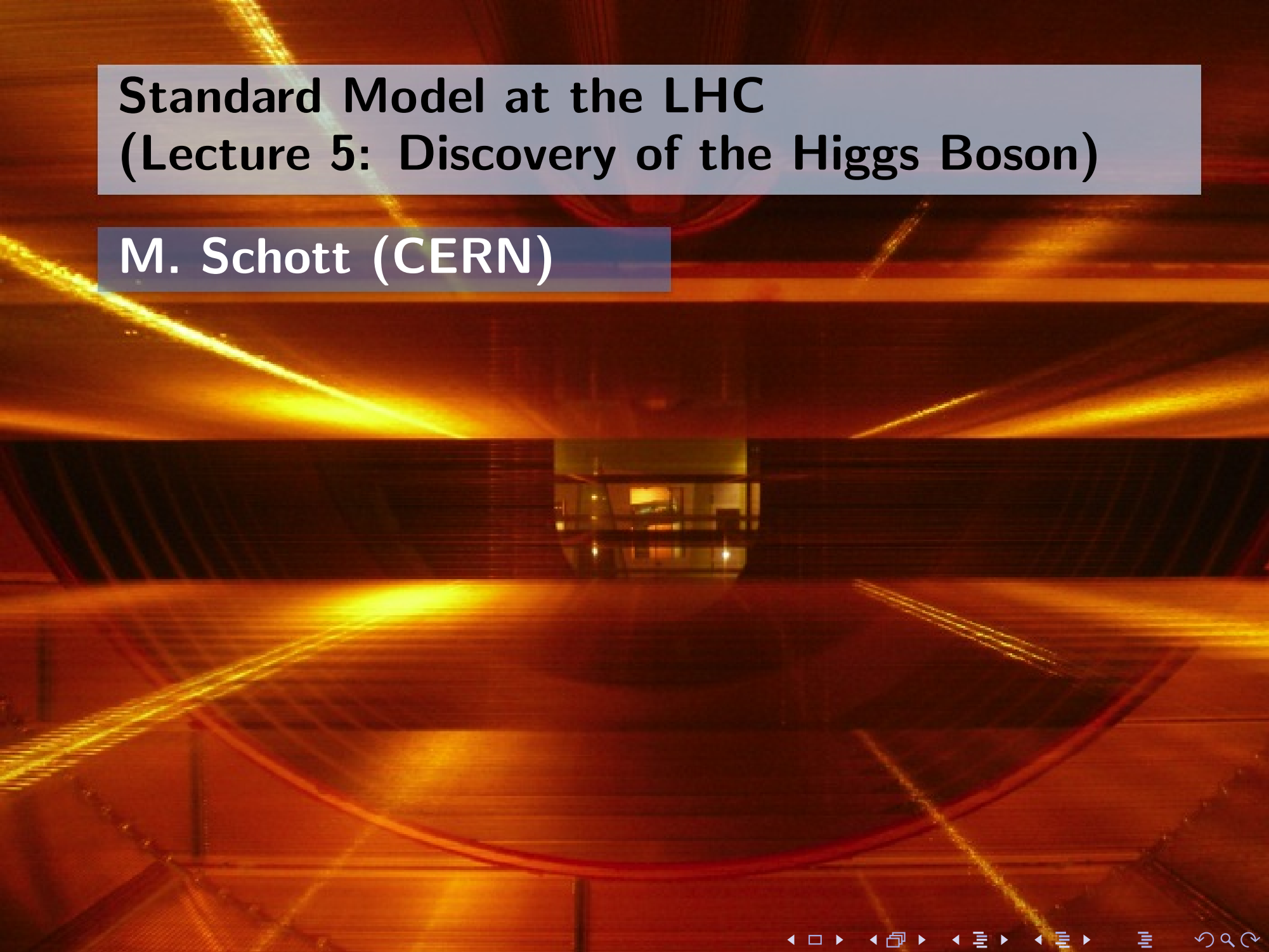


Standard Model at the LHC (Lecture 5: Discovery of the Higgs Boson)

M. Schott (CERN)

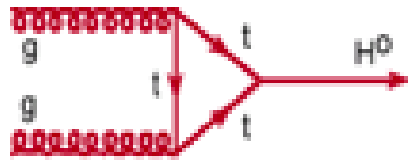
Content

Production of the Higgs Boson

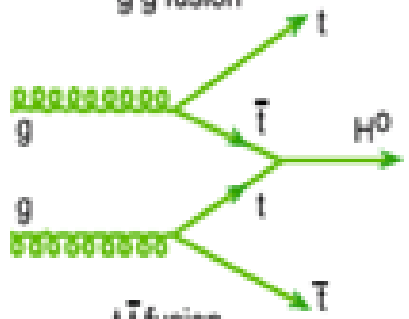
Since all properties of the SM(!) Higgs-Boson are known except of its mass, we can predict very precisely its production and decay rates at the LHC.
Production of the Higgs Boson at the LHC

- Gluon fusion
- WW,ZZ fusion
- Higgs-radiation with W and Z
- Higgs-Bremsstrahlung from top

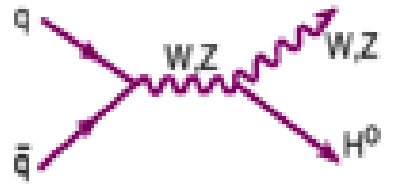
Dominant process at the LHC is gluon fusion



g g fusion



t t̄ fusion

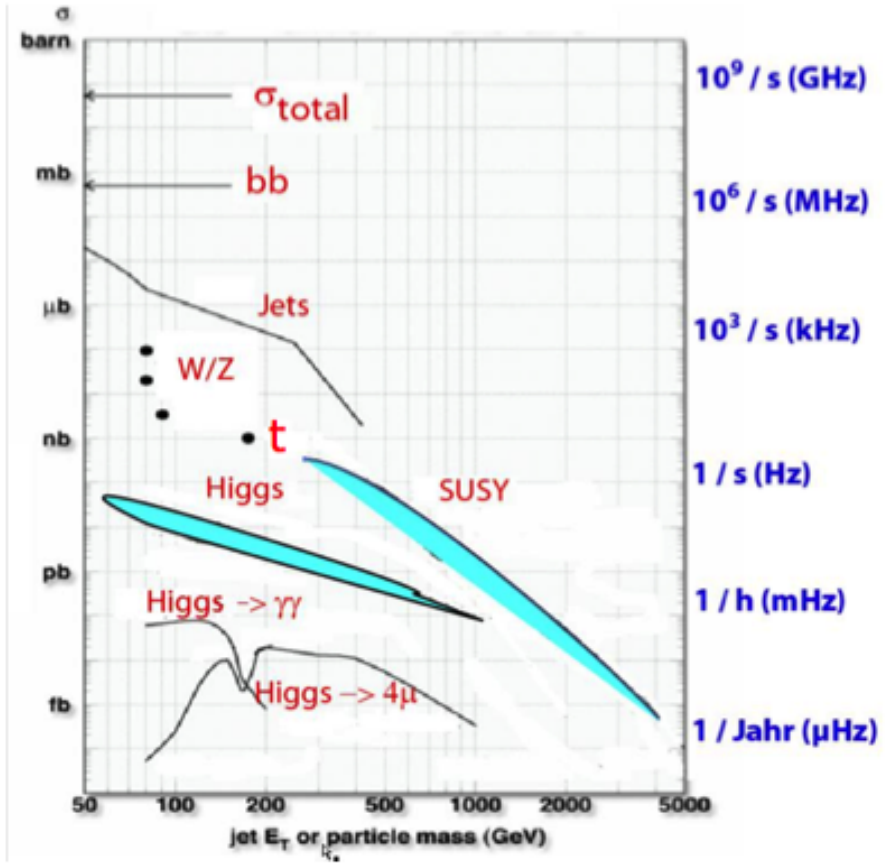


W, Z bremsstrahlung

WW, ZZ fusion

Signal and Background Rates

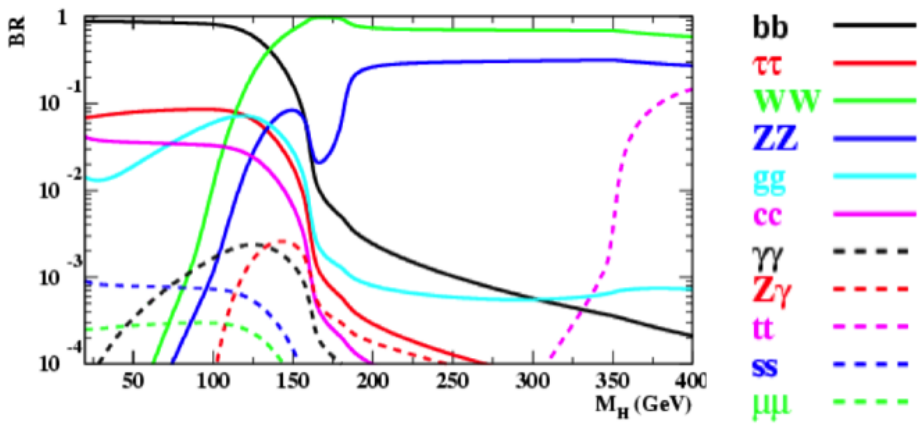
- Large cross-sections for the Higgs-Boson production at the LHC
  - One Higgs boson in every 1 000 000 000 000 proton-proton collisions
- Even larger background rates



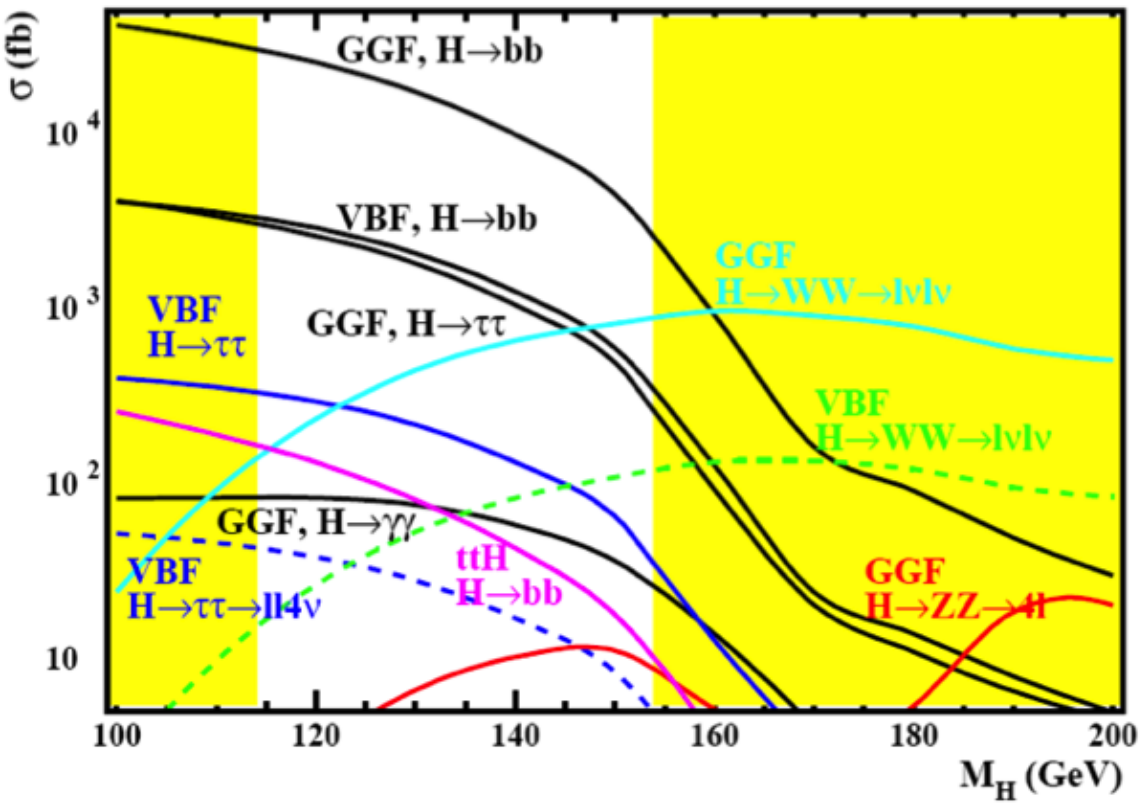
Decay of the Higgs Boson

Higgs-Decay depends on the mass of the Higgs-Boson

- ZZ
- WW
- $b\bar{b}$
- τtau
- $\gamma\gamma$
- ...

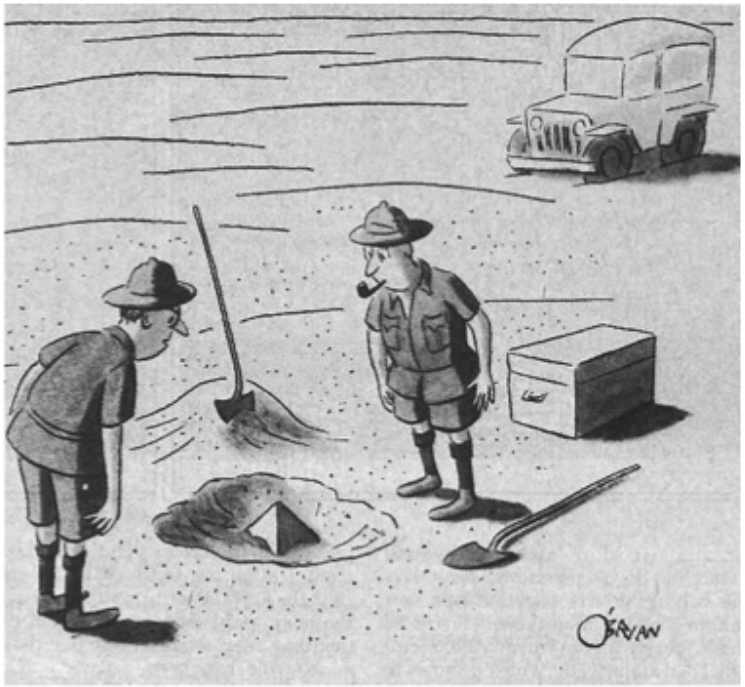


Combined Higgs Production and Decay



How to discover a new particle (1/2)

- Discovery is a significant deviation from your background-only hypothesis
  - new peak in a mass-distribution
  - more events than expected in some kinematic distribution
- For discovery: You only need to know which background you expect
- For exclusion: You also need a signal shape



"This could be the discovery of the century. Depending, of course, on how far down it goes."

How to discover a new particle (2/2)

'Poor-mans' approach of an discovery:

- ignore all systematic uncertainties
- just look at the statistics

Estimation of significance (S)

- N_S = number of measured events
- N_B = number of expected background events
- $S = \frac{N_S}{\sqrt{N_B}}$

If significance S is larger than 5, then we call it a discovery ($p < 2.87 \cdot 10^{-7}$)

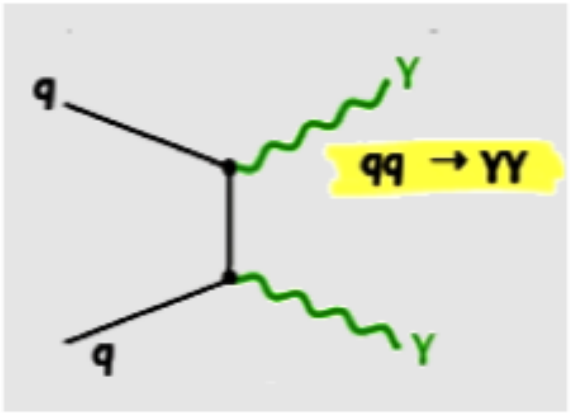
$H \to \gamma\gamma$ channel (1/2)

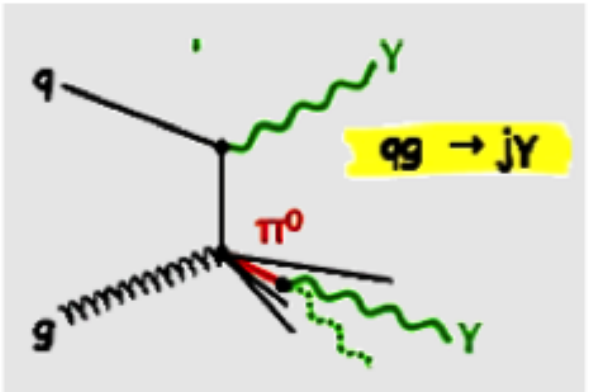
Signal

- two high energetic photons

Background

- irreducible: $\gamma\gamma$ (30pb)
  - need good mass resolution
- reducible
  - γ, jet and jet, jet
  - Try to distinguish photons and jets in the detector
  - Seperate photons and jets e.g. through the form to of the electromagnetic shower





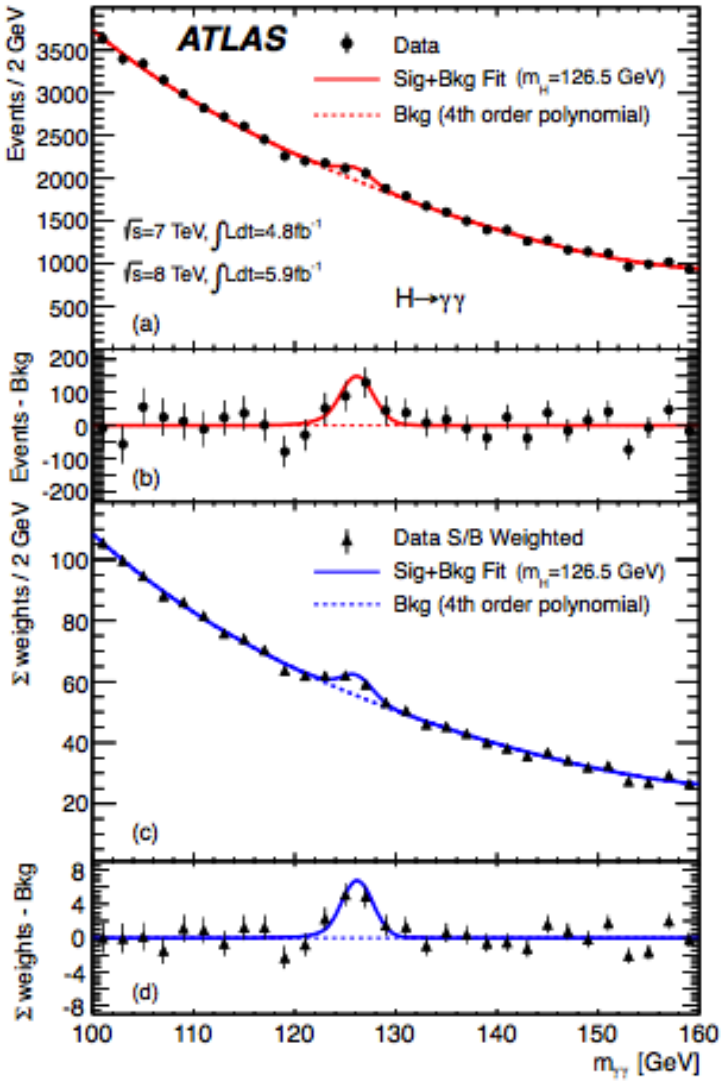
$H \to \gamma\gamma$ channel (2/2)

Event Selection

- photons with $E_T 25, 35 GeV$
- Calculate invariant mass of the two photons

Background Estimation

- Sideband method: 4th order polynomial



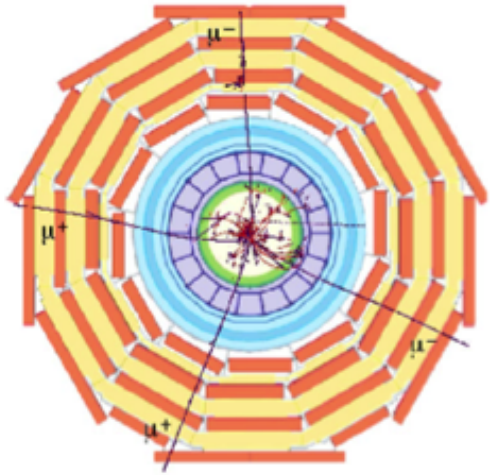
$H \to ZZ$ channel (1/2)

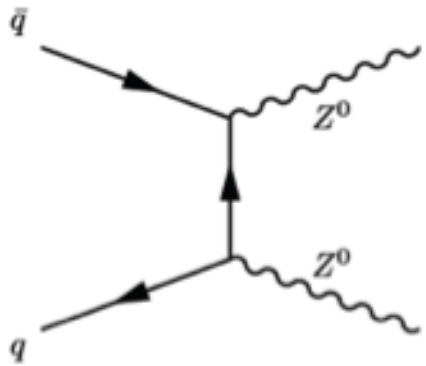
Event Signature

- $H \to ZZ^* \to l^+l^-l^+l^-$
  - four leptons in the final state (only e, μ)

Background: very small ZZ, Zbb, tt

- irreduzibel: Standard Model ZZ
- reduzibel: Â $t\bar{t}$, Zbb





$H \to ZZ$ channel (2/2)

Reduction of reducible Background

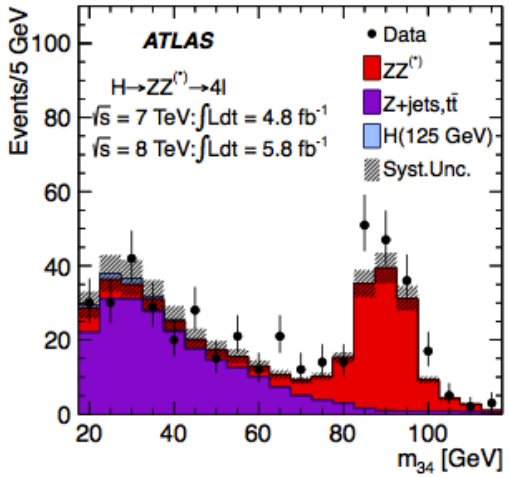
- Isolation of Leptons
- B-Tagging

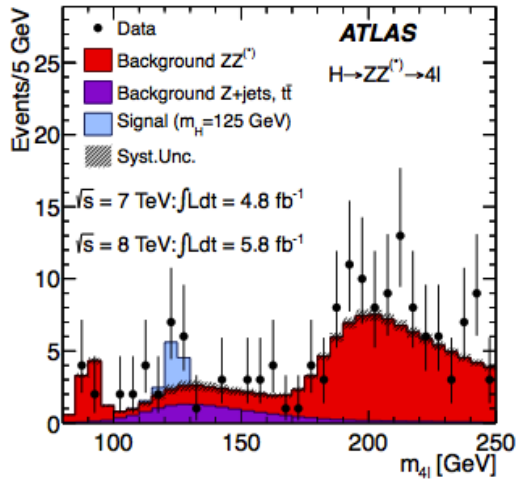
Reduction of irreducible Background

- Requirement of Z-Boson mass constraint

Event Selection

- most energetic lepton: $p_T 20 GeV$
- 2nd most energetic lepton: $p_T 15 GeV$
- 3rd most energetic lepton: $p_T 10 GeV$





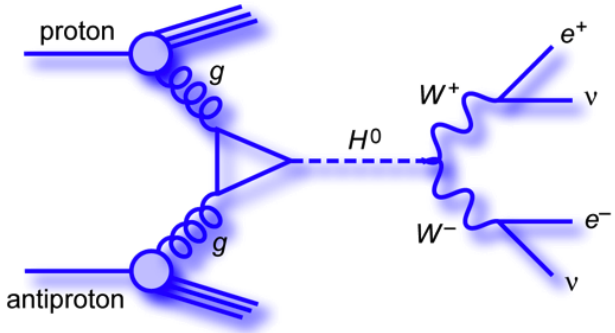
$H \to WW$ channel (1/2)

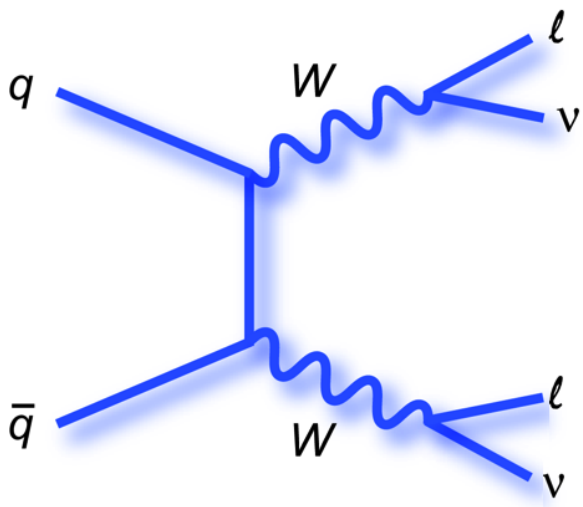
Event Signature

- two high energetic leptons ($e\mu$)
  - oppositely charged
- missing energy due to neutrinos

Main Backgrounds

- WW-Production
- $t\bar{t}$
- W+Jets
- Z+Jets





$H \to WW$ channel (2/2)

Estimate WW Background

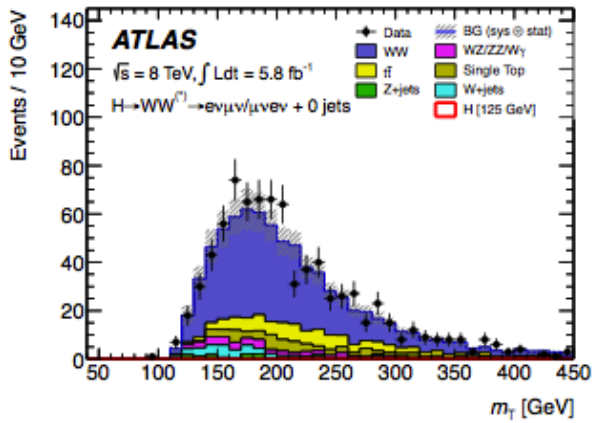
- set invariant mass-cut $m_{ll} 80 GeV$

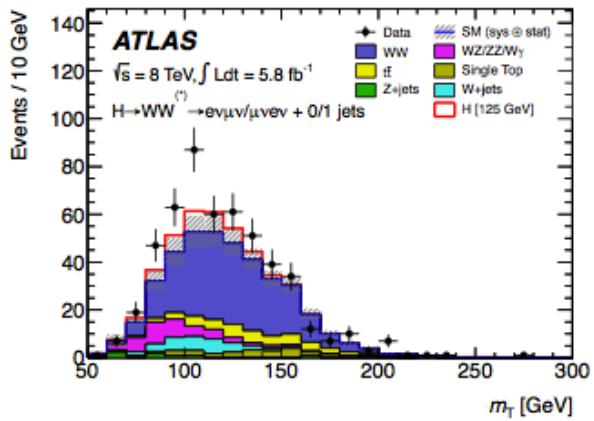
Estimate W+Jets Background

- Fake-Faktor method

Estimate $t\bar{t}$ Background

- Use b-tagged jets distribution!

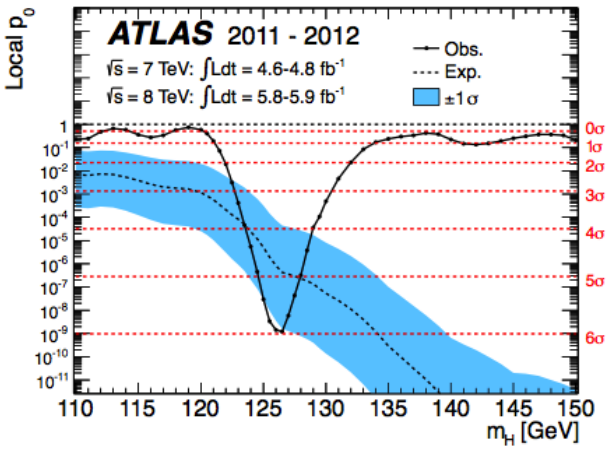




Combination of all channels

We can combine now this information to a single signficance

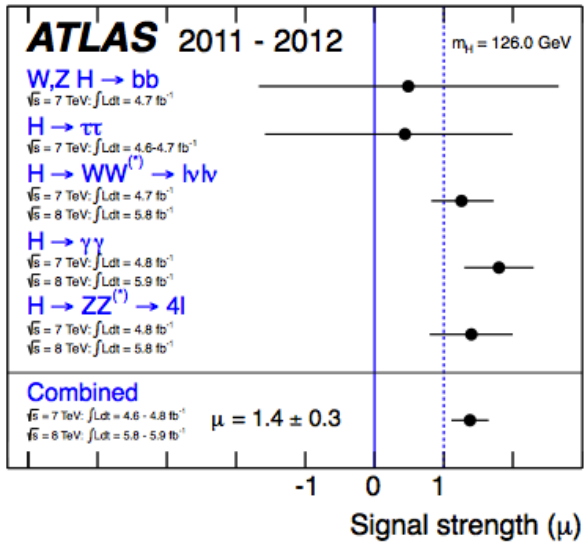
- Combination of $H \to \gamma\gamma$, $H \to ZZ$, $H \to WW$
- Do not forget the 'look-elsewhere' effect



The discovery of a new particle

5.9σ excess Mass of the new particle

$m_H = 126.0 \pm 0.4 \pm 0.4 GeV$



How do we know that it is the SM Higgs Boson?

It is clear that we found a new particle! But is it the Higgs-Boson?

Not a Spin-1 particle!

Young-Landau theorem: Spin-1 particles cannot couple to a pait of massless spin 1 particles

Which spin does it have?

Flat distribution on the Higgs rest-system: other spin-hypothesis change the angle-distribution

Measure futher Quantum Numbers

- CP Quantum Numbers
- Determination of couplings
- Determination of cross-sections and decay-rates
- Precision measurement of m_{top} and m_W

Summary of Lecture 5

We discovered a new particle at the LHC, which is at the right mass to be the Standard Model Higgs-Boson!
To be sure, we need to do lots of work in the comming years in Experimental High Energy Physics!
Very fascinating times are coming!