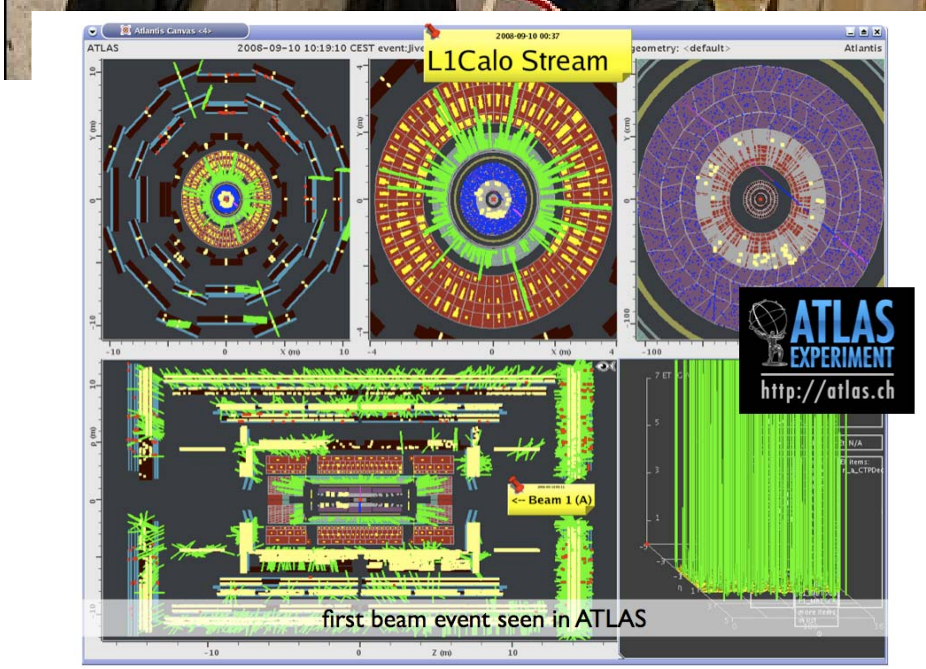
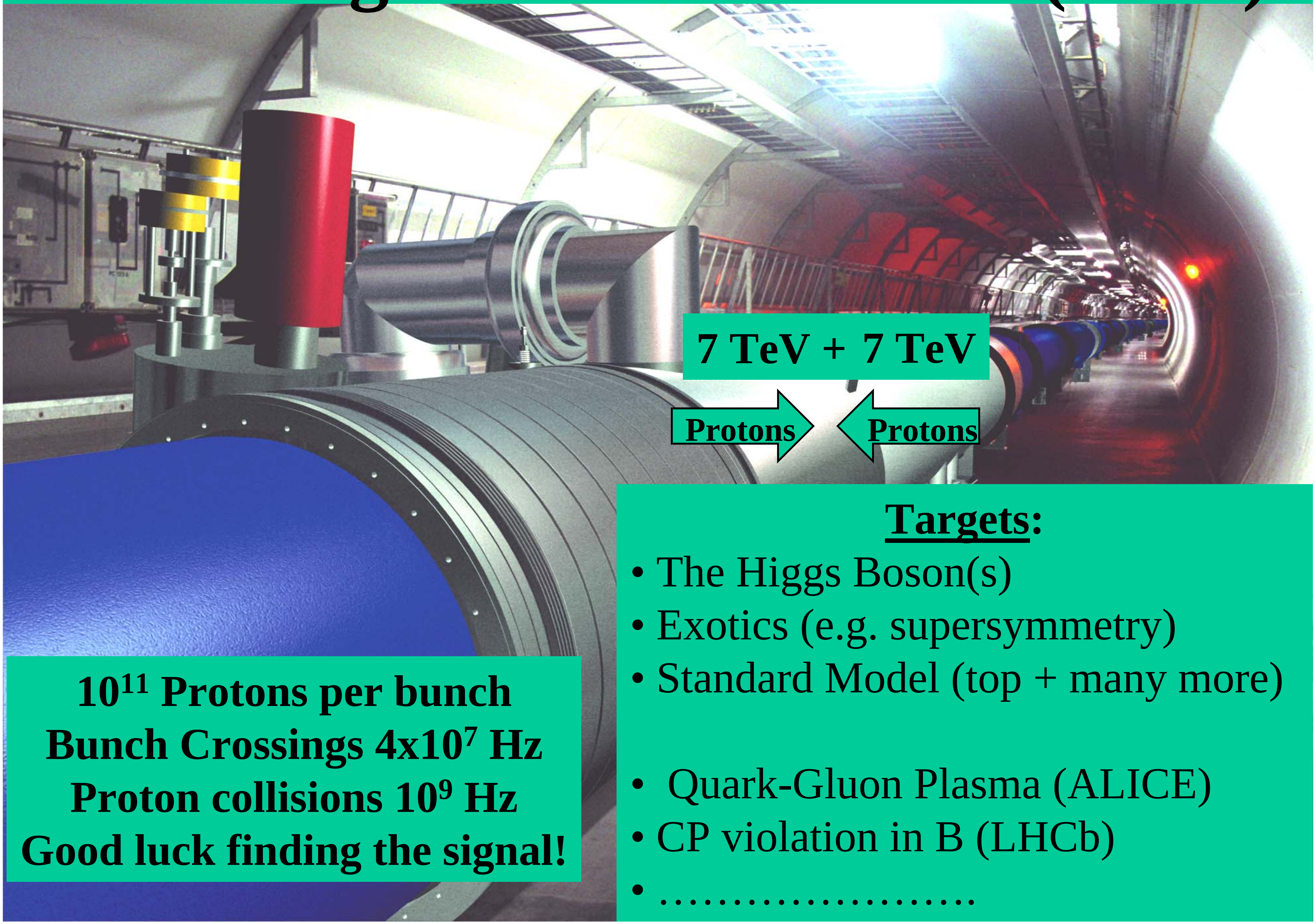
Last Friday: pp(bar) Physics Intro, the TeVatron
Today: The Large Hadron Collider (LHC)



The Large Hadron Collider (LHC)



10^{11} Protons per bunch
Bunch Crossings $4x10^7$ Hz
Proton collisions 10^9 Hz
Good luck finding the signal!

Targets:

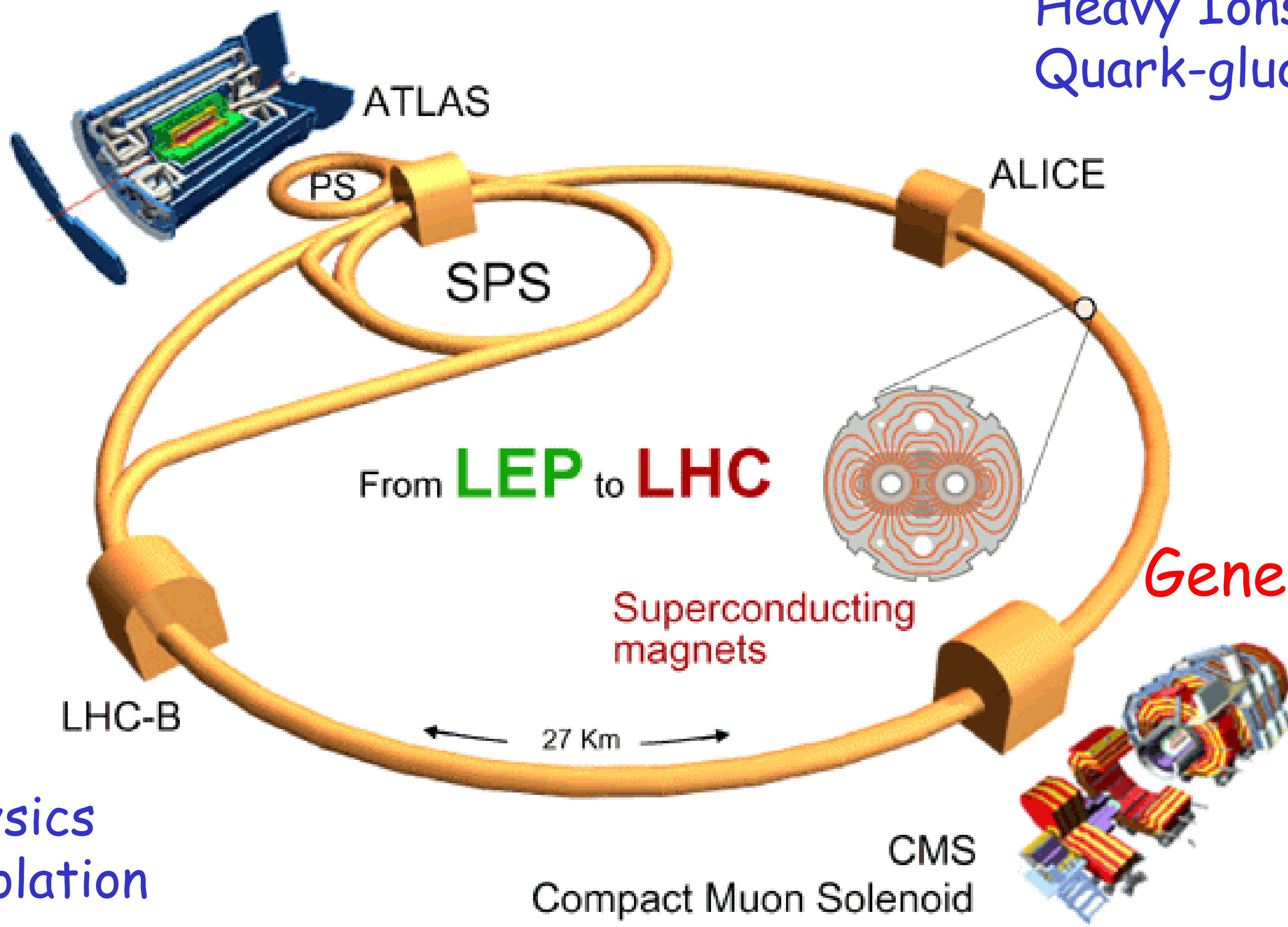
- The Higgs Boson(s)
- Exotics (e.g. supersymmetry)
- Standard Model (top + many more)

- Quark-Gluon Plasma (ALICE)
- CP violation in B (LHCb)
- ……………………

LHC Overview

General-purpose
Higgs
SUSY
??

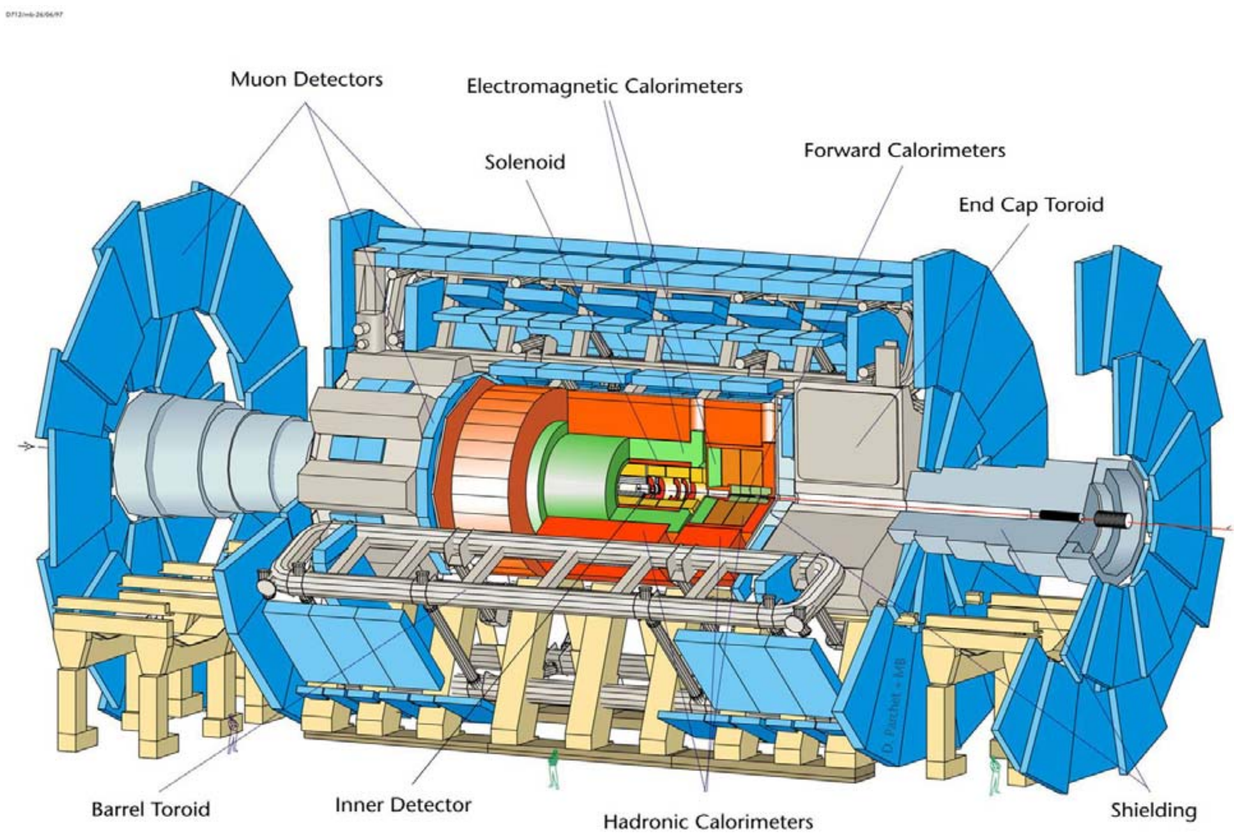
Heavy Ions
Quark-gluon plasma



General-purpose
Higgs
SUSY
??

B-physics
CP Violation

ATLAS in More Detail



- Solenoidal magnetic field (2T) in the central region (momentum measurement)

  High resolution silicon detectors:
  - 6 Mio. channels (80 μm x 12 cm)
  - 100 Mio. channels (50 μm x 400 μm)

  space resolution: ~ 15 μm

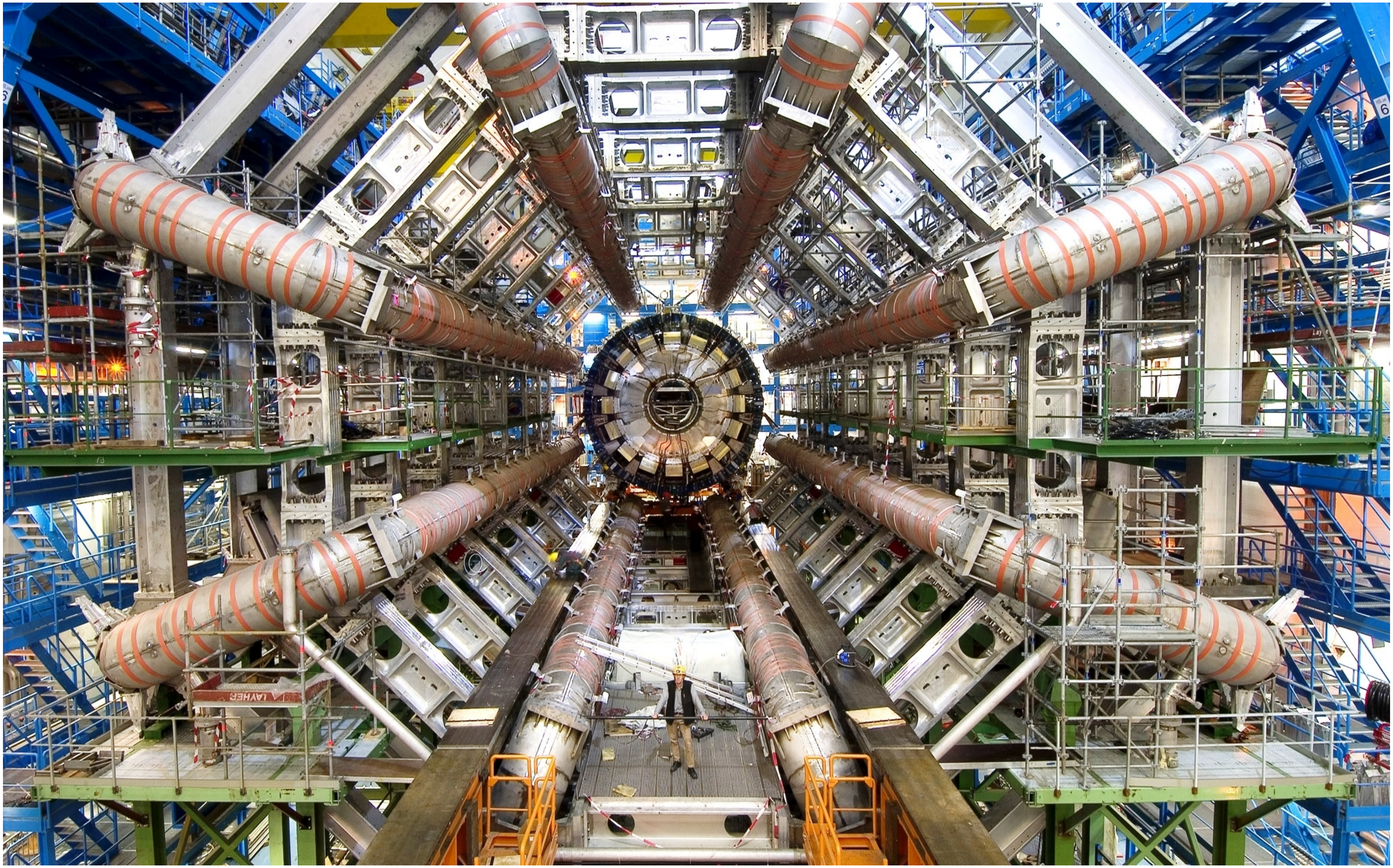
- Energy measurement down to 1º to the beam line

- Independent muon spectrometer at outside (toroid system 1-2T)

Diameter	25 m
Barrel toroid length	26 m
End-cap end-wall chamber span	46 m
Overall weight	7000 Tons

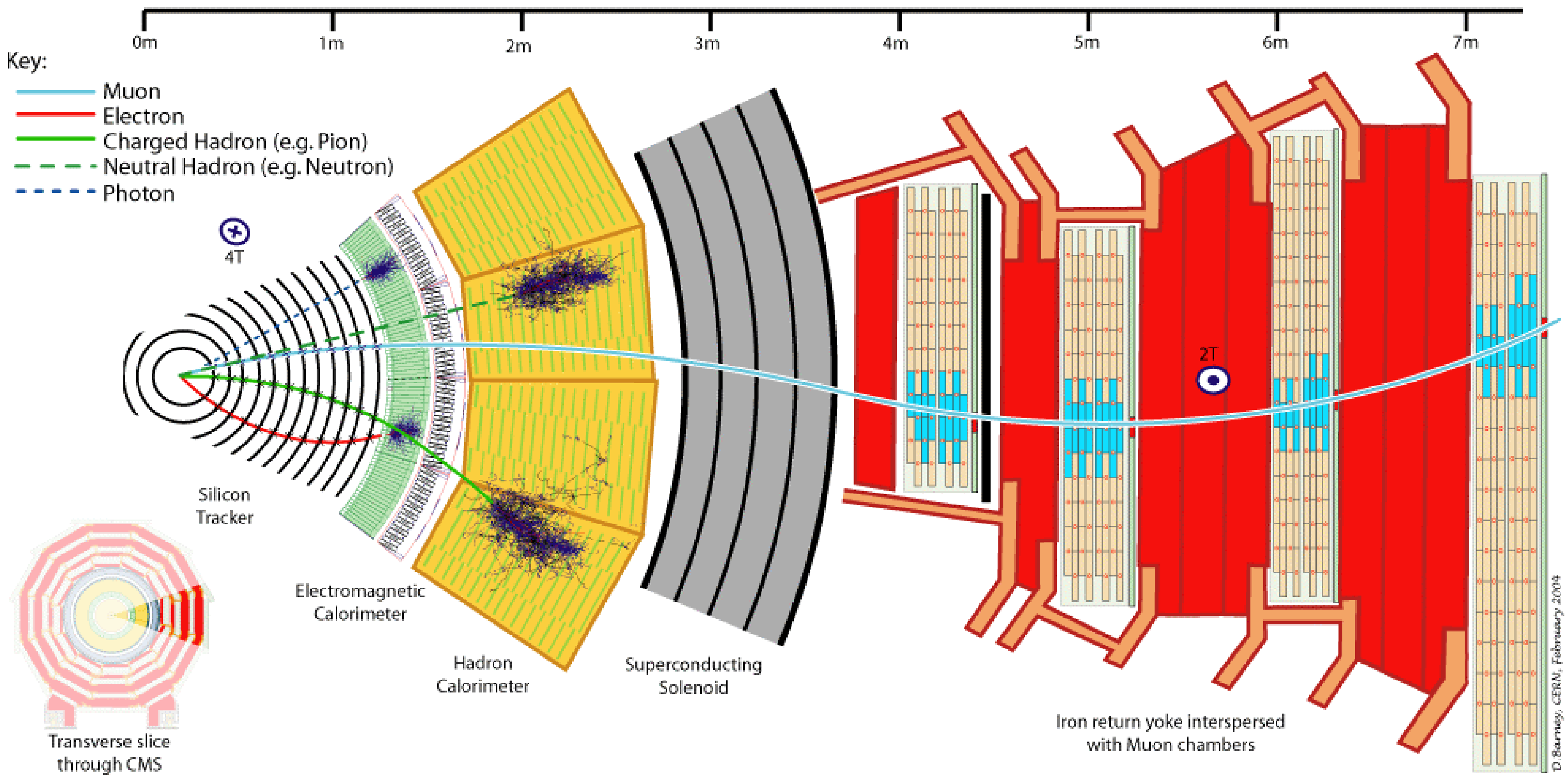
Installing ATLAS Toroids and Calorimeter

ATLAS Toroids in Place



CMS in More Detail

Total weight	12500 t
Overall diameter	15 m
Overall length	21.6 m

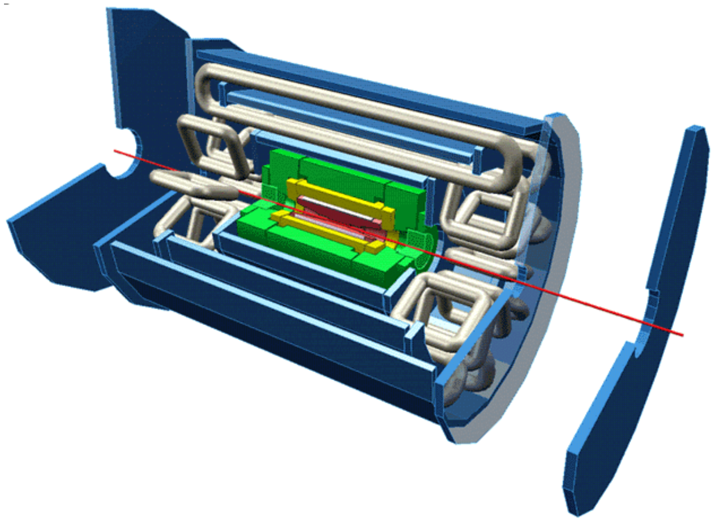


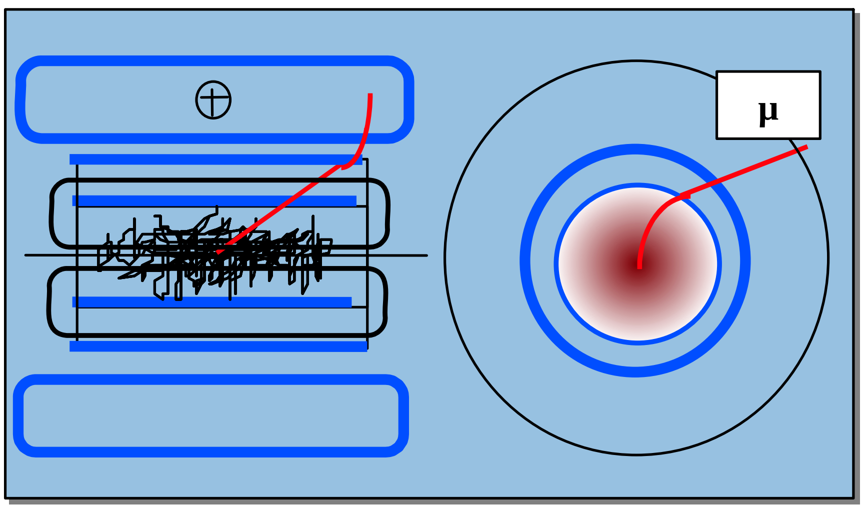
.... In a very messy environment, muons may be your best friend!

.... Field inside solenoid ~4T. Iron return yoke conducts ~2T

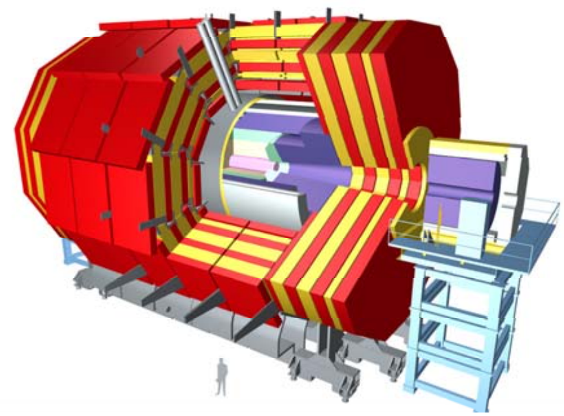
ATLAS, CMS Magnetic Fields

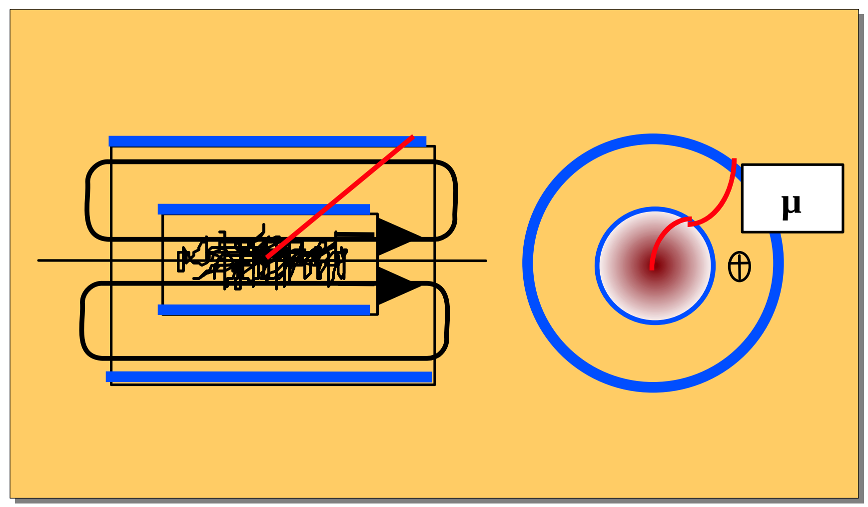
ATLAS A Toroidal LHC ApparatuS





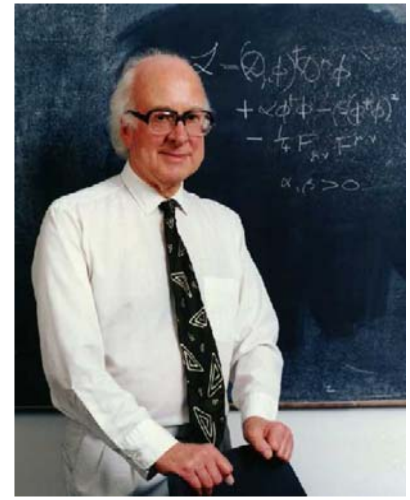
CMS Compact Muon Solenoid





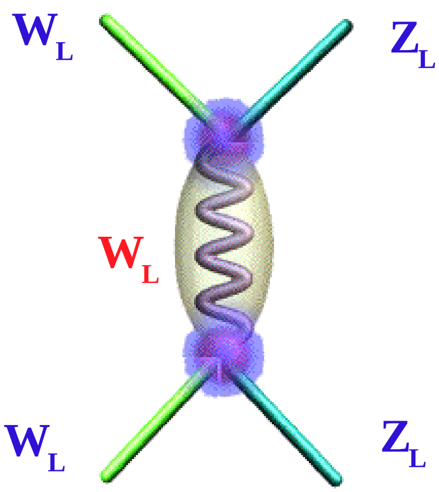
Note the difference …

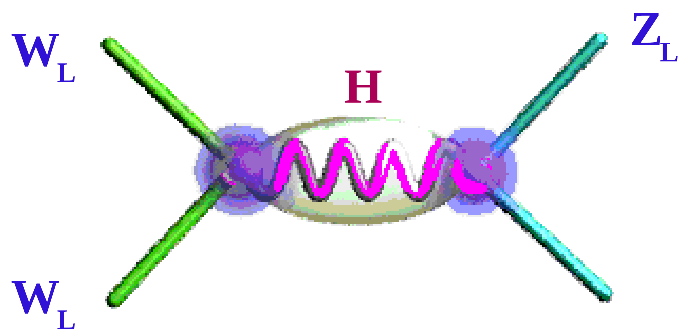
Why do we believe in Higgs bosons?



Standard answer: Standard model particles are massless … Higgs boson gives them mass

Also: Around 1 TeV, Standard Model cross section for WW scattering grows out of control.
… something has to happen on a 1TeV (LHC) energy scale

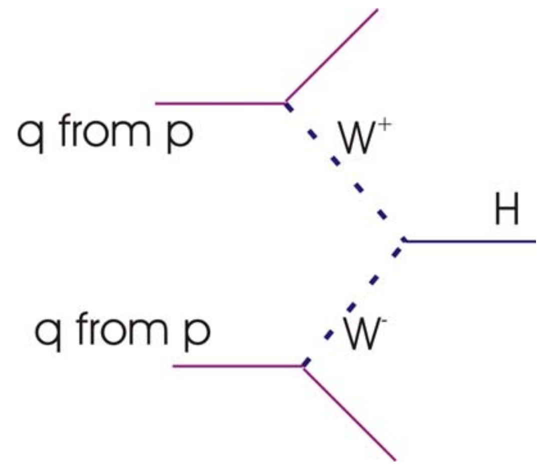




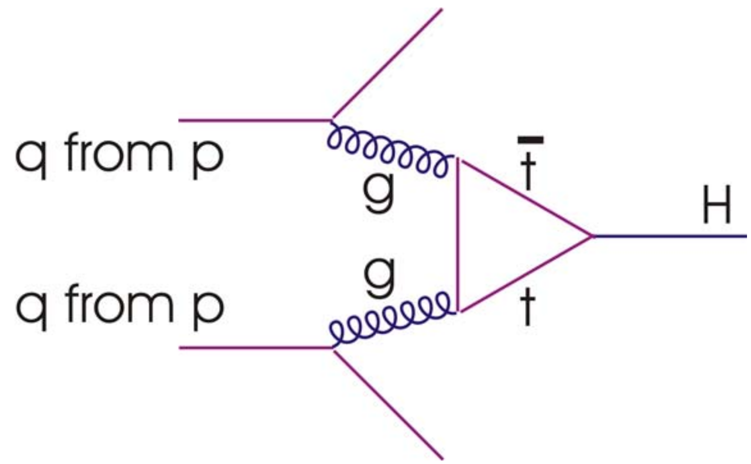
Introducing Higgs perfectly cancels this high energy disaster!
Finding the Higgs will be interesting, not finding it, will be even more interesting!… see Dr Kenyon's lectures for more …

How could Higgs bosons be produced at LHC?

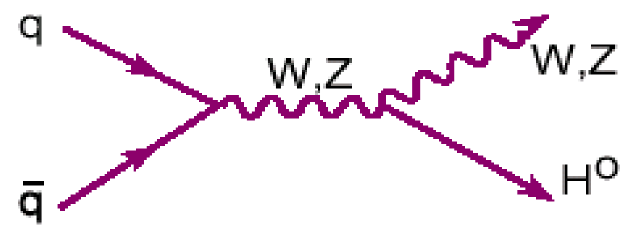
Higgs boson couples to mass
…. Can be produced (or decay to)
and pair of particles with mass



It can also be produced (or decay to) photon or gluon pairs via (eg top) loops…
In fact, due to large gluon PDF, gg is by far the dominant channel



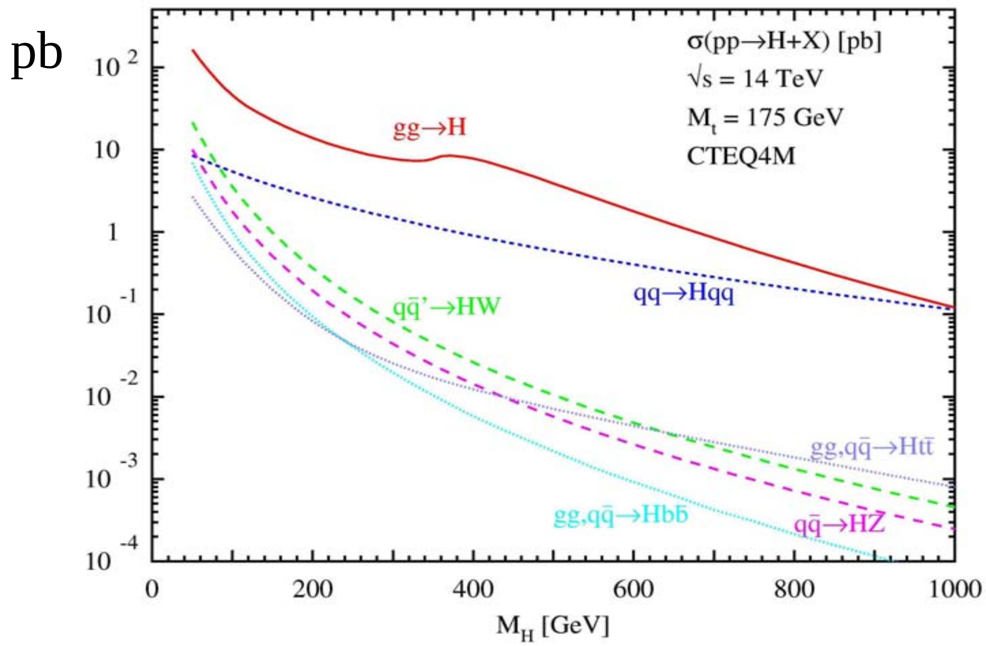
It can also be radiated by heavy particles



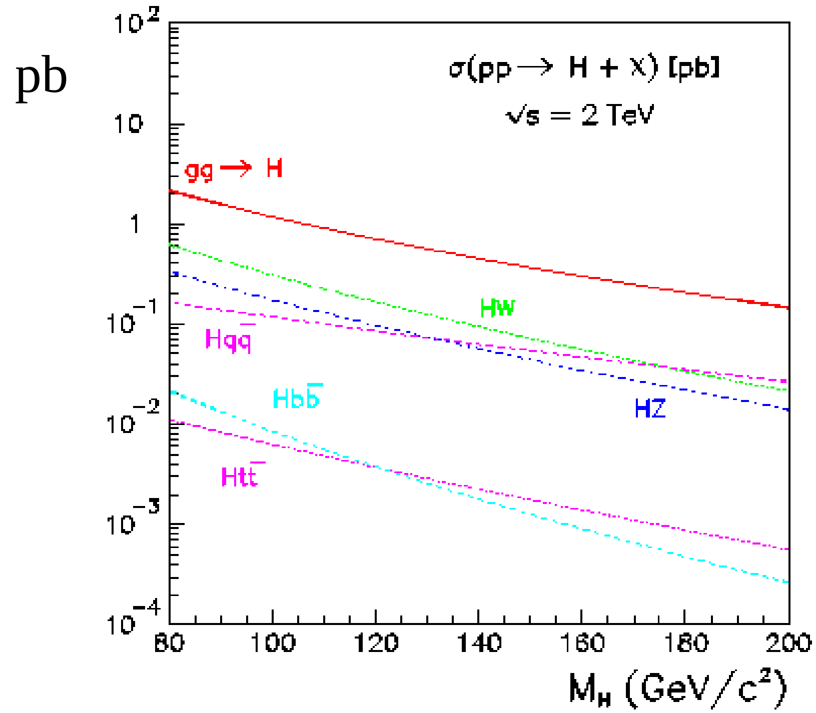
W, Z bremsstrahlung

Higgs Boson Production cross sections

LHC



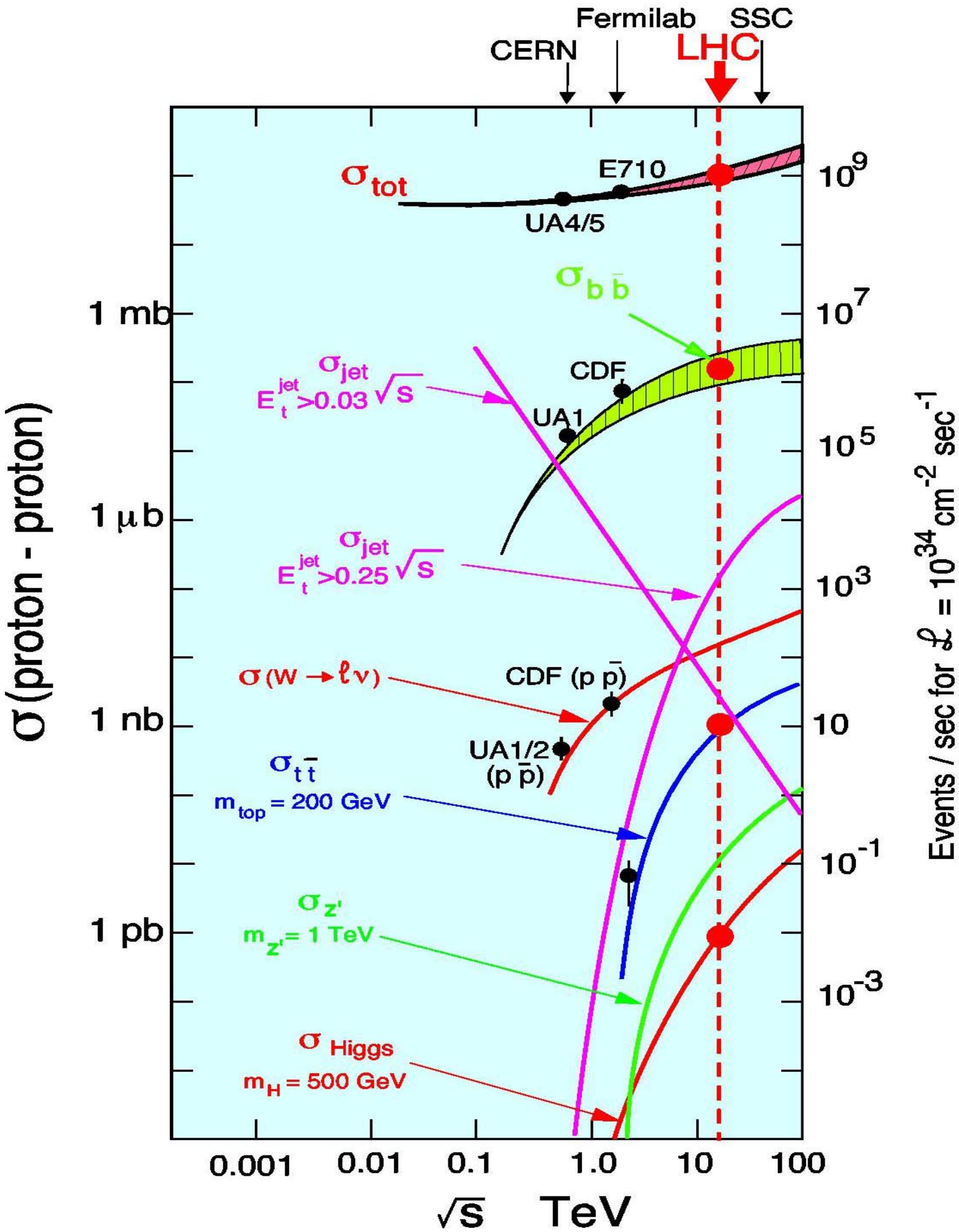
Tevatron



Higgs production may be kinematically possible at Tevatron, but e.g. gg → H cross section ~75 times larger at the LHC.

(c.f. non-observation of top at the SPS).

Cross Sections and Production Rates



Rates at peak LHC Luminosity:

- Total pp interactions: 10^9/s

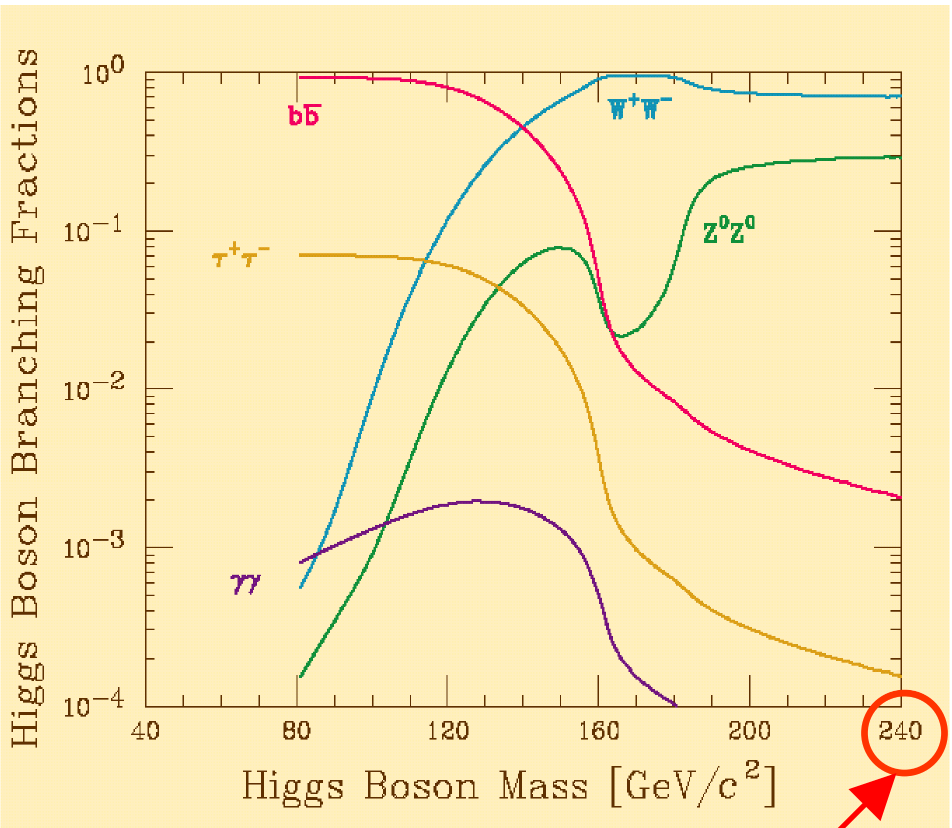
- bb pairs: 5. 10^6/s
- tt pairs: 8/s

- **Higgs (150 GeV): 0.2/s**

It could take several years to dig out a Higgs signal from among the huge rates of other signal (& background!) processes!

What does Standard Model Higgs decay to?

Higgs decay branching fractions depend on its mass ...

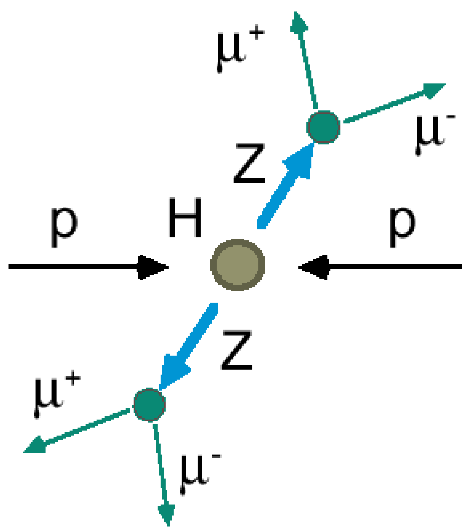


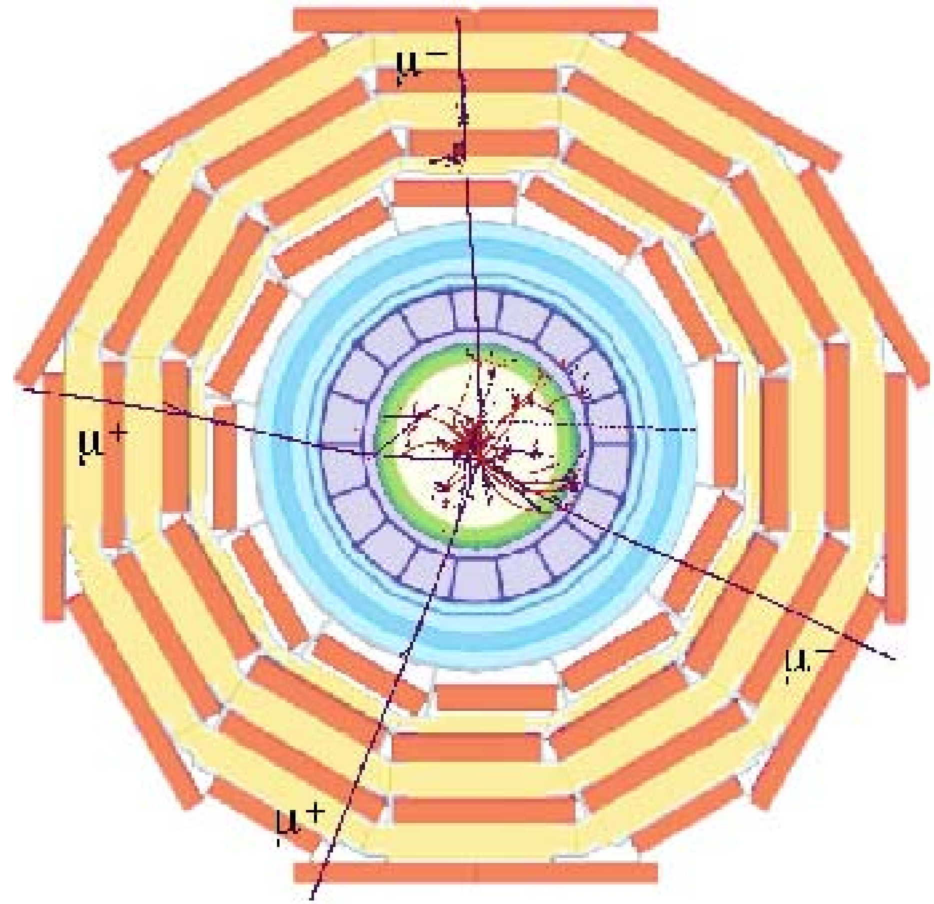
LEP, Tevatron suggest its light...

For detection, ideally want clean decays to high p_t e or μ

- For low M_H, tricky!
  - Higgs decay products are at low p_t
  - b bbar has biggest branching ratio, but high background decays to jets!
  - $\gamma\gamma$ more promising, but rate is low!
- For high M_H, dream scenario is to use WW or ZZ, decays to leptons

Dream scenario - `heavy` Higgs

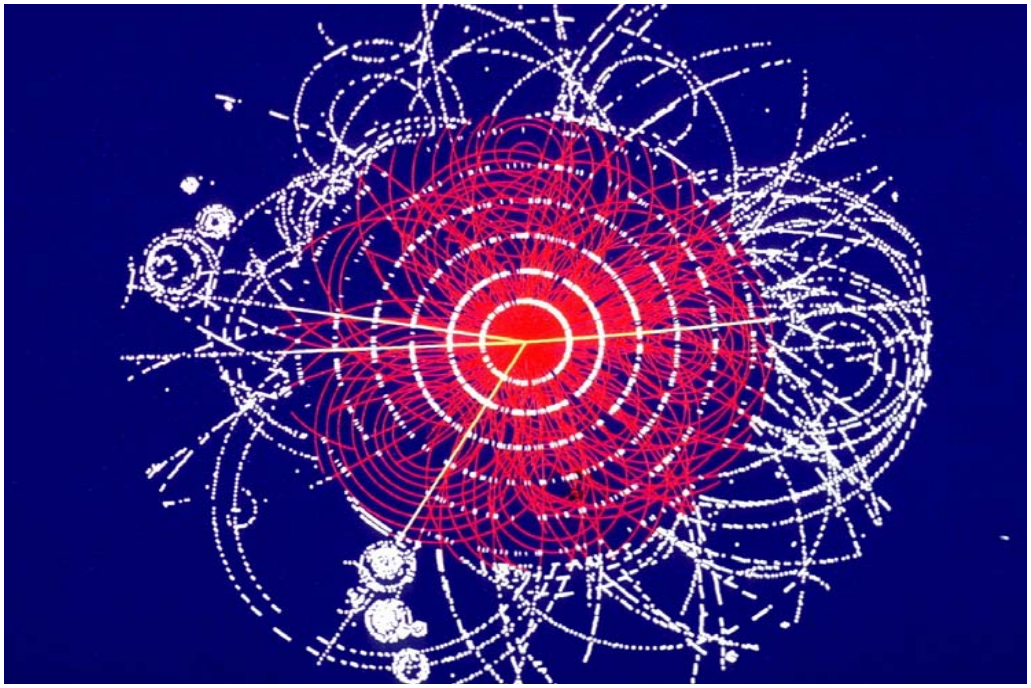




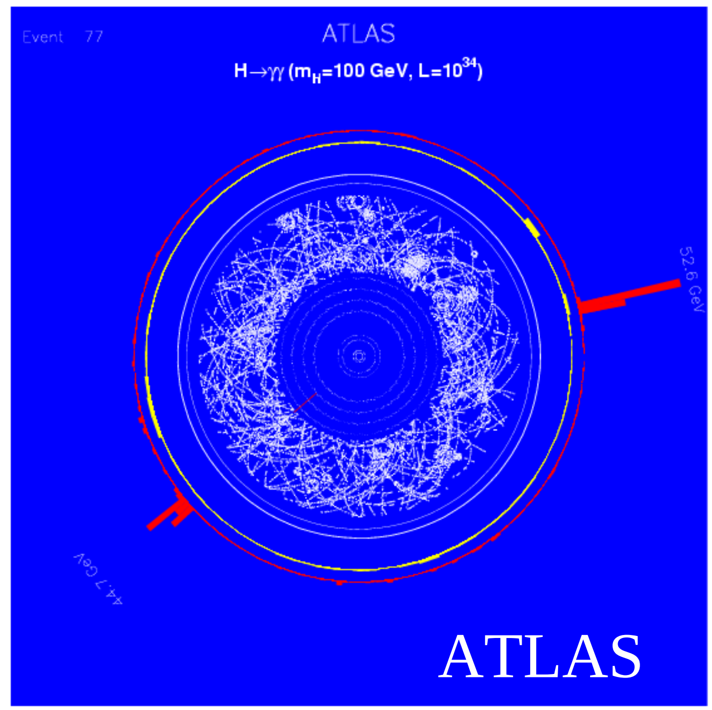
If Higgs is heavy enough,
detect $H \rightarrow ZZ \rightarrow \mu^+\mu^-\mu^+\mu^-$

e.g. if M_H=200 GeV, muons could have p_t=50GeV each
.... fast discovery, M_H could be measured to 1GeV or better

… even then a full simulation looks scary!

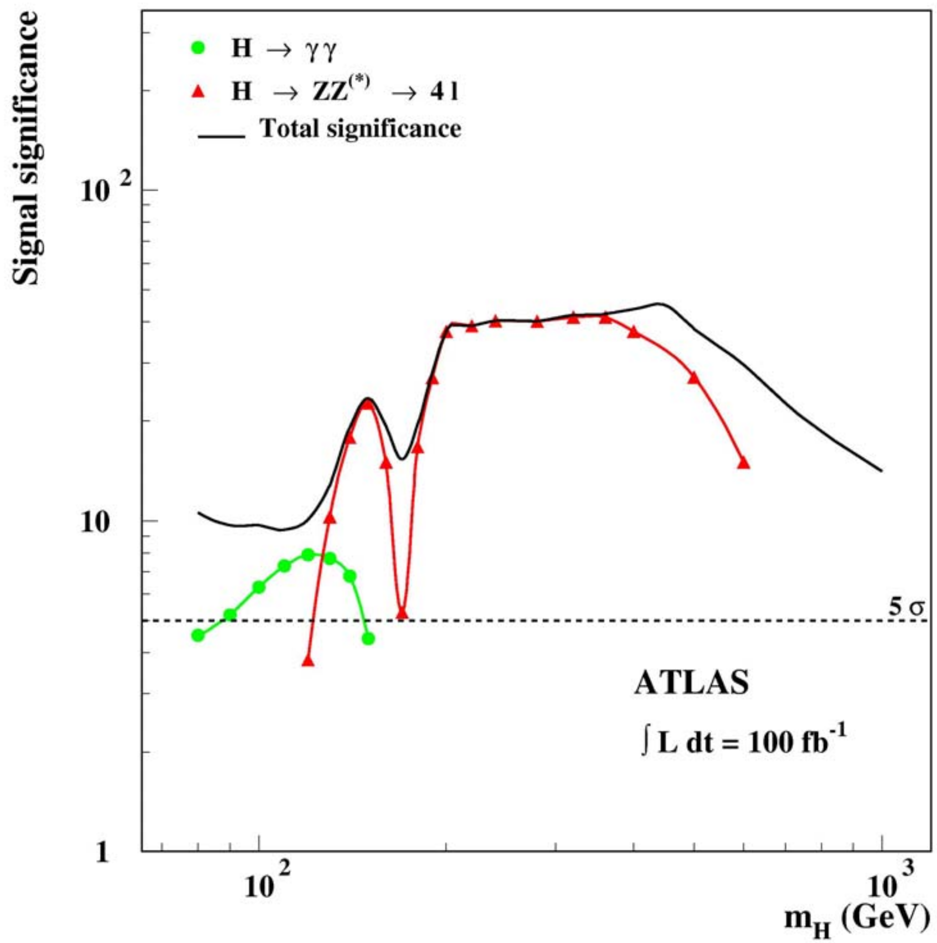


H→ZZ→4 leptons



Another example: H→γγ

Higgs Discovery Significance at LHC



Expected signal significance (see later lectures) …

… "number of standard deviations by which signal lies above the background"

- 5σ `Discovery': prob. of statistical fluctuation < 0.0001 %
- With $100 fb^{-1}$, all masses covered by γγ and ZZ channels

.... but that could take a few years!

Some "Big Bang Day" Headlines

Journey to the Centre of the Universe begins [Scotsman]

'Big Bang' Large Hadron Collider is switched on [Telegraph]

New era of Understanding about the origins and evolution of the Universe as Hadron Collider turns on [Scotsman]

CERN throws switch on largest machine ever built [Guardian]

Large Hadron Collider `likely' to uncover sought-after God Particle [Telegraph]

Large Hadron Collider fired up in `God particle' hunt [CNN]

Black Holes Provide a big bang of publicity [Independent]

You're reading this - the world hasn't ended [Independent]

Our biggest black hole was in the budget [The Times]

Some more "Big Bang Day" Headlines

`awe-inspiring' Large Hadron Collider should enthuse next generation of Scientists [CBI press release]

How Important is the Big Bang Experiment? [BBC]

Why hate the LHC? [A Blogger]

Welsh scientist leads worlds largest experiment [Wales online]

Big Bang Boffins are comfortable in their work at the CERN Collider Centre [Safety and Health Practicioner Magazine]

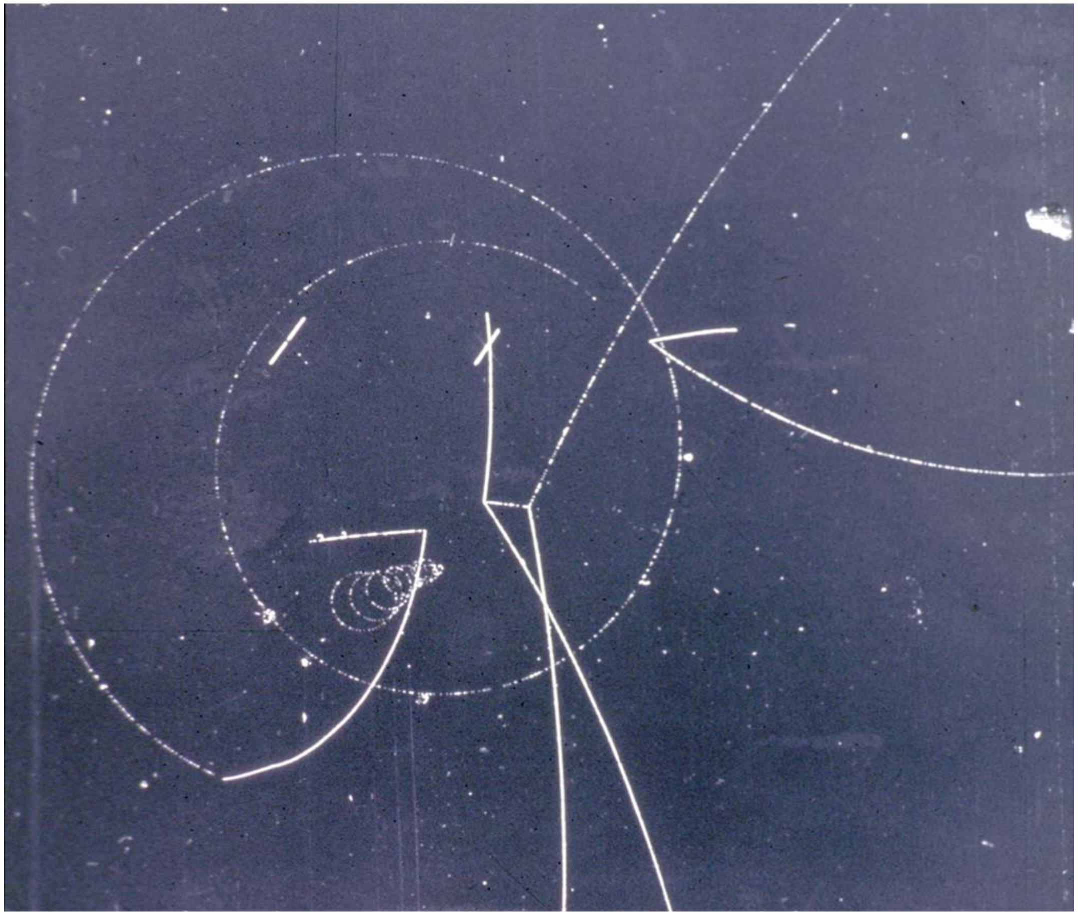
Large Hadron Collider rap hits YouTube [Star]

I'll eat my hat if the Large Hadron Collider Experiment works [Lilly Allen]

Well, the earth DID move for us [Sun]

First test of collider goes well [Columbia Daily Tribune]

Next Part of Course: How detectors work



... starting with tracking of charged particles

... an old subject with applications way beyond particle Physics!

Annihilation of an antiproton in the 80 cm Saclay liquid hydrogen bubble chamber. A negative kaon (K^- meson) and a neutral kaon (K^0 meson) are produced in this process as well as a positive pion (π^+ meson).

Tracking Detectors in Context

- To detect a particle, we have to make it interact with our detector!
- Tracking detectors detect **CHARGED PARTICLES** … want them to interact as little as possible to precisely track the particle trajectory in conditions as close to vacuum as possible.
- In calorimeters, we want them to interact as much as possible to stop the particle and measure all of the energy it leaves behind.
- Trackers are therefore located inside calorimeters!
- Also often provide an important role in triggering events