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

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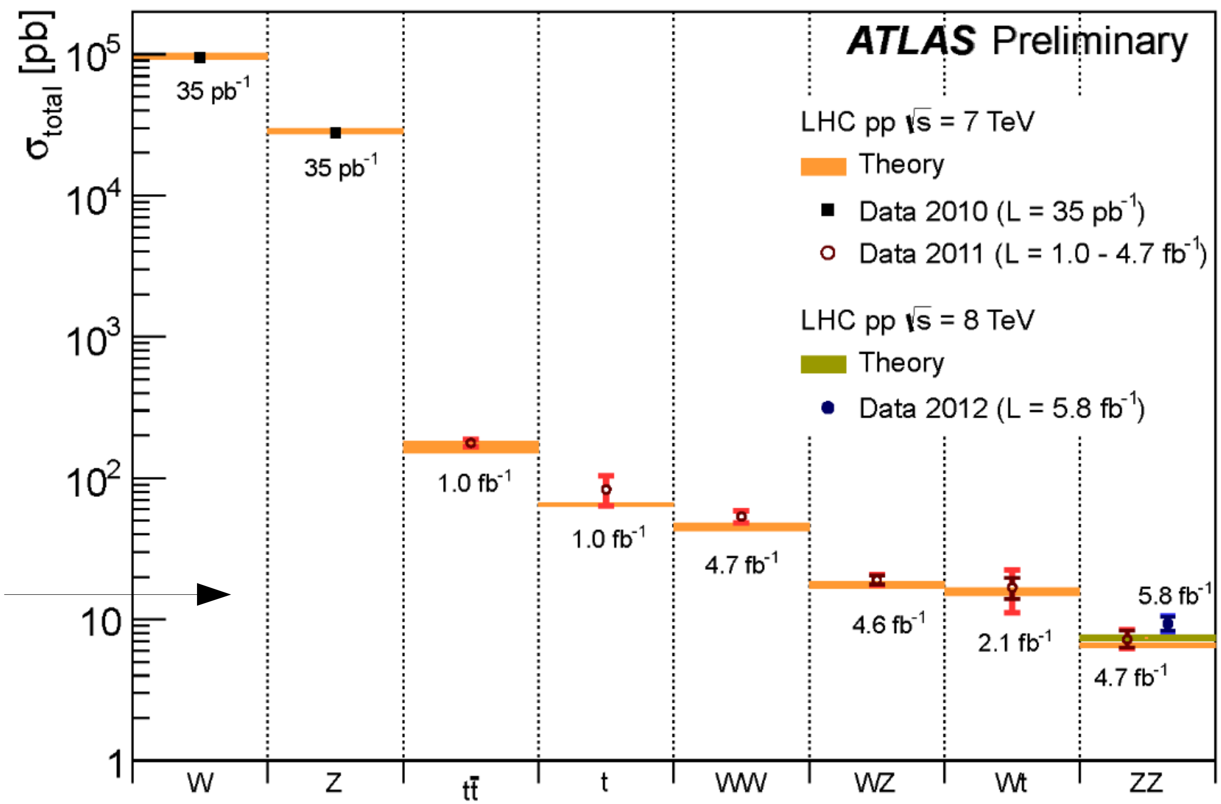
Introduction: Standard Model

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 the mass of the gauge bosons

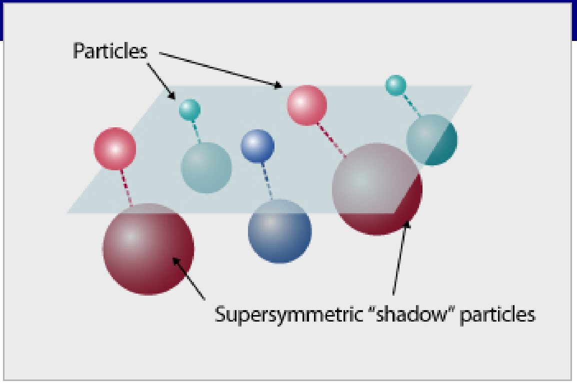
(Brout & Englert, Higgs, Gouralnik, Hagen & Kibble in the 1960's)

→ A new scalar particle (Higgs boson) must exist

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



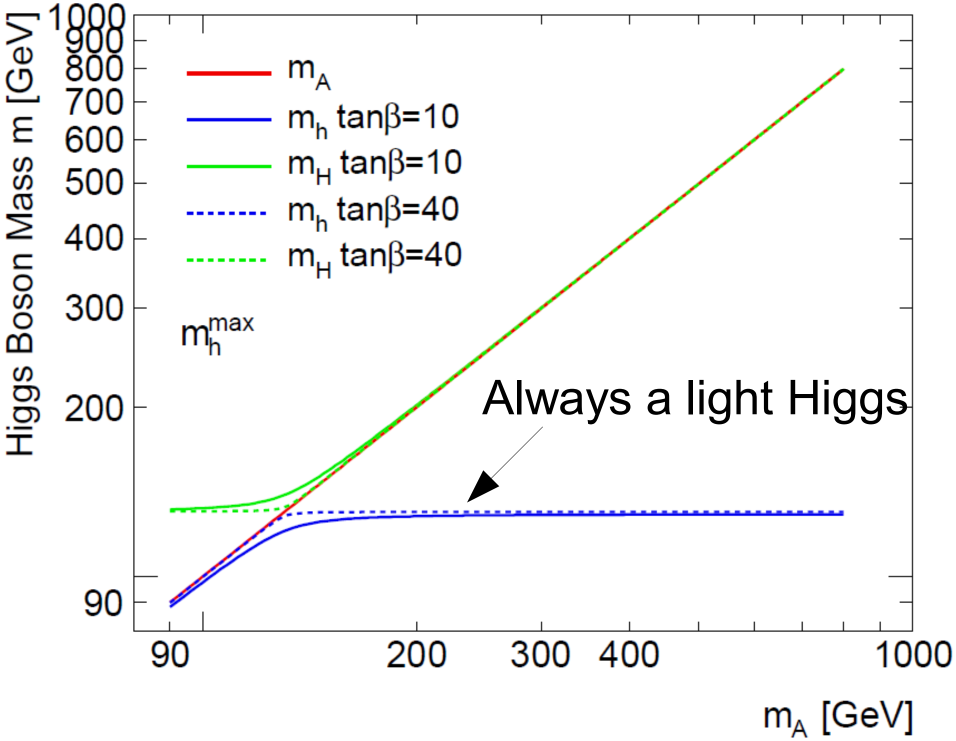
It is a symmetry linking bosons and fermions, postulating new heavy partners of the SM particles

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:

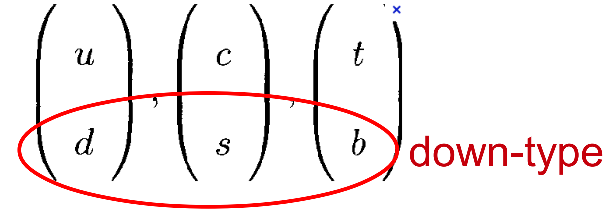
h, H, A, H^+, H^-



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

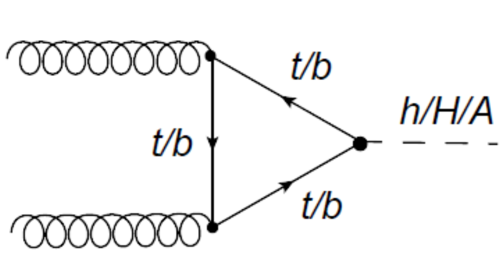
- Coupling parameter **tanβ** (tanβ = vev_{up}/vev_{down})
- Mass of the A boson $\mathbf{m_A}$

MSSM Higgs

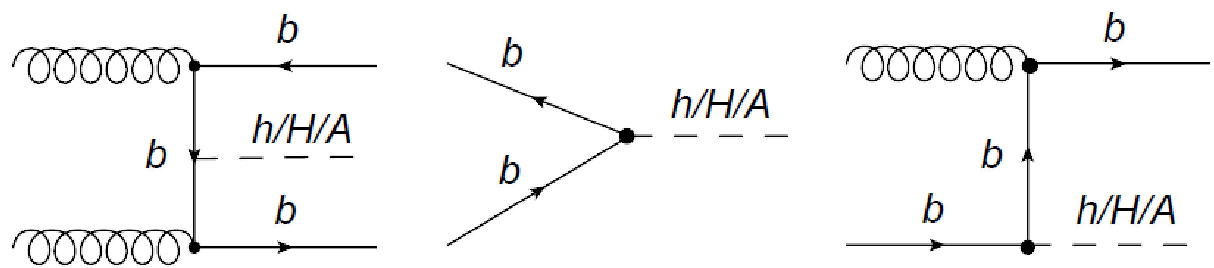


In the MSSM: Coupling of down-type fermions enhanced with tanβ

Higgs Production



gluon fusion



b-quark associated production (irrelevant in the SM)

Higgs Decay

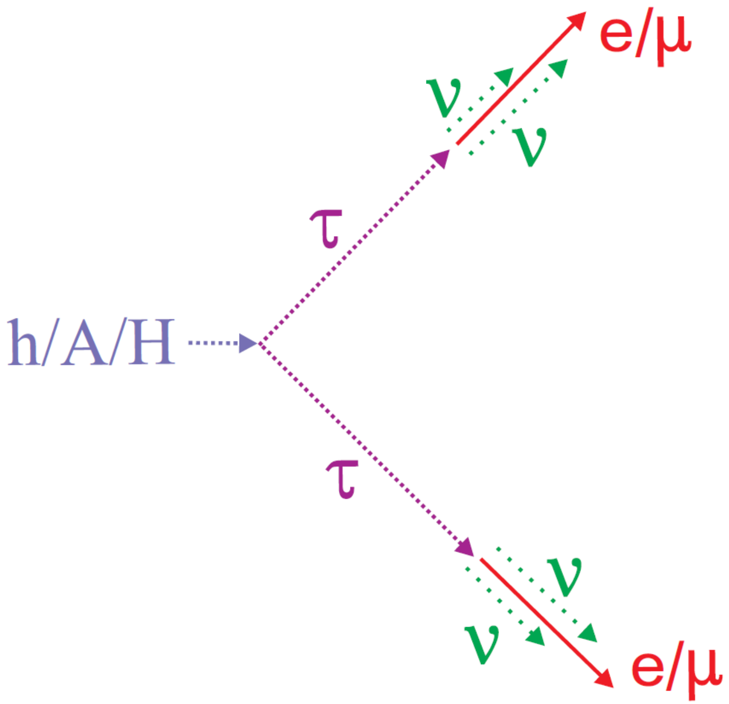
MSSM Higgs decay different to that in the SM: Decay to vector bosons is suppressed, decay to fermions is enhanced. Branching fraction to ττ at high tanβ: 10%, for m_A=0.1-1 TeV.

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/A/H → ττ Mass Reconstruction



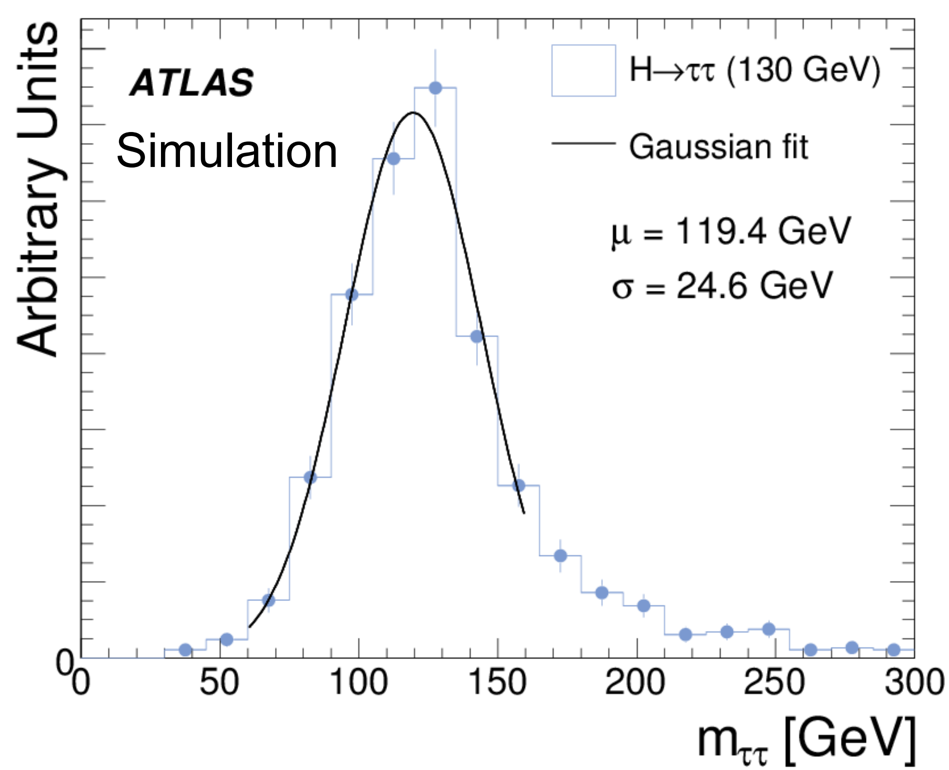
Mass reconstruction is difficult, because there are neutrinos in the final state, they escape detection, They cause an E_T imbalance (missing E_T, MET).

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

→ Collinear approximation:

$p_T\,(tau_i) = p_T\,(lepton_i \text{ or } \pi_i) \,/\, x_i$ (x: scale factor)

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



Expected h/A/H → ττ mass resolution:

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

MSSM h/A/H $\to \tau\tau$ Event Selection

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

Event selection:

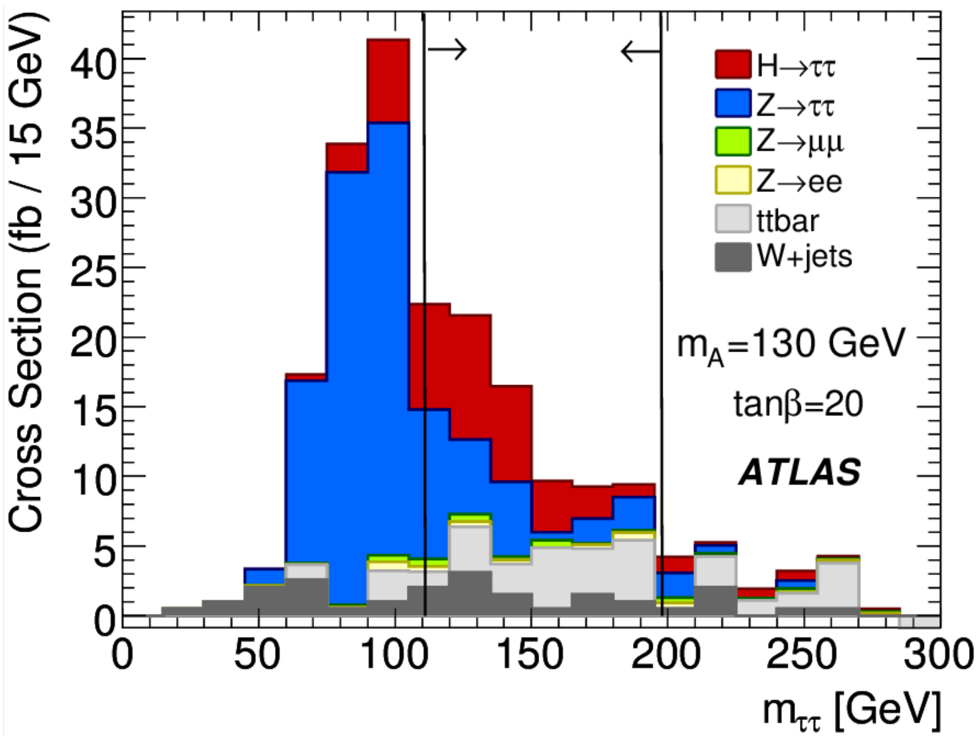
- Trigger on leptons (electrons or muons)
- Good identification of leptons and/or hadronically decaying taus
- Require presence of b-jets
- Cuts on event kinematics: p_T of the b-jet, $p_T^{\tau\tau}$, MET, $\Delta\phi_{ll}$, etc. These are m_A-dependent.

Expected mass spectrum after selection:

- At low masses, $Z \to \tau\tau$ background is irreducible and dominant
- At higher masses, top-pairs are dominant

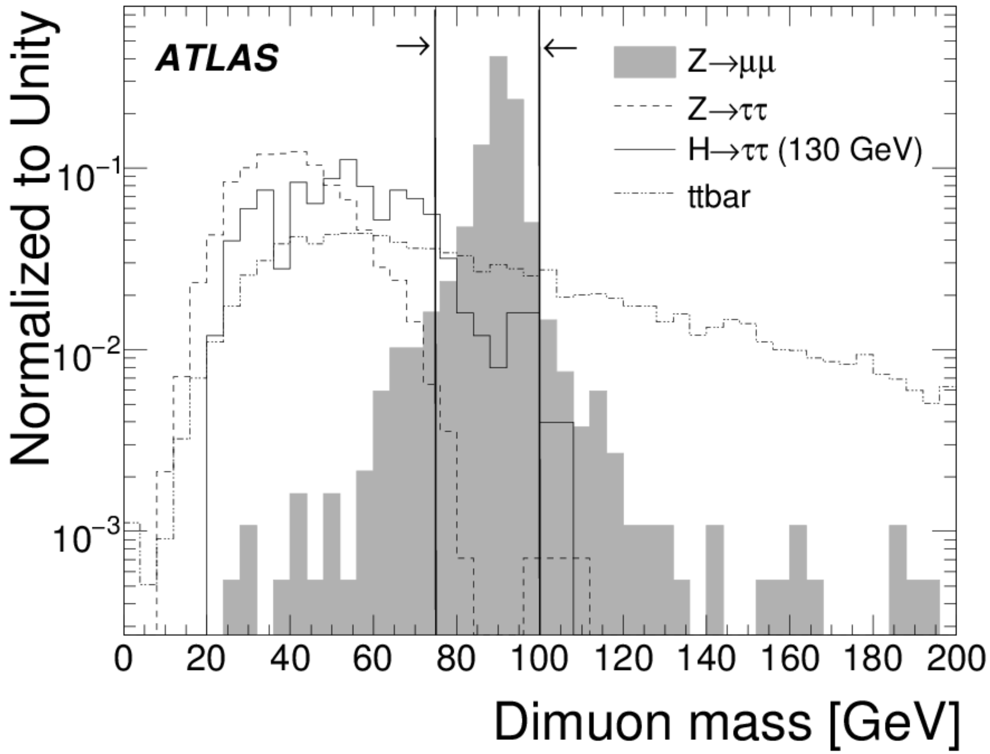
In the lepton-hadron channel the W+jet background is also important.

Example for the dilepton channel:



$Z \rightarrow \tau\tau$ Background Estimation

$Z \rightarrow \mu\mu$ control region selection:

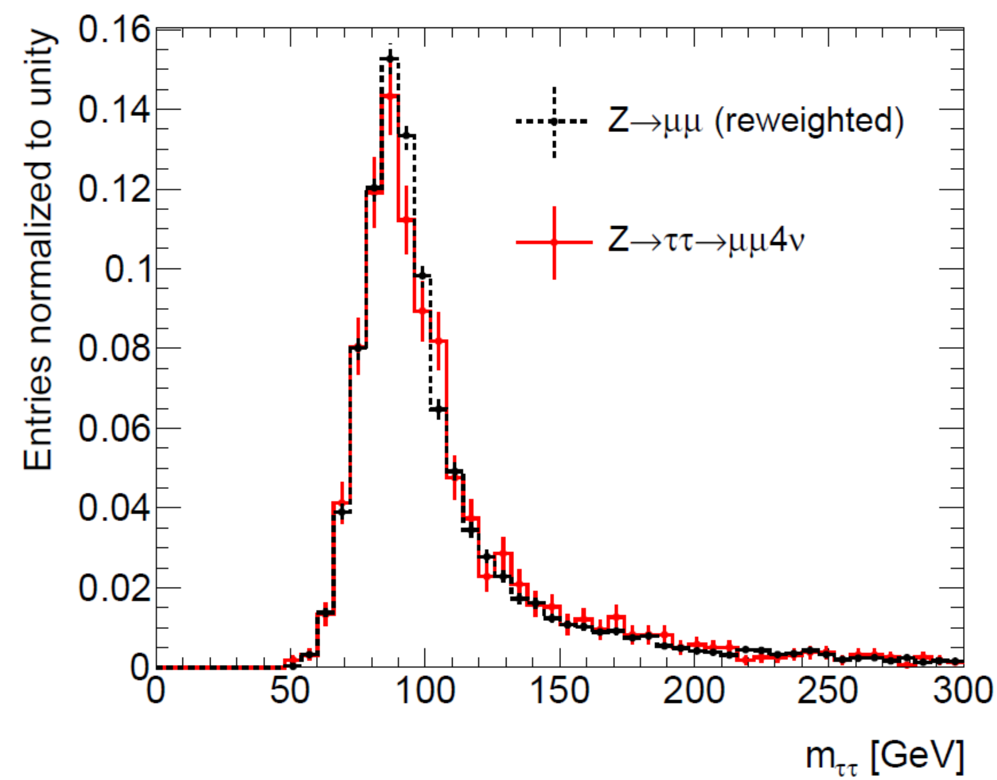


$Z \rightarrow \tau\tau$ background shape estimated from data

$\rightarrow$ Reduce MC dependance and systematic uncertainties

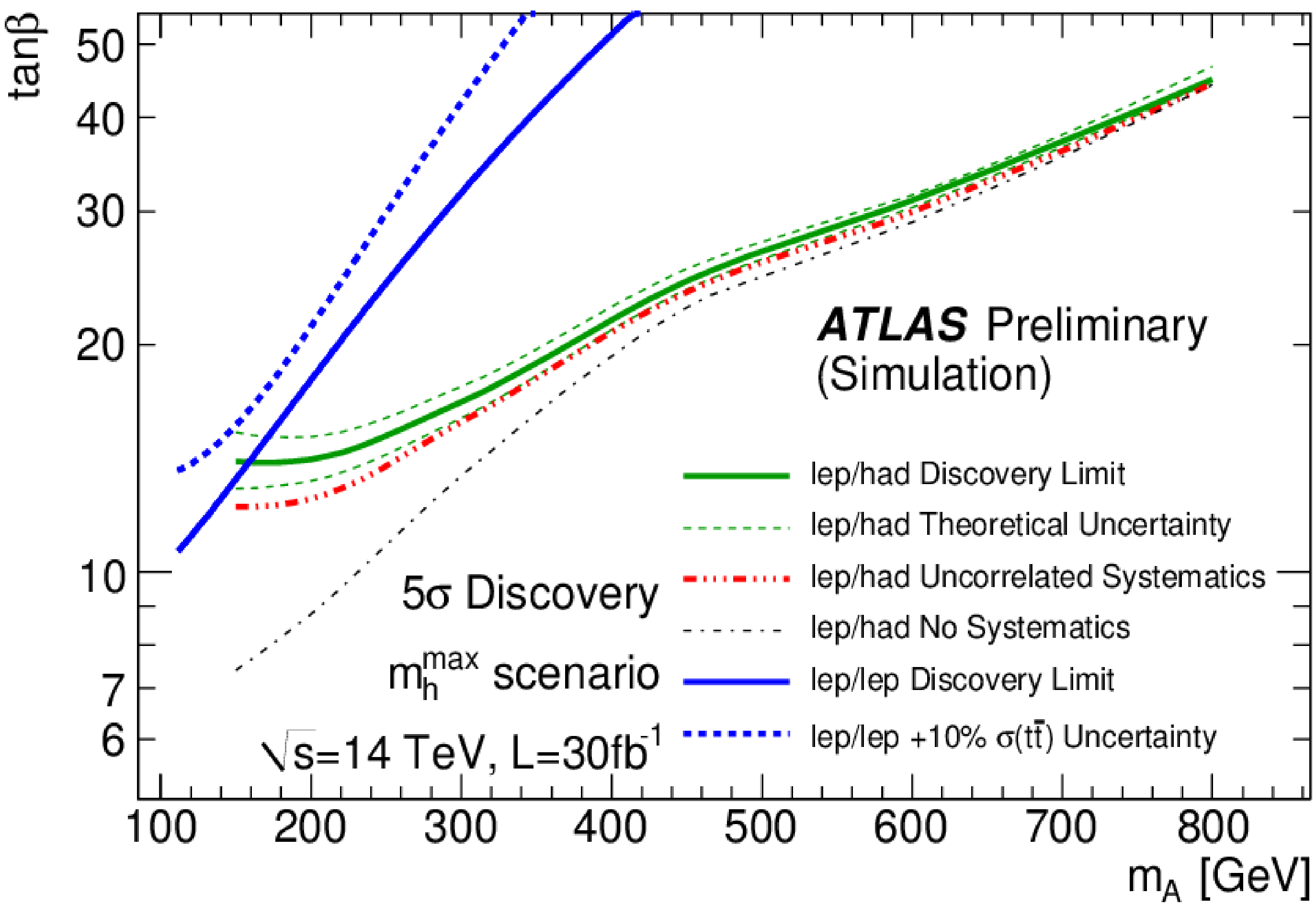
1. Select $Z \rightarrow \mu\mu$ events,
2. Replace the prompt muon kinematics by that of a muon from a $\tau \rightarrow \mu+2\nu$ decay
3. Recalculate the missing E_T

Result: $m_{\tau\tau}$



MSSM h/A/H → ττ Discovery Potential

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



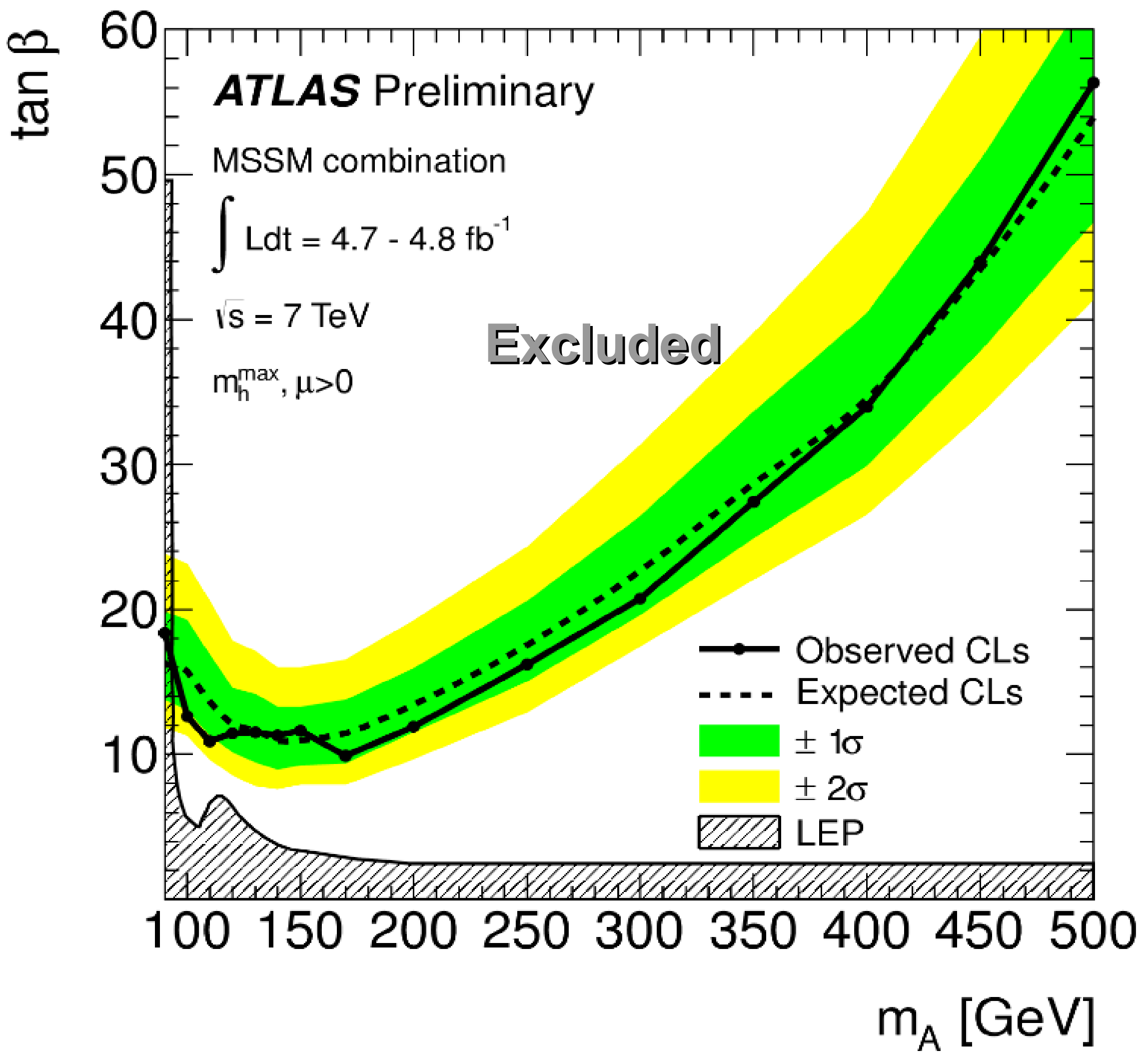
30 fb^{-1} expected after 1 year of data taking at 14 TeV

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/A/H Limits

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



Combined limits of MSSM
$H \rightarrow \mu\mu$ and $H \rightarrow \tau\tau$

ATLAS-CONF-2012-094

No excess found, results in agree with the SM backgrounds

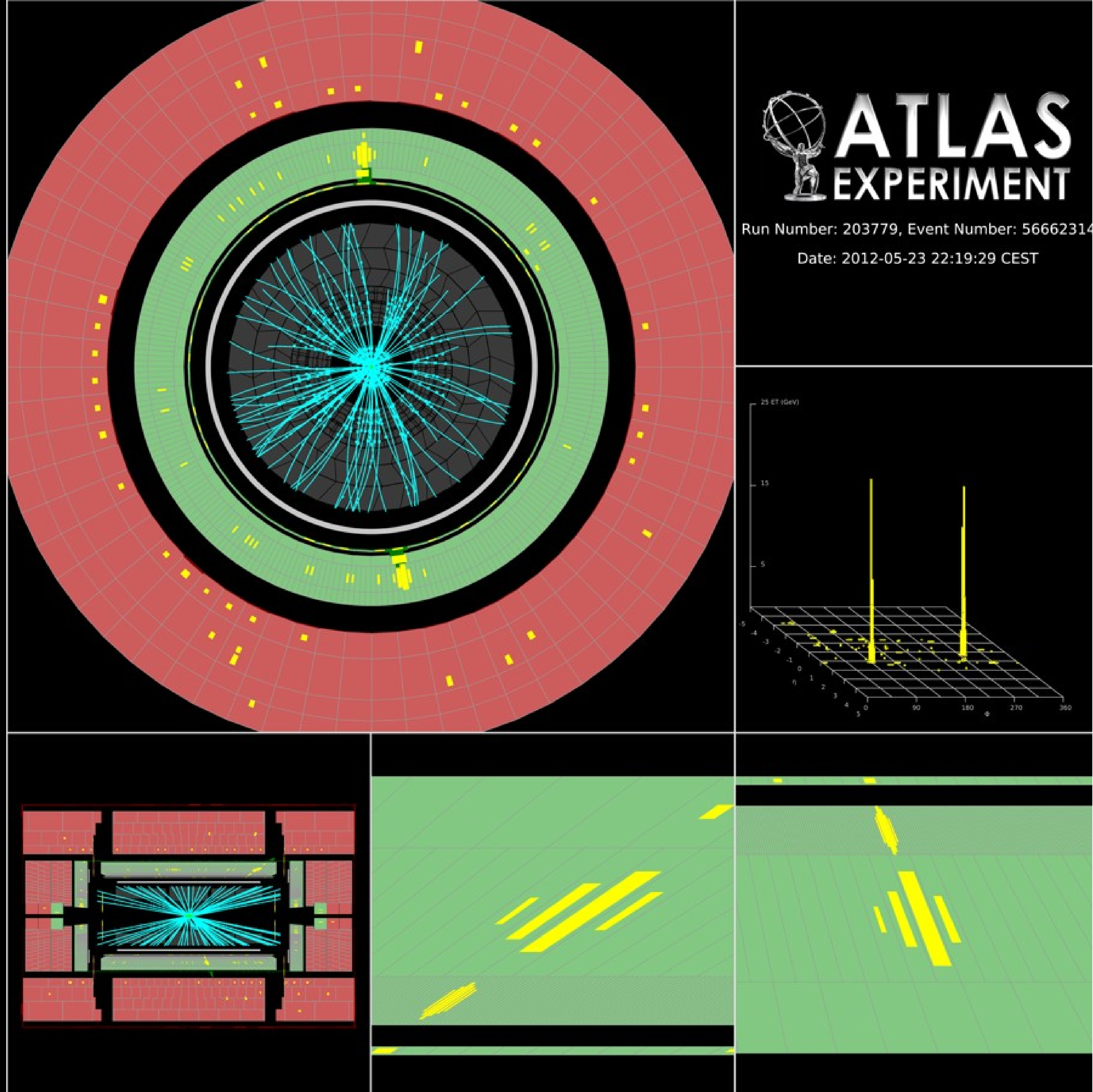
→ Exclusion limits set in m_A-tanβ plane

(this was not anymore a part of my PhD work)

Work after my PhD:

$$H \rightarrow \gamma\gamma$$

Data analysis



Candidate Event

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

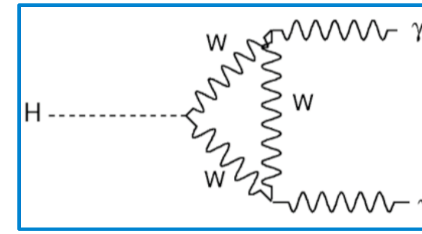
Dataset:

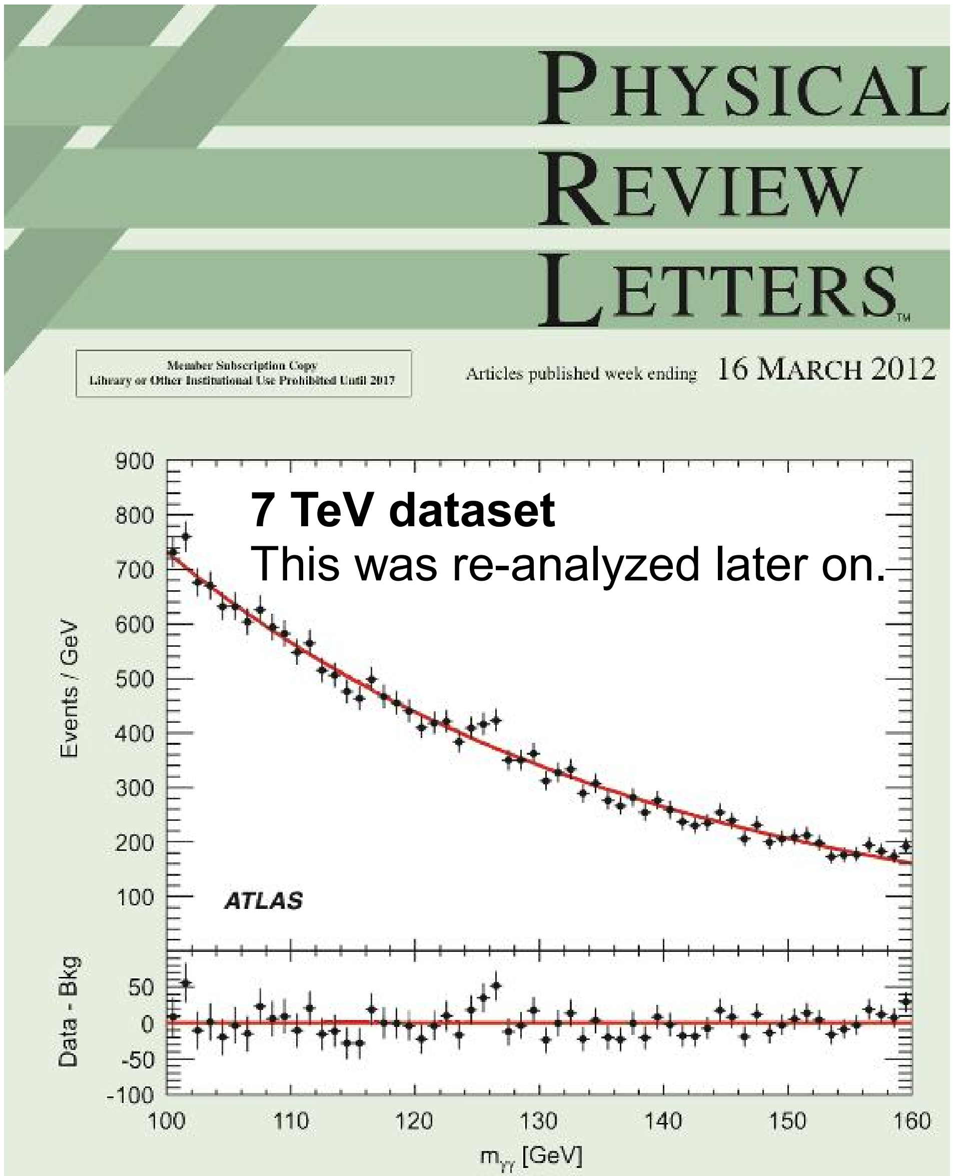
4.8/fb 2011 data
+ 13.0 /fb 2012 data

H $\rightarrow$ $\gamma\gamma$ Analysis

Channel with the best mass resolution (1.6 GeV)

$\rightarrow$ Expect a sharp mass peak on top of a smoothly falling background





„Inclusive“ Event Selection:

- Diphoton trigger
- Select events with two high-p_T photons
- Tight identifcation and isolation applied

$\rightarrow$ Data-driven techniques reveal that 75% of the events are diphotons (not jets)

Background Estimation:

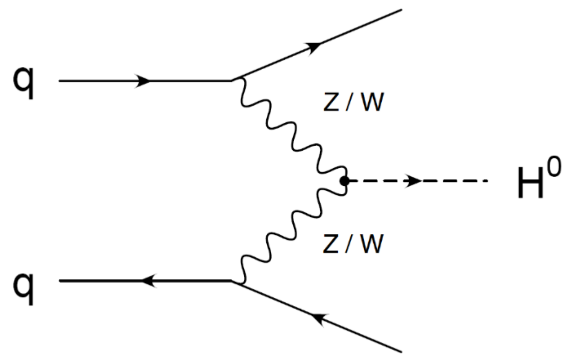
- Background estimated from data with a fit of $m_{\gamma\gamma}$
- Choice of the fit function is crucial, decided by the study of MC samples (eg. 10 billion Diphox events)

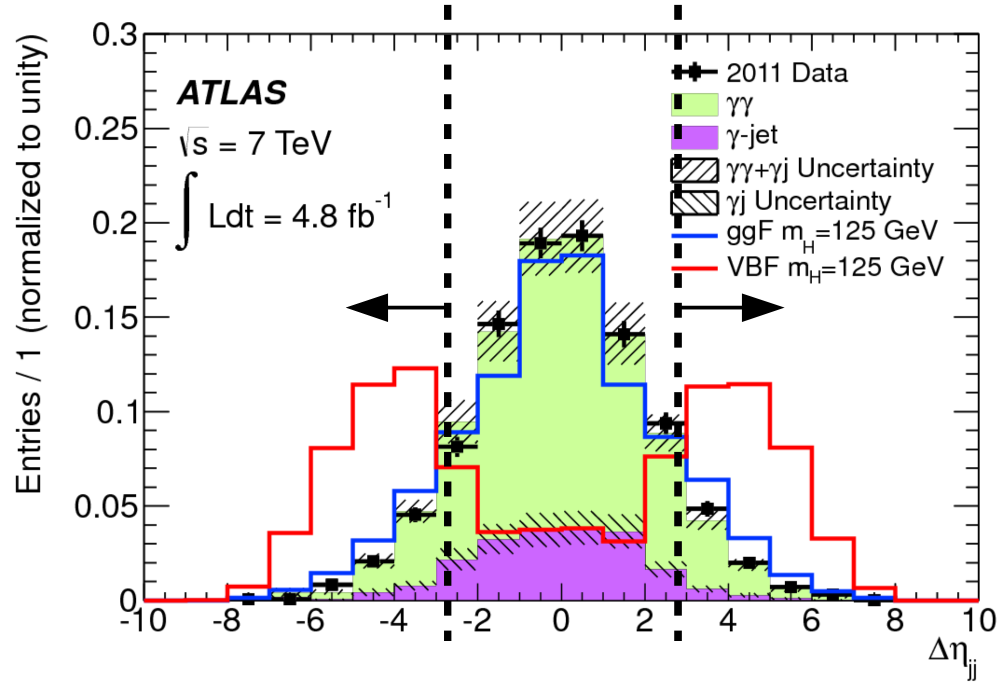
$\rightarrow$ Use either exponentials, 4^{th} order polynomials or exponential of 2^{nd} order polynomials

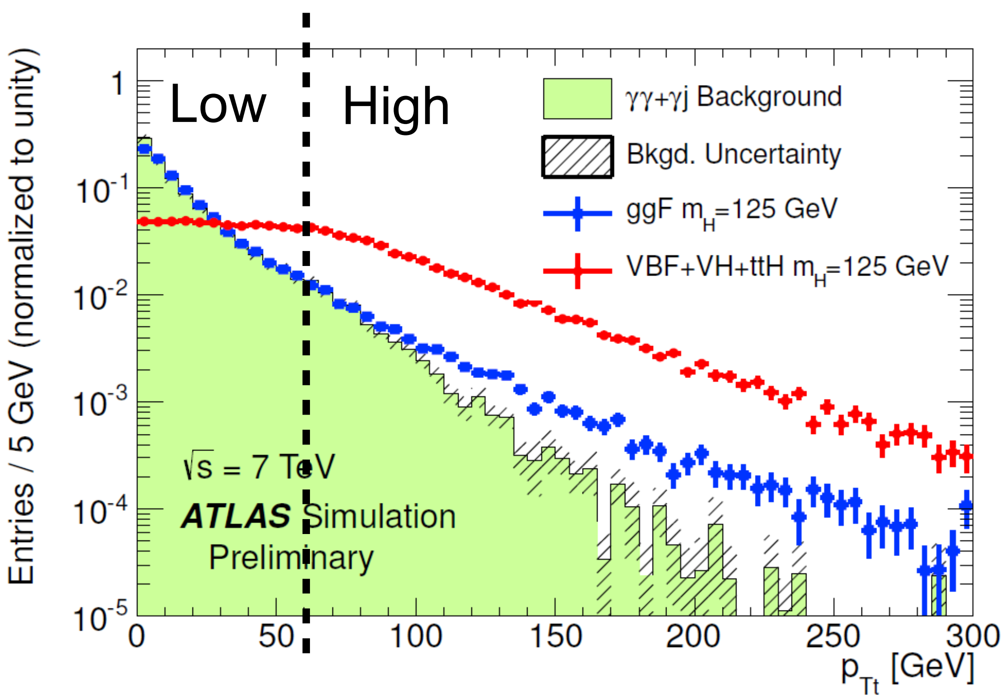
$H \to \gamma\gamma$ Categorization

2-jet category:

Enrich subsample with Vector-boson-fusion

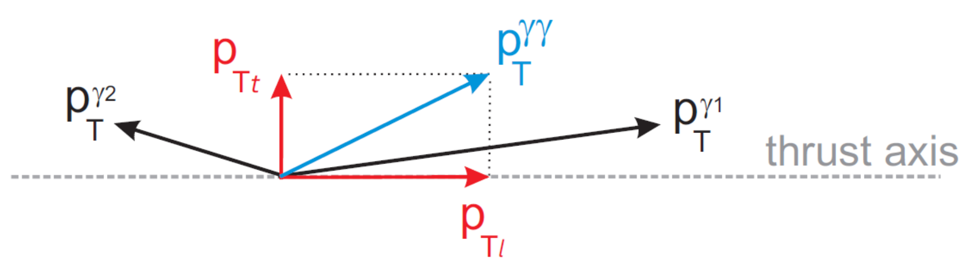






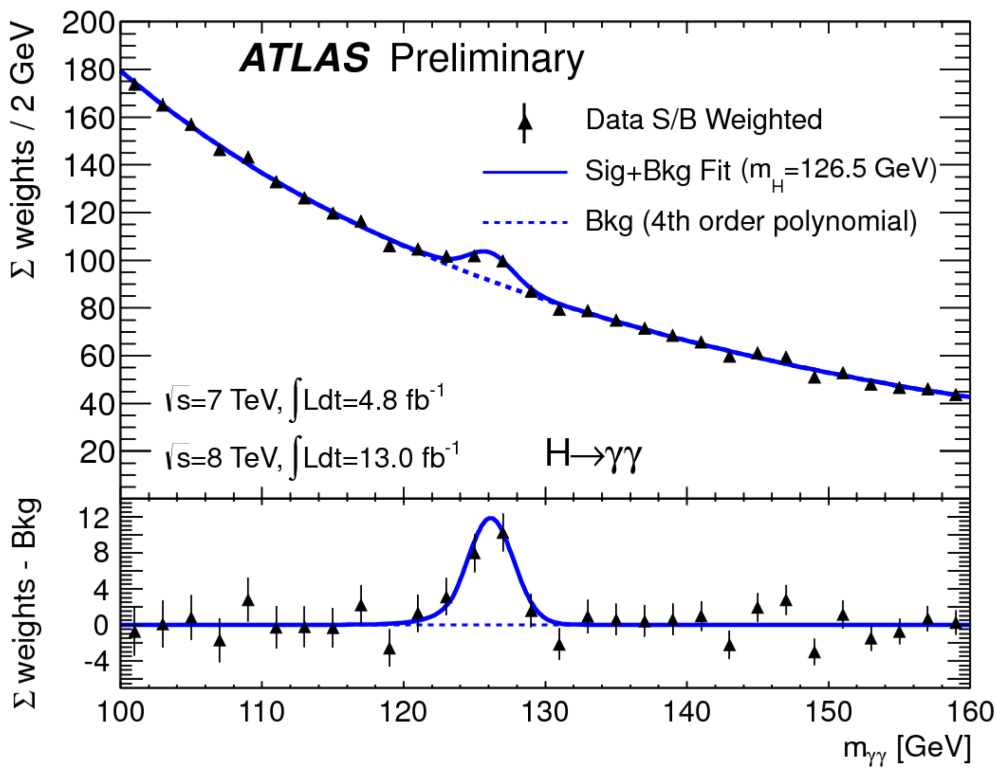
9 other categories:

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

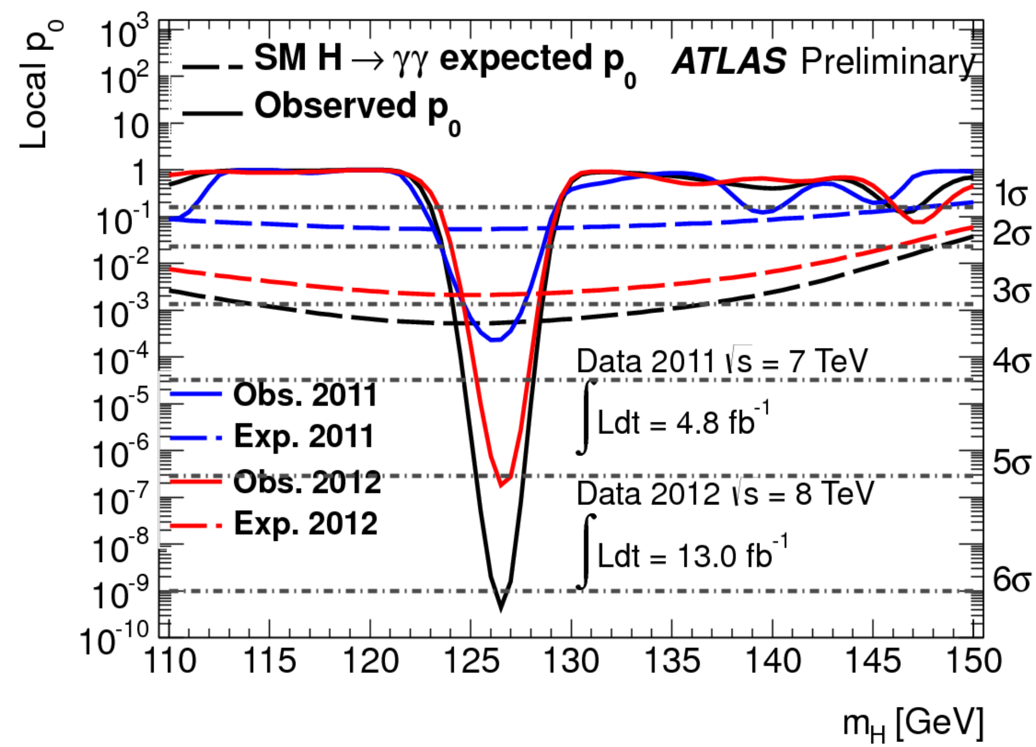


H → γγ Latest Results

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: 6.1σ

Best-fit signal strength:

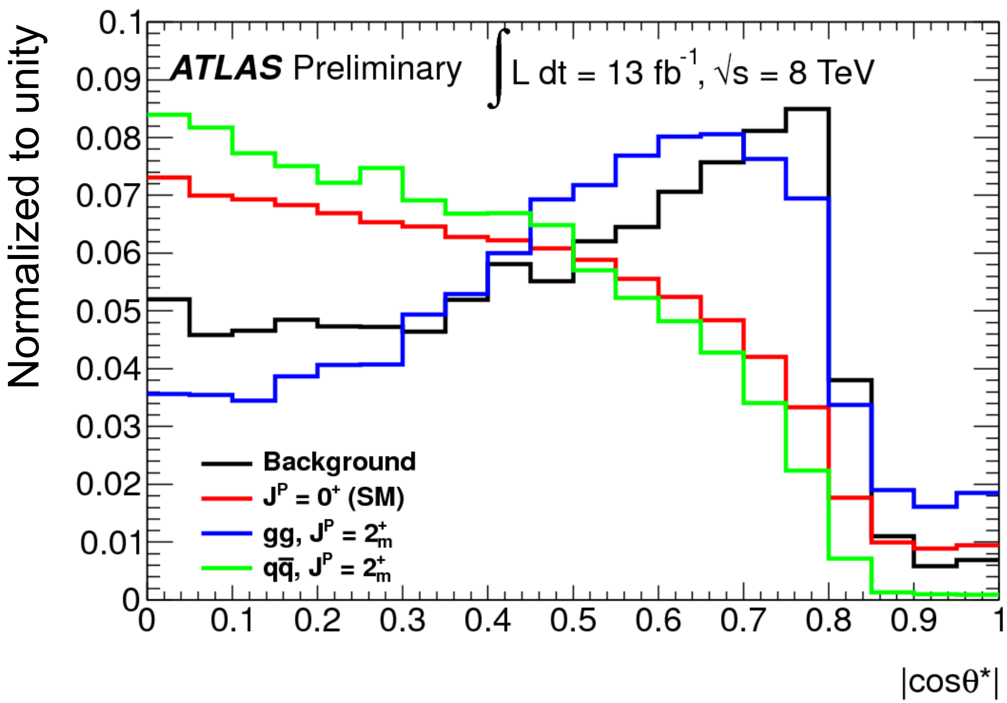
$\mu = 1.8 \pm 0.4$

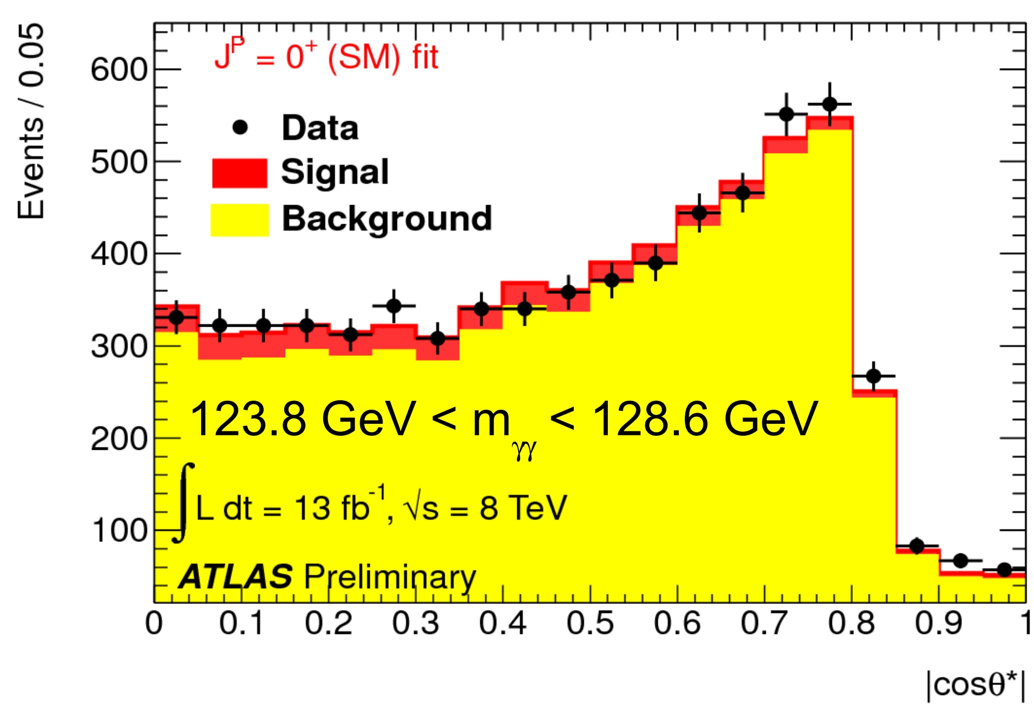
First Measurements with H $\rightarrow \gamma\gamma$: Spin

The SM Higgs boson is a scalar with even parity $\rightarrow J^P = 0^+$.

Need to discriminate this from spin-2 hypothesis (Graviton-like particles, $J^P = 2_m^{\ +}$).

Information on the spin inferred from the production angle in the diphoton rest frame, θ^*.





Background shape estimated from data from mass sidebands.

Result: The data slightly prefers spin-0 hypothesis over spin-2 hypothesis at the 1σ level.

Summary

PhD thesis in Dresden (2007-2010):

Study of Neutral MSSM Higgs bosons decaying to τ-pairs

- Signal-background discrimination
- Data-driven background estimation
- Evaluation of the discovery potential

Supported by the Graduiertenkolleg

Post-Doc in Orsay (France) since 2010 on data analysis for $H \rightarrow \gamma\gamma$

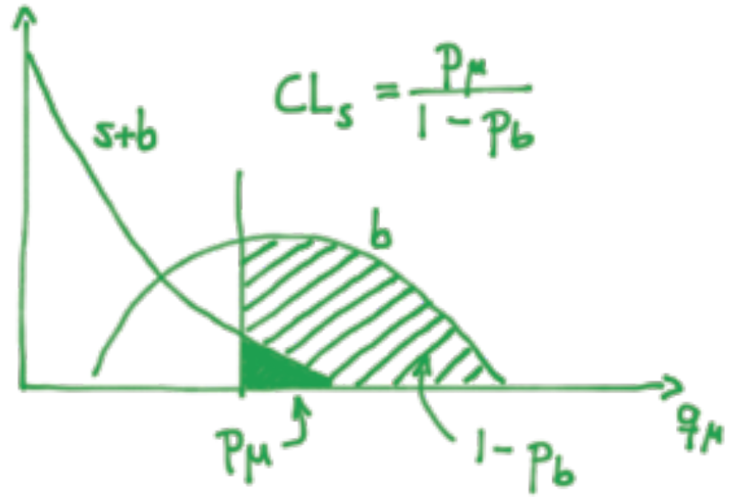
- Discovery of a new Higgs-like particle with a mass of ~126 GeV
- Several editorships
- Major contributions in the categorization, background estimation and background uncertainties, spin analysis

Back up

Statistics in a Nutshell

Figures from Kyle Cranmer, Alex Read

CLs to test signal hypothesis:



Test statistics based on profile likelihood ratio:

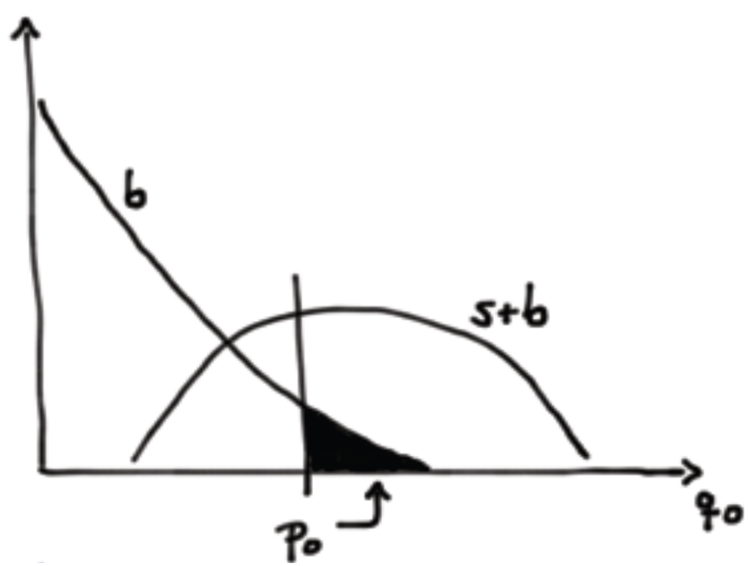
$$q_\mu = -2\ln\frac{L(\mu,\hat{\hat{\theta}})}{L(\hat{\mu},\hat{\theta})}$$

μ fixed

unconditional

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

p_0 to test bkg hypothesis:



Signal strength: