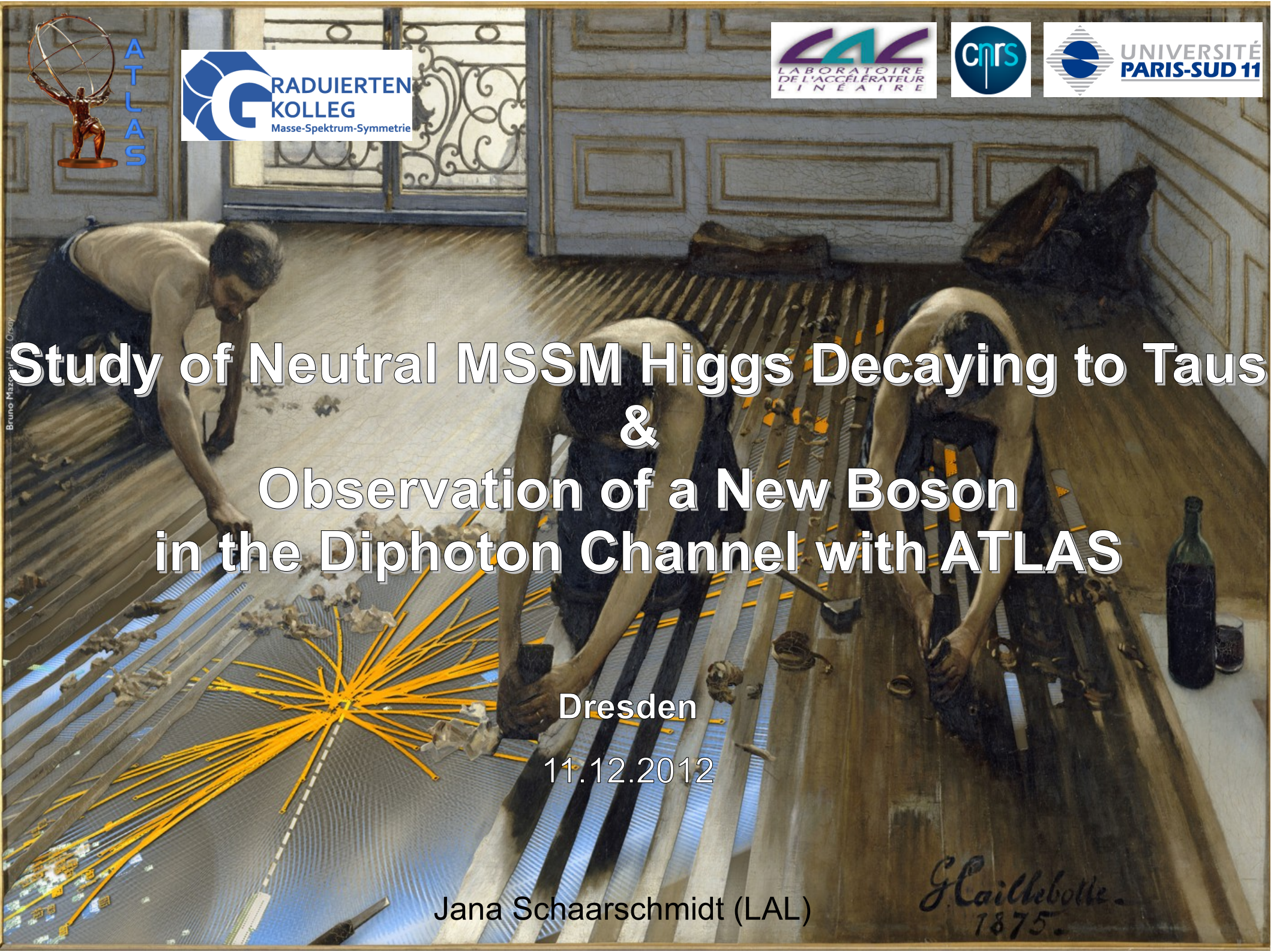


Study of Neutral MSSM Higgs Decaying to Taus & Observation of a New Boson in the Diphoton Channel with ATLAS

Dresden

11.12.2012

Jana Schaarschmidt (LAL)

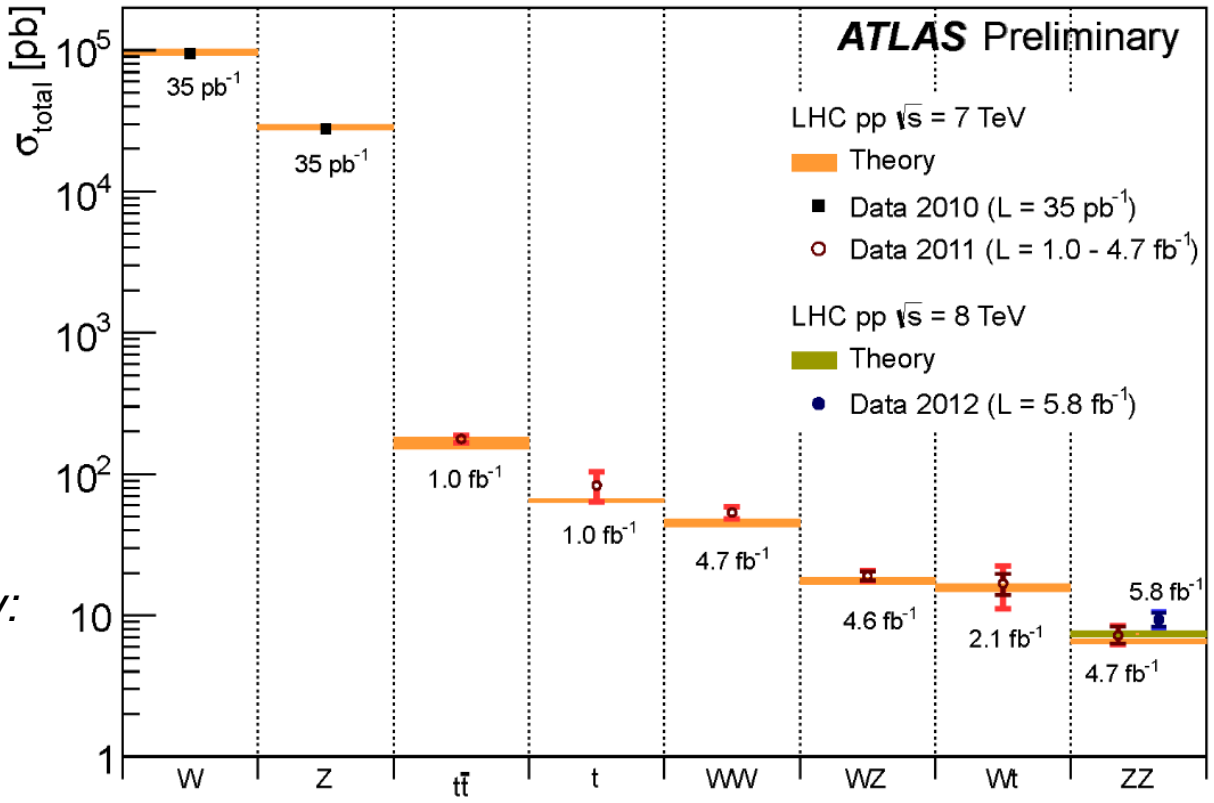
Introduction: Standard Model

Standard Model (SM) of particle physics

- Matter constituted by quarks and leptons and forces are mediated by gauge bosons

- Tested and verified experimentally with exceptional precision

Cross section measurements of SM processes and comparison to theory:

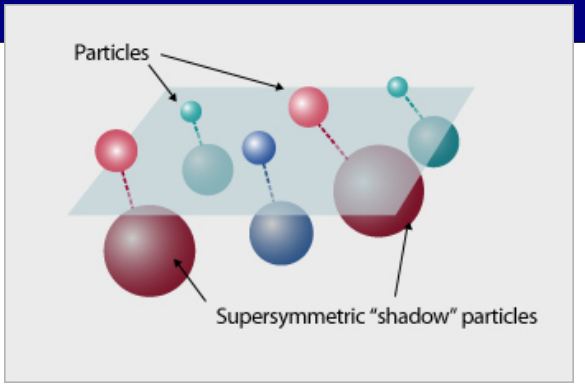


The **Higgs mechanism** is a substantial component of this theory and it was introduced to explain the electroweak symmetry breaking and how fundamental fermions acquire mass

→ A new scalar particle (Higgs boson) must exist

(Brout & Englert, Higgs, Gouralnik, Hagen & Kibble in the 1960's)

Supersymmetry



One possible extension of the SM theory, offering for example:

- Solution to the Fine-tuning problem
- Dark-matter candidates
- Unification of the coupling constants at high energies

It is a symmetry linking bosons and fermions, postulating new heavy partners of the SM particles

So far, no hints of SUSY particles found by ATLAS and CMS! Maybe at higher energies?

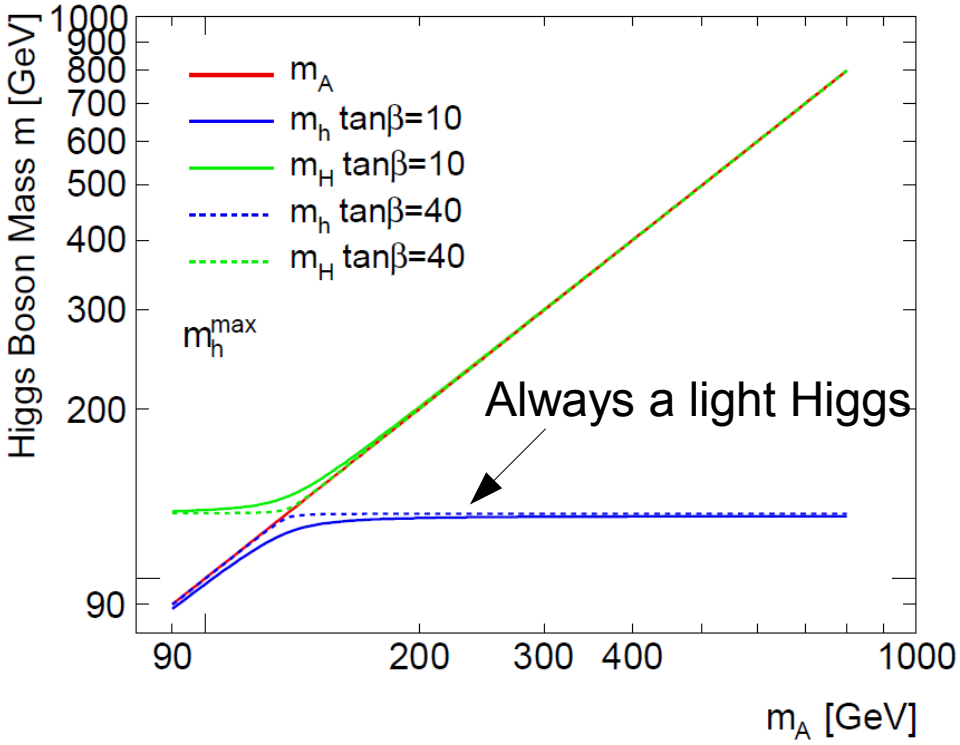
Minimal SUSY (MSSM) Higgs sector:

Two Higgs doublets, five detectable Higgs bosons:

h, H, A, H^+, H^-

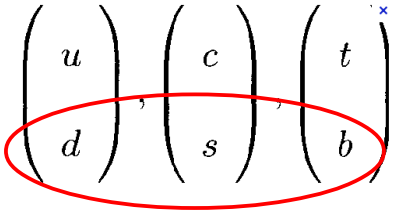
Fixing the SUSY breaking parameters in a specific scenario allows to describe the Higgs sector by just two free parameters:

- Coupling parameter tanβ (tanβ = vev_{up}/vev_{down})
- Mass of the A boson m_A

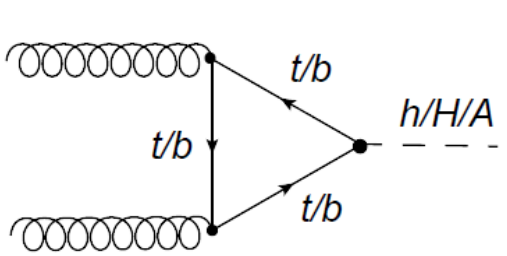


MSSM H → ττ

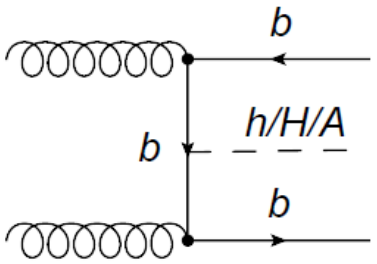
In the MSSM: Coupling of down-type fermions enhanced with tanβ

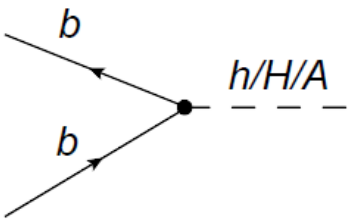


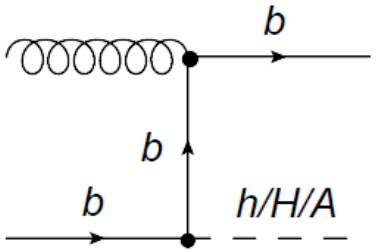
Higgs Production



gluon fusion







b-quark associated production (irrelevant in the SM)

Higgs Decay

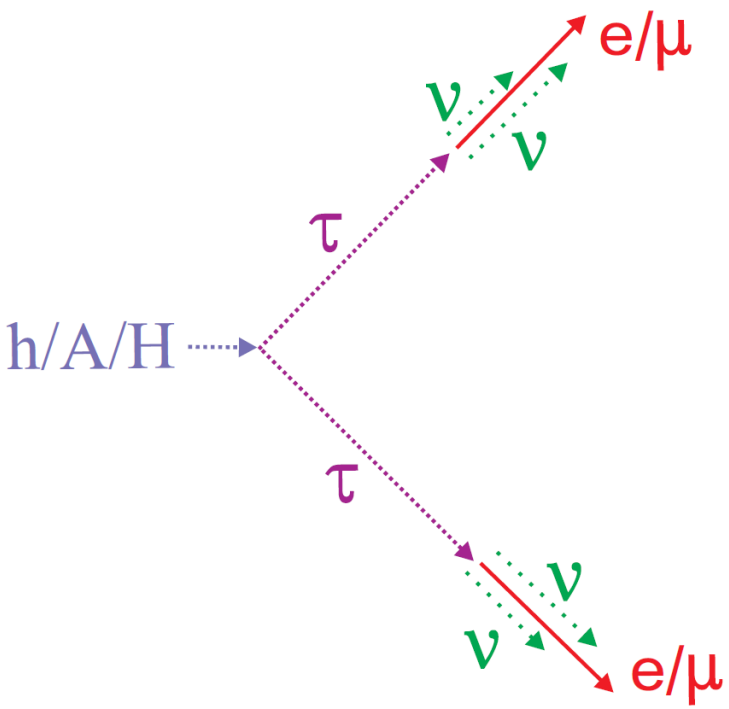
MSSM Higgs decay different to that in the SM: Decay to vector bosons is suppressed, decay to fermions is enhanced. Branching fraction to ττ at high tanβ: 10%, for m_H=0.1-1 TeV.

Tau Decay

Tau lepton is unstable and decays to either hadronically (h) to pions (and/or kaons) (65%) or leptonically (l) to electron (17.8%) or muon (17.4%)

→ Several final states: 2l + 4ν
lh + 3ν
hh + 2ν (not covered here)

MSSM H → ττ Mass Reconstruction



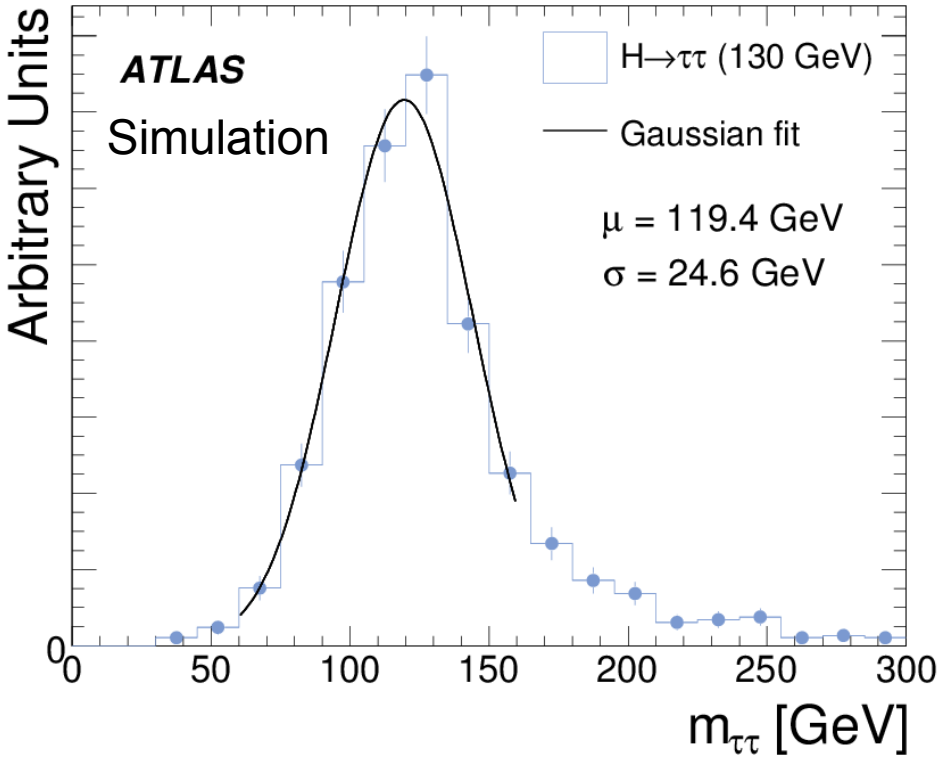
Mass reconstruction is difficult, because there are neutrinos in the final state, they escape detection, They cause an E_T imbalance (missing E_T, MET).

Tau's are boosted, and so are their decay products

→ **Collinear approximation:**

p_T (tau$_i$) = p_T (lepton$_i$ or π_i) / x_i (x: scale factor)

$$m_{\tau\tau} = \frac{m_{\ell/h,\ell/h}}{\sqrt{x_1 \cdot x_2}}$$



Expected H → ττ mass resolution:

10-30% of m_H depending on production mode, Higgs mass hypothesis and the final state.

MSSM H → ττ Event Selection

Expected backgrounds: Electroweak processes (mostly Z,W, top), QCD

Event selection:

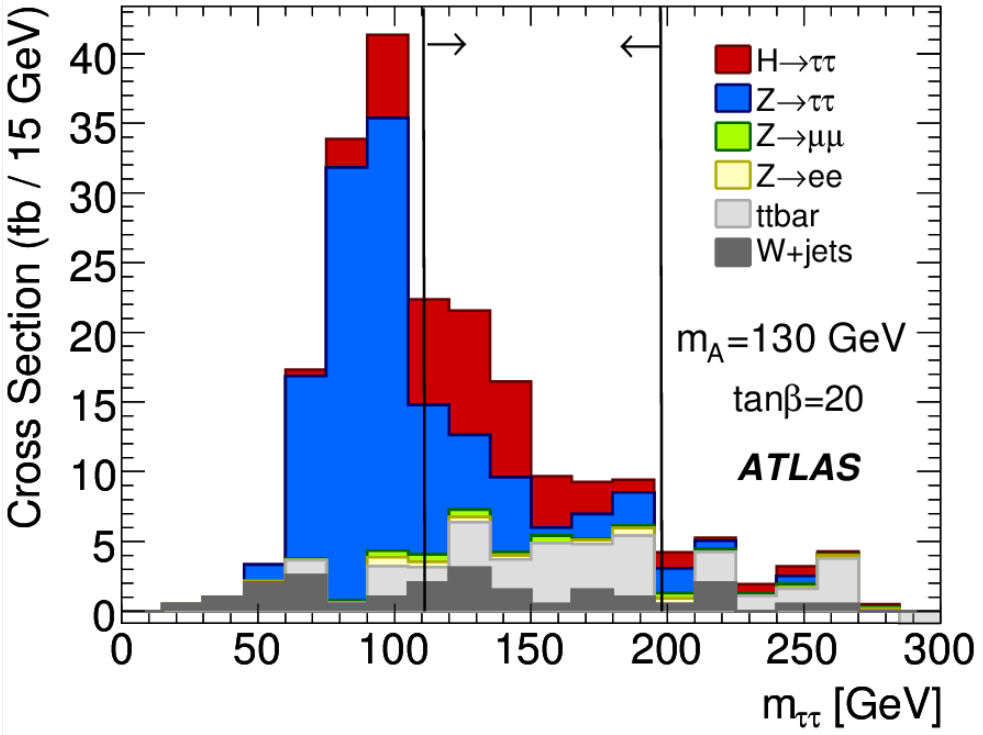
- Trigger on leptons (electrons or muons)
- Good identification of leptons and/or hadronically decaying taus
- Require presence of b-jets
- Cuts on event kinematics: p_T of the b-jet, $p_T^{\tau\tau}$, MET, $\Delta\phi_{ll}$, etc. These are m_A-dependent.

Expected mass spectrum after selection:

- At low masses, Z → ττ background is irreducible and dominant
- At higher masses, top-pairs are dominant

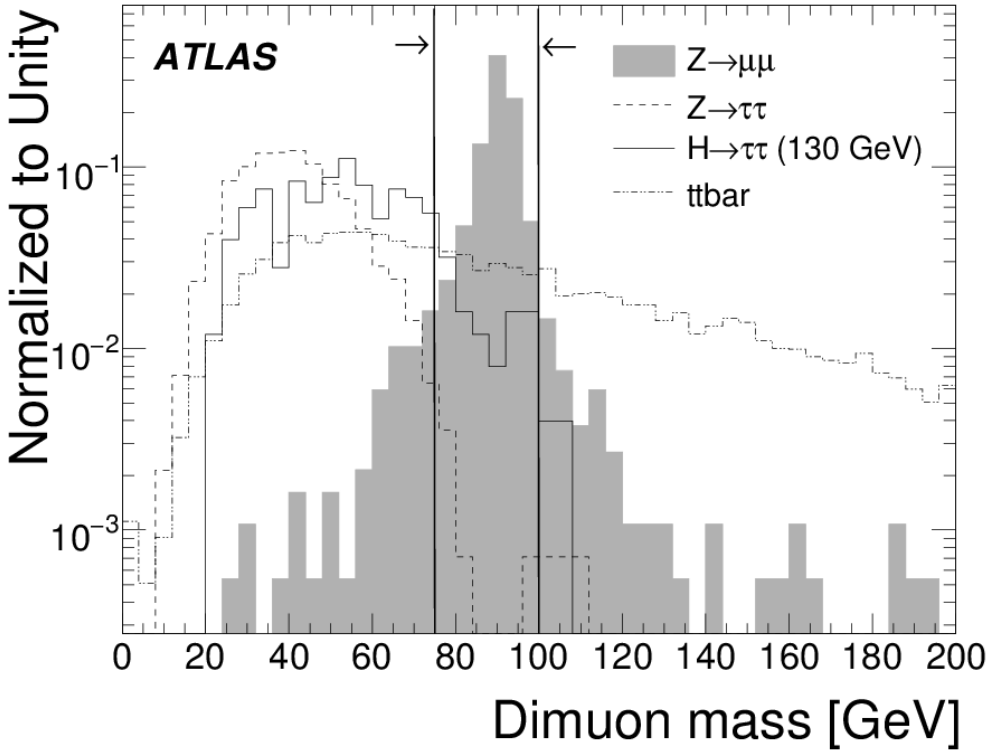
In the lepton-hadron channel the W+jet background is also important.

Example for the dilepton channel:



Z → ττ Background Estimation

Z → μμ control region selection:

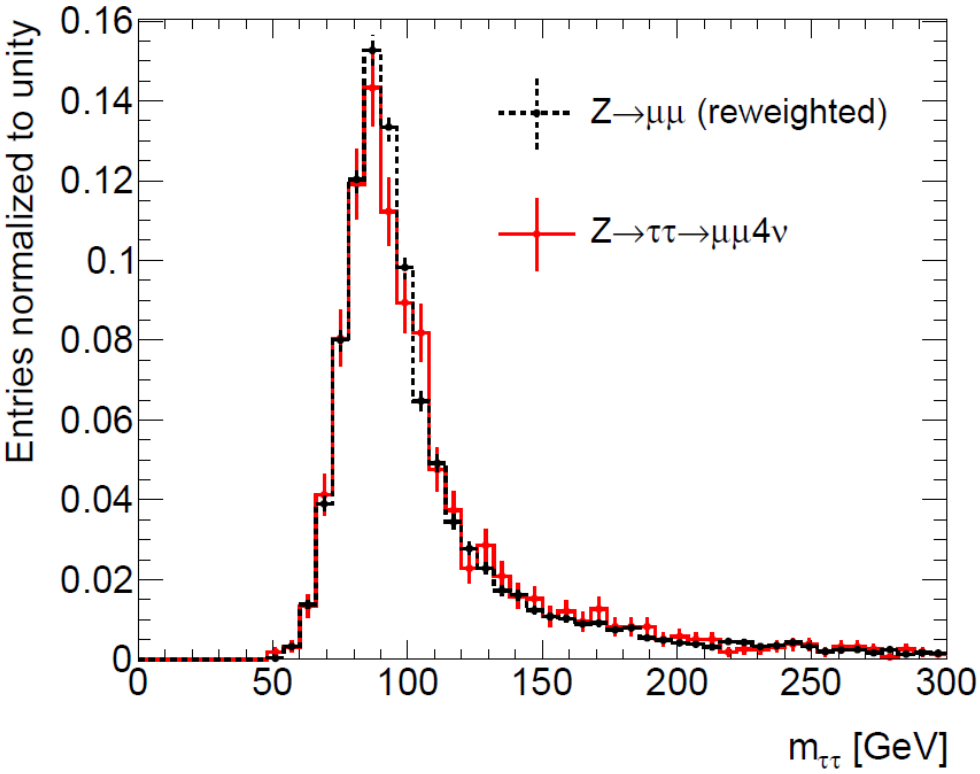


1. Select Z → μμ events,
2. Replace the prompt muon kinematics by that of a muon from a τ → μ+2ν decay
3. Recalculate the missing E_T

Z → ττ background shape estimated from data

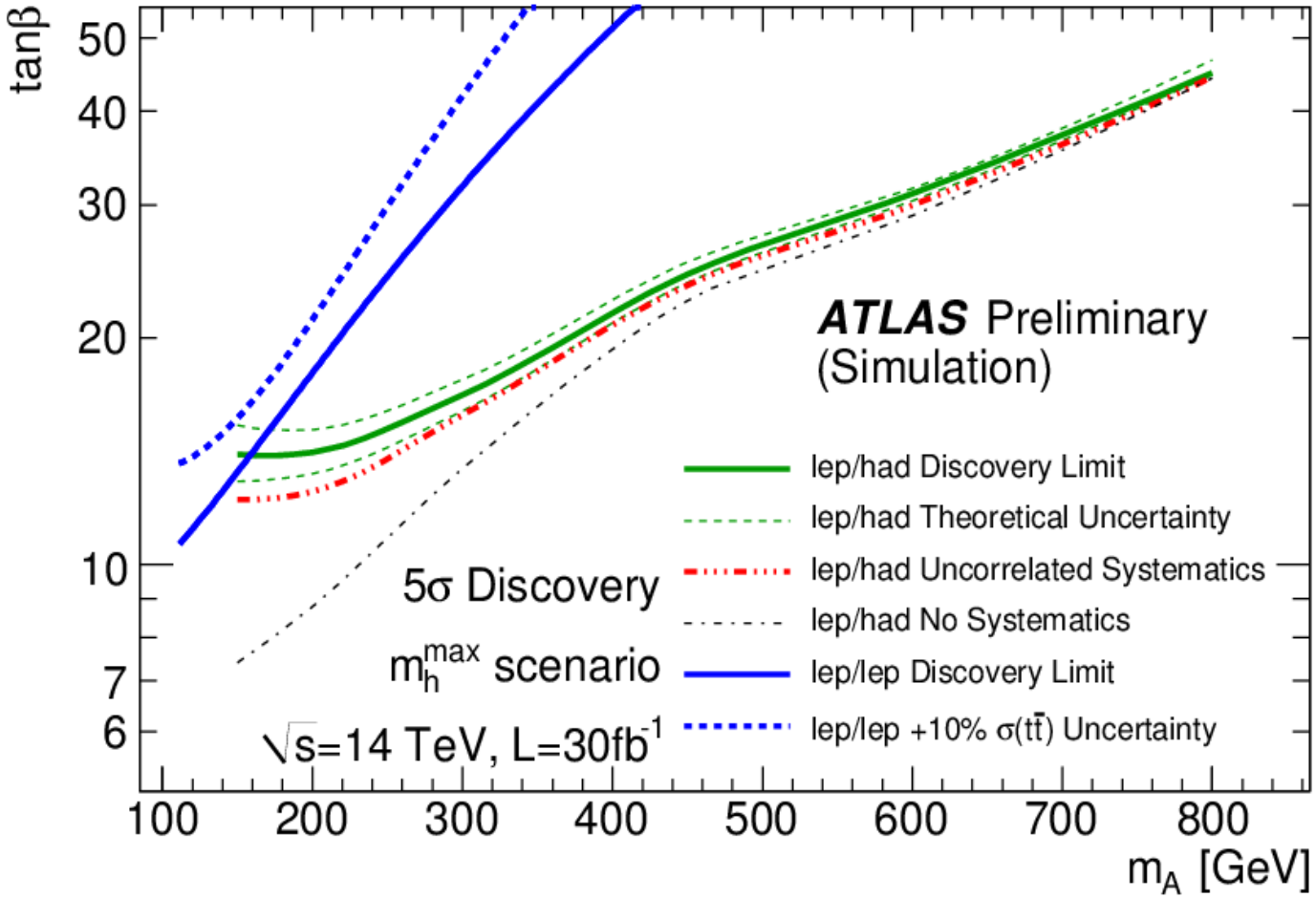
→ Reduce MC dependance and systematic uncertainties

Result: $m_{\tau\tau}$



MSSM H → ττ Discovery Potential

Expected 5σ discovery limits for 14 TeV based on simulation (2010):

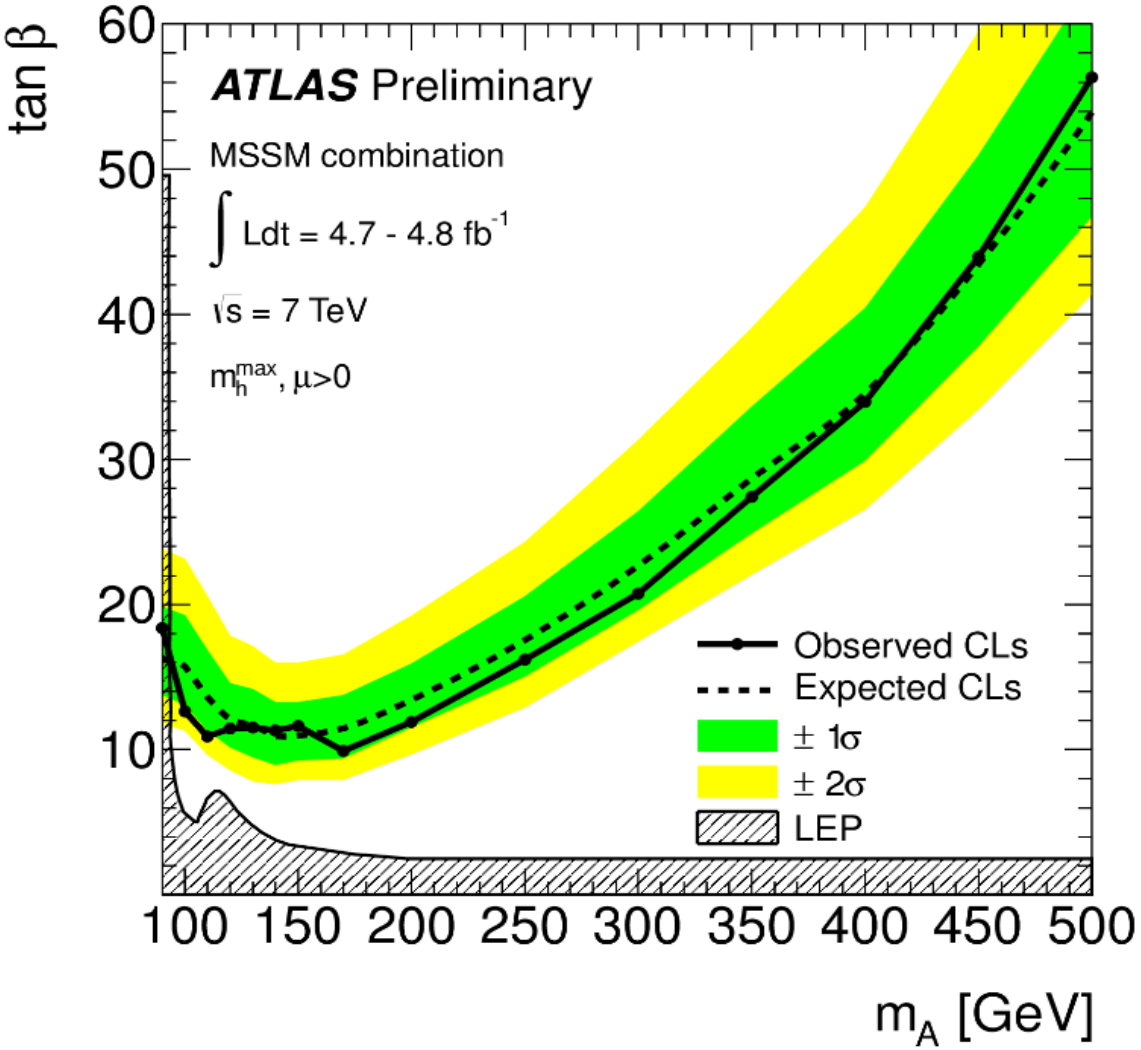


CERN-THESIS-2010-164
CERN-Open-2008-020
ATL-PHYS-PUB-2010-011

Results include systematic uncertainties and data-driven estimations of all major backgrounds

MSSM H → ττ Limits

ATLAS Data results (4.8/fb of 7TeV data)



Combined limits of MSSM
H → μμ and H → ττ

ATLAS-CONF-2012-094

No excess found, results in agree with the SM backgrounds

→ Exclusion limits set in m_A-tanβ plane

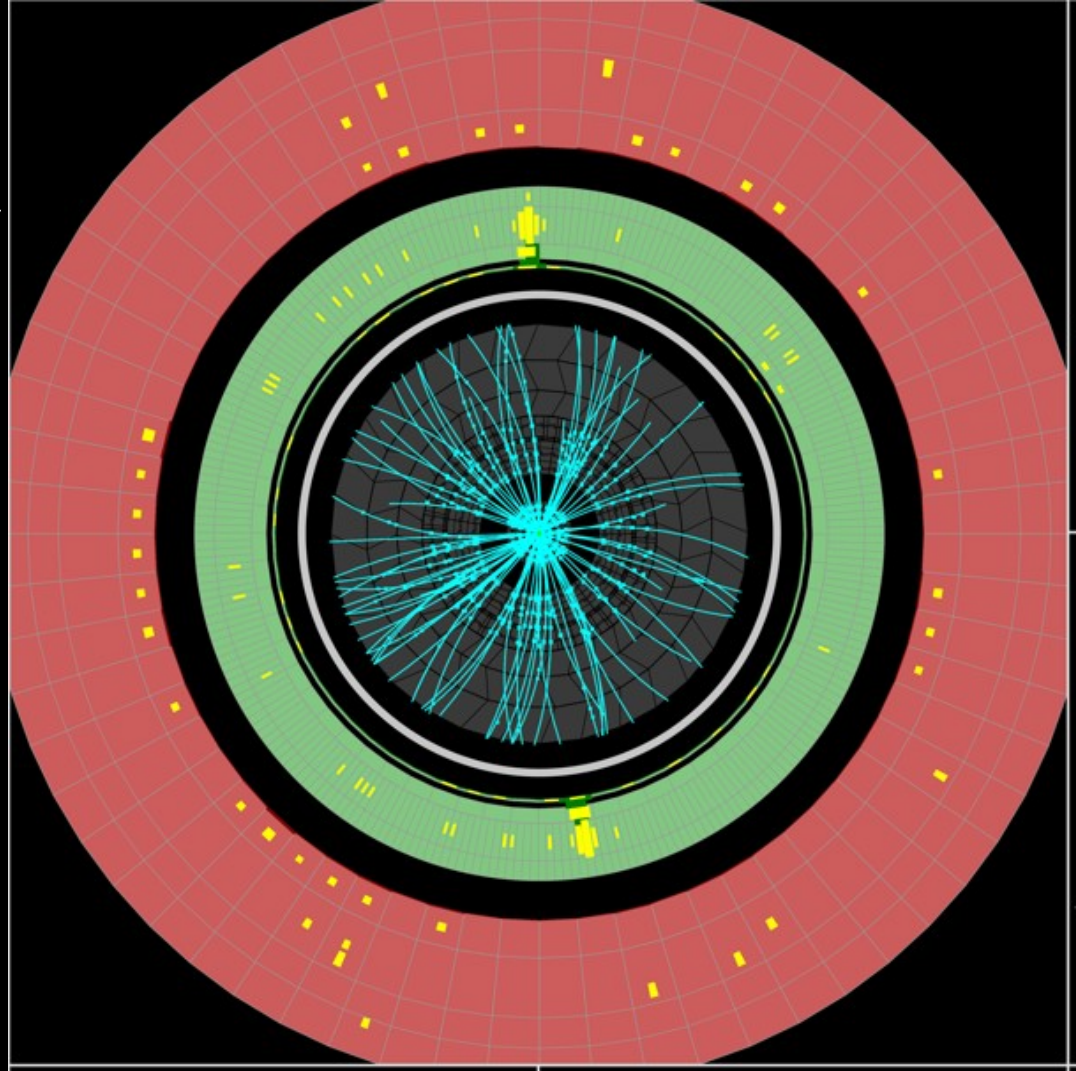
$H \rightarrow \gamma\gamma$

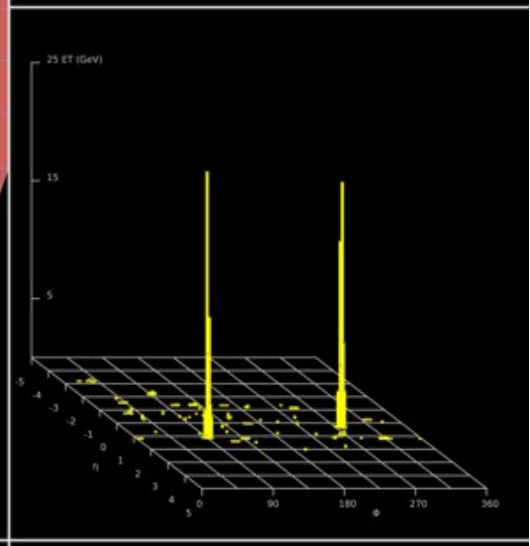
Candidate Event

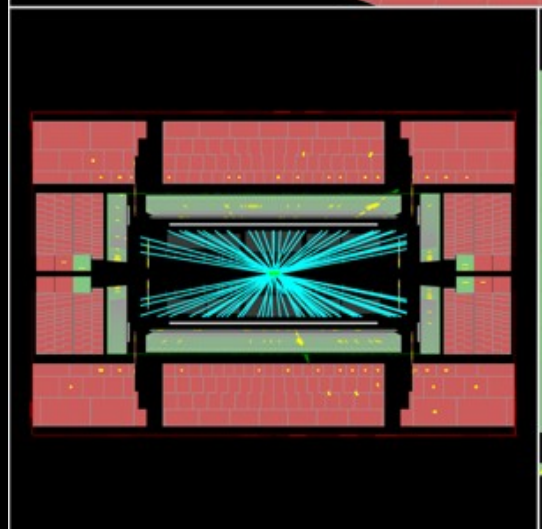
$m_{\gamma\gamma}$ = 127 GeV

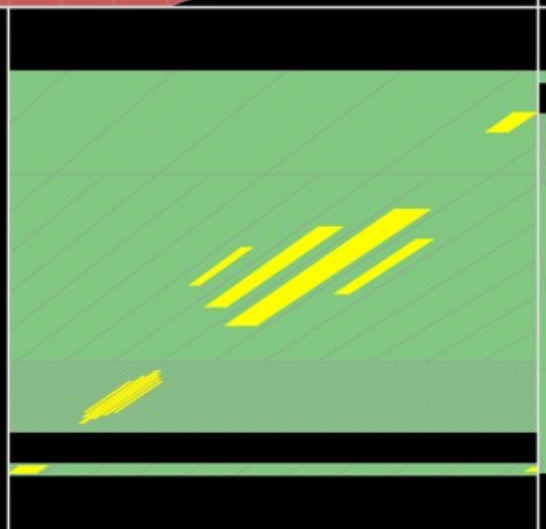
Dataset:

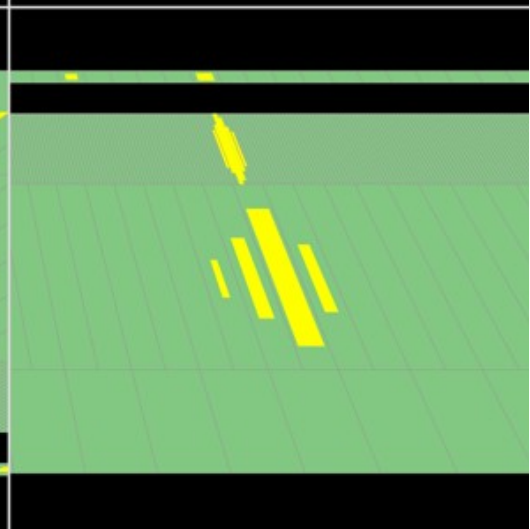
4.8/fb 2011 data
+ 5.9 /fb 2012 data





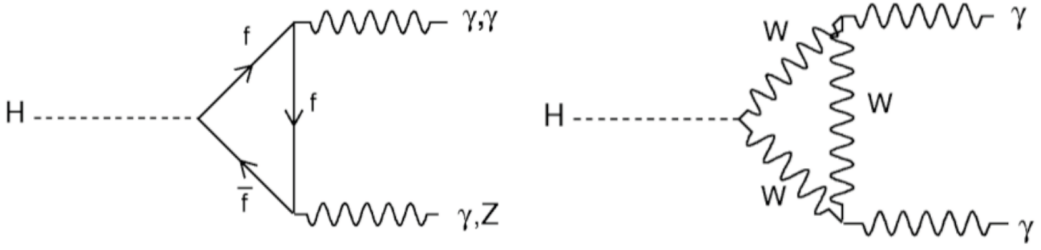






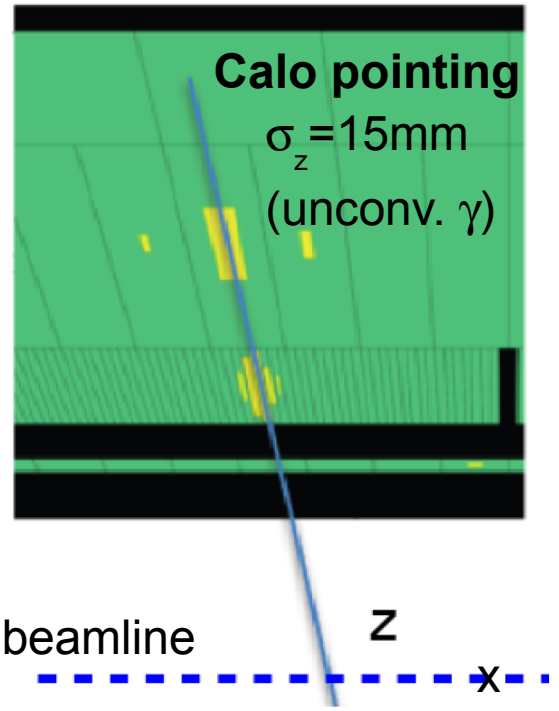
Introduction H → γγ

Higgs decay to two photons via quantum loops:

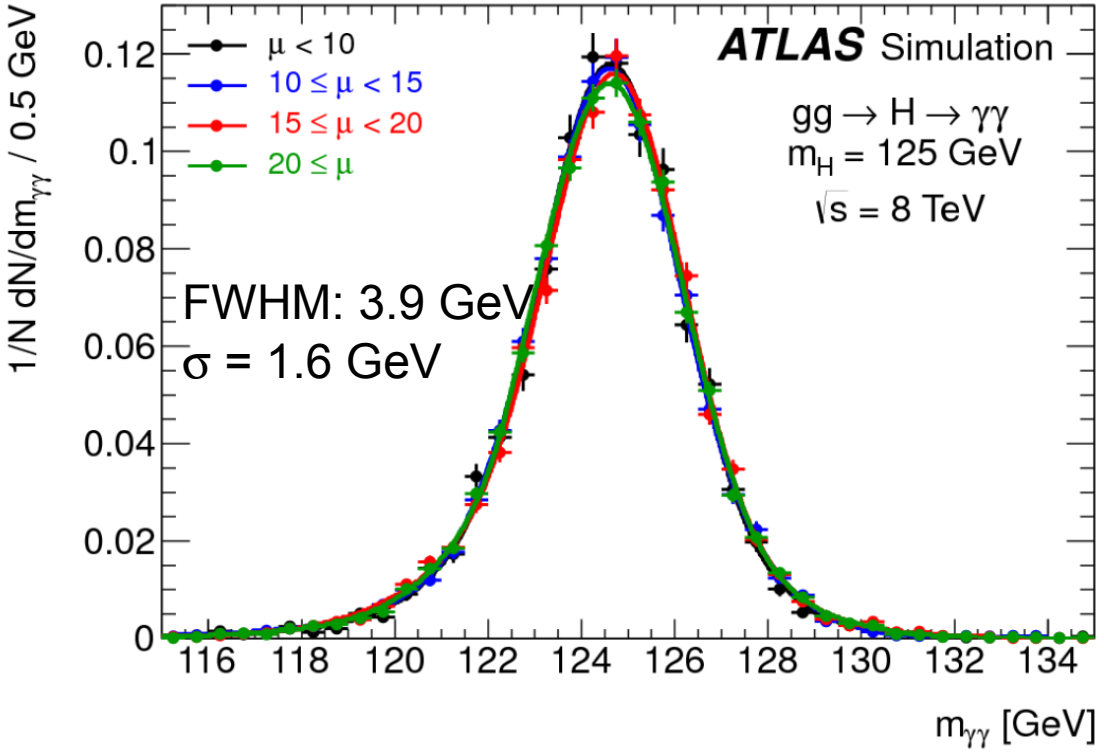


Expected branching fraction: 0.2%, relevant channel only for ~110-140 GeV

New particles might enter in the loops and enhance the decay



Best mass resolution of all the Higgs channels:



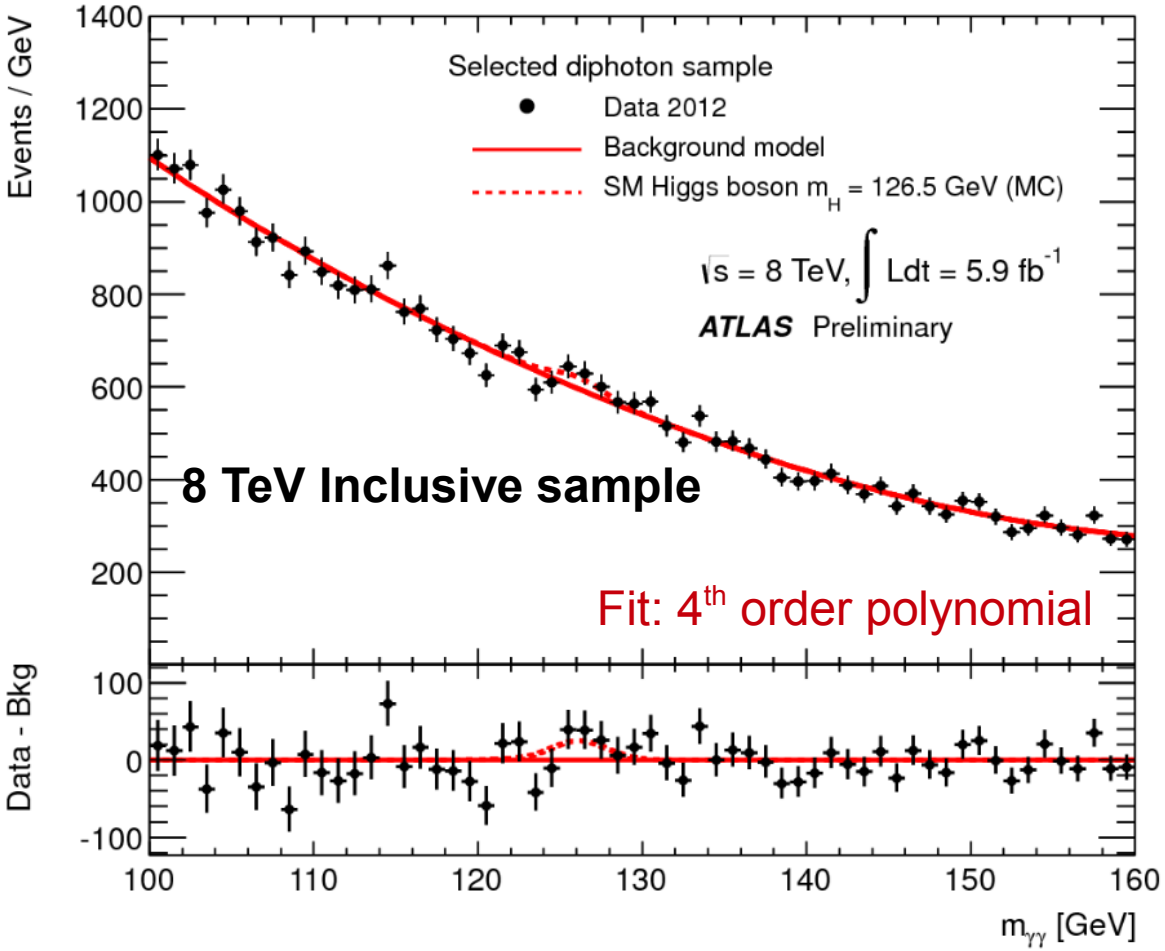
Very stable in presence of additional interactions (pile-up)

H → γγ Analysis

„Inclusive“ Event Selection:

→ 75% of the selected events are diphoton events (not jets)

- Diphoton trigger
- Select events with two photons
- pT cuts: 40 (30) GeV leading (subleading) γ
- Tight identifcation and isolation applied



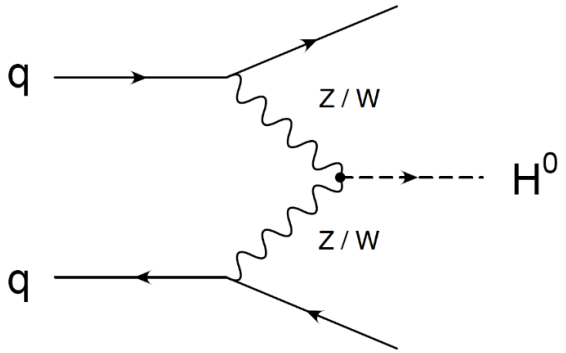
Background Estimation

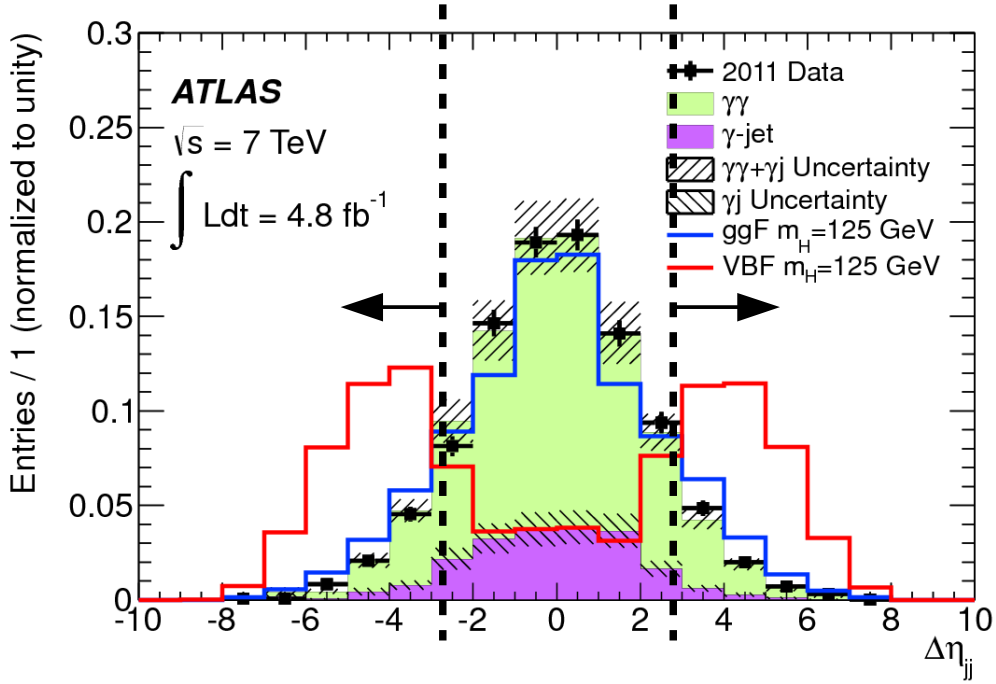
- Smoothly falling QCD background estimated from data with a fit of $m_{\gamma\gamma}$
- Choice of the fit function is crucial, decided by the study of MC samples (for example 10 billion Diphox events)
- Eponentials, 4th order Polynomials or exponential of 2nd order polynomials

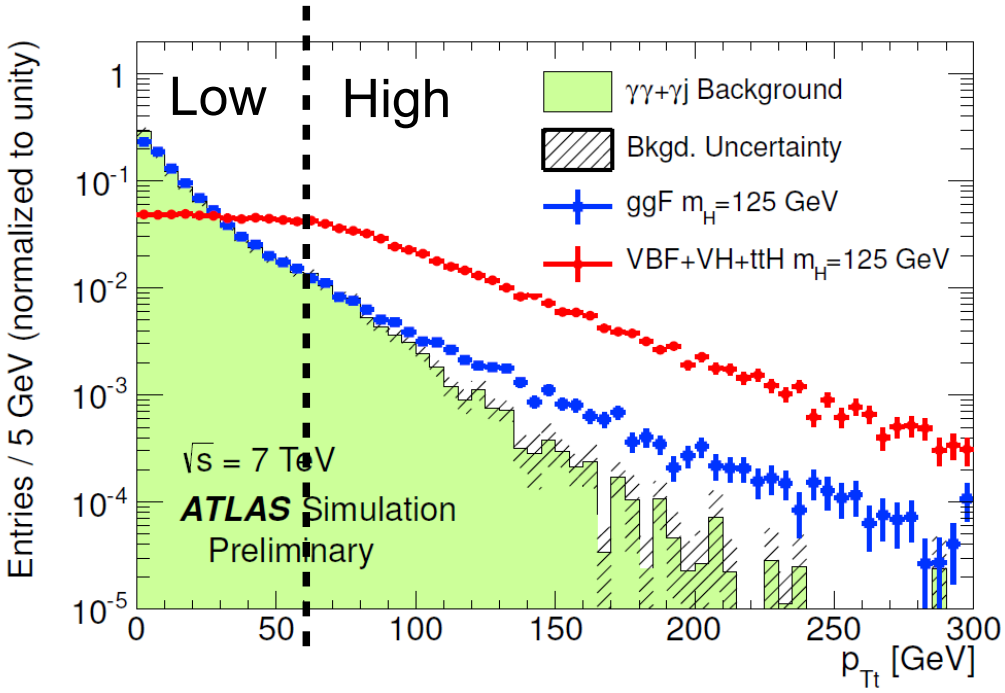
H → γγ Categorization (10 categories)

2-jet category:

Enrich subsample with Vector-boson-fusion

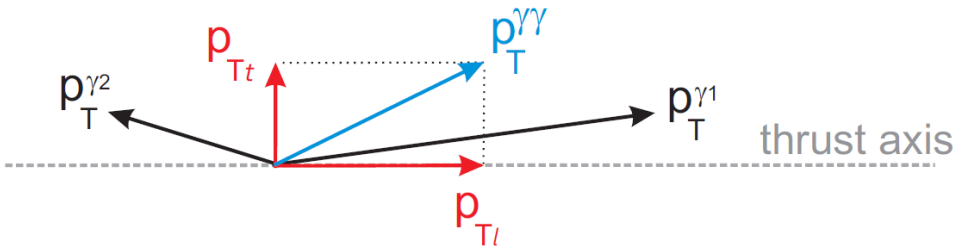






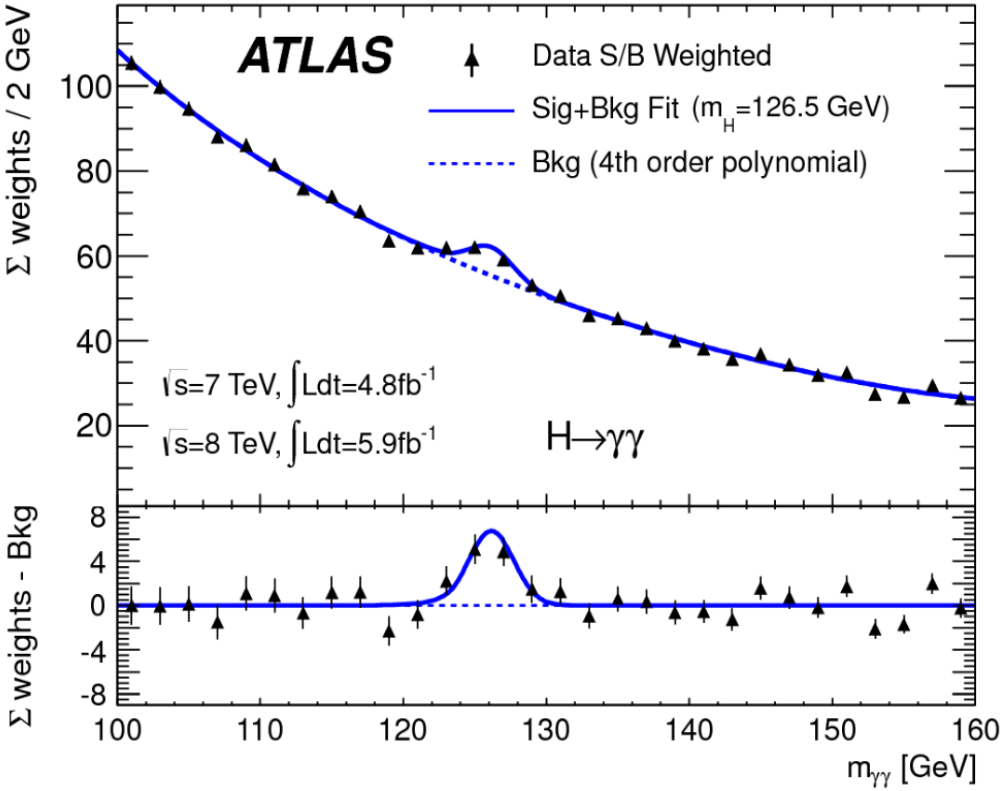
9 other categories:

- conversion status
- γ position in the calorimeter
- p_{Tt} value:

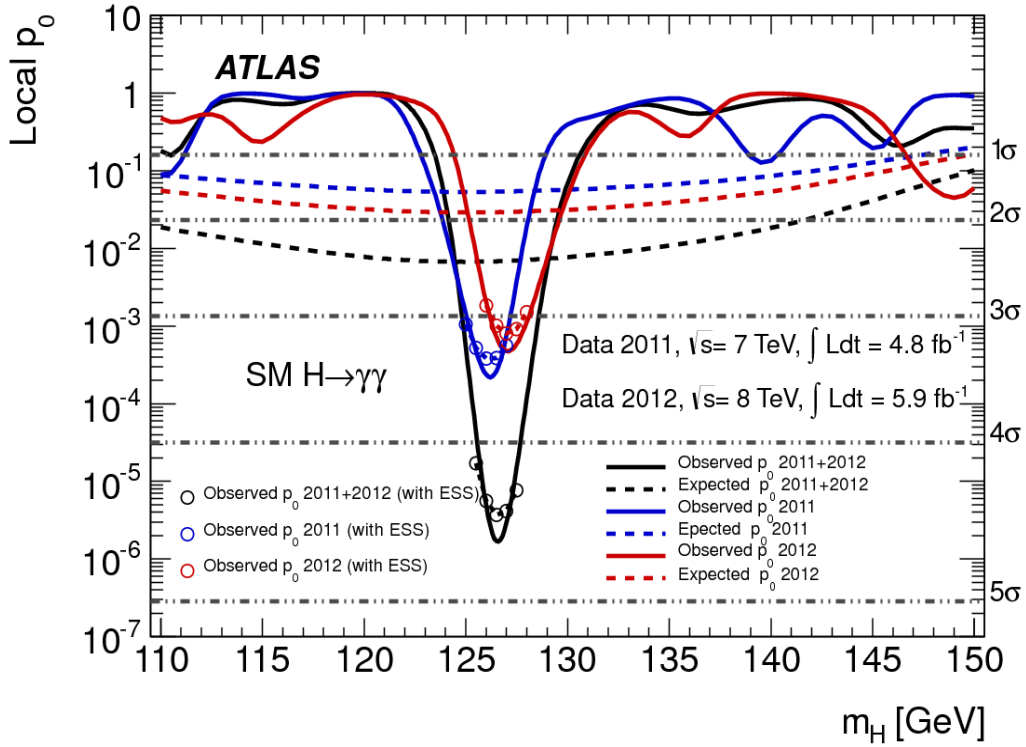


H → γγ Results

Weighted mass spectrum:



Probability of a background fluctuation:



Weight events with expected ln(1+S/B) per category

The more sensitive a category, the more weight is given to an event.

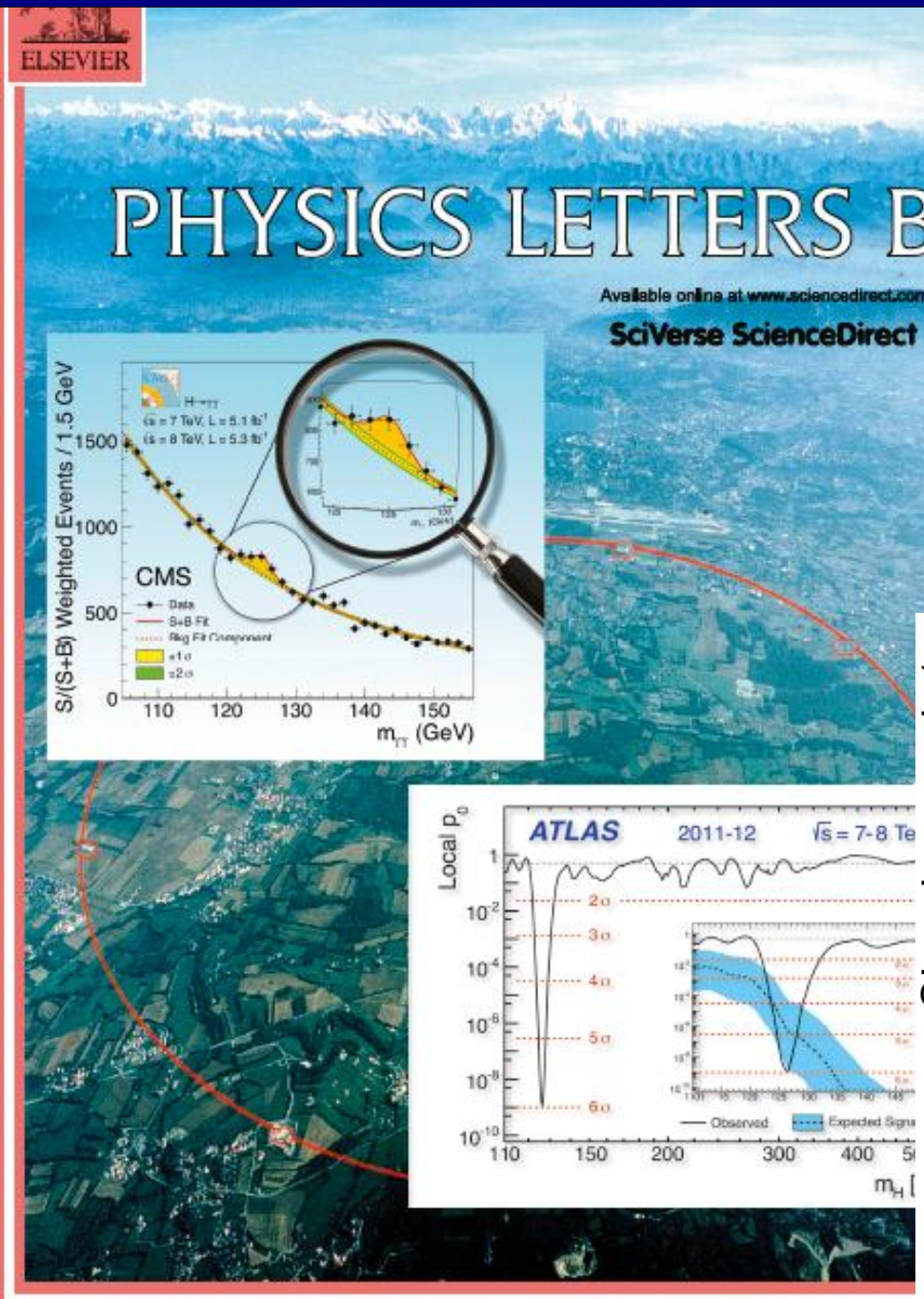
→ Clear excess at 126.5 GeV

Observed significance: 4.5σ

Best-fit signal strength:

$\mu = 1.8 \pm 0.5$

Discovery

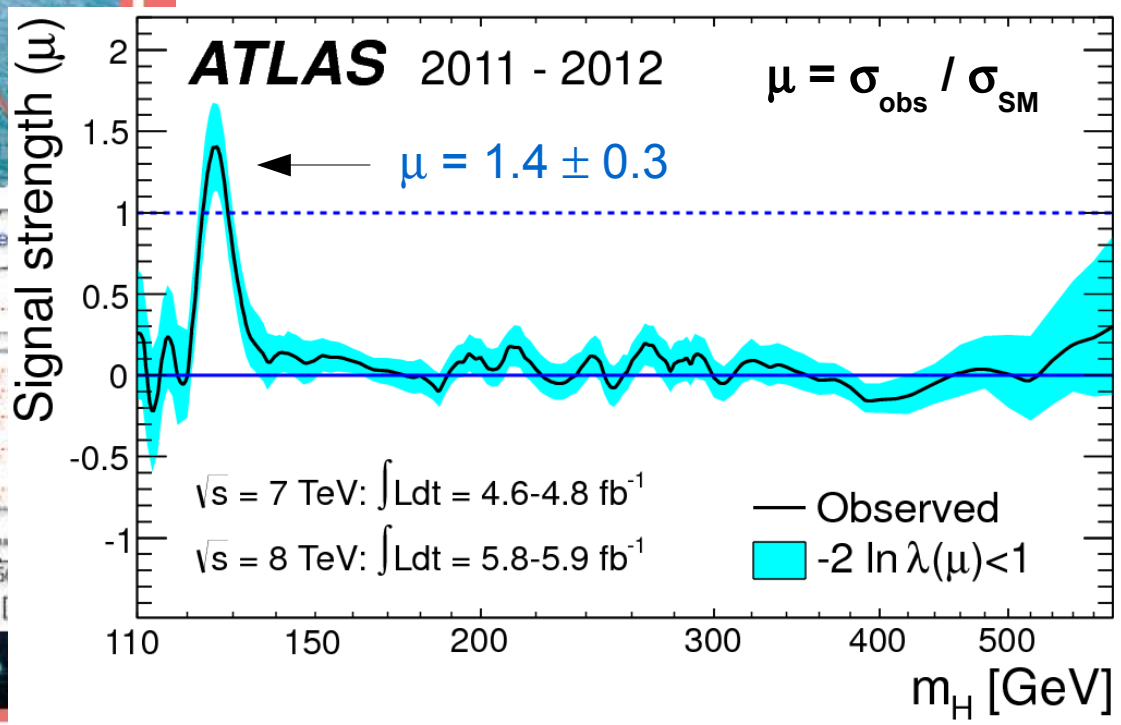


Discovery of a new Higgs-like particle by ATLAS and CMS in summer 2012.

Combined ATLAS significance: 6σ.

Clear evidence in γγ, 4l and lνlν channels.

Combined signal strength (all channels):



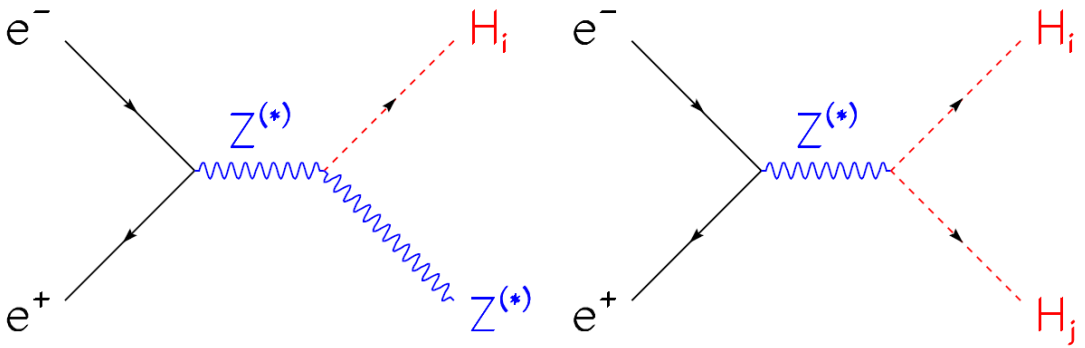
Outlook

Next steps for ATLAS:

- Look for evidence of Higgs decaying to fermions ($b\bar{b}$, $\tau\tau$)
- Measurement of Spin, CP and couplings
- Continue the search for SUSY with increased LHC energy after shutdown
- Study of weak boson scattering

LHC is a discovery machine, but the very precise measurement of Higgs boson properties will be subject of a **future international (linear) collider**:

Design not yet fixed, but likely possibilty: e^+e^- collider operating at the Higgs resonance

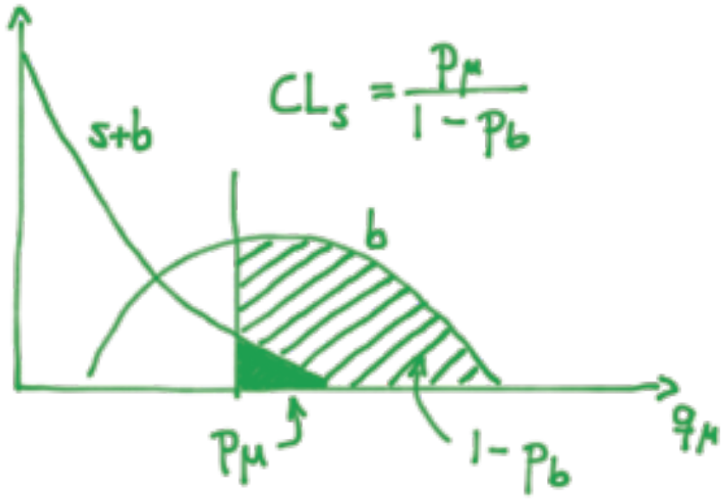


Back up

Statistics in a Nutshell

Figures from Kyle Cranmer, Alex Read

CLs to test signal hypothesis:



Test statistics based on profile likelihood ratio:

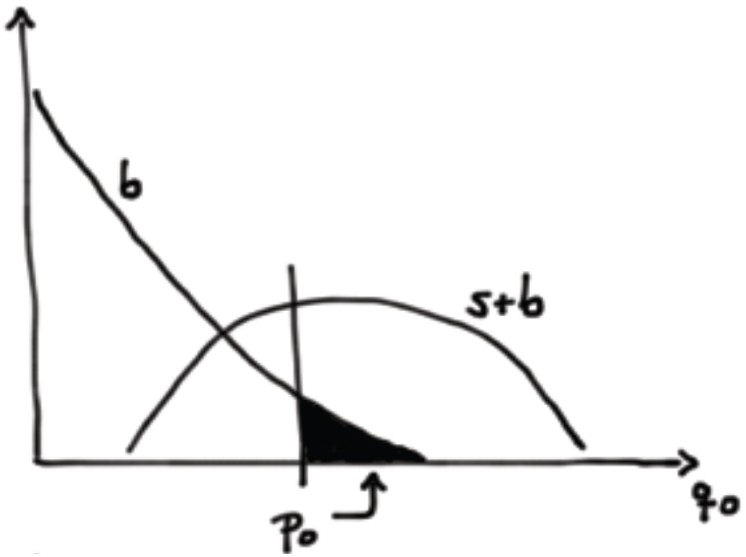
$$q_\mu = -2 \ln \frac{L(\mu, \hat{\hat{\theta}})}{L(\hat{\mu}, \hat{\theta})}$$

← μ fixed

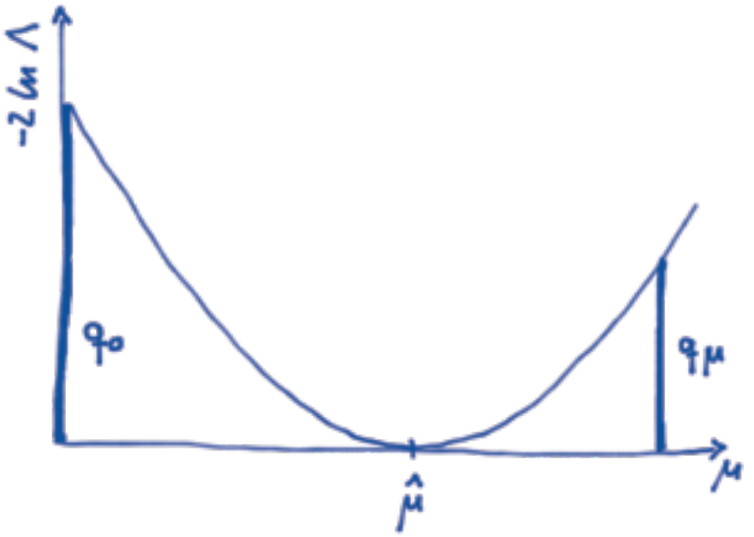
← unconditional

$$\tilde{q}_0 = \begin{cases} -2 \ln \lambda(0) & \hat{\mu} > 0, \\ +2 \ln \lambda(0) & \hat{\mu} \leq 0. \end{cases}$$

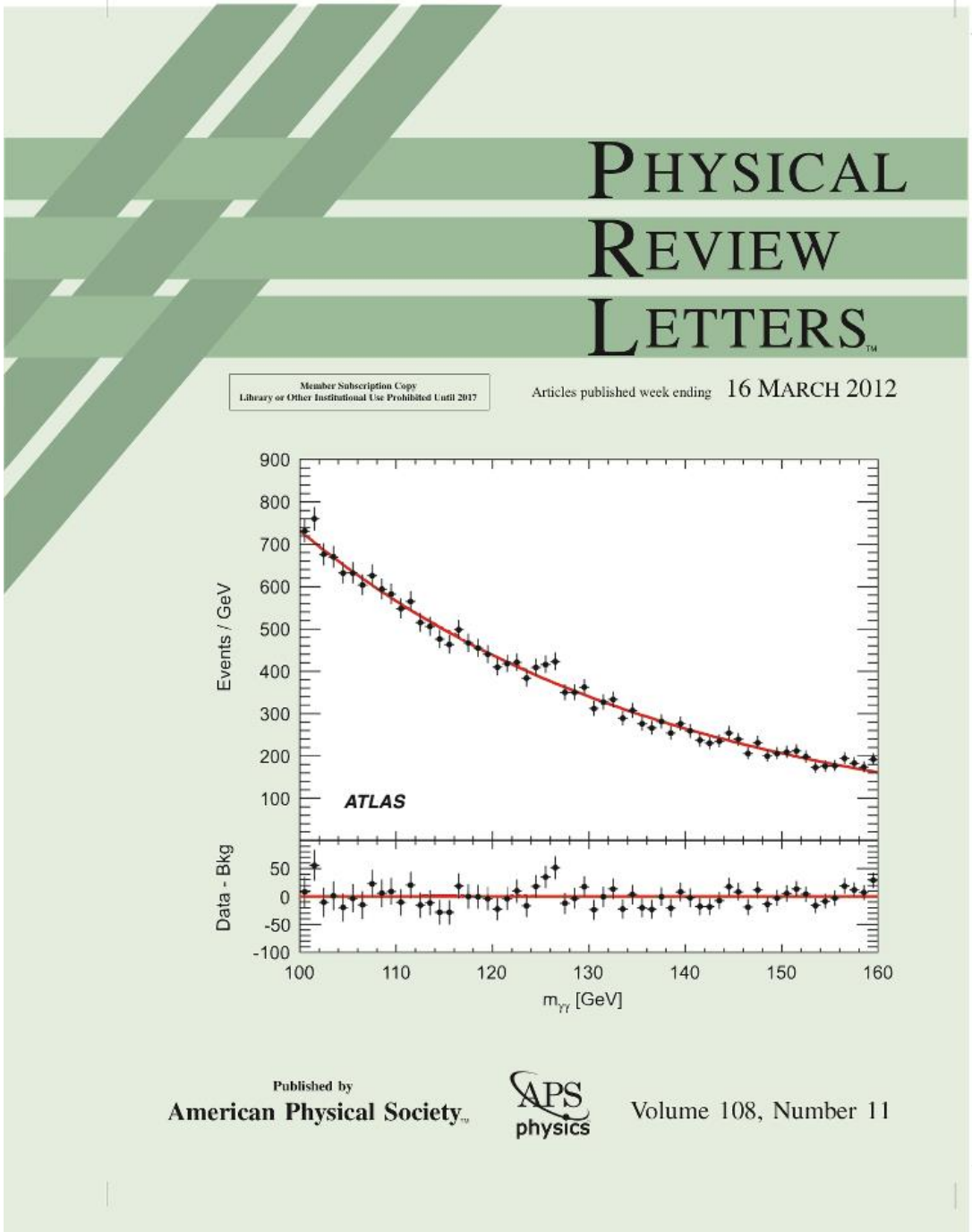
p_0 to test bkg hypothesis:



Signal strength:

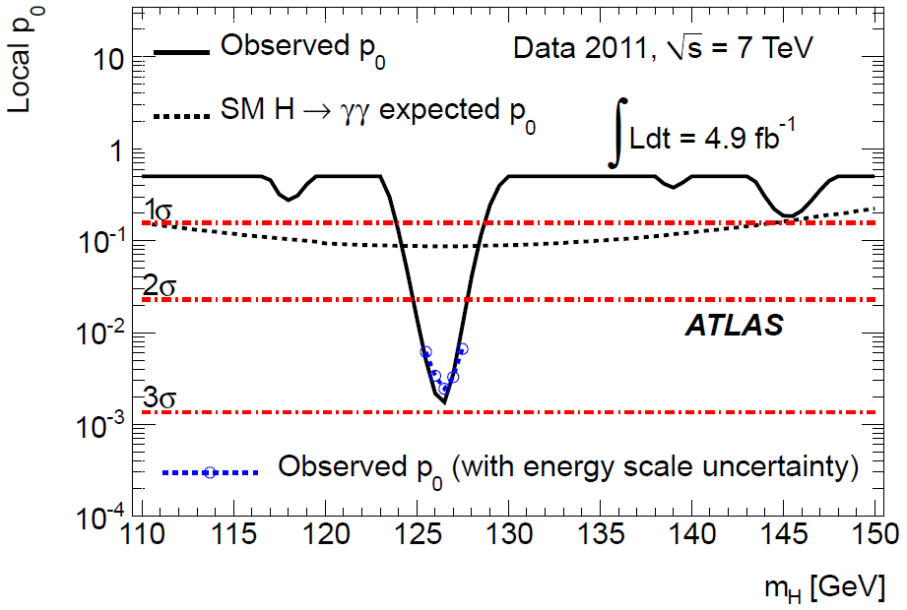


H → γγ: First Hints in 2011 Data



Tentalizing mass spectrum based on 4.9/fb of 2011 data

Probability of a background fluctuation:



Local significance: 2.8σ

This was before 2012. The analysis was then improved and optimized.