SM Higgs Searches at the LHC

Maiko Takahashi
Imperial College London / University of Manchester

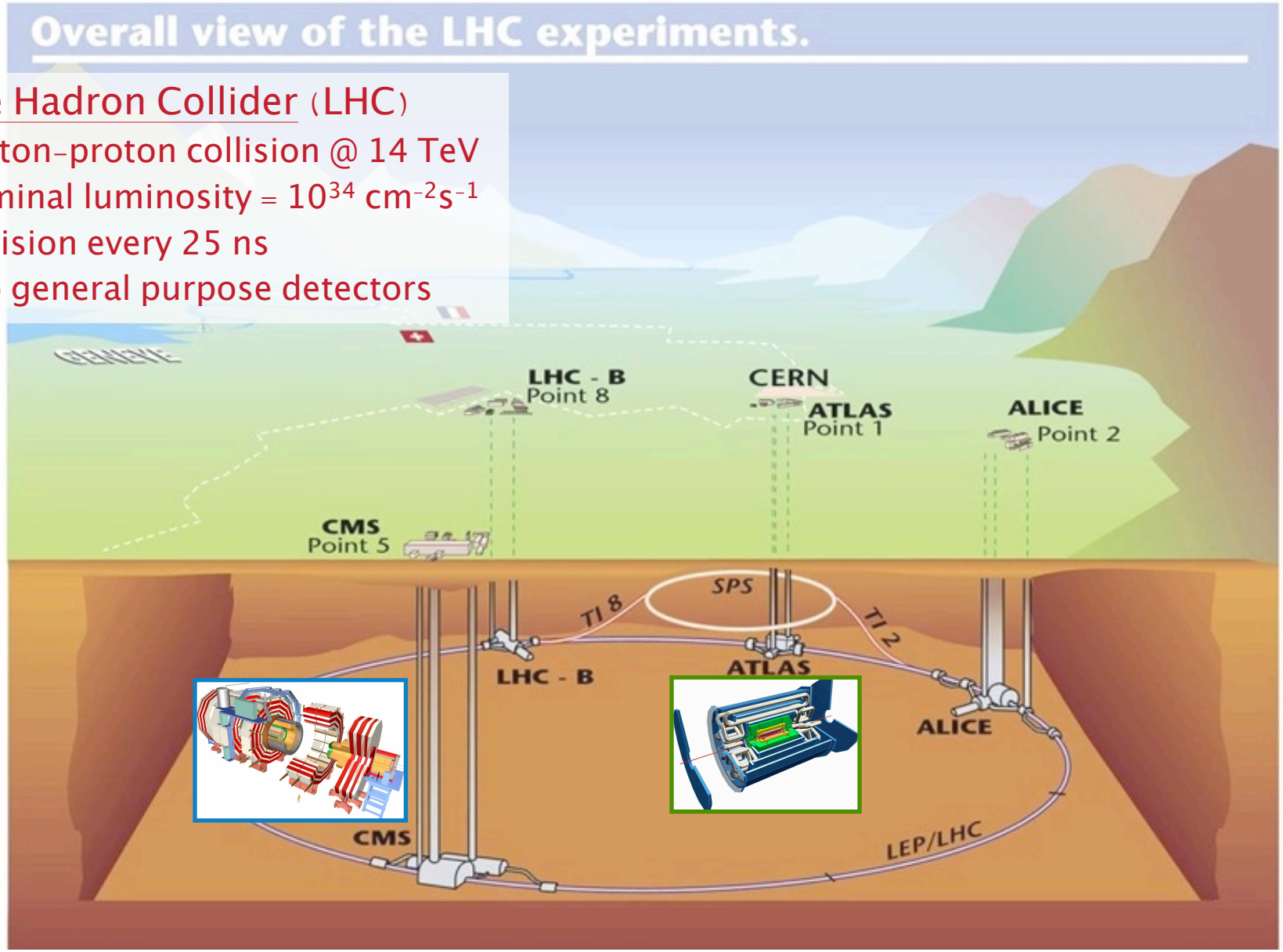
on behalf of the ATLAS and CMS Collaborations

HCP2008, Galena IL

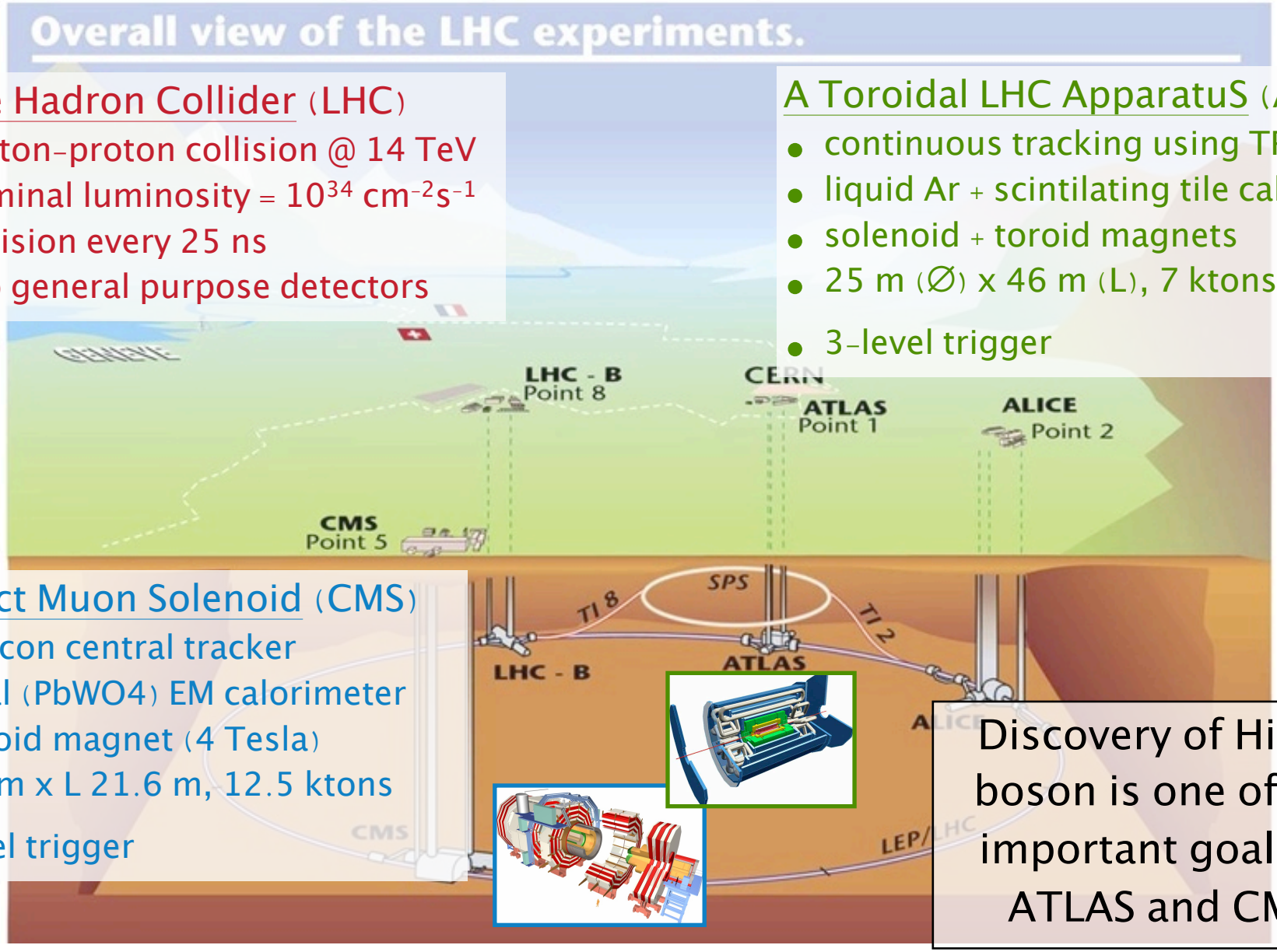
LHC Experiments

Large Hadron Collider (LHC)

- proton-proton collision @ 14 TeV
- nominal luminosity = 10^{34} $cm^{-2}s^{-1}$
- collision every 25 ns
- two general purpose detectors



LHC Experiments



Large Hadron Collider (LHC)

- proton-proton collision @ 14 TeV
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A Toroidal LHC ApparatuS (ATLAS)

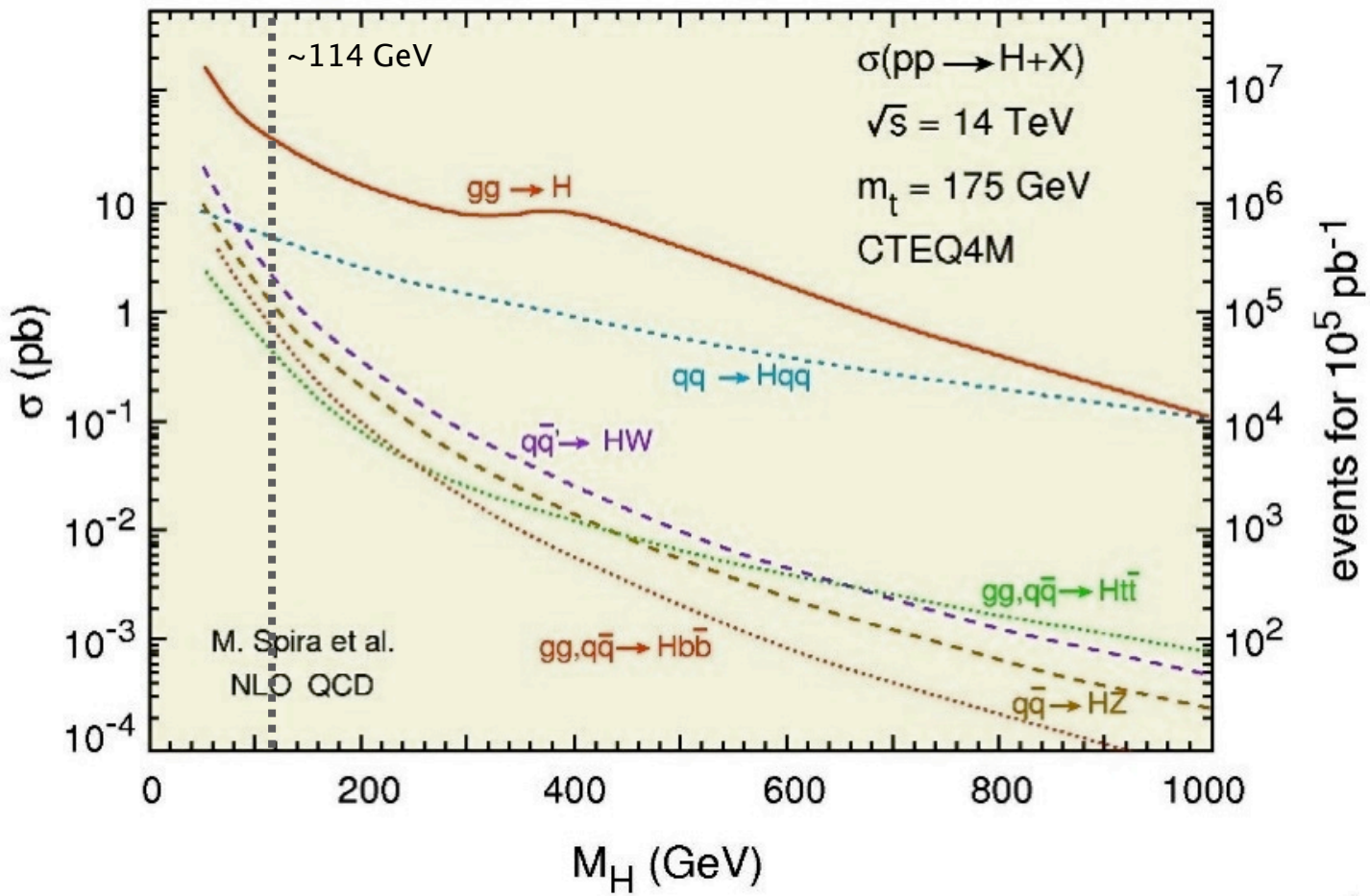
- continuous tracking using TRT
- liquid Ar + scintilating tile calorimeter
- solenoid + toroid magnets
- 25 m (∅) x 46 m (L), 7 ktons
- 3-level trigger

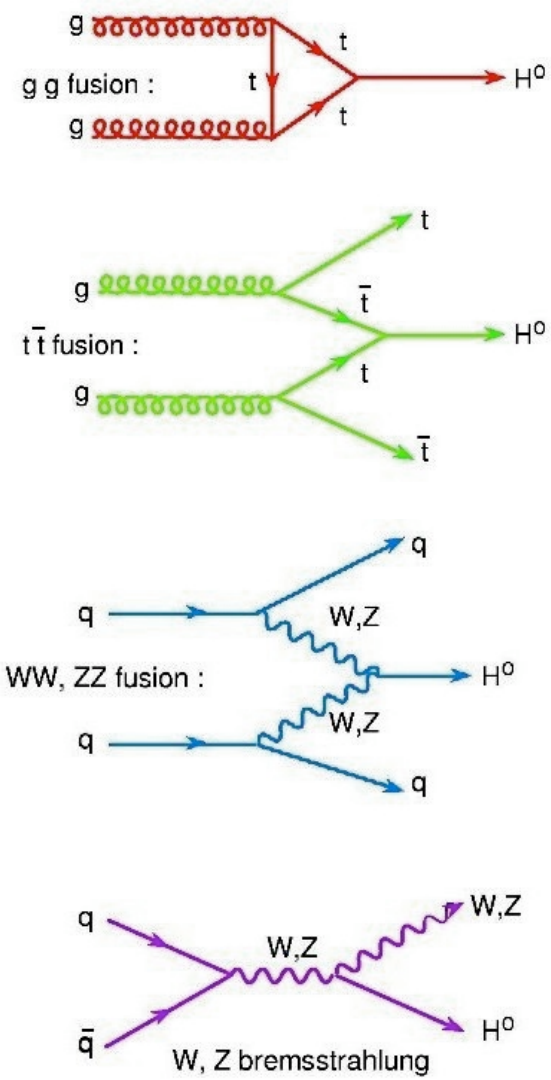
Compact Muon Solenoid (CMS)

- all silicon central tracker
- crystal (PbWO4) EM calorimeter
- solenoid magnet (4 Tesla)
- ∅ 15 m x L 21.6 m, 12.5 ktons
- 2-level trigger

Discovery of Higgs boson is one of the important goals of ATLAS and CMS

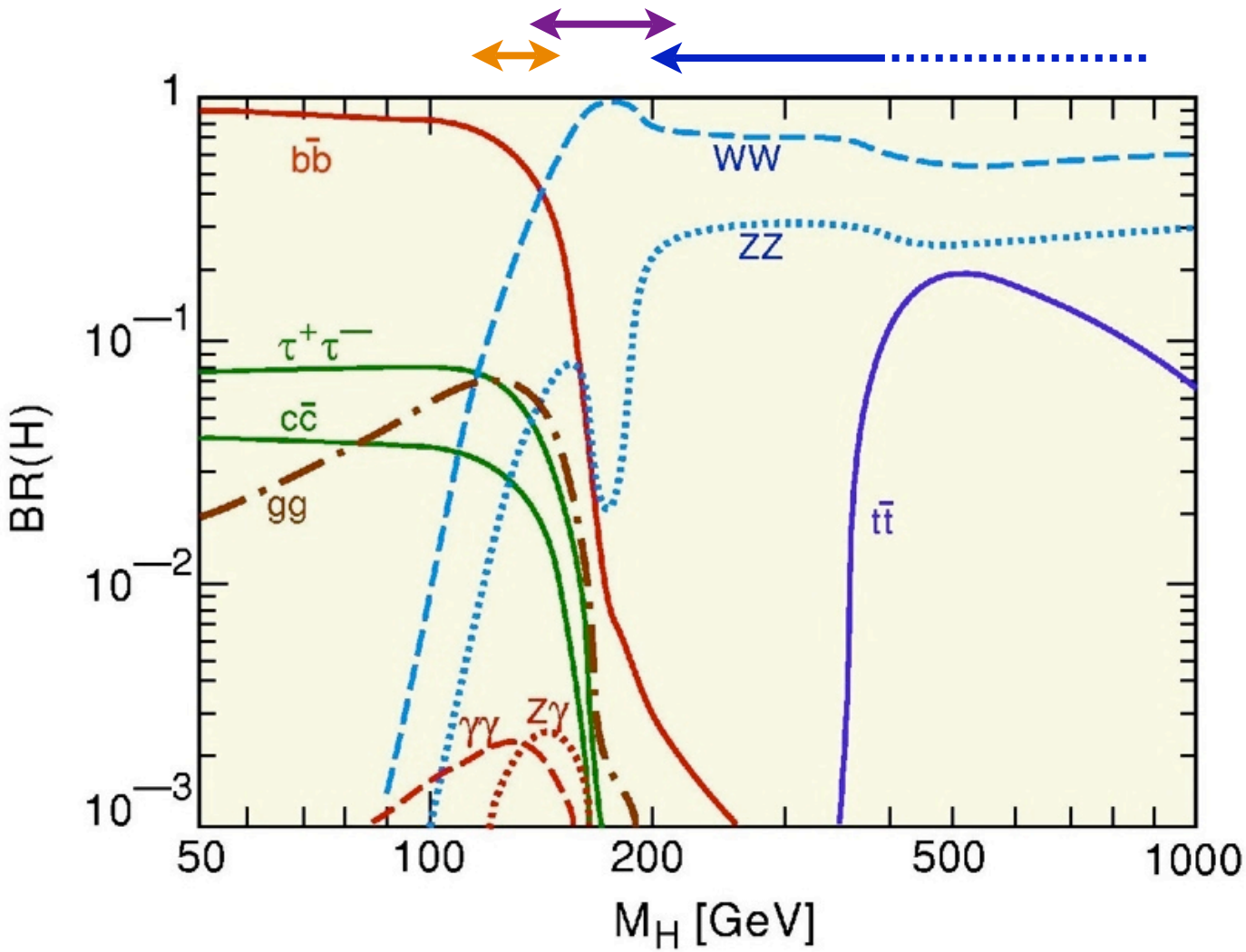
SM Higgs Production at LHC





- Gluon fusion (gg → H) dominates (10's pb)
- Vector-boson fusion (qq → qqH) 2nd dominant and becomes comparable to gg → H at very high mass

SM Higgs Branching Ratio



Low Mass

- $H \to \gamma\gamma$
- $H \to \tau\tau$ (qqH)
- $H \to bb$ (ttH)

Intermediate Mass

- $H \to WW$
- $H \to WW$ (qqH)

High Mass

- ($H \to WW$)
- $H \to ZZ$

(also significant at low mass)

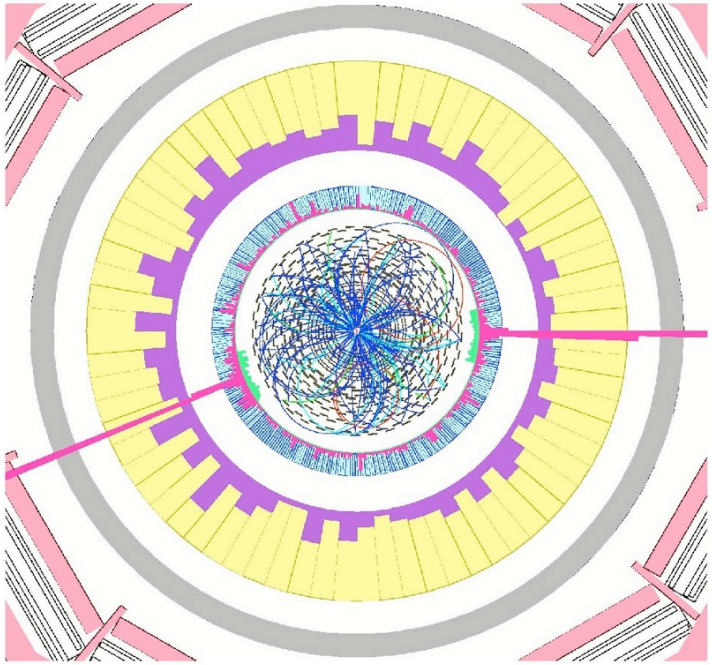
Low Mass Higgs Searches

Channels for low mass Higgs searches

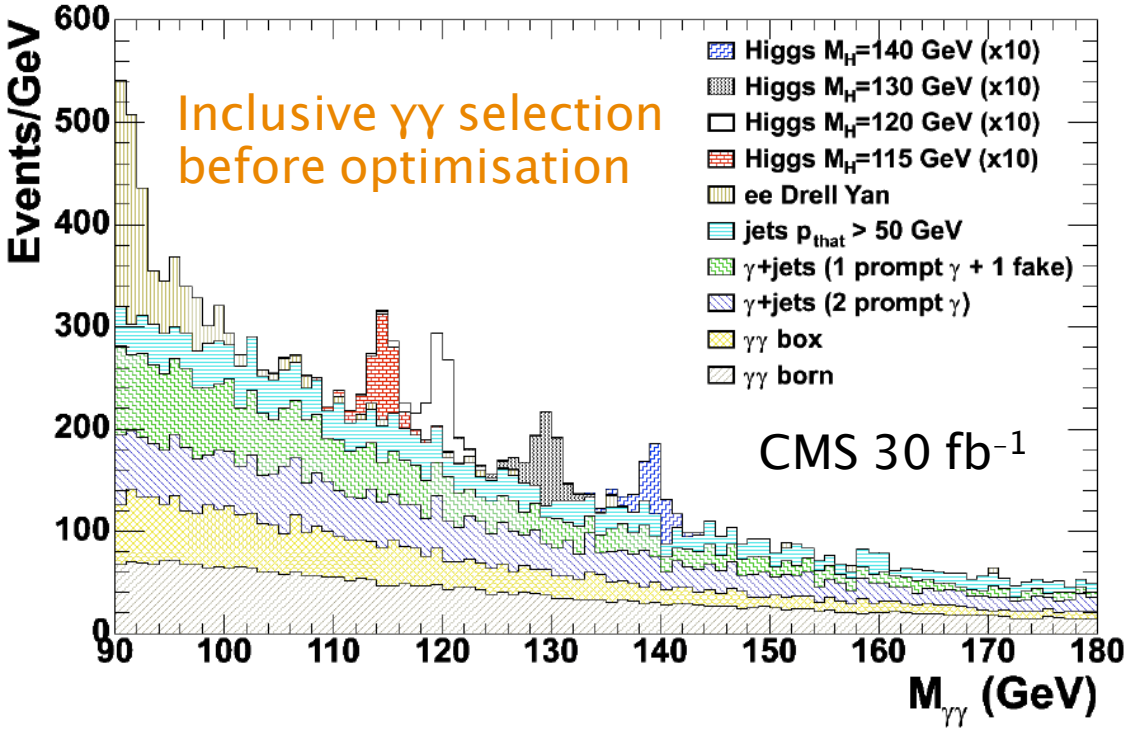
- $H \to \gamma\gamma$
- $H \to \tau\tau$ (qqH)
- $H \to bb$ (ttH)

H → γγ

- Promising for early discovery in low mass scenario
- Small branching ratio + large background (prompt γγ, γ + jets, …)
  → Fit the well-defined side band of M(γγ) shape to estimate
  → good energy resolution, isolation and photon ID are crucial



H → γγ CMS event display

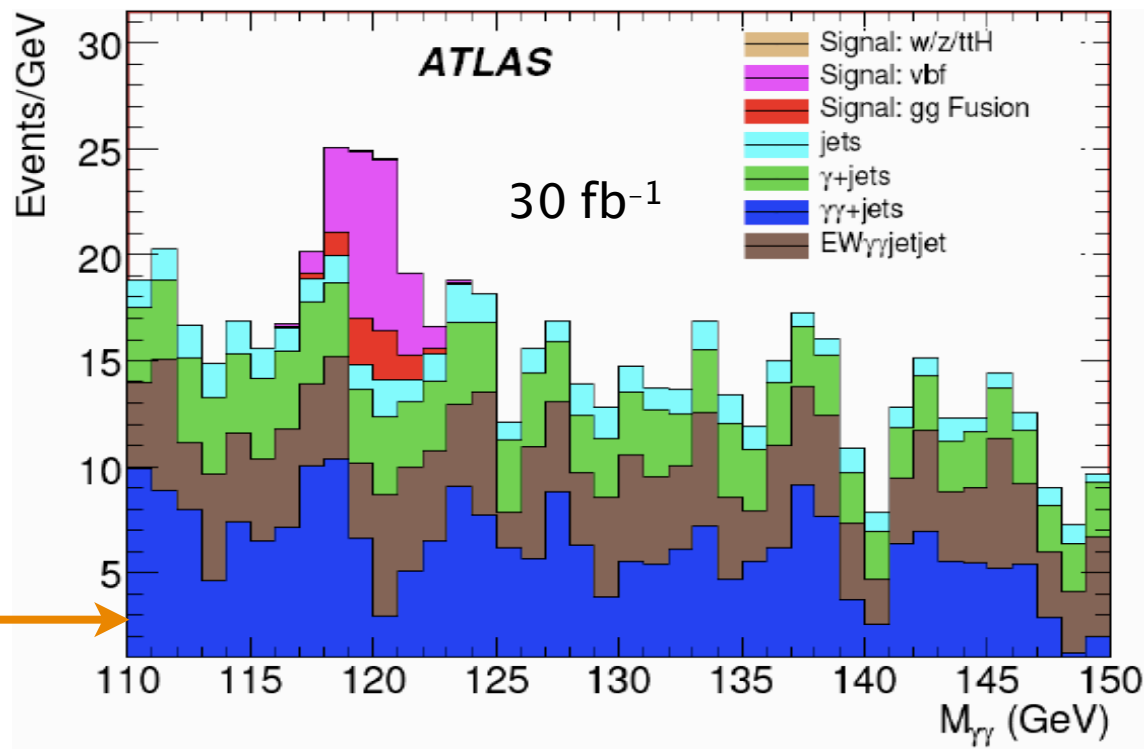


H → γγ

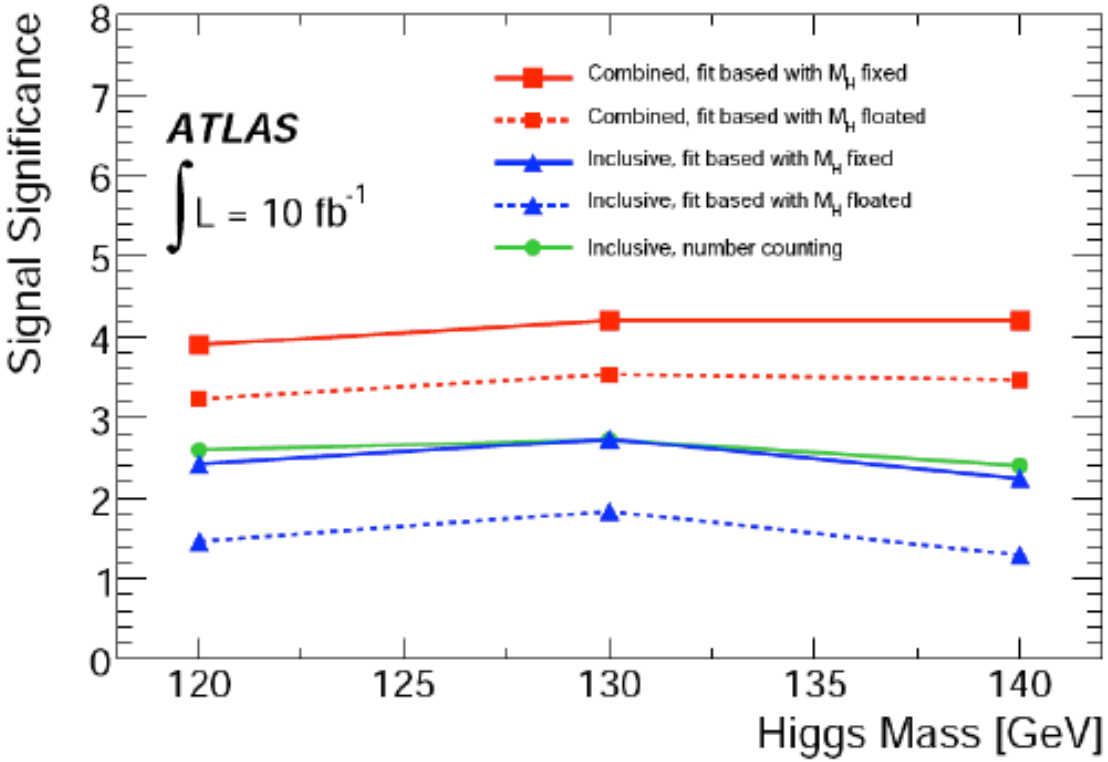
- Analysis Strategies
  - Cut-based initial analysis + further optimisation

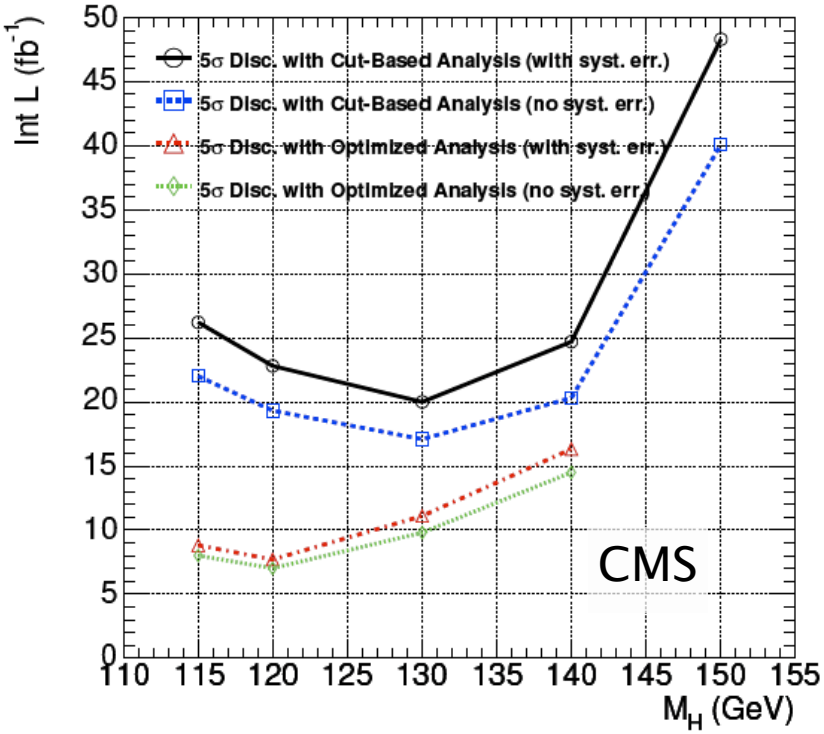
    → Likelihood or Neural Net based on kinematic variables
    (e.g. p_T of γγ system, photon decay angle, isolation parameters)
  - Categorised optimisation
    - jet multiplicity
    - detector region
    - γ shower shape

γγ + 2 jets



H → γγ : Sensitivity

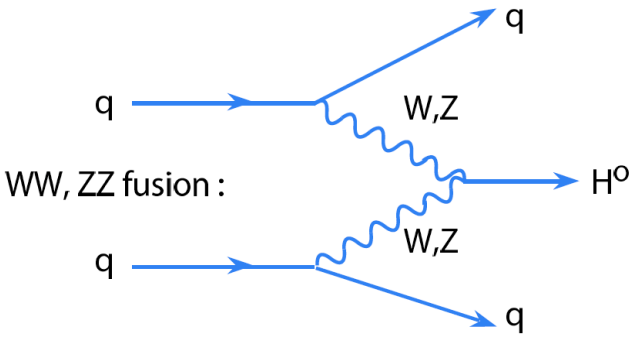




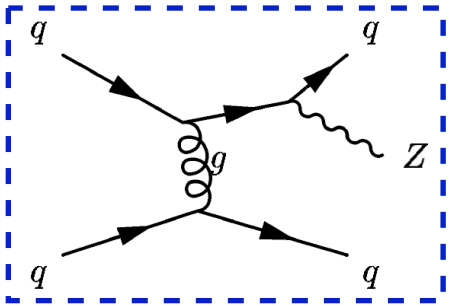
- Separating into categories increases the combined sensitivity
- Discovery possible for low mass range at 10 fb^{-1}
  (~1 year at low luminosity of 2×10^{33} $cm^{-2}s^{-1}$)

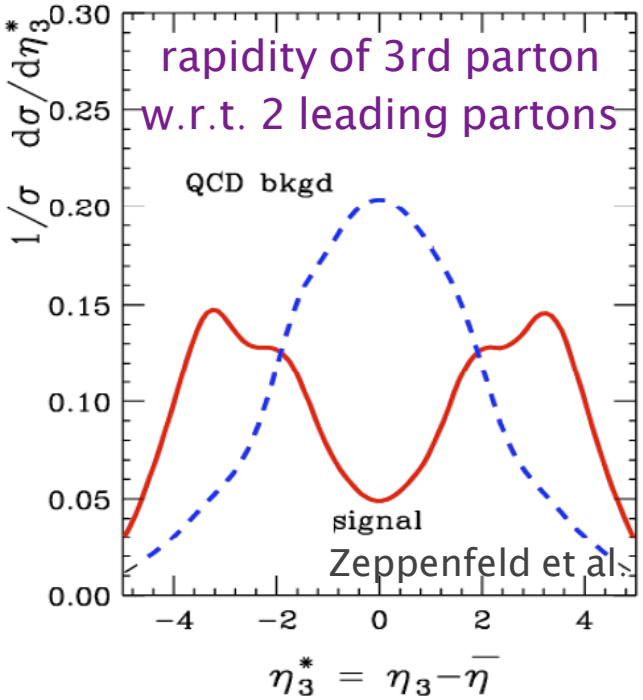
qqH, H → ττ

- H → ττ combined with Vector-Boson Fusion (VBF) production
- Signatures (ττ → $l+\tau_h$): electron or muon + hadronic decay of τ lepton + missing E_T + forward-backward quark jets



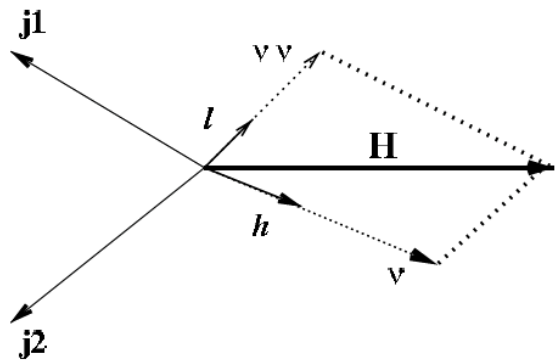
- Analysis Strategies
  - Kinematic cuts on VBF jets: Δη, Δφ, M(jj)
  - Veto events with central jets or tracks between the VBF jets
    → hadronic activities different for VBF and QCD process



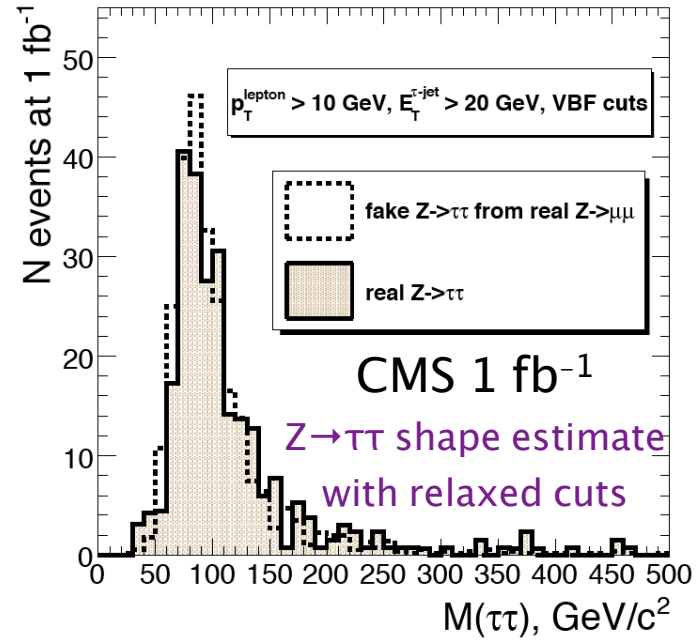


qqH, H → ττ (e.g. ττ → l+τ_h)

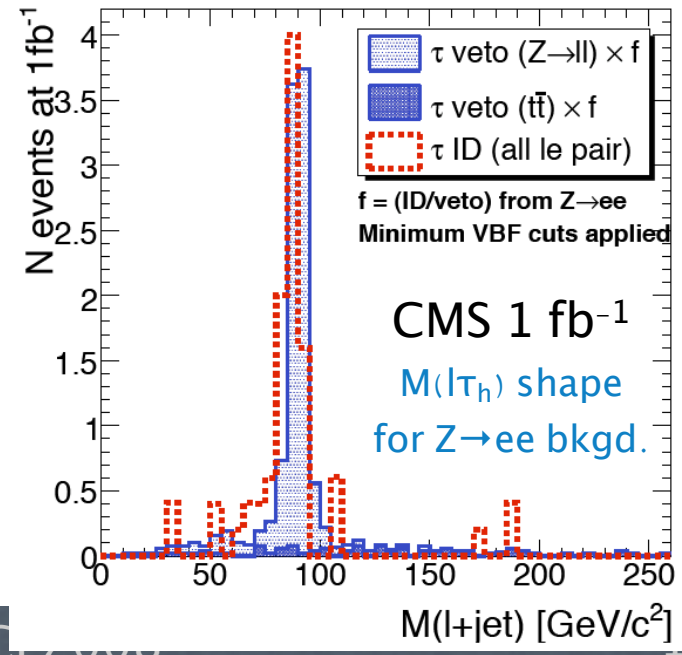
- Reconstruction of ττ mass
  - Partial mass, M(lτ_h), using only visible decay
  - Full mass, M(ττ), with collinear approximation



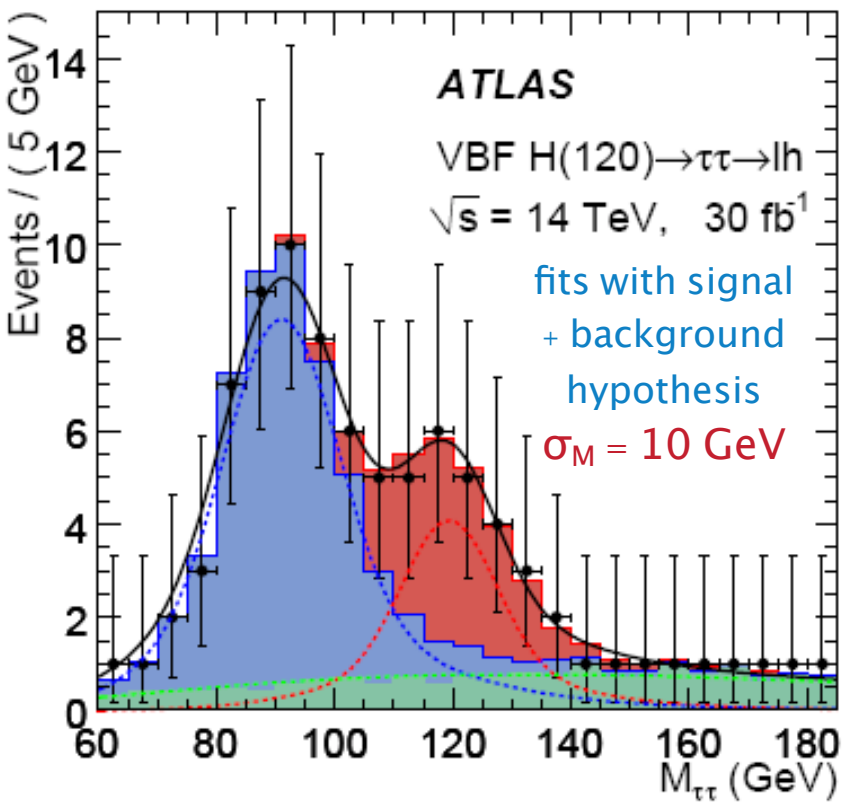
Assume neutrinos are collinear with the visible decay
→ project E_T^{miss} to get full τ energy

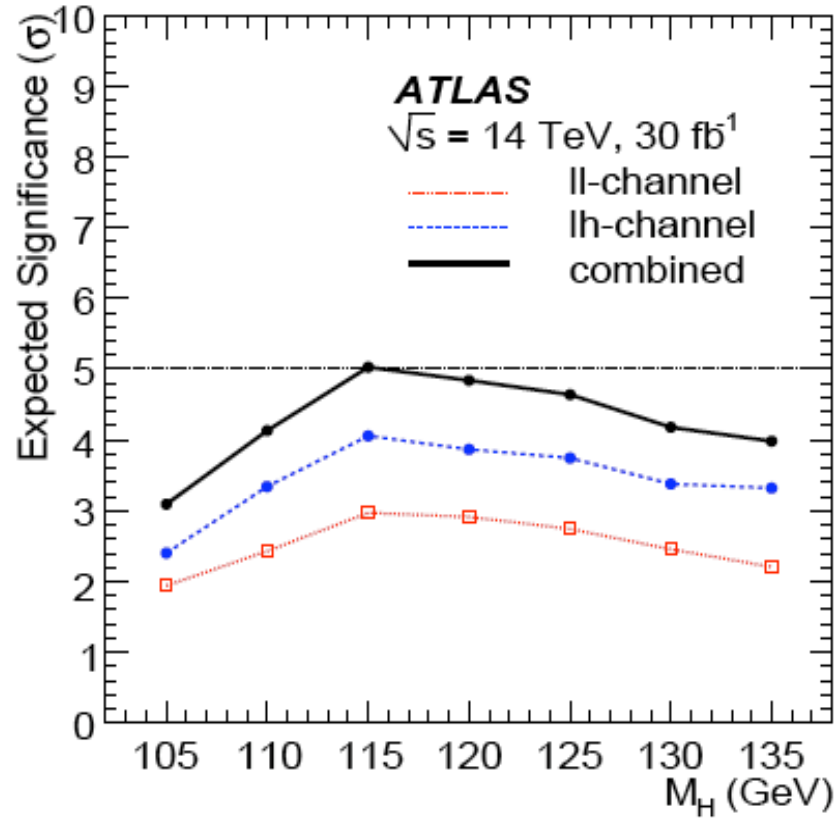


- Methods to estimate background from data
  - Z → ττ shape extracted from Z →μμ data (μ replaced by simulated τ)
  - Z → ee shape extracted by inverting the electron rejection cut for hadronic τ ID (efficiency evaluated from Tag & Probe)



qqH, H → ττ : Sensitivity

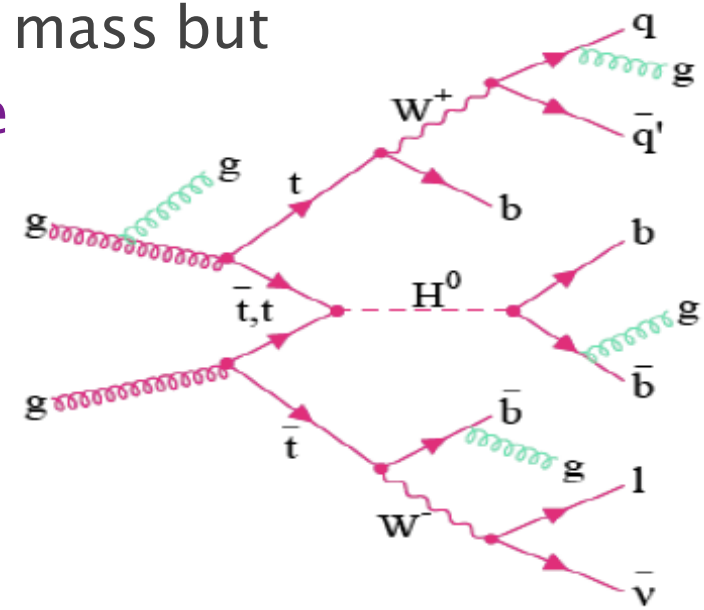


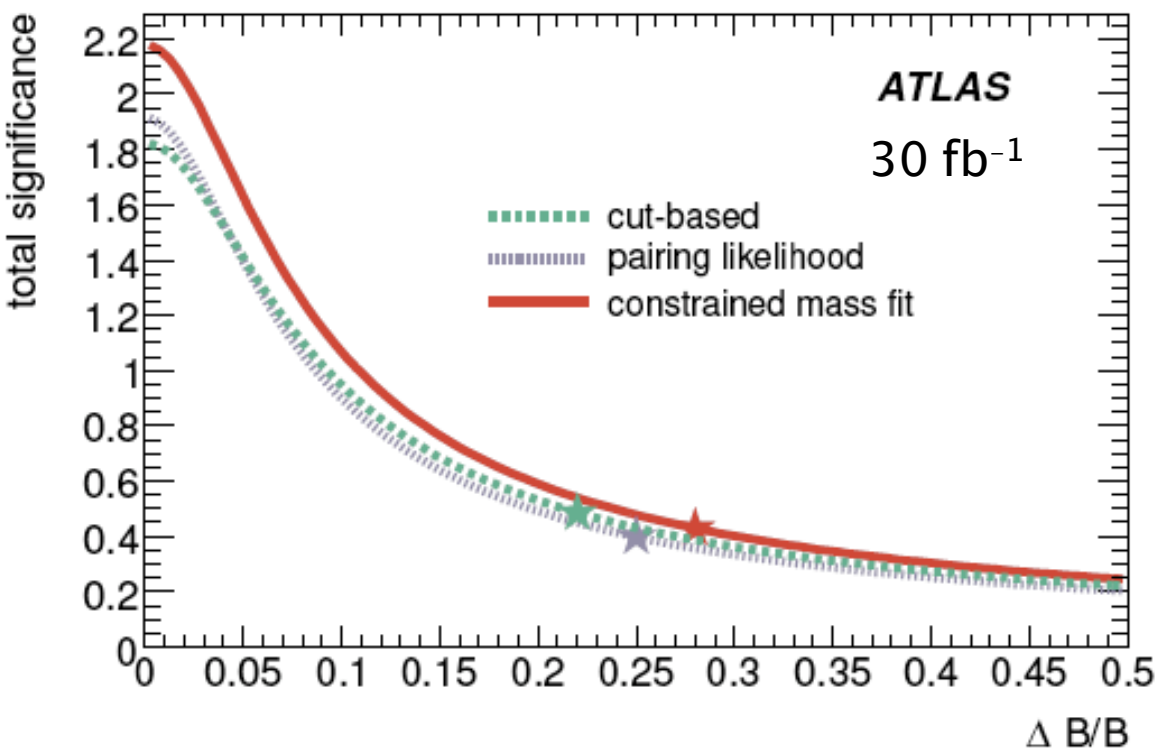


- 5σ discovery within the reach at 30 fb^{-1} (~3 years of low luminosity)
- Exclusion at 95% CL is possible at 10 fb^{-1} for most of the mass range concerned

ttH, H → bb

- Large decay branching fraction for low mass but difficult because of hadronic final state
  → combine with tt fusion production
  (high jet multiplicity + b-tagging
  + W decays to reduce background)





Additional combinatorial background from 4 b's in the signal process

Background uncertainty (ΔB/B) needs to be small (~few %) → very challenging

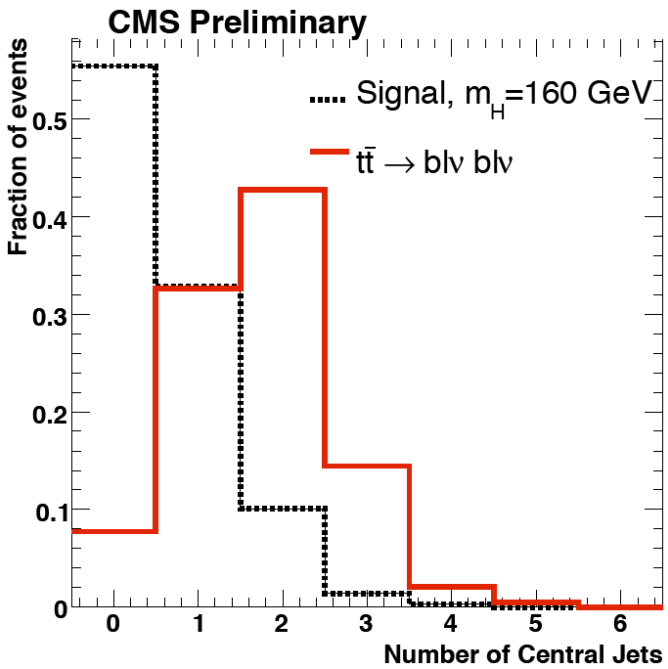
Higher Mass Higgs Searches

Channels for intermediate – high mass Higgs searches

- $H \rightarrow WW$
- $H \rightarrow WW$ (qqH)
- $H \rightarrow ZZ$

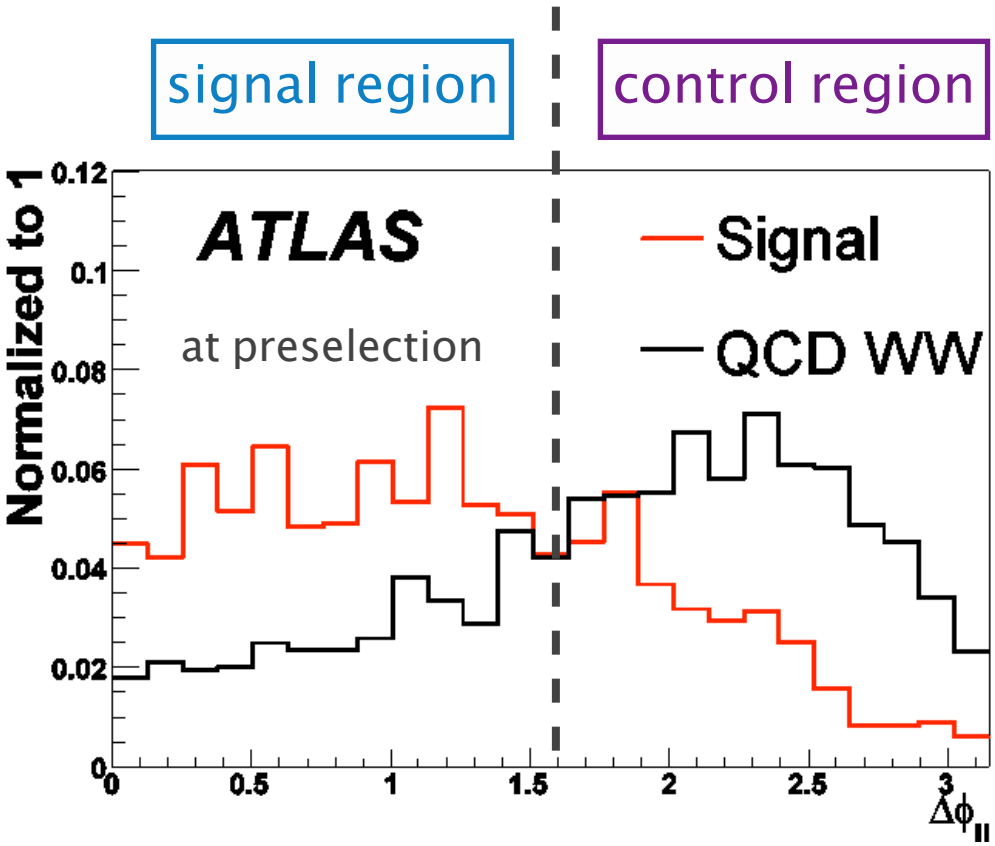
H → WW

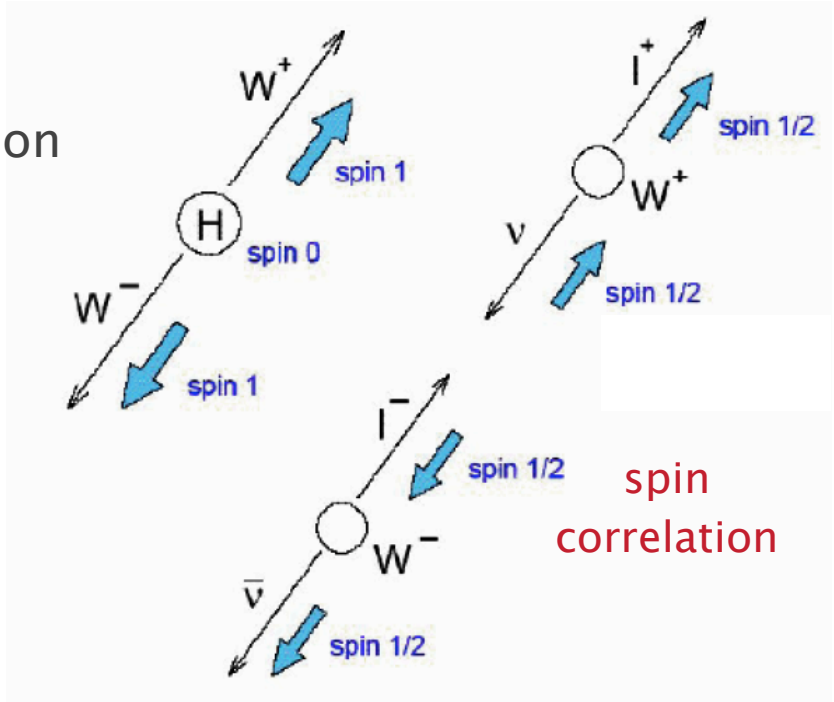
- Very powerful channel for intermediate Higgs mass range
- Challenging because of missing E_T involved in W decay
  → "Counting Experiment"
  → Precise background estimate is very important
- Analysis Strategies
  - Selection based on kinematic variables: di-lepton angular separation, di-lepton mass, E_T^{miss}, …
  - Central jet veto (effective against the dominant tt background)
  - Multivariate technique to increase the sensitivity



H → WW

- Spin correlation of two leptons:
  Spin 0 Higgs constrains the spin configuration of the final state leptons
  → small angular separation

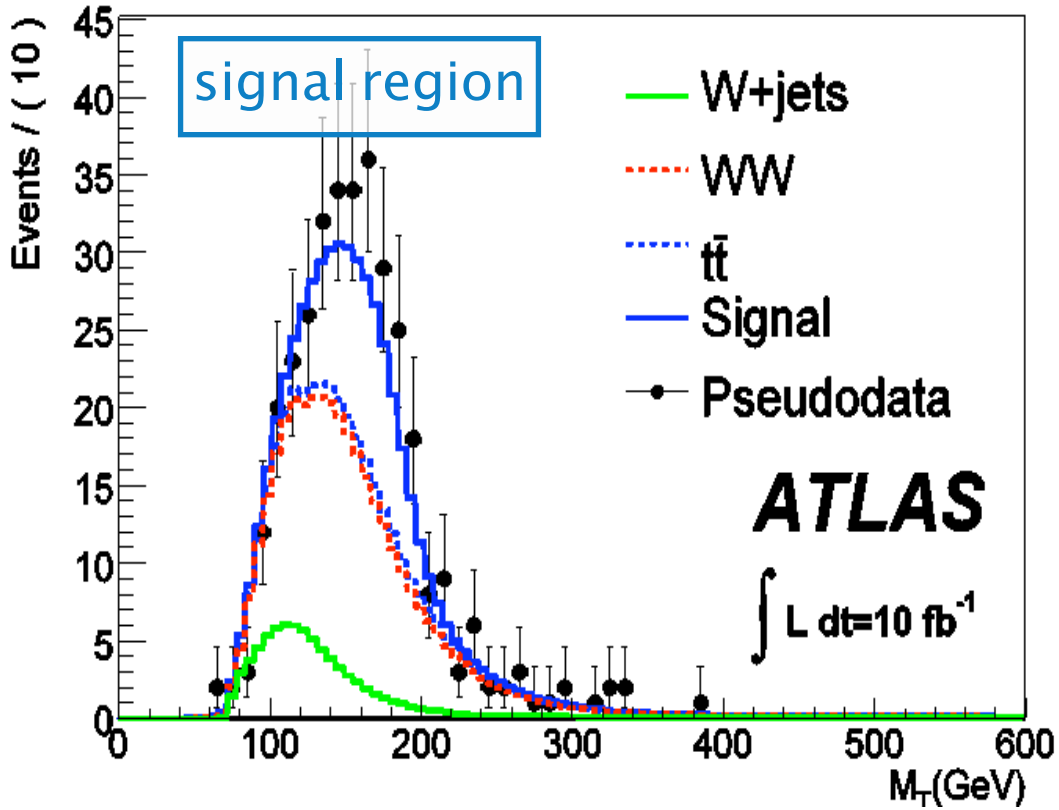


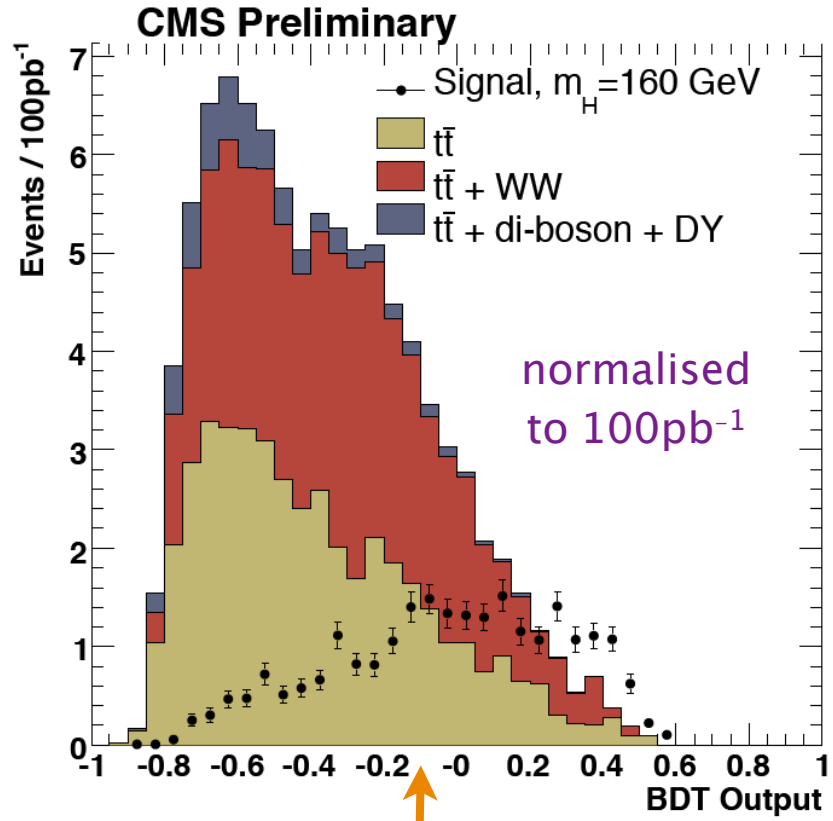


- Background Estimation:
  Normalisation to data using control samples selected with additional and/or inverted cuts

  e.g. WW background
  → extract from high $\Delta\varphi_{ll}$ region

H → WW

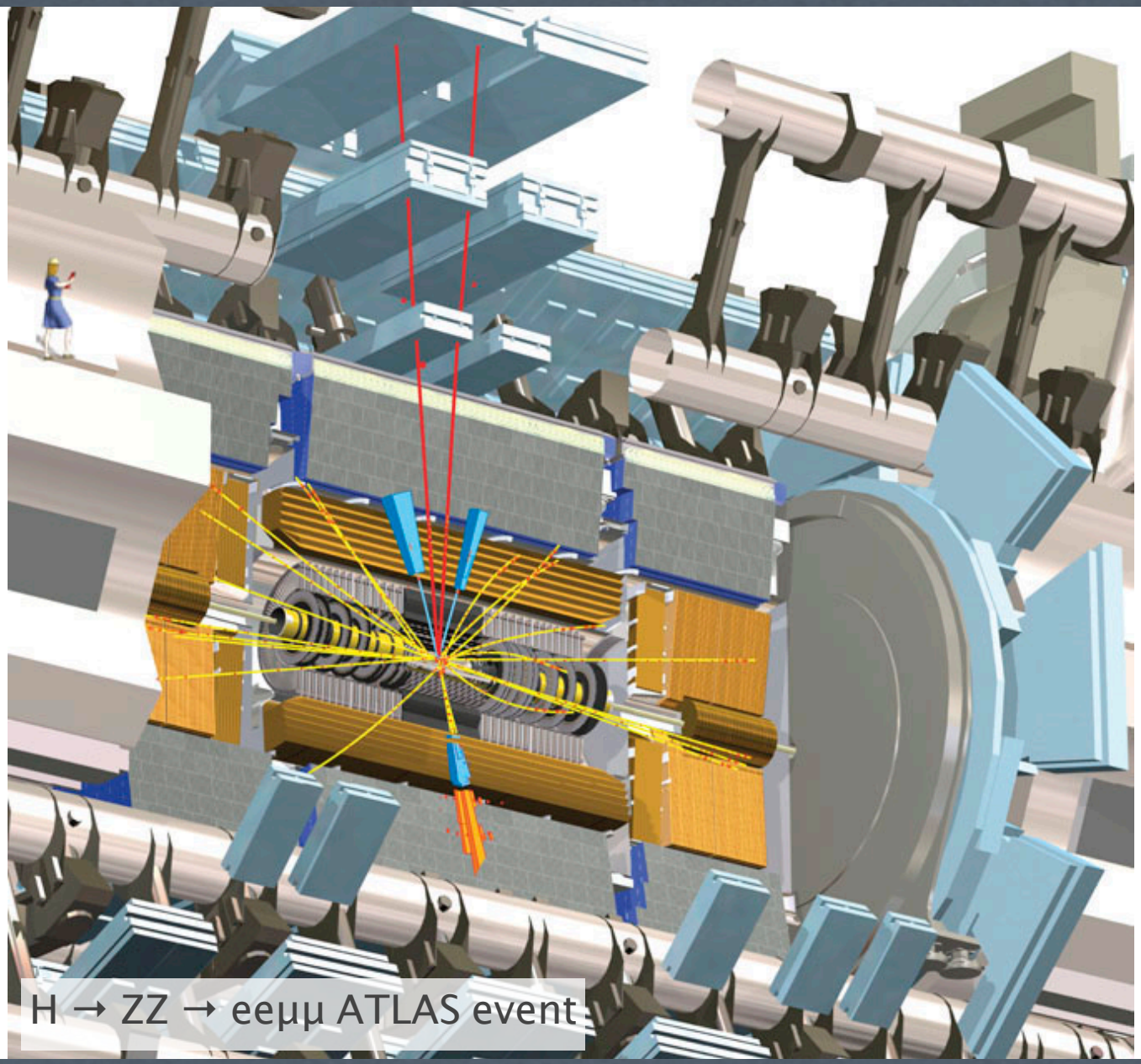




Boosted Decision Tree output

- A large signal excess in signal region
- Expect ~15% (up to 50% at 100 pb^{-1}) uncertainties in background estimate

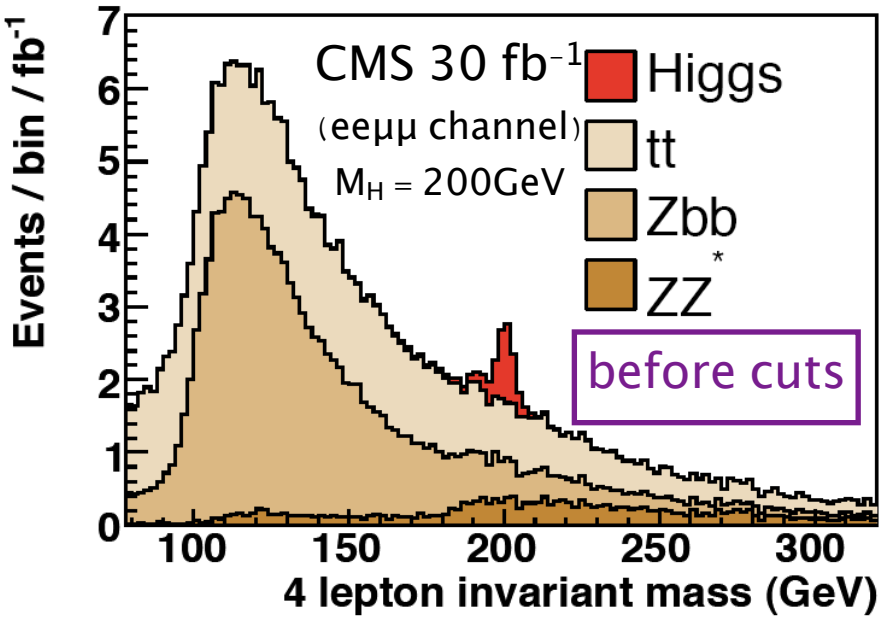
H → ZZ → 4 leptons

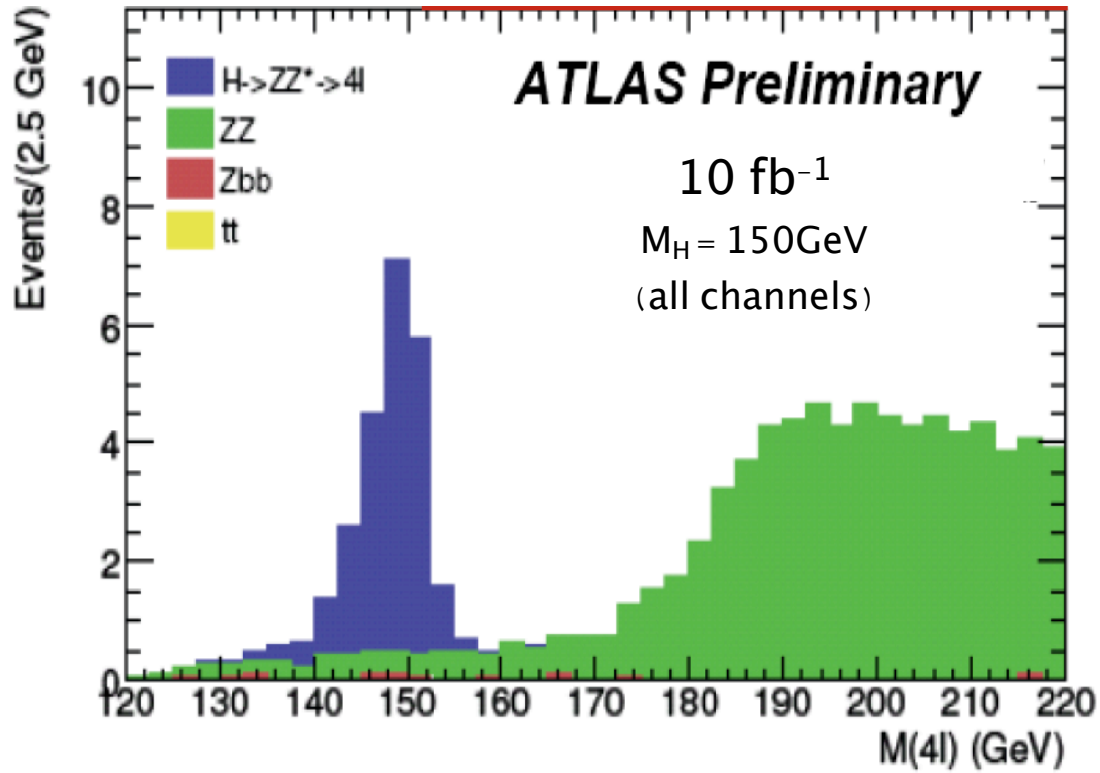


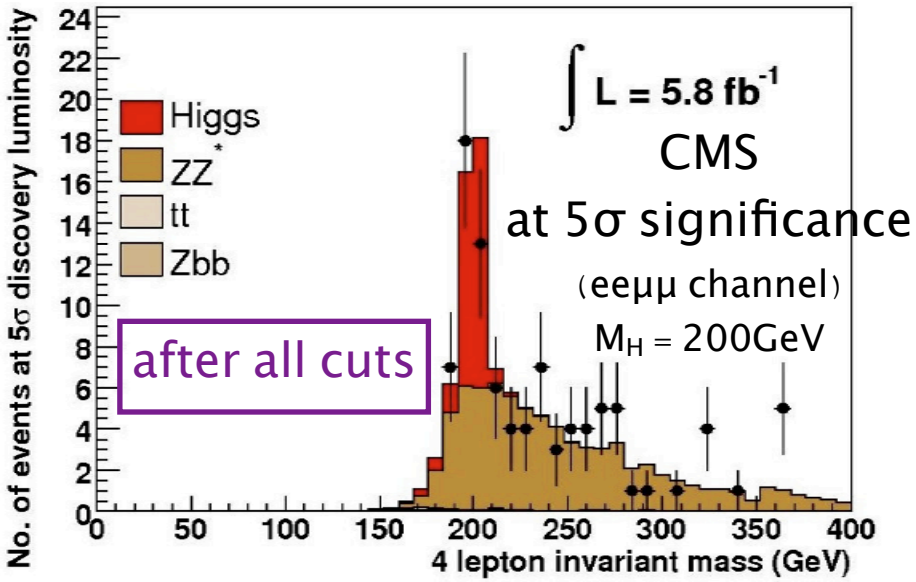
H → ZZ → 4 leptons

- "Golden Channel" with 4 leptons (electrons or muons)
  → very clean signature with small backgrounds
  → excellent e/μ reconstruction using ATLAS and CMS detectors
  (particularly important for low p_T leptons to access low mass Higgs)
  → no hadronic objects nor neutrinos involved
- Set as the original bench mark for the design of the detectors
- Analysis Strategies
  - Tight lepton identification and selection (quality, charge, vertex)
  - Di-lepton mass reconstruction to select a pair of Z bosons
  - Irreducible ZZ background estimated from side bands of M(ZZ) or by normalising to the measured Z cross section
  - Higher order correction applied for qq → ZZ cross section

H → ZZ → 4 leptons

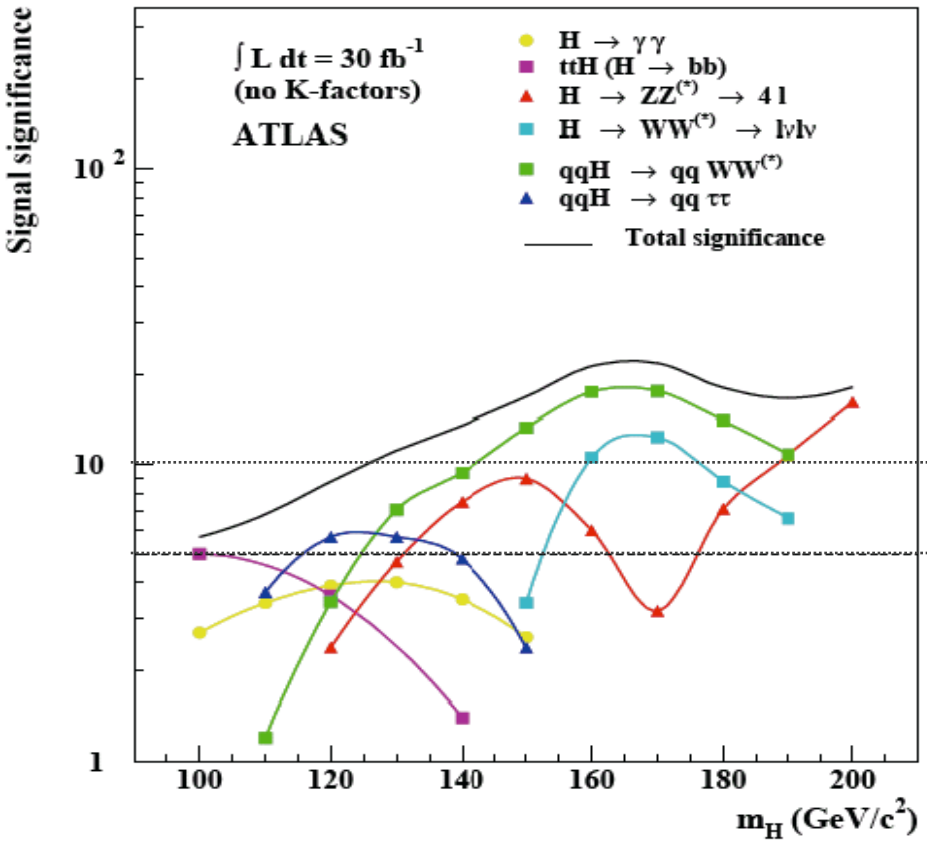


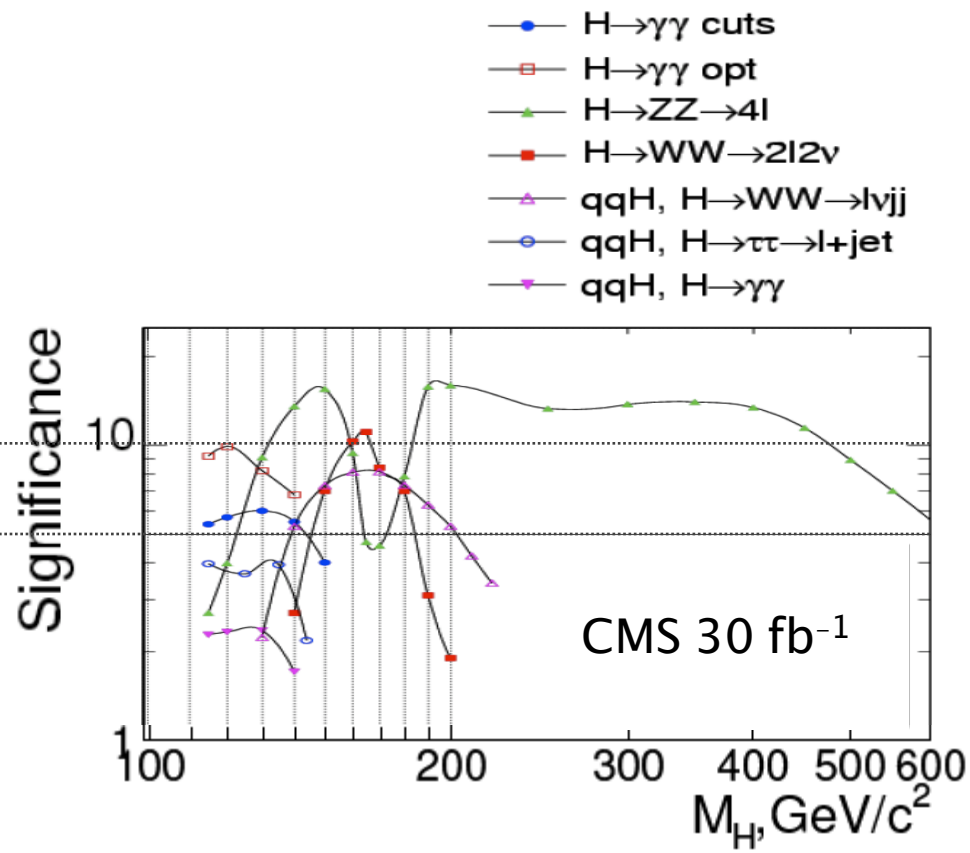




Background negligible after all selections except for ZZ

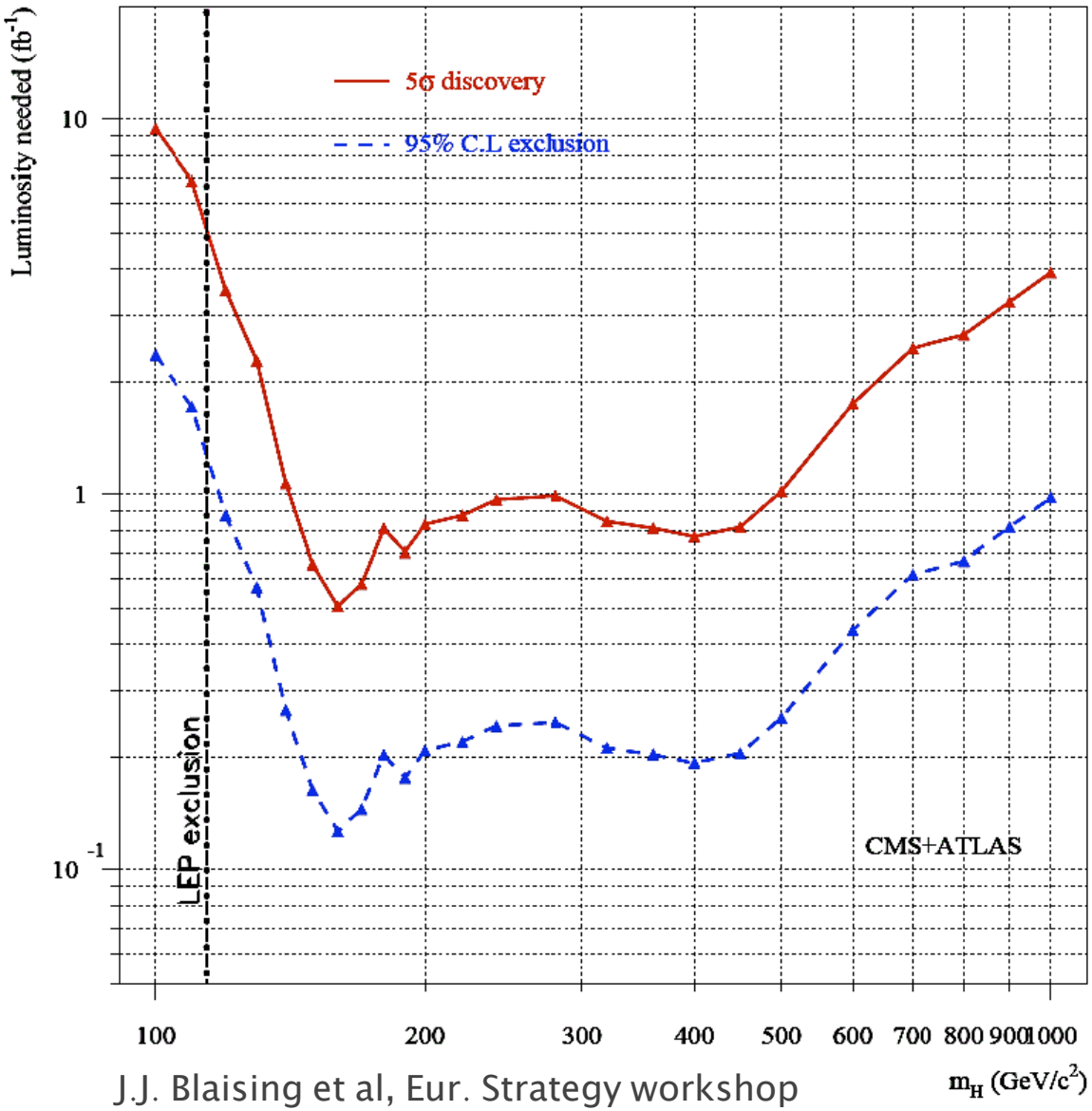
SM Higgs Discovery Reach





- H → ZZ/WW channels contribute significantly to the sensitivity
- Combination of all channels provide 5σ discovery at all mass points above the LEP limit after a few years of data

ATLAS+CMS Combined Reach



J.J. Blaising et al, Eur. Strategy workshop

- Combined limits based on "old" results
- Studies on-going with improved simulation & analysis techniques

→ Updated results from ATLAS and CMS expected to be public very soon

Summary

- ATLAS and CMS are very active in evaluating the potential of the SM Higgs searches at the LHC
- Several different Higgs boson production + decay channels are extensively studied for an extended range of Higgs mass
- Results look promising, demonstrating that the discovery is well within the reach during the early years of the LHC operation

Jura as seen from Point-5