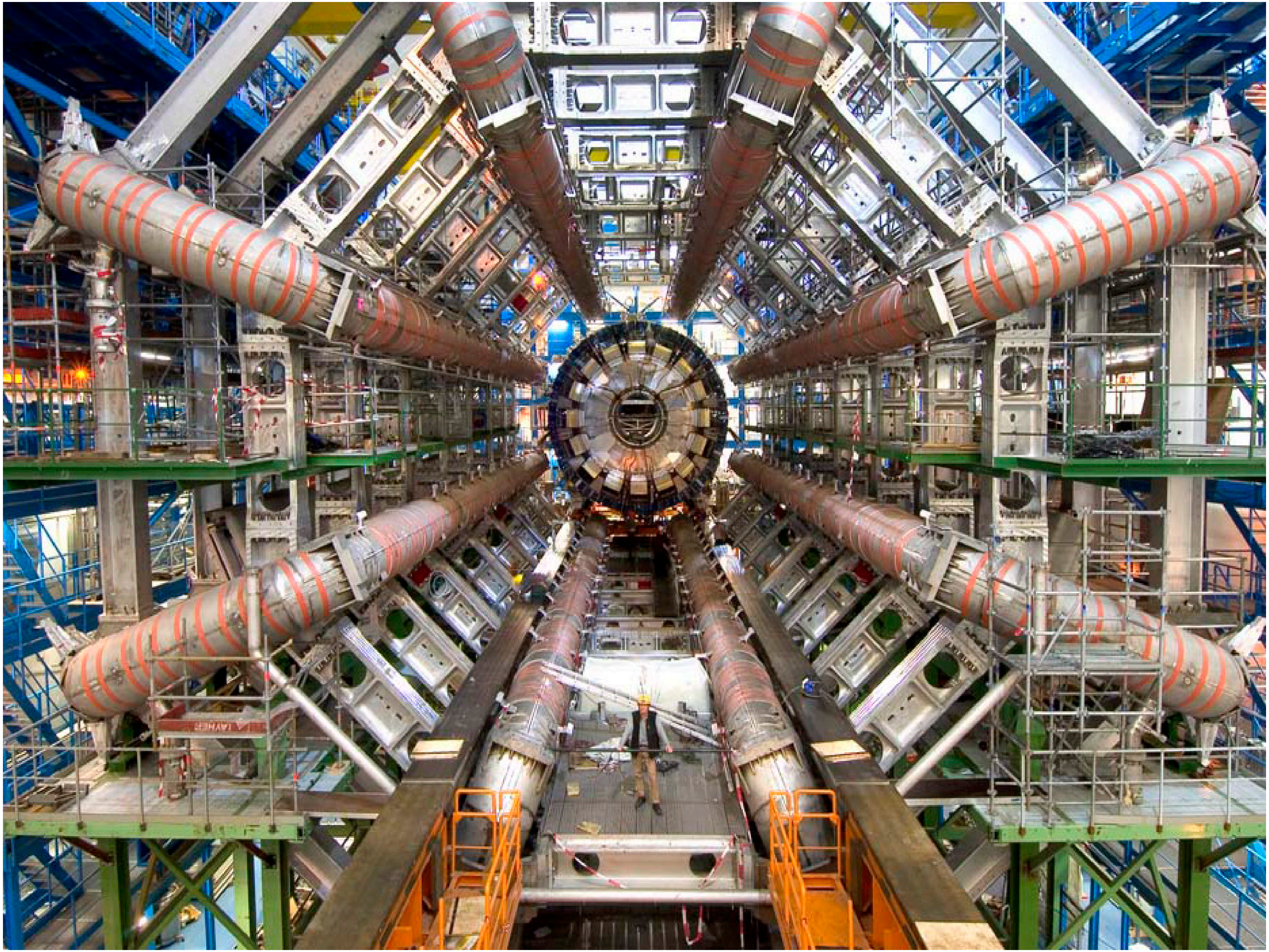
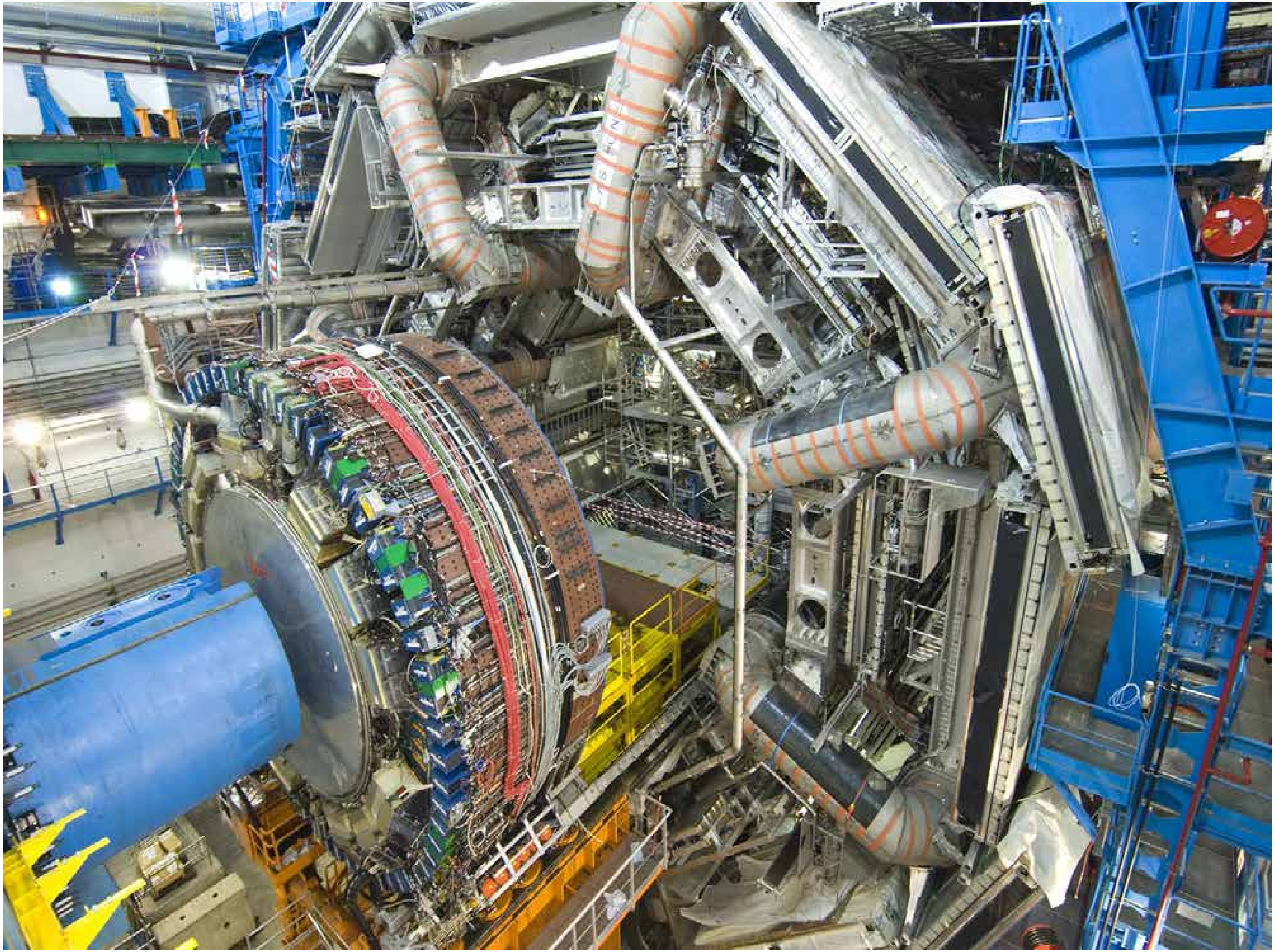




Muon Detectors

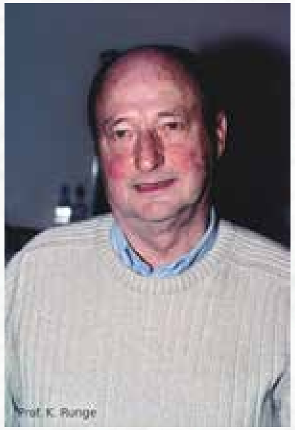
Prof. Gregor Herten

Prof. Ulrich Landgraf

Assembly in Freiburg

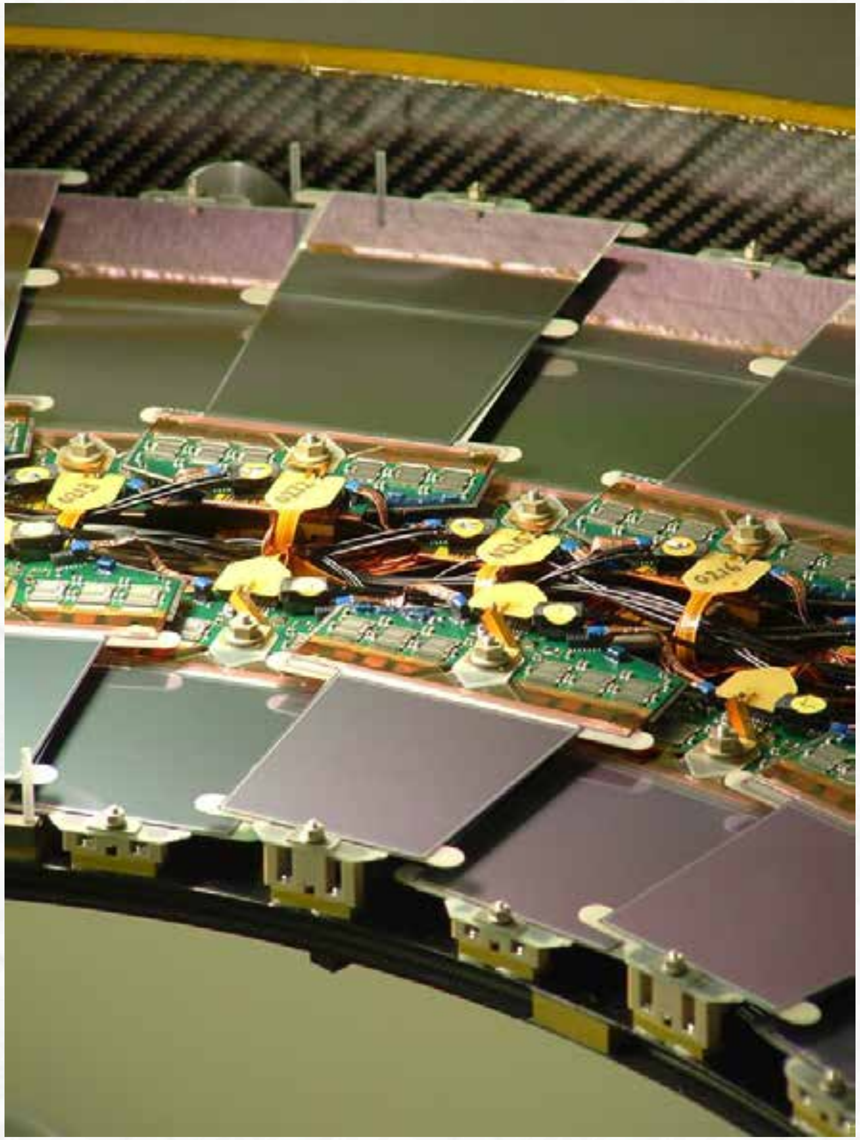
Installation at CERN (2005)

Silicon Tracking Detectors



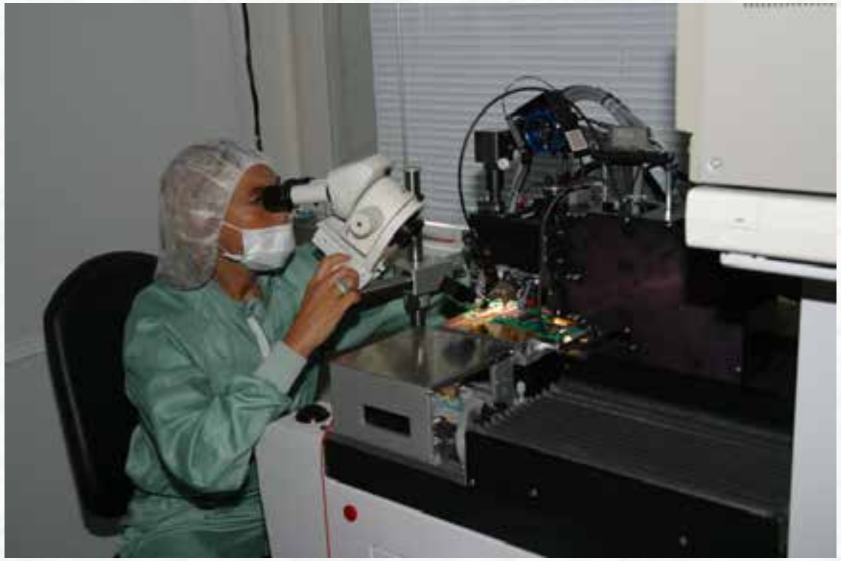
Prof. Kay Runge

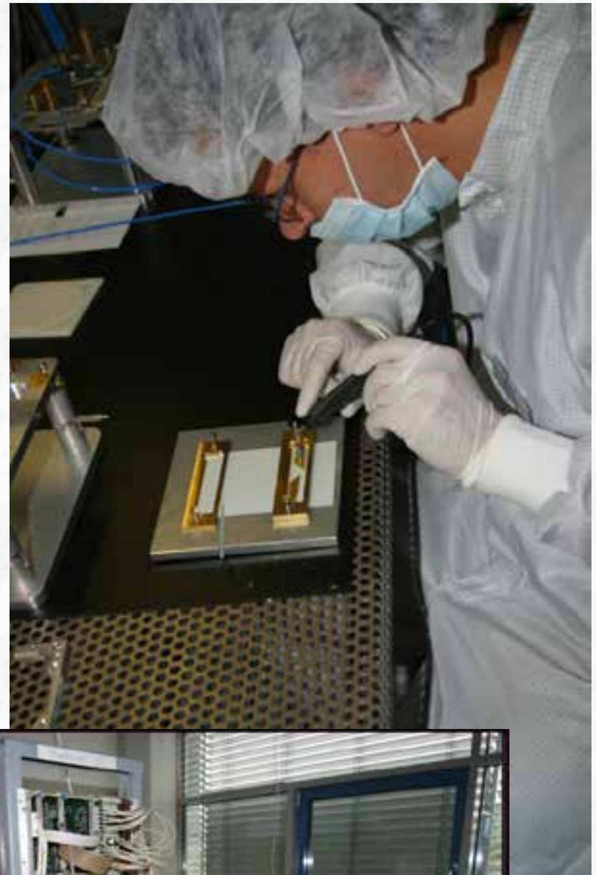
Prof. Jens Ludwig



Modules „made in Freiburg“

During module construction in Freiburg



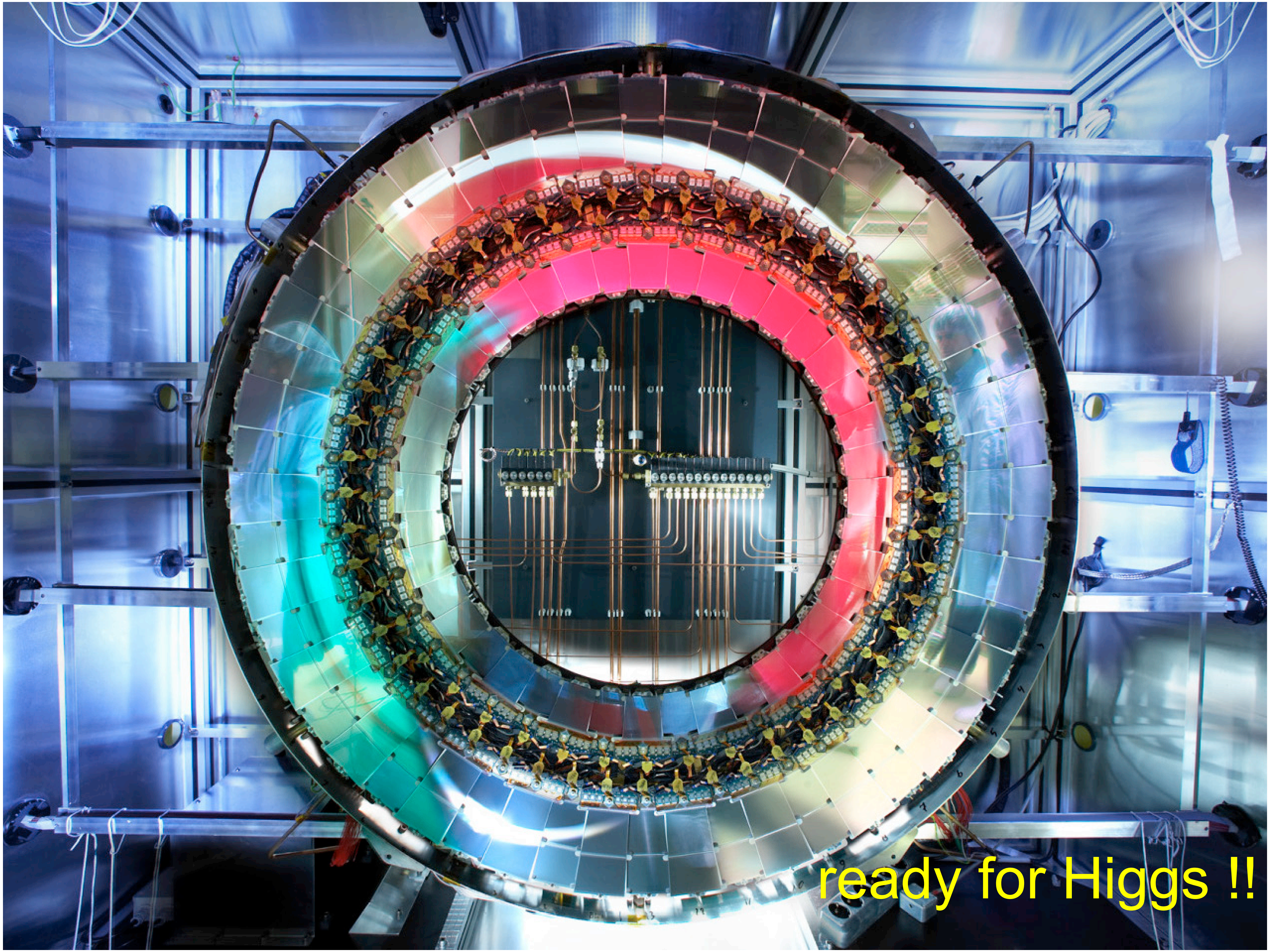


The "ATLAS Silicon detector team"

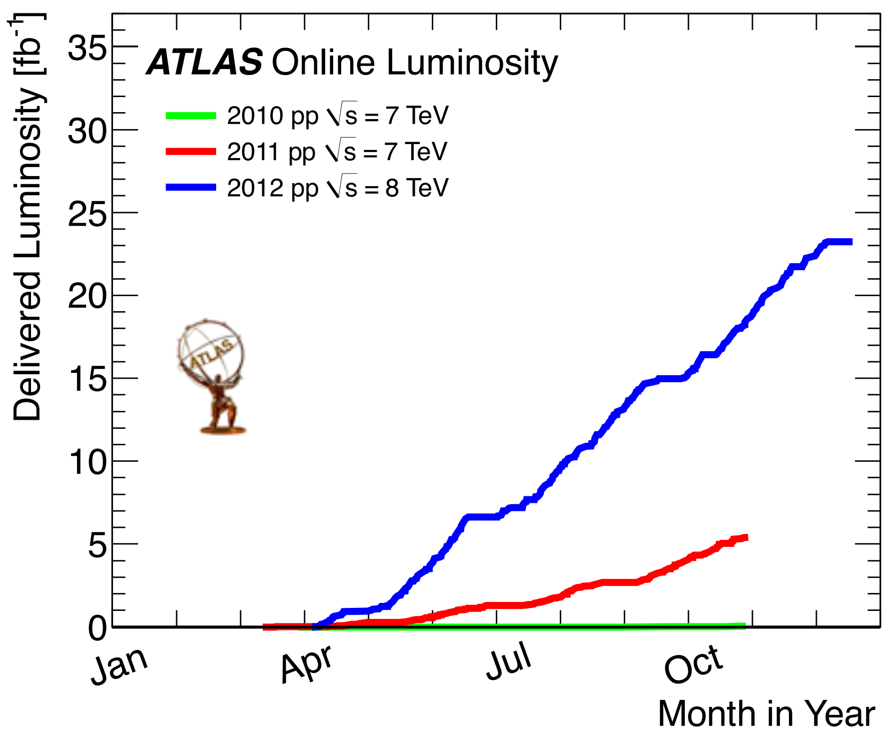
… + Electronics and Mechanical Workshop of the Institute

The "ATLAS Silicon detector team"

… + Electronics and Mechanical Workshop of the Institute


ready for Higgs !!

Data taking in 2011/ 2012



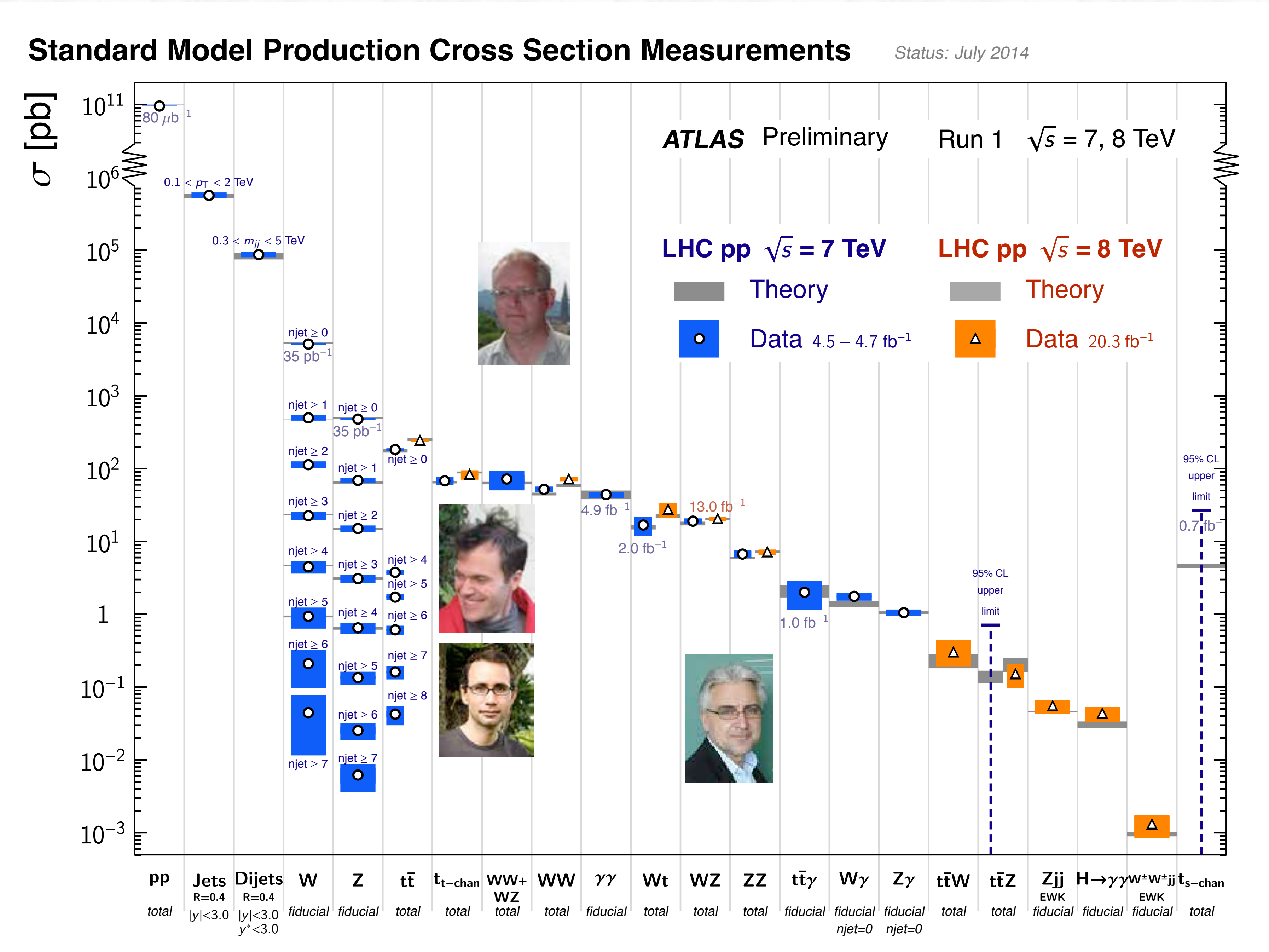
Until end 2012:

> 10^{15} pp collisions
~10^{10} pp collisions recorded

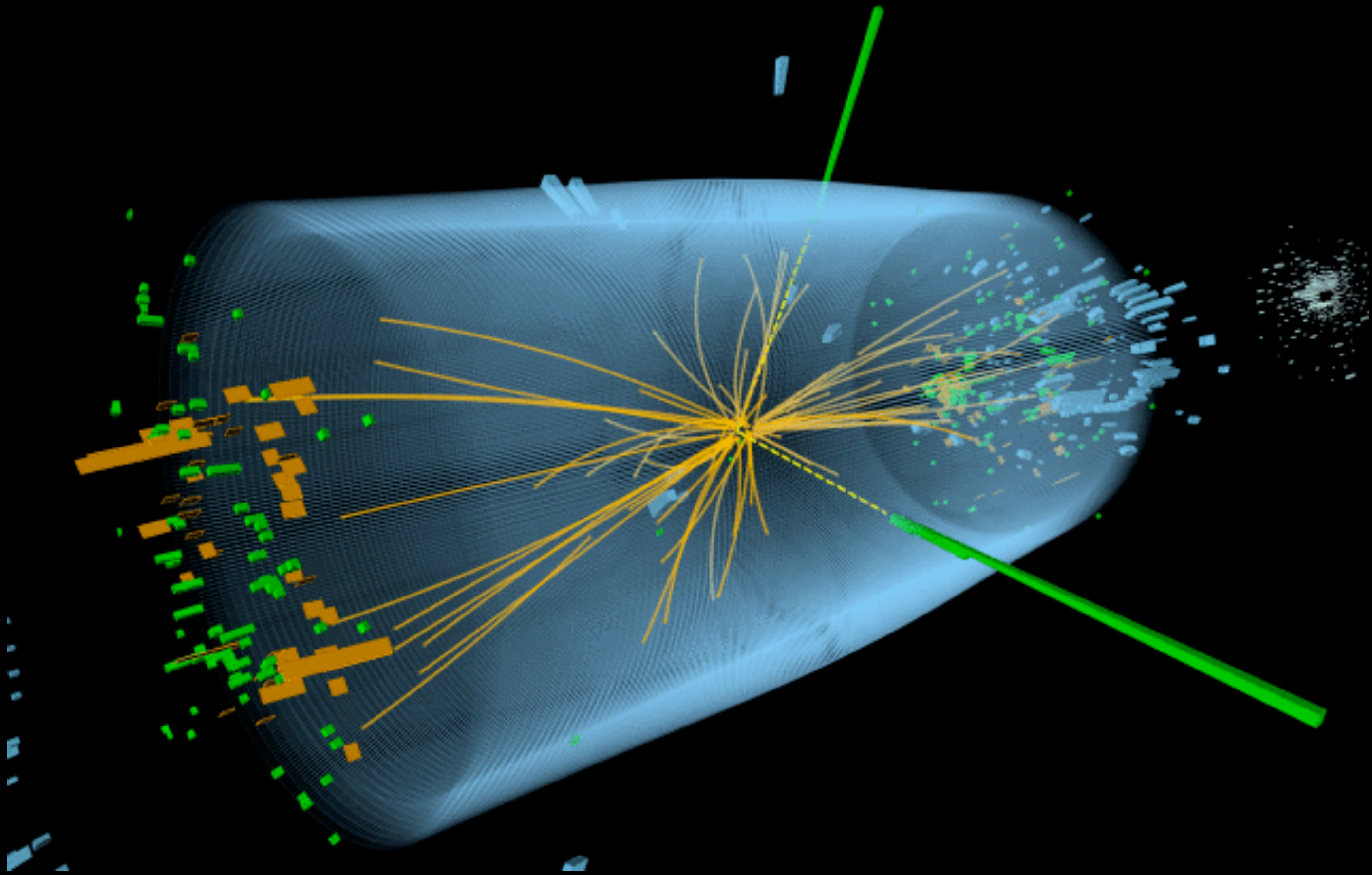
25 $\cdot 10^6$ Z → $\mu\mu$ decays produced

- Excellent LHC performance
  Peak luminosities > 7 10^{33} cm^{-2} s^{-1} (world record, 2012)

- Excellent performance of the experiments:
  - Data recording efficiency ~93.5%
  - Working detector channels >99%
  - Speed of data analysis


Standard Model Production Cross Section Measurements
Status: July 2014
σ [pb]
ATLAS Preliminary
Run 1 √s = 7, 8 TeV
LHC pp √s = 7 TeV
Theory
Data 4.5 – 4.7 fb⁻¹
LHC pp √s = 8 TeV
Theory
Data 20.3 fb⁻¹
80 μb⁻¹
0.1 < pT < 2 TeV
0.3 < mjj < 5 TeV
35 pb⁻¹
4.9 fb⁻¹
2.0 fb⁻¹
13.0 fb⁻¹
1.0 fb⁻¹
0.7 fb⁻¹
95% CL upper limit
pp total
Jets R=0.4 |y|<3.0
Dijets R=0.4 |y|<3.0 y*<3.0
W fiducial
Z fiducial
tt̄ total
t t-chan total
WW+WZ total
WW total
γγ fiducial
Wt total
WZ total
ZZ total
tt̄γ fiducial
Wγ fiducial njet=0
Zγ fiducial njet=0
tt̄W total
tt̄Z total
Zjj EWK fiducial
H→γγ fiducial
W±W±jj EWK fiducial
t s-chan total

Discovery of a Higgs boson at the LHC

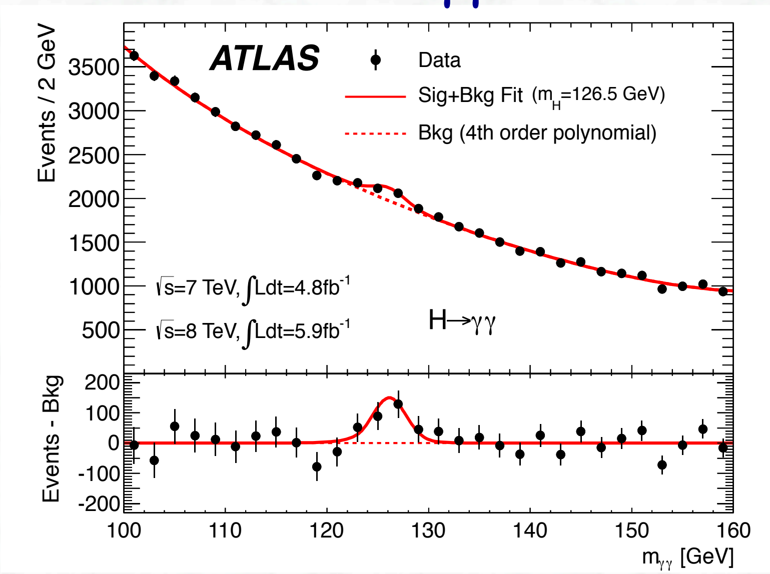


Expected number of decays in the data:
m_H = 125 GeV

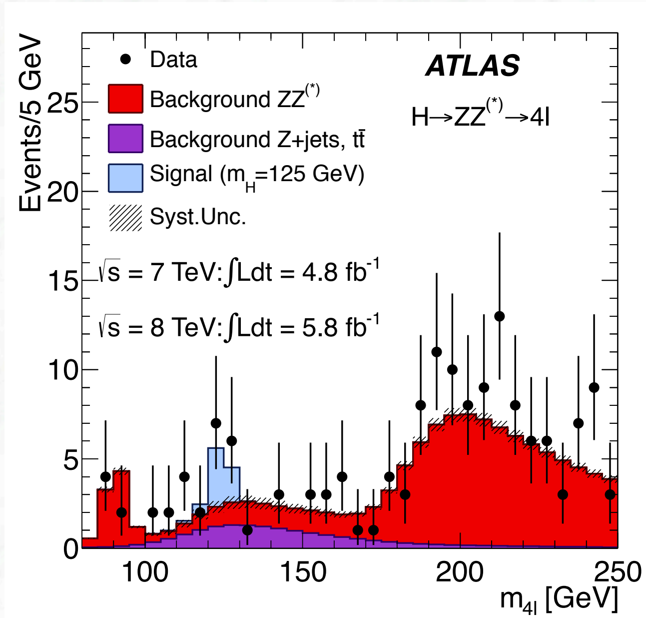
~ 950 H → $\gamma\gamma$
~ 60 H → ZZ → 4 ℓ
~ 9000 H → WW → $\ell\nu$ $\ell\nu$

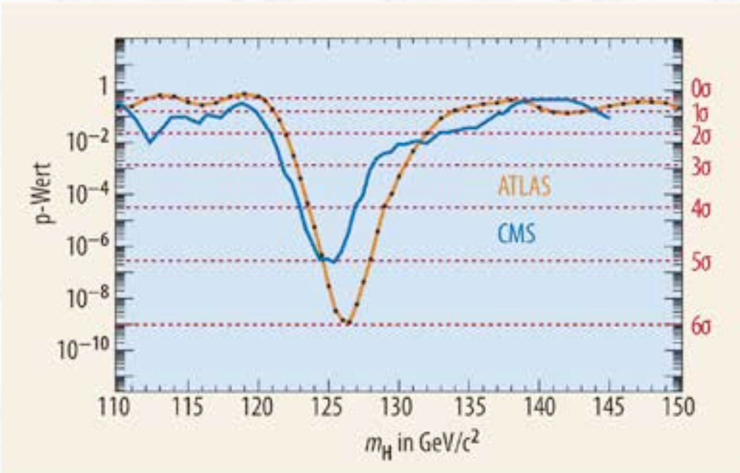
Result of the Search for the Higgs Boson in the ATLAS experiment (July 2012)

H → γγ



H → ZZ → 4ℓ





M. Schumacher, C. Weiser (2012), Physik Journal 11, Nr. 8/9.

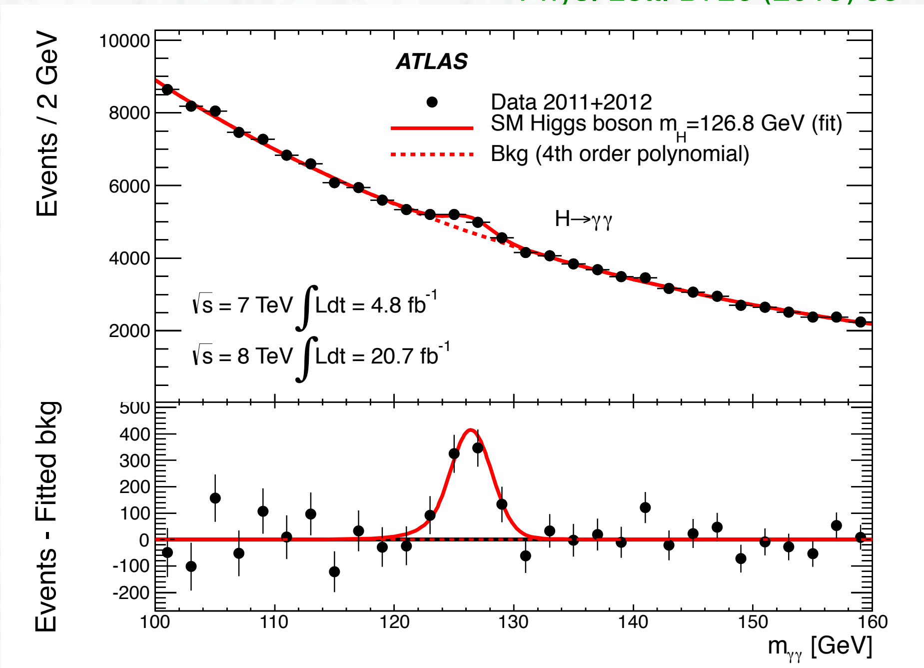
Probability for background fluctuation: $p = 10^{-9}$ = 1 : 1 000 000 000

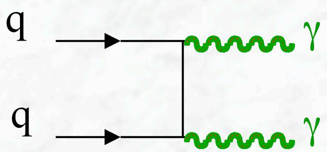
→ Discovery of a „Higgs-like particle“ (neutral, integer spin = boson)

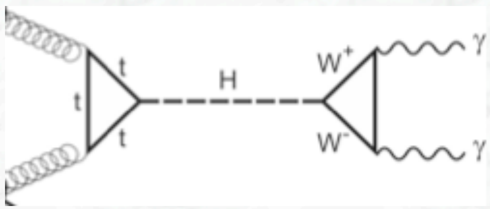
Where do we stand today?

Result of the ATLAS search for H → $\gamma\gamma$

Phys. Lett. B726 (2013) 88





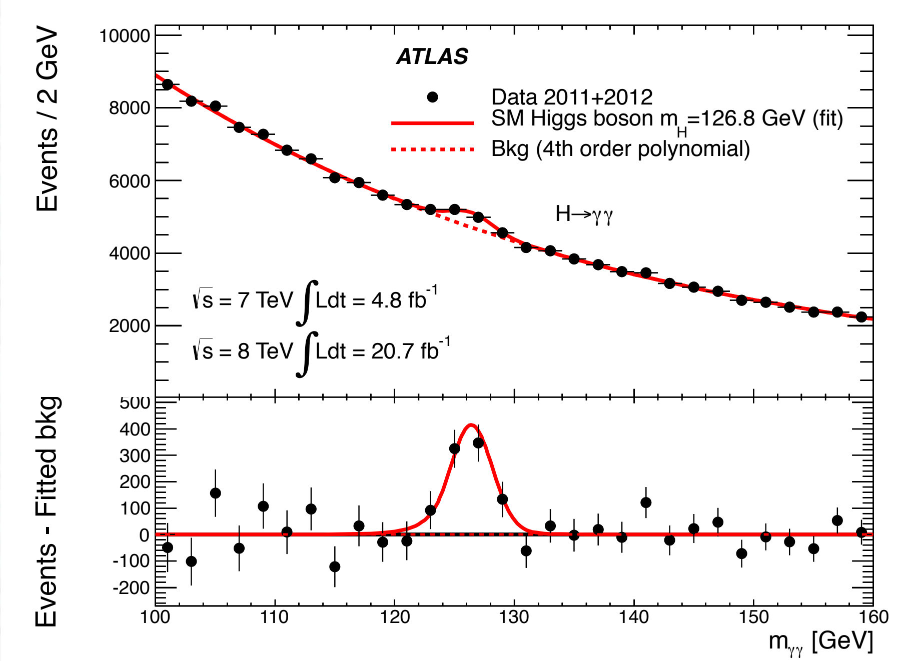


Background

Higgs signal (main production process via gluon fusion)
(mass can be reconstructed from $\gamma\gamma$)

Result of the ATLAS search for H → $\gamma\gamma$

Phys. Lett. B726 (2013) 88

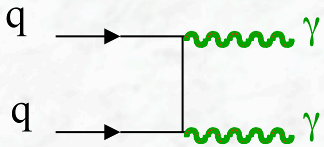


p-value for consistency of data with background-only: $\sim 10^{-13}$ (7.4σ observed)

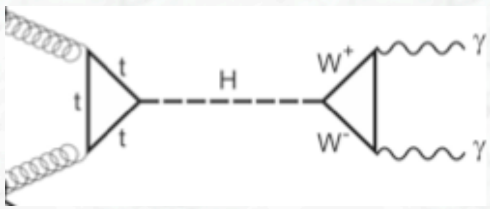
Measured signal strengths:

ATLAS: $\mu = \sigma_{obs}/\sigma_{SM} = 1.17 \pm 0.27$

CMS: $\mu = \sigma_{obs}/\sigma_{SM} = 1.14 \pm 0.26$

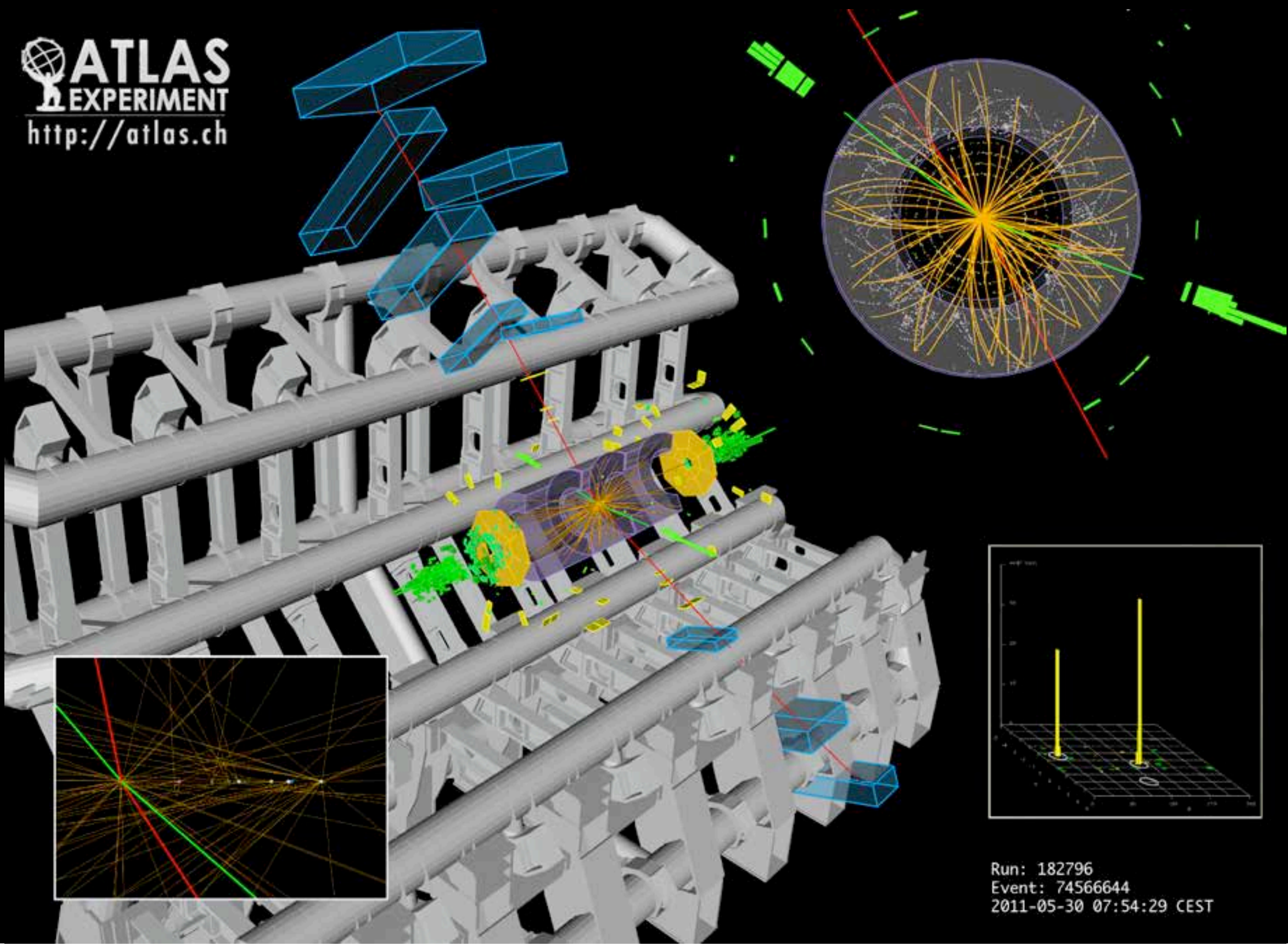


Background



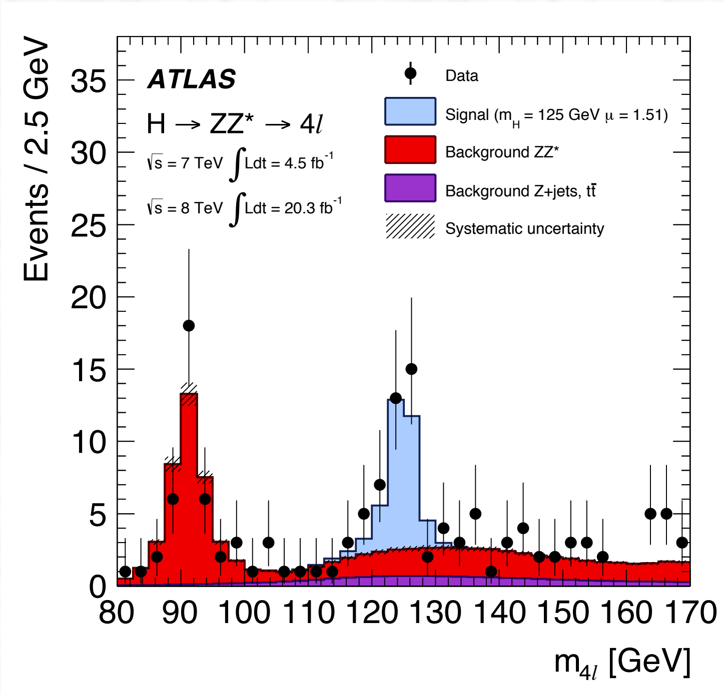
Higgs signal (main production process via gluon fusion)
(mass can be reconstructed from $\gamma\gamma$)

Candidate event for a $H \rightarrow ZZ \rightarrow e^+e^- \mu^+ \mu^-$ decay

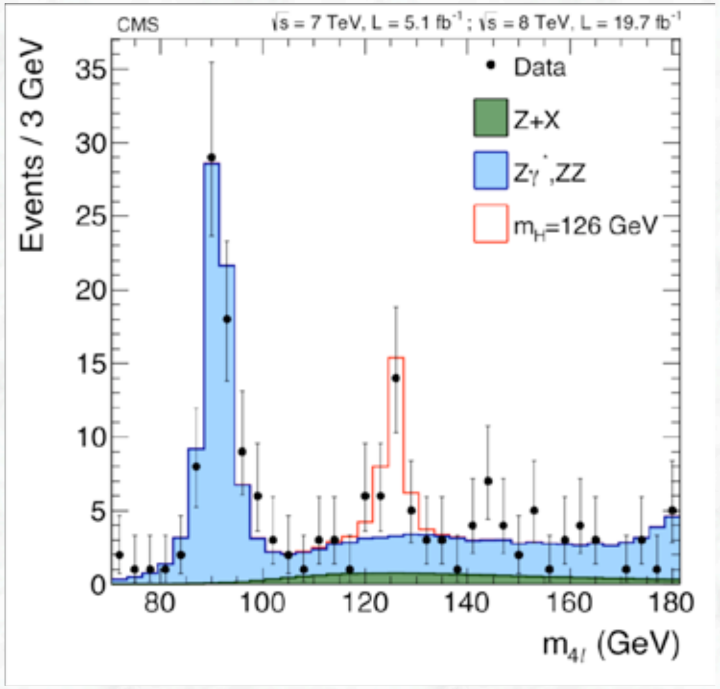


Reconstructed mass spectra from 4ℓ decays

Phys. Rev. D91 (2014) 012006



Phys. Rev. D89 (2014) 092007



Measured signal strengths:

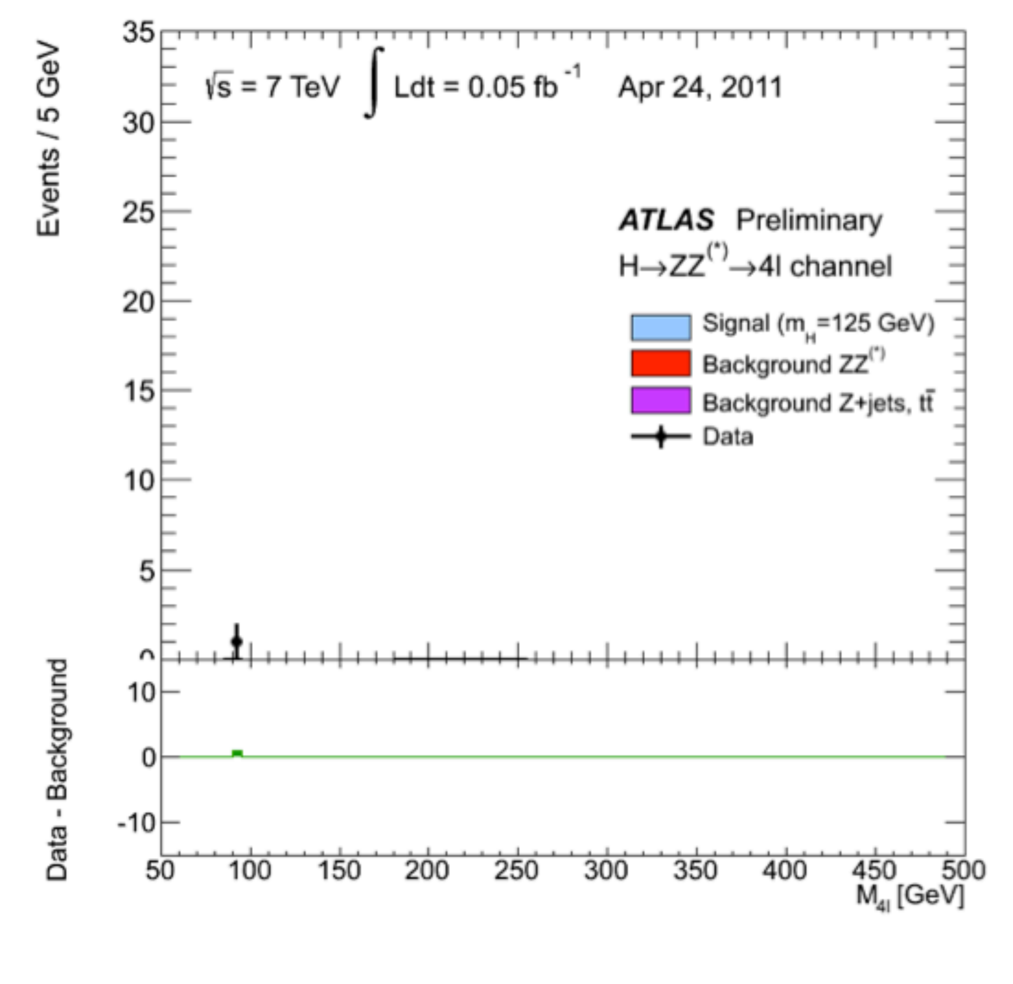
ATLAS: $\mu = 1.44\,^{+0.40}_{-0.33}$

CMS: $\mu = 0.93\,^{+0.29}_{-0.23}$

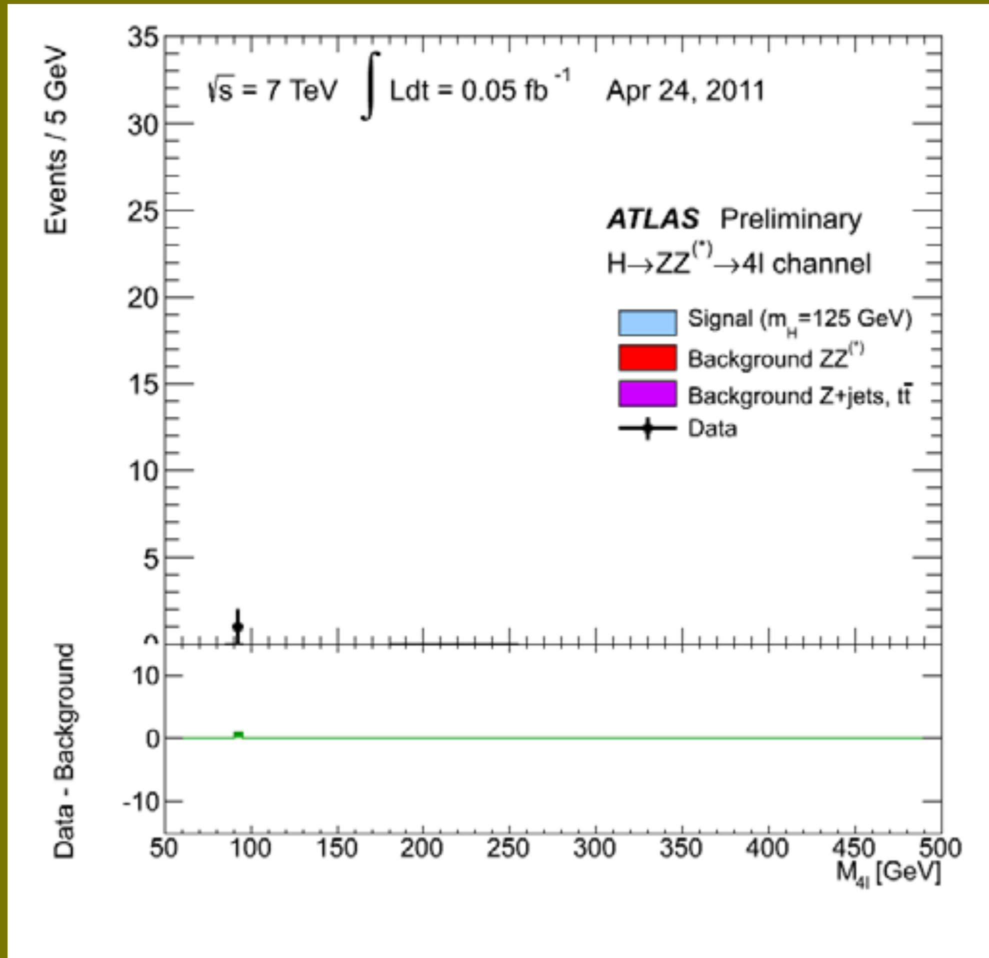
Significance in each experiment $> 6\sigma$

Time evolution of the $H \rightarrow ZZ \rightarrow 4\ell$ signal

Time evolution of the H → ZZ → 4ℓ signal



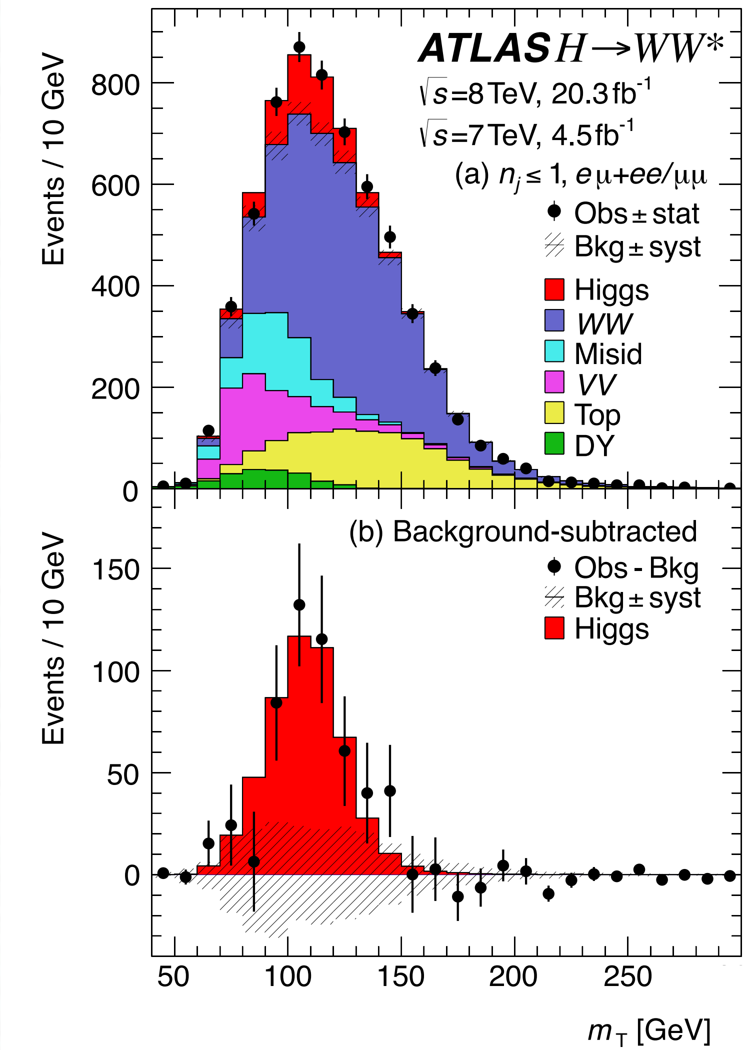
Time evolution of the H → ZZ → 4ℓ signal

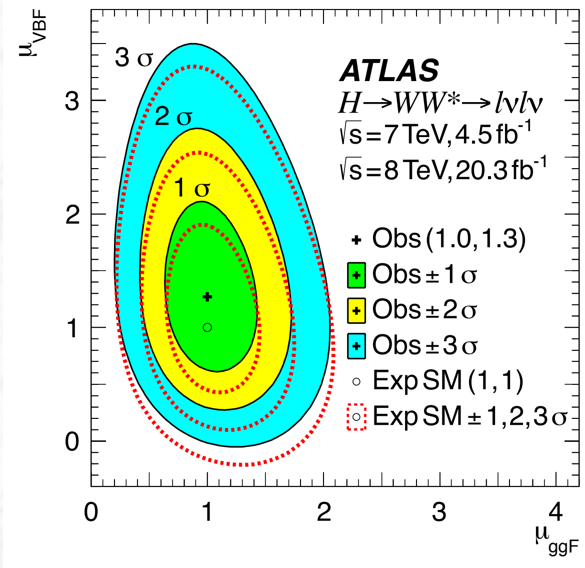


$H \rightarrow WW^*$?

H → WW* → ℓν ℓν signal

arXiv:1412.2641





Measured signal strengths:

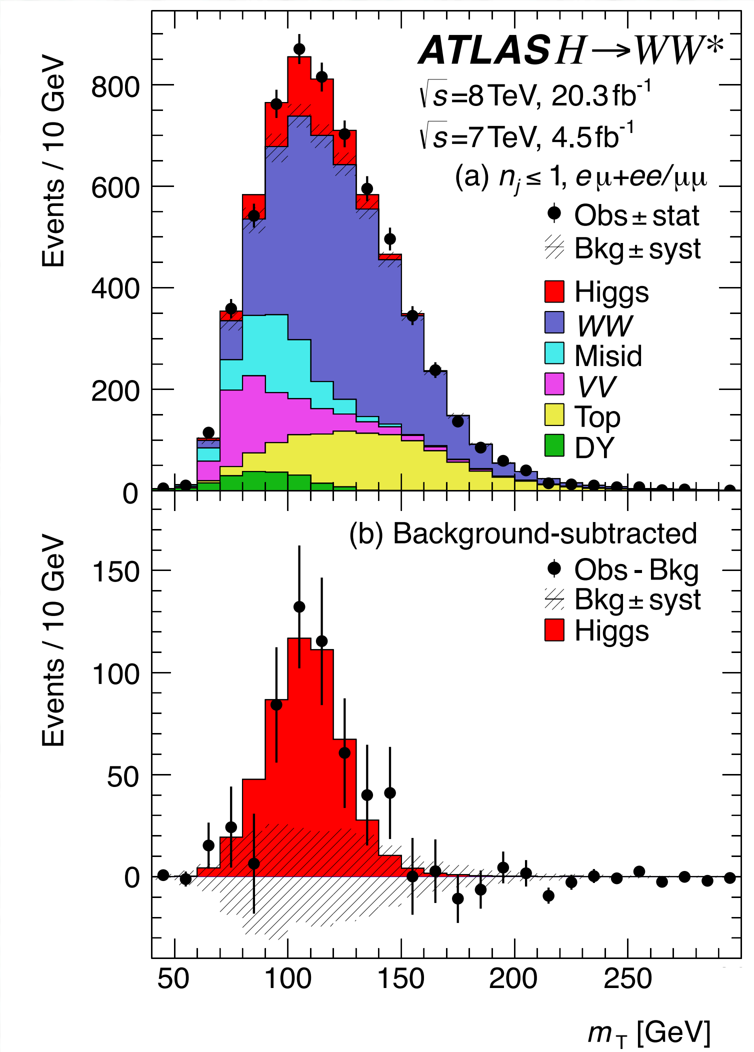
ATLAS: ggF: $\mu = 1.02^{+0.29}_{-0.26}$
VBF: $\mu = 1.27^{+0.53}_{-0.45}$

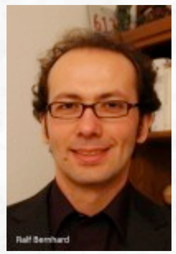
CMS: $\mu = 0.72^{+0.20}_{-0.18}$

- Very significant excess in the “transverse mass” distribution visible
- Signals for both gluon-fusion (ggF) and vector-boson fusion (VBF) production

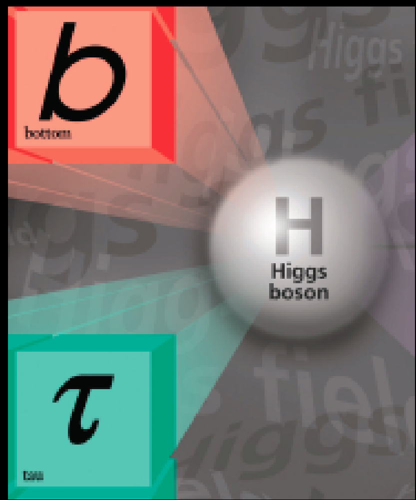
H → WW* → ℓν ℓν decays

arXIv:1412.2641





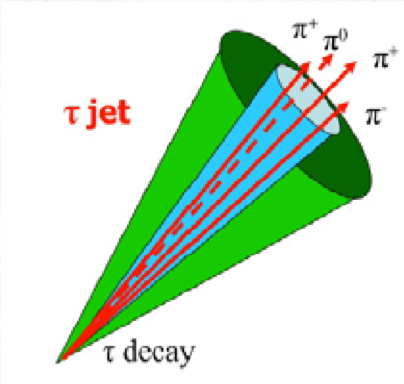
Couplings to quarks and leptons ?



Search for H → ττ and H → bb decays

Search for H → ττ decays

- The tau lepton (heaviest lepton, 1.77 GeV) decays predominantly into hadrons:
  BR ($\tau \rightarrow$ had ν) = 0.65
  BR ($\tau \rightarrow \ell\, \nu\nu$) = 0.35, ℓ = e,μ



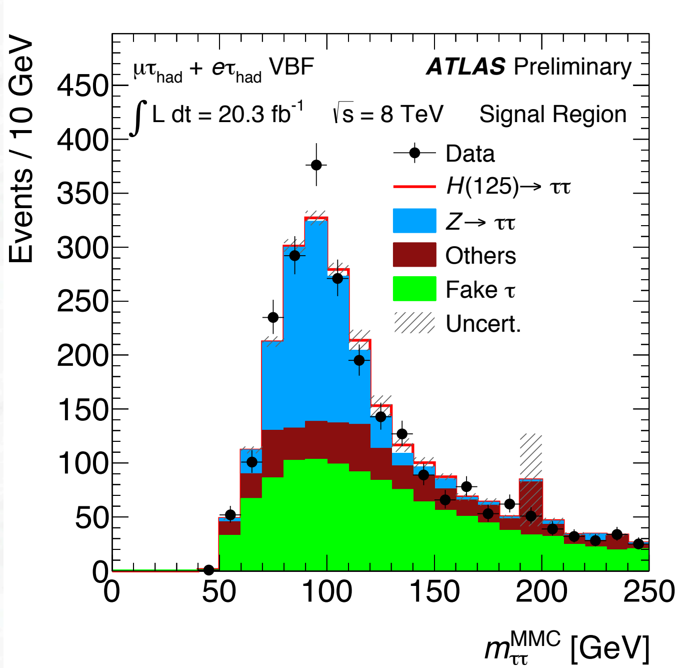
- Challenging signature (separation against jets from QCD processes)
  Separation: narrow jet, only 1 or 3 charged particles

- 2-4 neutrinos in final state, mass reconstruction difficult;
  and a bad resolution (~15 GeV)

- Major background: Z → ττ decays;

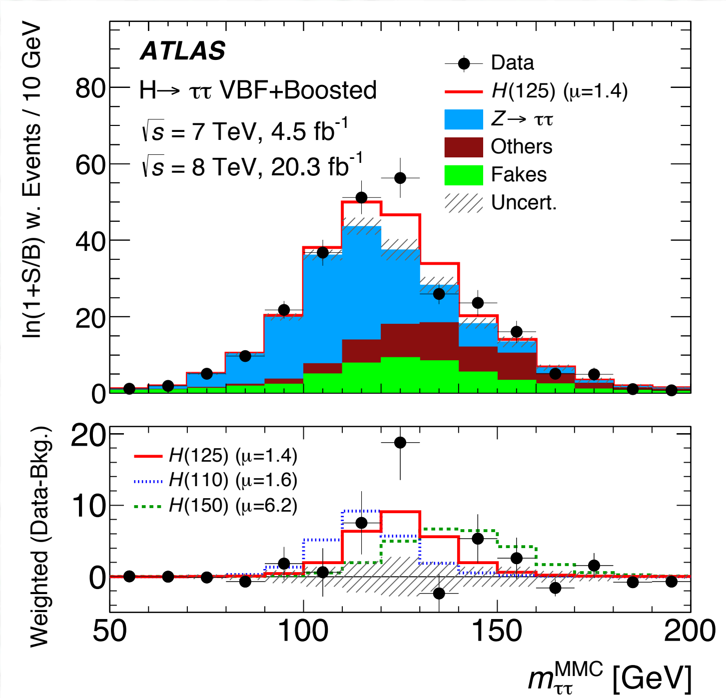
  Challenging signal-to-background conditions

  → use multivariate analysis techniques



Evidence for H → ττ decays

arXiv:1501:04943 (2015)



$m_{\tau\tau}$ distribution, events weighted by ln (1+S/B)

Measured signal strengths:

ATLAS: $\mu = 1.43\ ^{+0.43}_{-0.37}$ (4.5σ)

CMS: $\mu = 0.78 \pm 0.27$ (3.2σ)

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2014-262

Submitted to: Journal of High Energy Physics

arXiv:1501.04943v2 [hep-ex] 26 Jan 2015

Evidence for the Higgs-boson Yukawa coupling to tau leptons with the ATLAS detector

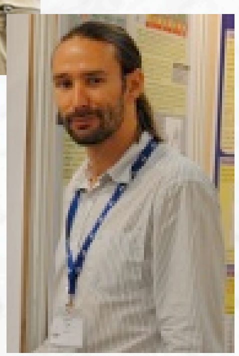
The ATLAS Collaboration

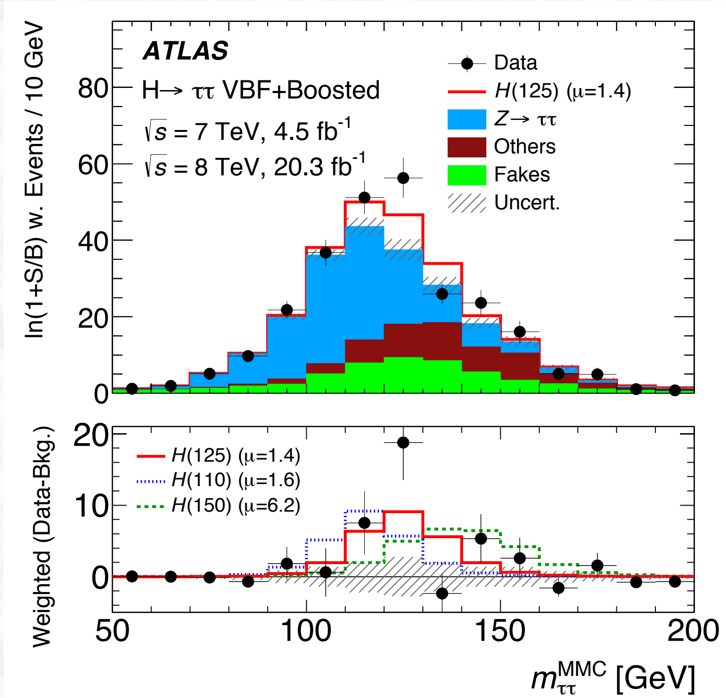
Abstract

Results of a search for $H \to \tau\tau$ decays are presented, based on the full set of proton–proton collision data recorded by the ATLAS experiment at the LHC during 2011 and 2012. The data correspond to integrated luminosities of 4.5 fb^{-1} and 20.3 fb^{-1} at centre-of-mass energies of $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 8 TeV respectively. All combinations of leptonic ($\tau \to \ell\nu\bar{\nu}$ with $\ell = e, \mu$) and hadronic ($\tau \to \mathrm{hadrons}\ \nu$) tau decays are considered. An excess of events over the expected background from other Standard Model processes is found with an observed (expected) significance of 4.5 (3.4) standard deviations. This excess provides evidence for the direct coupling of the recently discovered Higgs boson to fermions. The measured signal strength, normalised to the Standard Model expectation, of $\mu = 1.43\ ^{+0.43}_{-0.37}$ is consistent with the predicted Yukawa coupling strength in the Standard Model.

One of the most important LHC results in 2014

Evidence for H → ττ decays

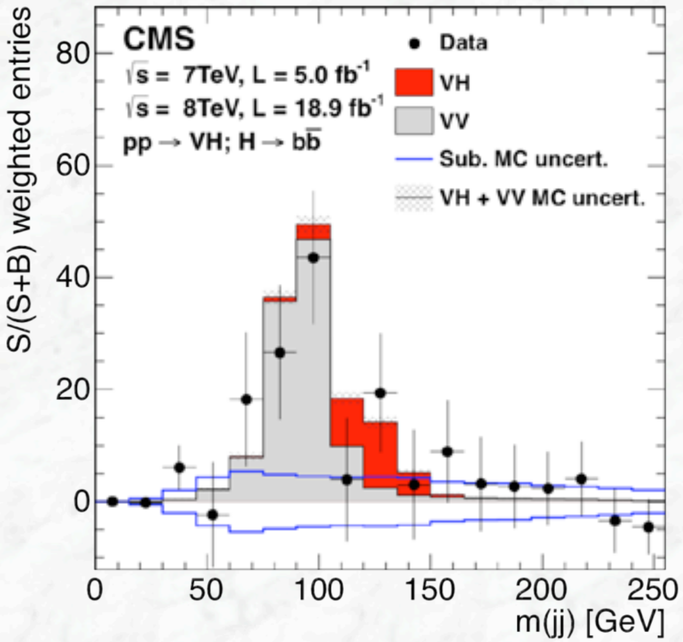




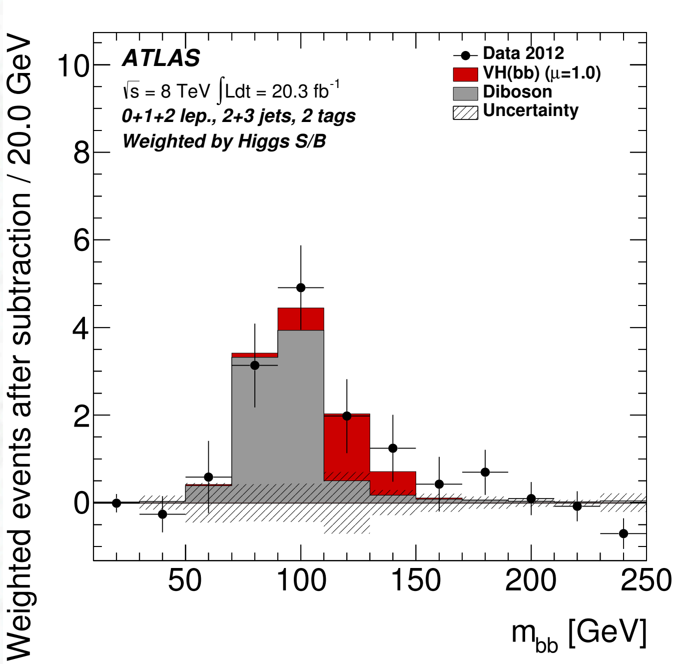
Jakobs und Schumacher groups

Results on the search for H → bb decays

Phys. Rev. D89 (2014) 012003



JHEP01 (2015) 069



Reconstructed m_{bb} signals (after subtraction of major backgrounds)

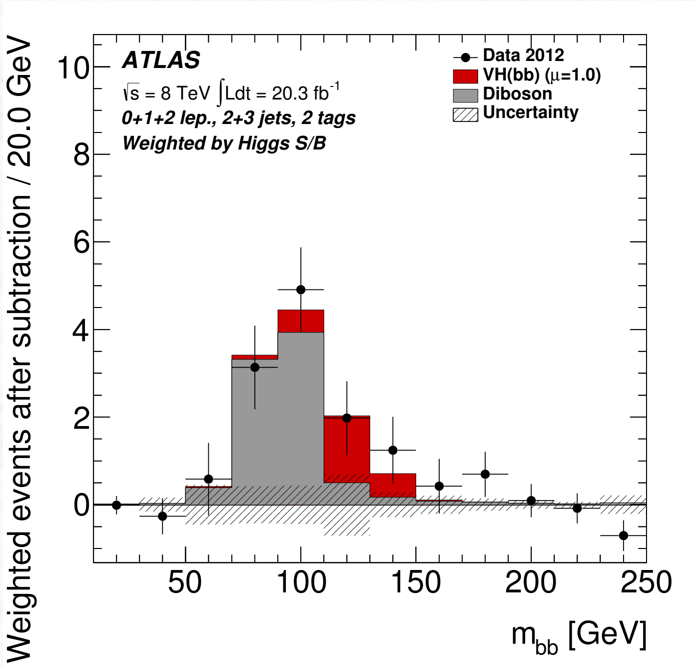
- Very challenging background conditions, difficult analysis
- Reference signal from WZ, and ZZ with Z → bb seen
- Positive, but non-conclusive Higgs boson signal contribution observed

Signal strengths:

ATLAS: $\mu = 0.50 \pm 0.36$

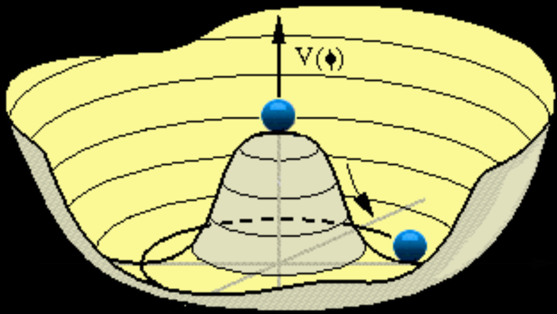
CMS: $\mu = 1.0 \pm 0.5$

Results on the search for H → bb decays



JHEP01 (2015) 069

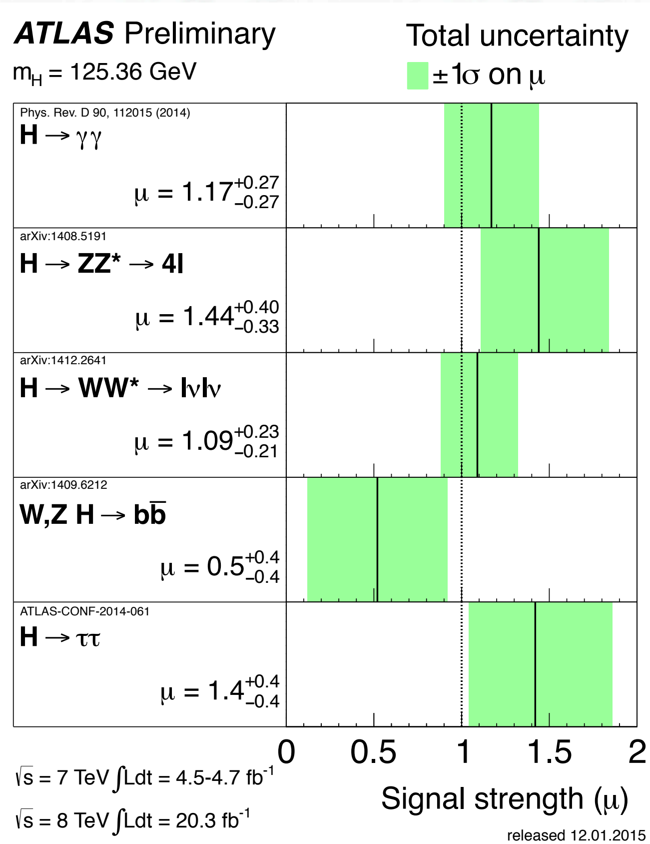
Is the new particle the Higgs Boson ?



- Production rates
- Spin, J^P quantum number
- Couplings to bosons and fermions

Signal strength in individual decay modes

-normalised to the expectations for the Standard Model Higgs boson-



ATLAS 2015

ATLAS: m_H = 125.36 ± 0.37 (stat) ± 0.18 (syst) GeV

CMS: m_H = 125.03 ± 0.27 (stat) ± 0.14 (syst) GeV

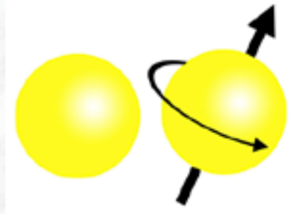
Signal strengths:

ATLAS: μ_{ges} = 1.30 ± 0.17 (prel.)

CMS: μ_{ges} = 1.00 ± 0.14 (new)

- Data are consistent with the hypothesis of the Standard Model Higgs boson
- If ATLAS and CMS combined: clear evidence for coupling to fermions

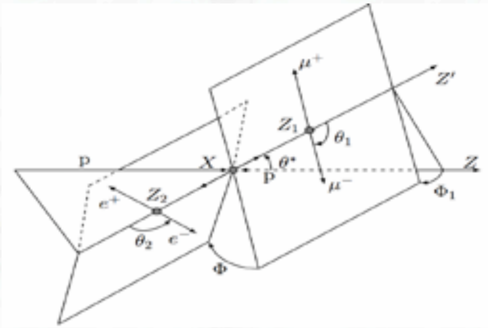
Spin and CP

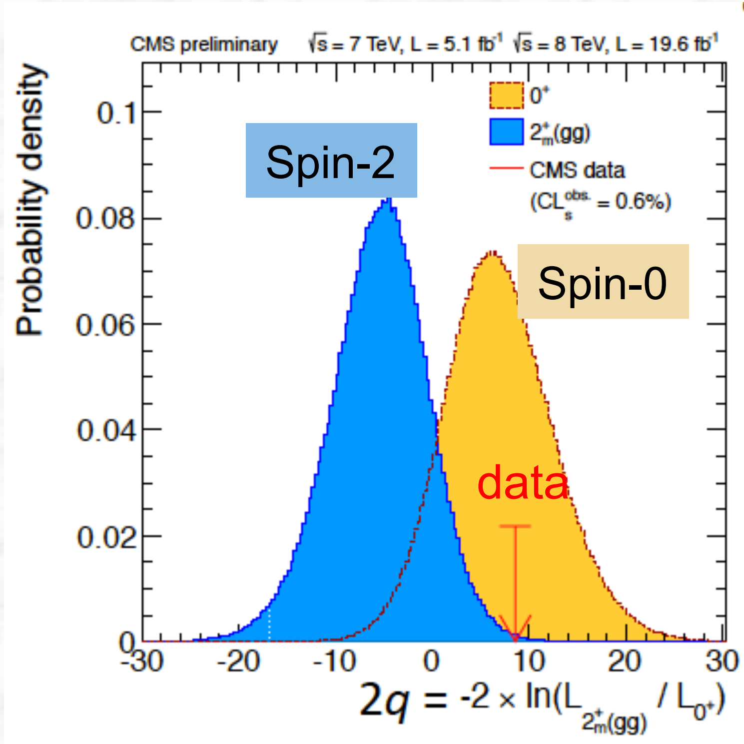


- If Standard Model Higgs boson: $J^P = 0^+$

  → strategy is to falsify other hypotheses (0^-, 1^-, 1^+, 2^-, 2^+)

- Angular distributions of final state particles show sensitivity to spin



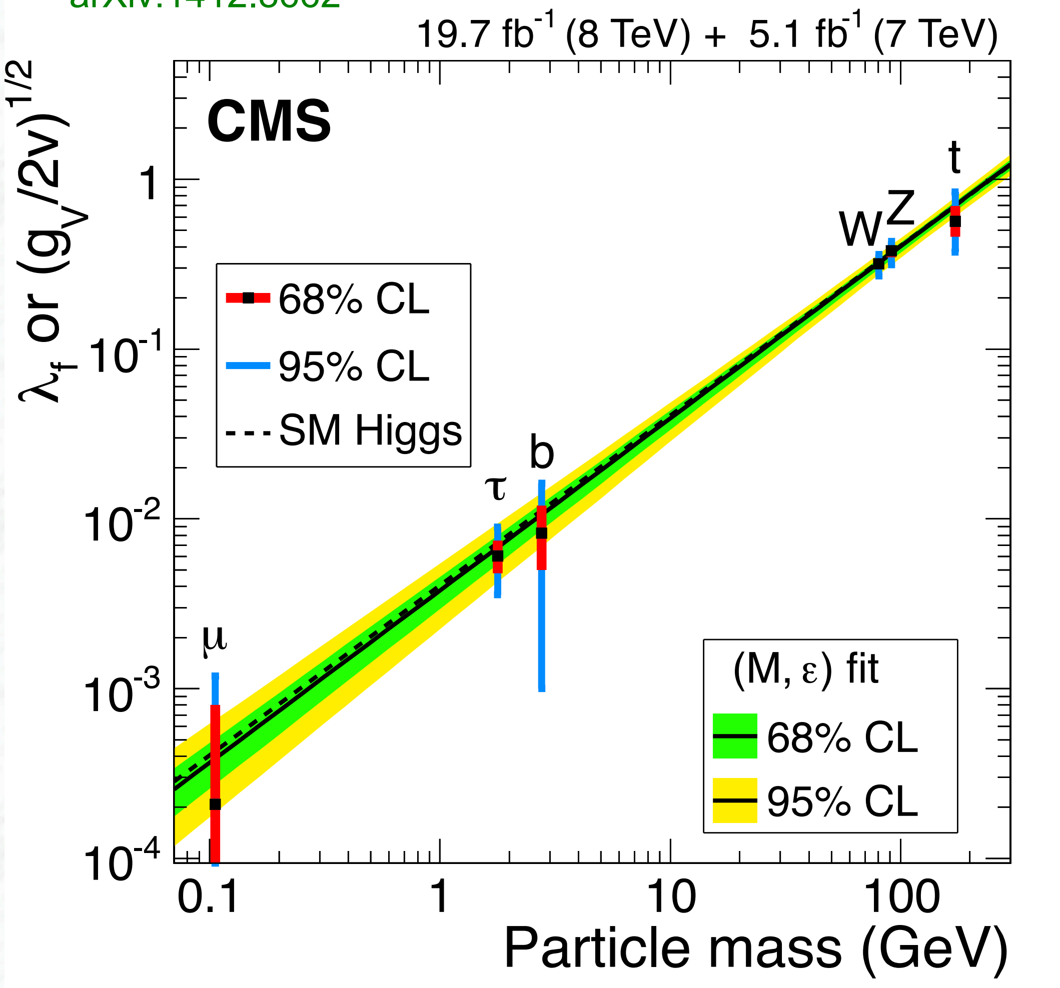


Data strongly favour the spin-0 hypothesis of the Standard Model

(Alternatives can be excluded with confidence levels > 99%)

CMS results on Higgs boson couplings

arXiv:1412.8662



λ = Yukawa coupling for fermions

$\sqrt{g/2v}$ = couplings for W/Z bosons

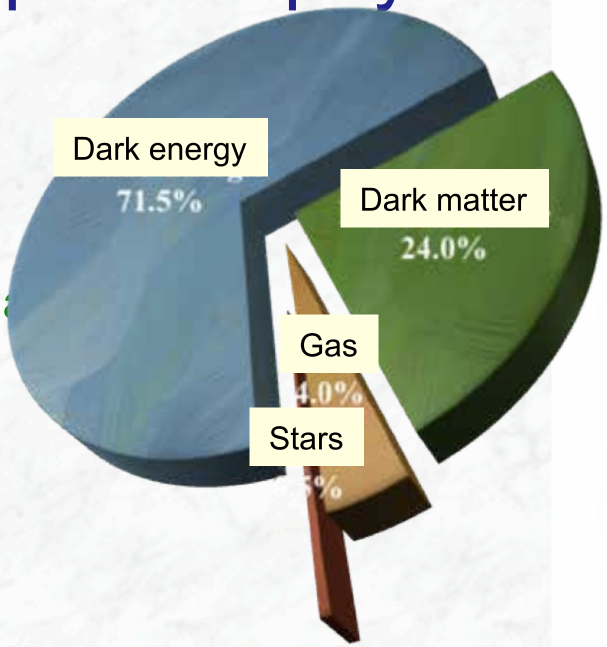
For the first time, non-universal, mass-dependent couplings observed

What next?

Key questions of particle physics

1. Mass

Precise profile of the Higgs boson
Additional Higgs bosons?
What stabilizes the Higgs boson ma

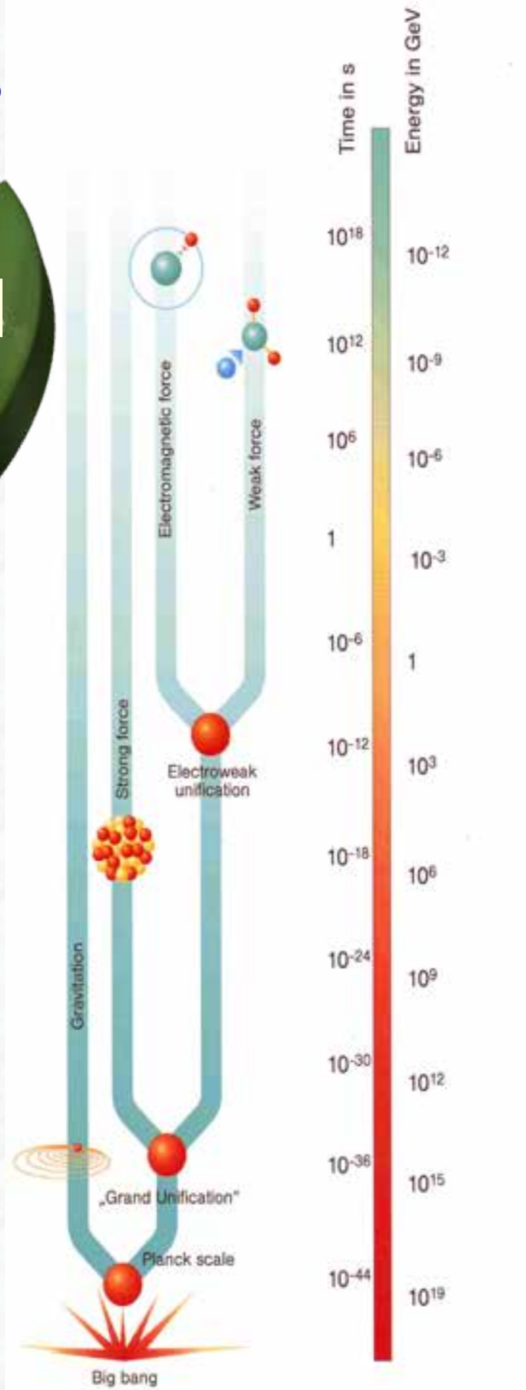


2. Unification

- Can the interactions be unified?
- Are there new types of matter, e.g. supersymmetric particles ? Are they responsible for the Dark Matter in the universe?

3. Flavour

- Why are there three generations of particles?
- What is the origin of the matter-antimatter asymmetry (Origin of CP violation)
- Is there CP-violation in the Higgs sector?



What next ?

- The LHC will resume operation at an increased energy (at √s = 13 – 14 TeV) in March / April 2015 (higher energy and higher luminosity)

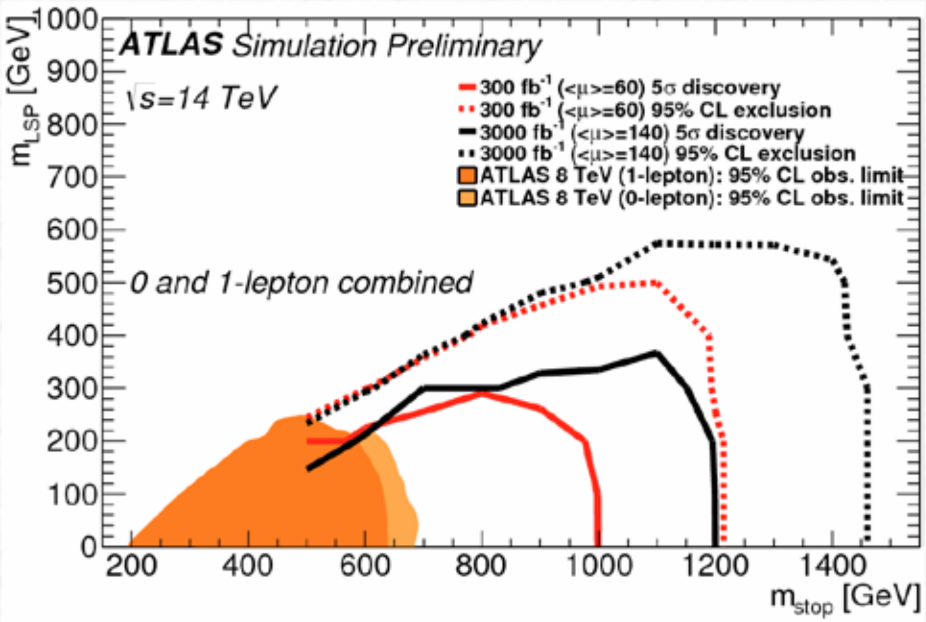
- A new energy range will be explored !!

Major physics topics:
(i) Extend the searches for New Physics

(ii) Precise measurements of the Higgs boson profile

(iii) Additional Higgs bosons?

(iv) Scattering of vector bosons



SUSY 2215

Quantum Mechanics and QFT still hold
The Orbital Collider still sees nothing
Two centuries of triumph for SUSY and Strings

Topical Conference on **SUSY: The New Hope**

DESY - Santander 01. – 05. April 2215

Highlights:

- Extremely weeny constrained SUSY
- The NSFWMSSM model
- The FF3C10ACBA9-MSSM model
- MSSM retrograde
- Susyfication of vdB models
- The anthropic landscape and trimming it down
- Strings: the perpetual revolution

Theorists Special:
" How to ensure your model remains predictability-free?"

Special Topic:
"If the universe is not supersymmetric, does it necessarily exist?"

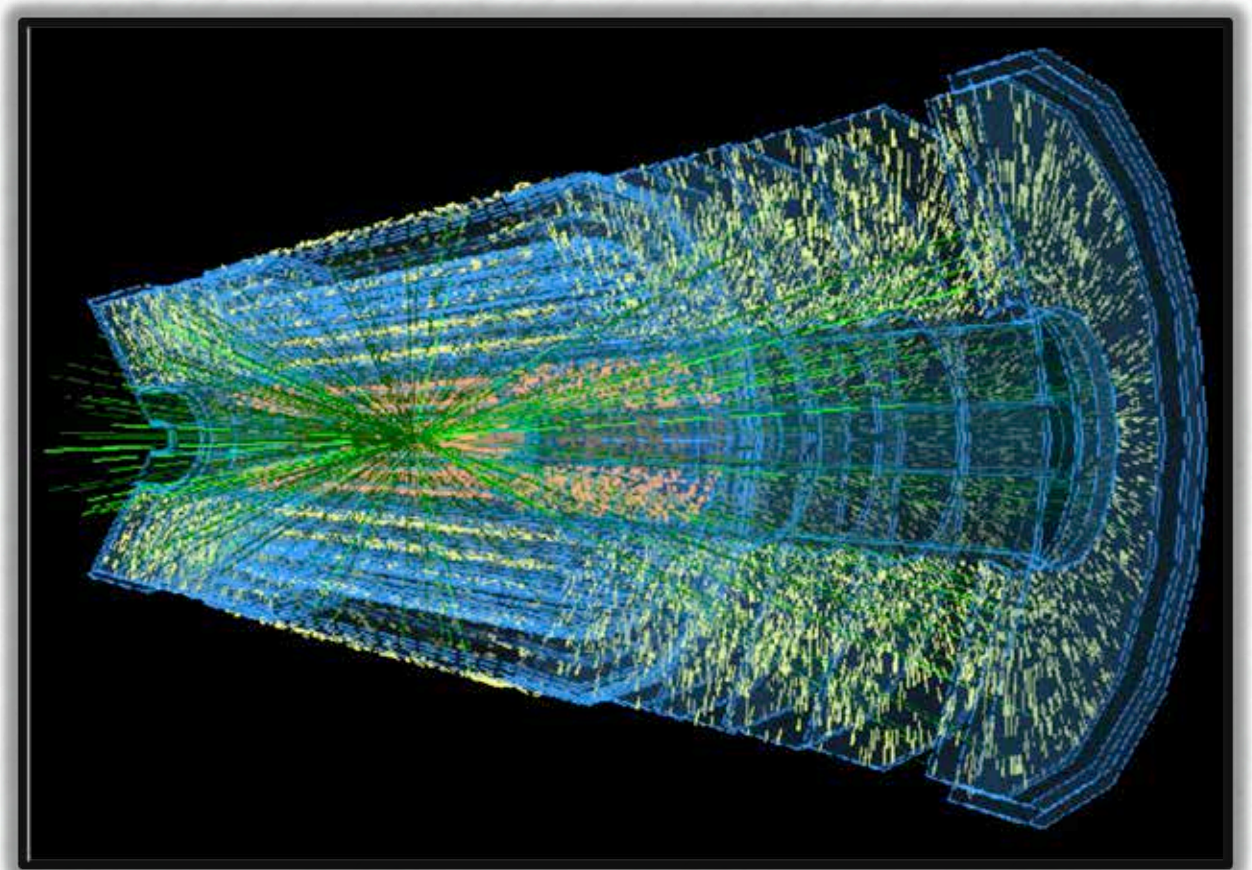
Ethics and strings:
"Every time you choose a path of action, a multiverse is killed

*) Inspired by an EPS-HEP-board "after dinner discussion", courtesy Yves Sirois

New Detectors

- Upgraded detectors are needed to cope with even higher luminosities, beyond 2025 for LHC running until 2035

Research and Development already ongoing, construction until 2022



Conclusions

- With the operation of the LHC at high energies, particle physics has entered a new era
- Performance of the LHC and the experiments is superb
- A milestone discovery announced in July 2012

  Strong evidence that the new particle is the long-sought Higgs Standard Model Higgs boson;
  We moved from the discovery to the measurement phase;
  Higgs boson might be portal to *New Physics* (precision required)

- So far no signals from New Physics, however, only a small fraction of the parameter space at reach at the LHC has been explored
- Exciting times ahead of us, with new, unexplored energy regime in reach