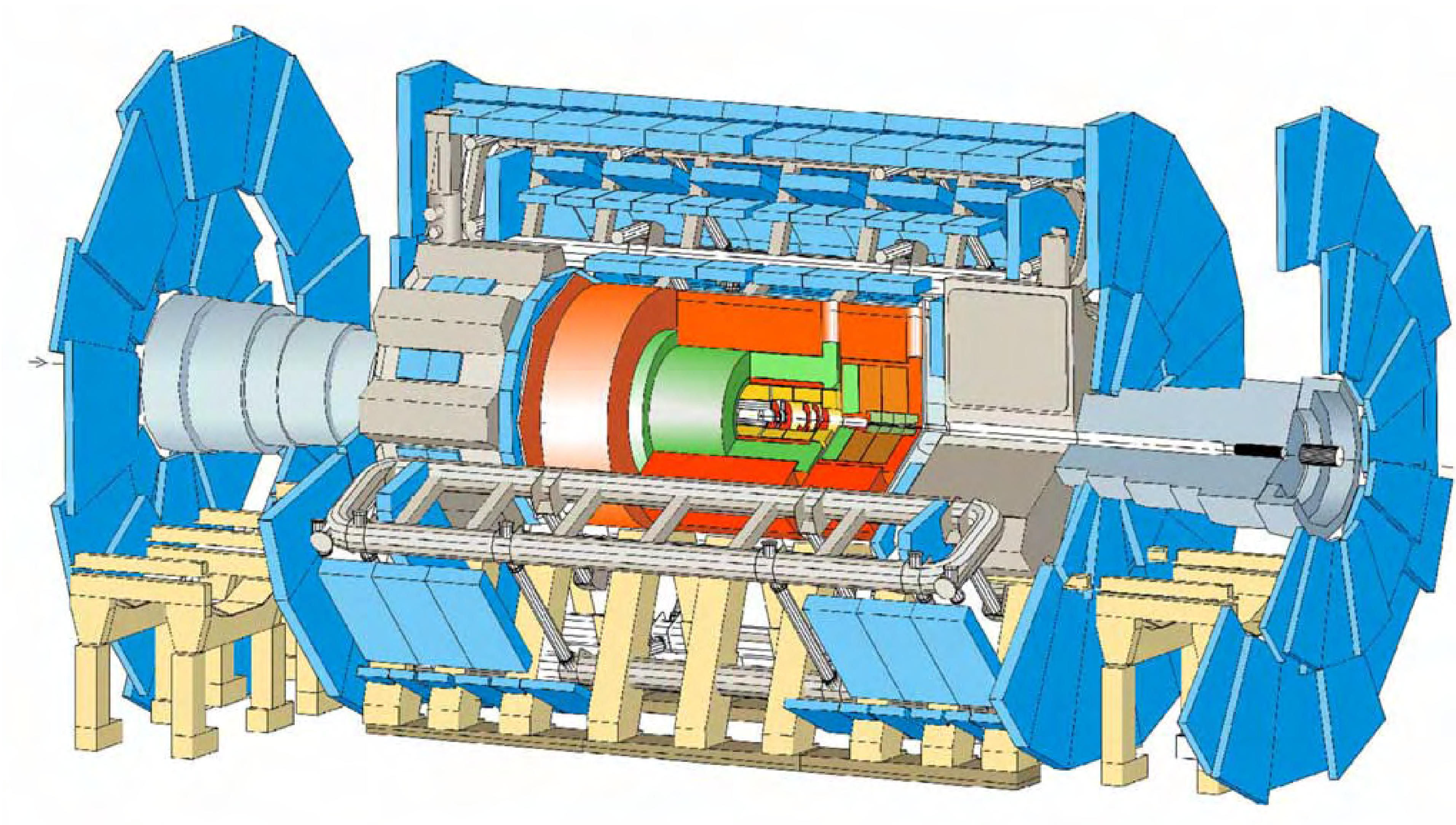
The Atlas Experiment









• http://www.atlas.ch/multimedia/index.html to see detector constuction

• http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html shows an animation of an event display

• The following candidate events display show examples of events of the type

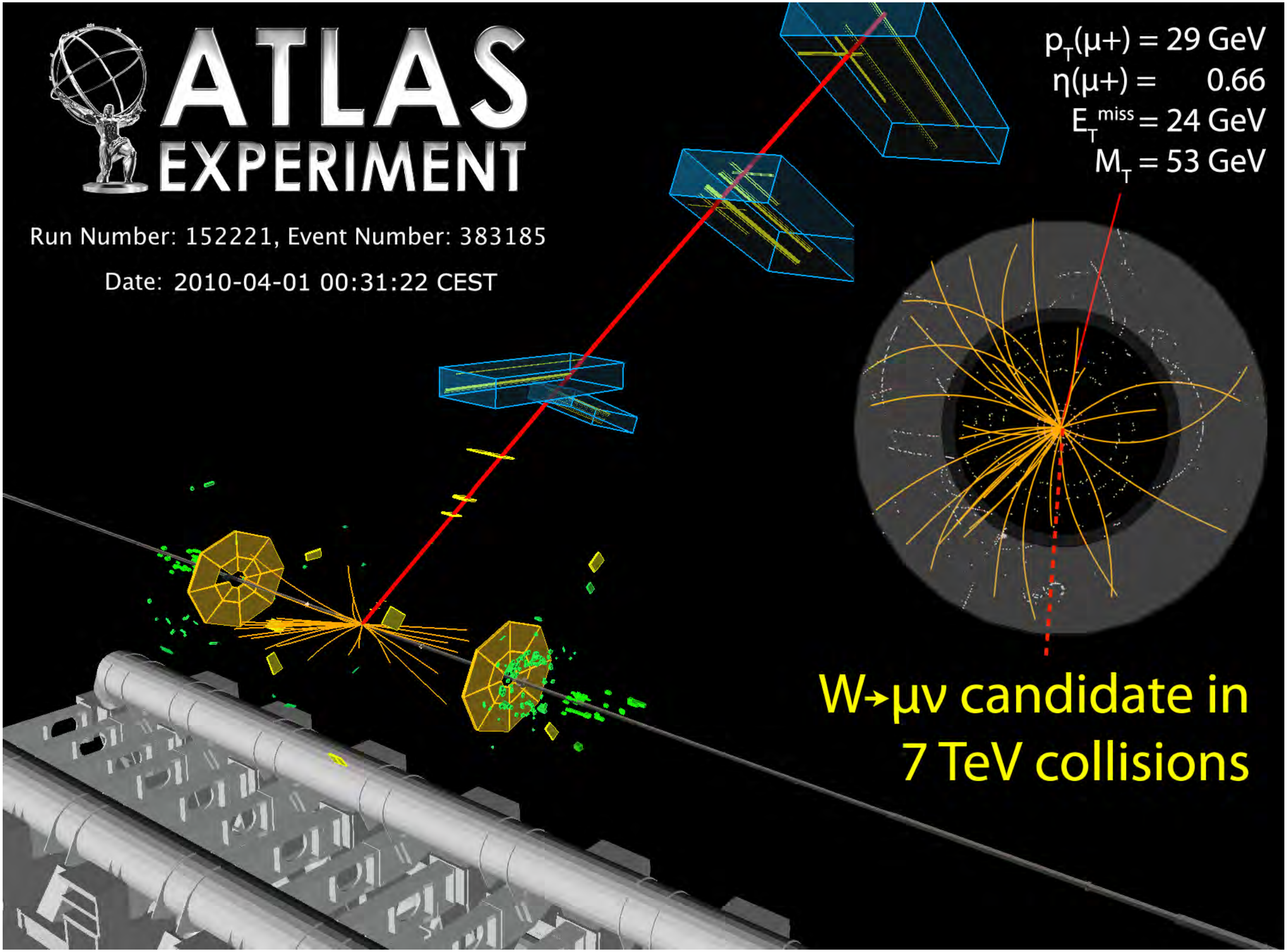
$$p + p \Rightarrow XW^{+}$$

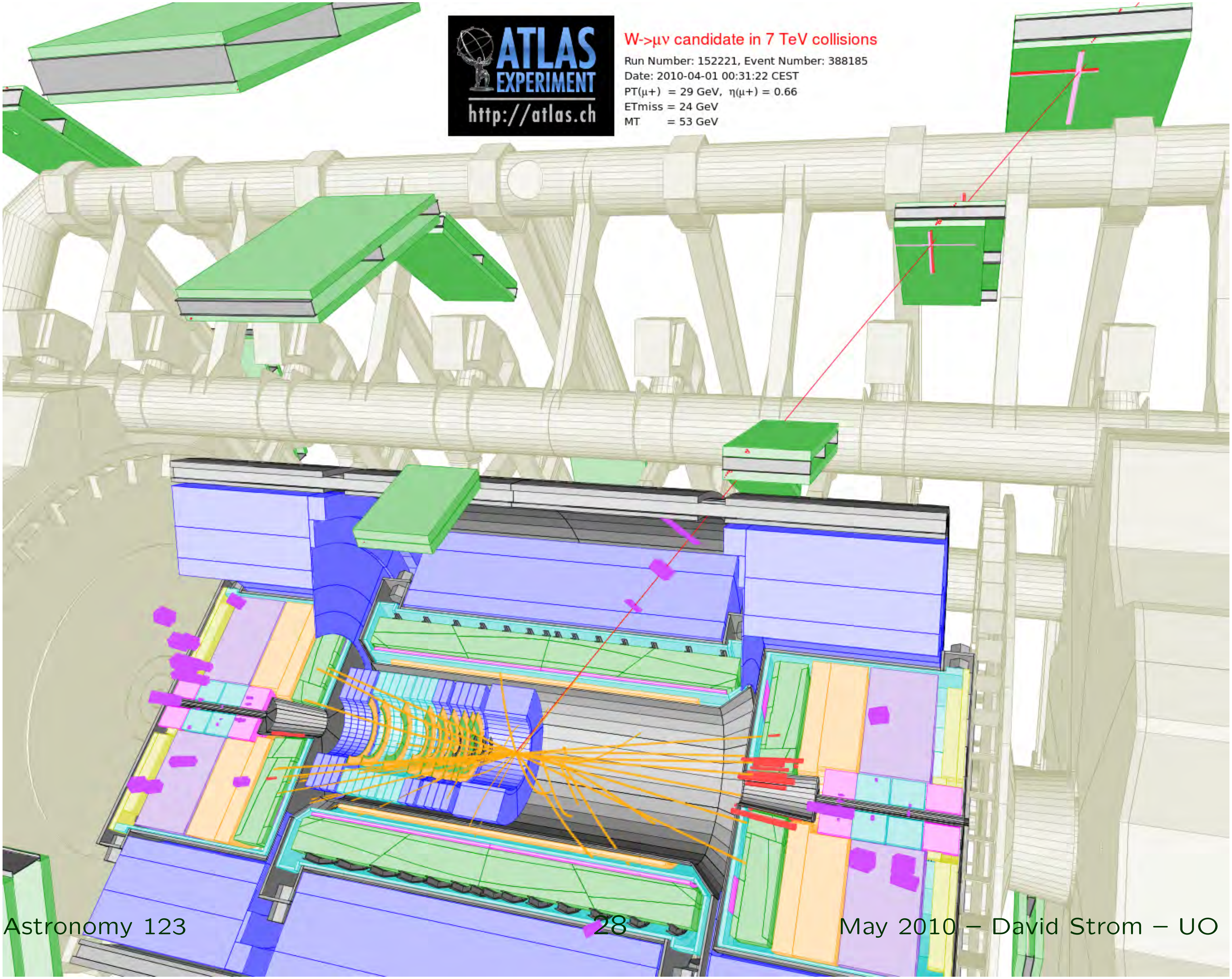
with the W decaying to either

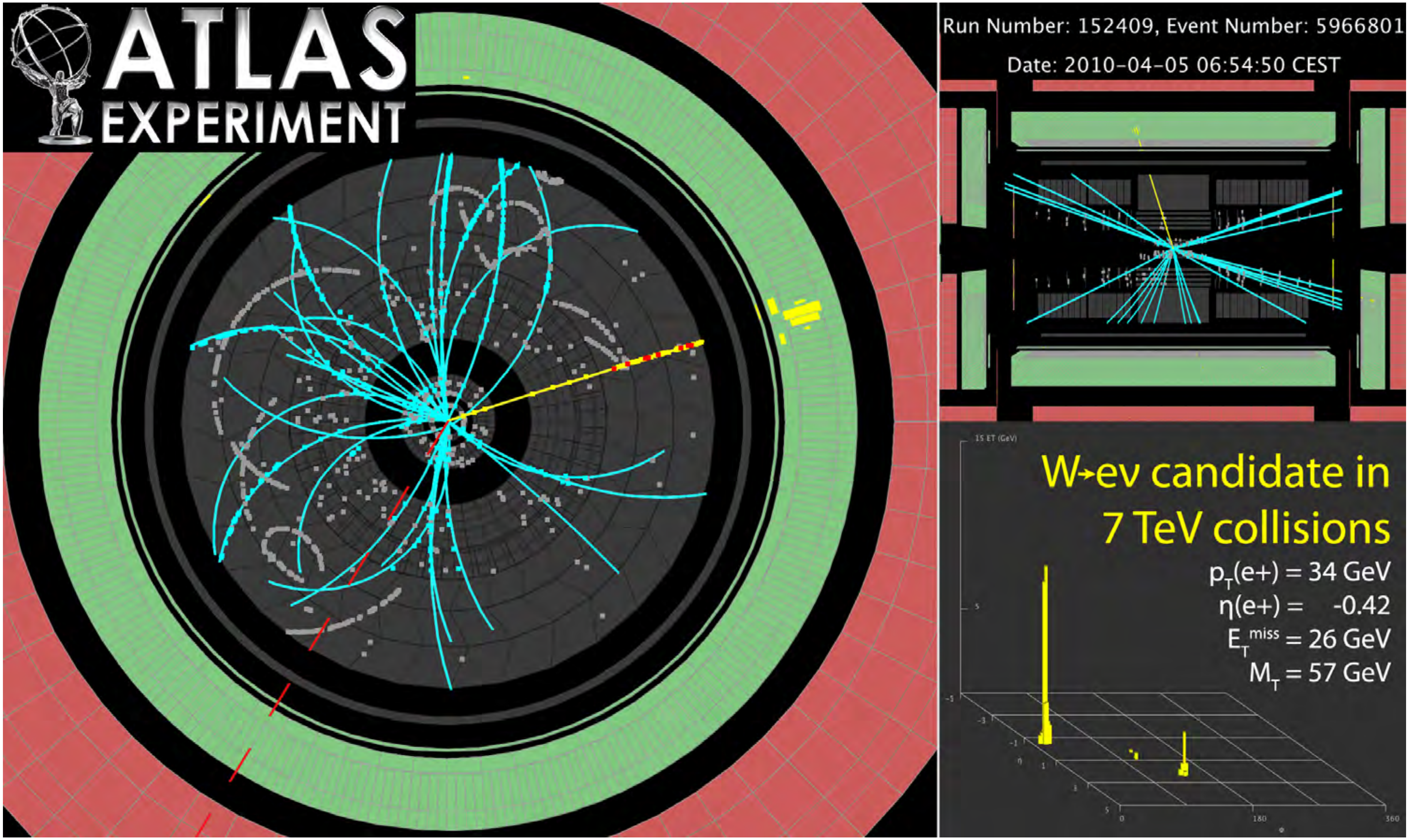
$$W^{+} \rightarrow \mu^{+}\nu_{\mu}$$

or

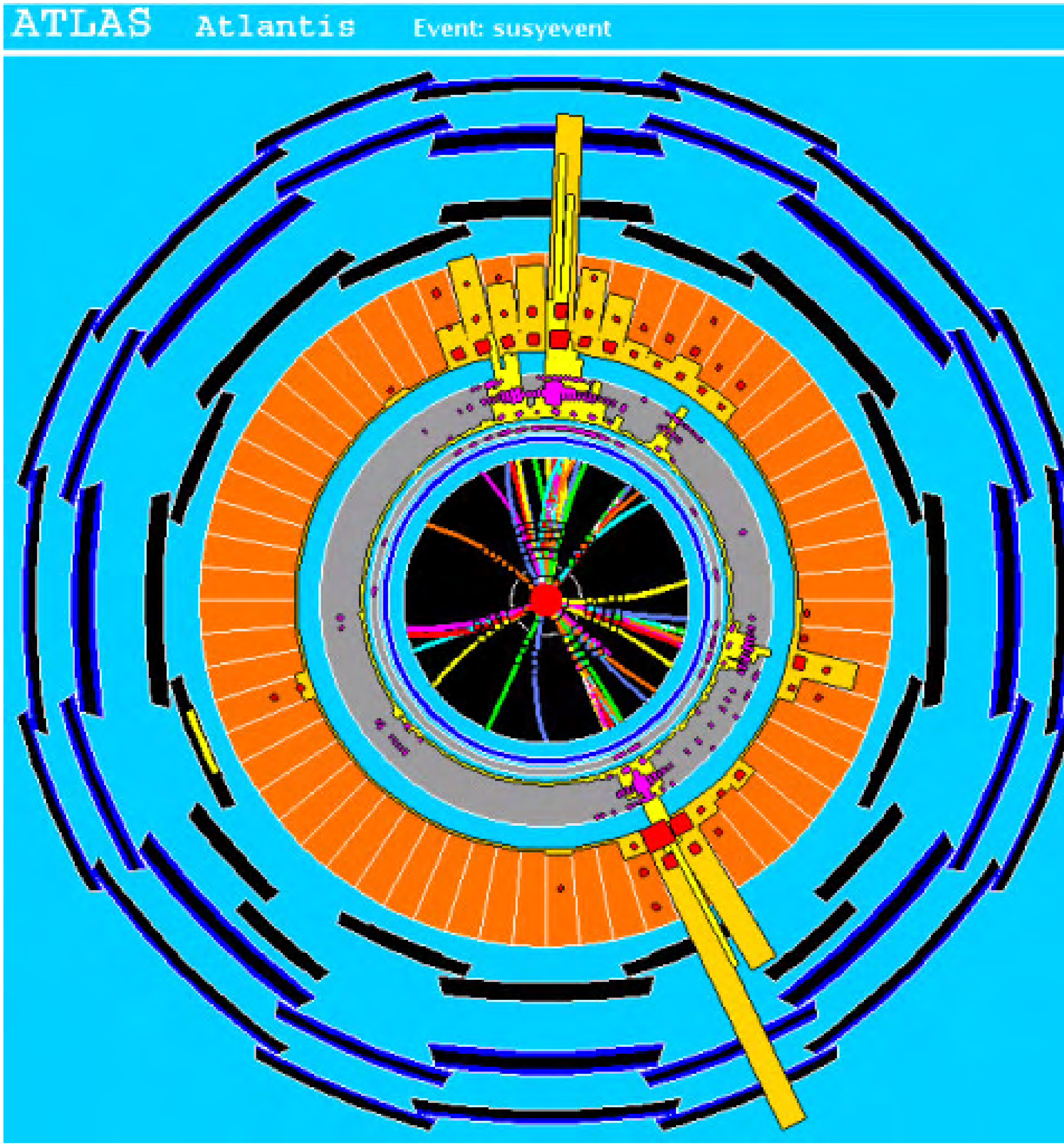
$$W^{+} \rightarrow e^{+}\nu_{e}$$


ATLAS EXPERIMENT
Run Number: 152221, Event Number: 383185
Date: 2010-04-01 00:31:22 CEST
$p_T(\mu+)$ = 29 GeV
$\eta(\mu+)$ = 0.66
E_T^{miss} = 24 GeV
M_T = 53 GeV
W→μν candidate in
7 TeV collisions


ATLAS EXPERIMENT
http://atlas.ch
W->μν candidate in 7 TeV collisions
Run Number: 152221, Event Number: 388185
Date: 2010-04-01 00:31:22 CEST
PT(μ+) = 29 GeV, η(μ+) = 0.66
ETmiss = 24 GeV
MT = 53 GeV


ATLAS EXPERIMENT
Run Number: 152409, Event Number: 5966801
Date: 2010-04-05 06:54:50 CEST
W→eν candidate in
7 TeV collisions
$p_T(e+)$ = 34 GeV
η(e+) = -0.42
E_T^{miss} = 26 GeV
M_T = 57 GeV

How a supersymmetry event might look in the ATLAS detector



- A schematic end-view of an event

- Asymmetric form indicates missing particles – possible dark matter candidate

How does Oregon Fit in?

- Four UO experimental faculty
- Eventually we will have four graduate students and two post-doctorial fellows at CERN
- There are five theoretical faculty at UO working on problems related to the LHC

$\sim$ 3000 Physicists

The Oregon experimental group is working mainly on the "Trigger" for the ATLAS experiment.

The “Trigger”

- There will be more than 40 million proton-proton collisions per seconds
- Each compressed ATLAS event is 25 megabytes
- In one second this is

$$1\,\text{petabyte} = 1000\ 000\ 000\ 000\ 000\ \text{Bytes}$$

- In one year of running this corresponds to

$$10\,\text{zettabytes} = 10\ 000\ 000\ 000\ 000\ 000\ 000\ 000\ \text{Bytes}$$

The total amount of stored data in the world is expected to reach a ZettaByte/year in 2010

• To handle the enormous data rate, we use thousands of computers to pick out 100 to 200 events per second for permanent storage.

• At UO, we are developing the software that selects the events to be saved.

We will only get one chance to save the interesting events!

Looking towards the future

- Luminosity is currently rapidly increasing (currently a factor of 10^6 below final value).

- In the next few months ATLAS will concentrate on what we call Standard Model processes, e.g. Z and W production

- We will have the first chance to discover SUSY this summer.

- In approximately 2 years the energy of LHC will be doubled from 7 TeV to 14 TeV

- **Full exploitation of the LHC will take us at least another 10 years**