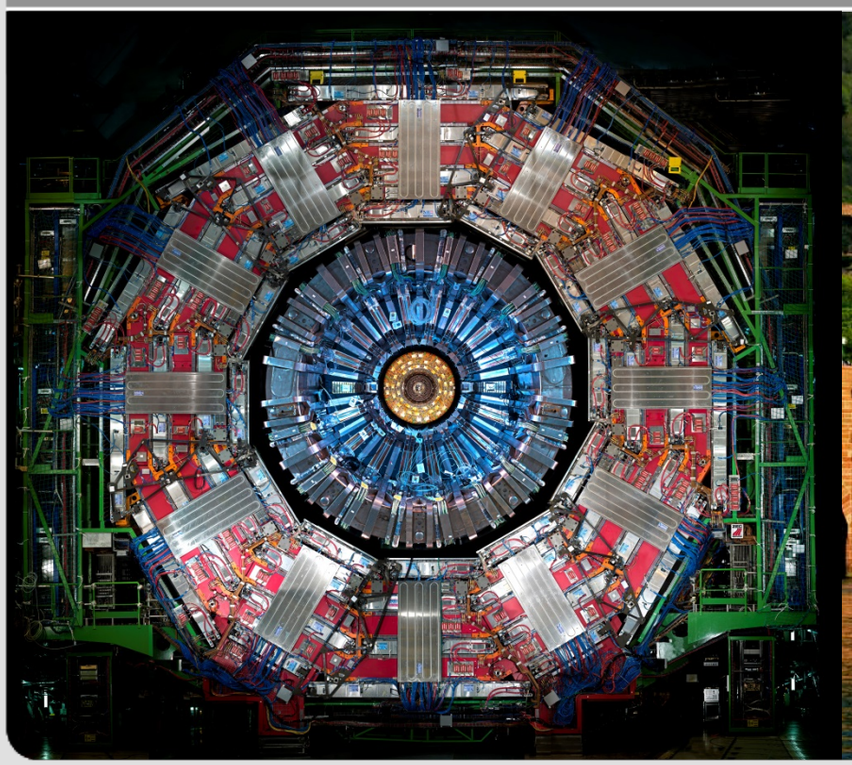
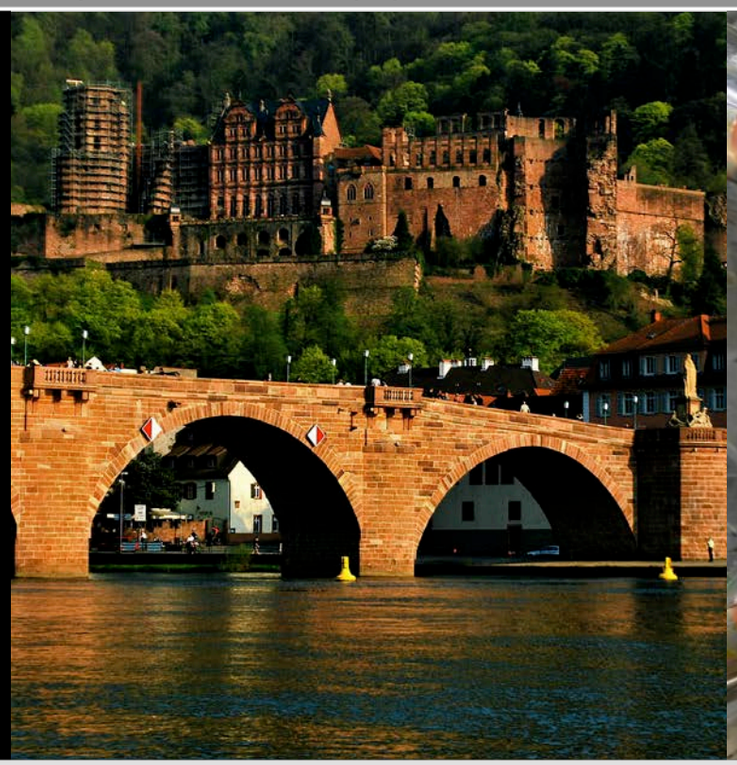
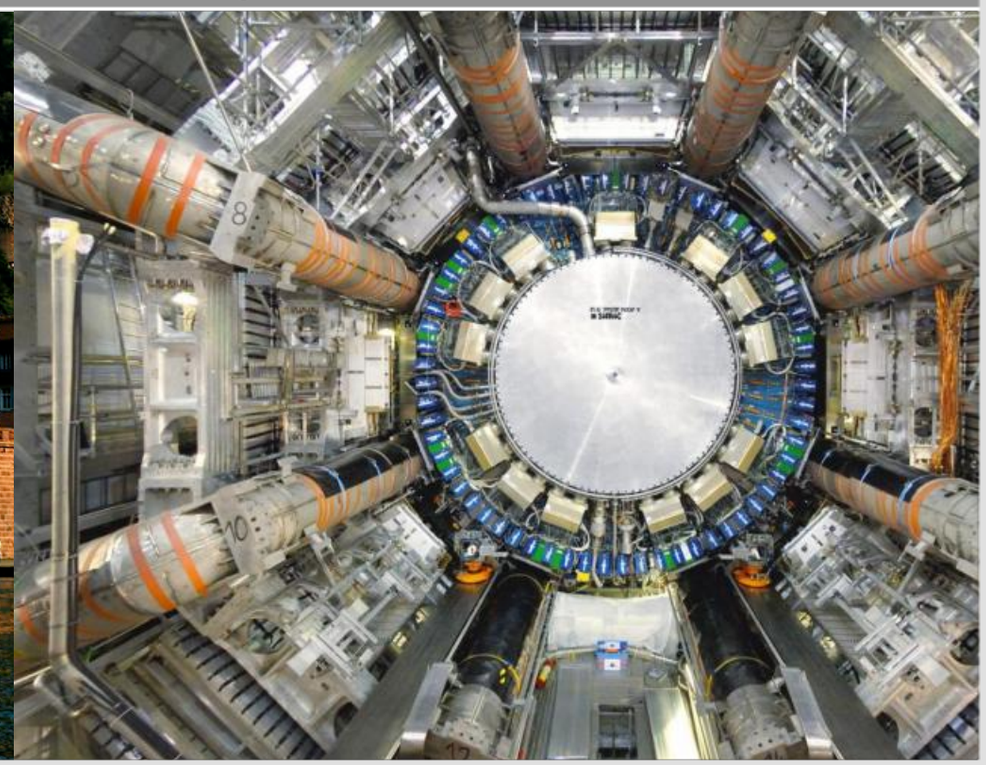
High Mass Higgs Searches

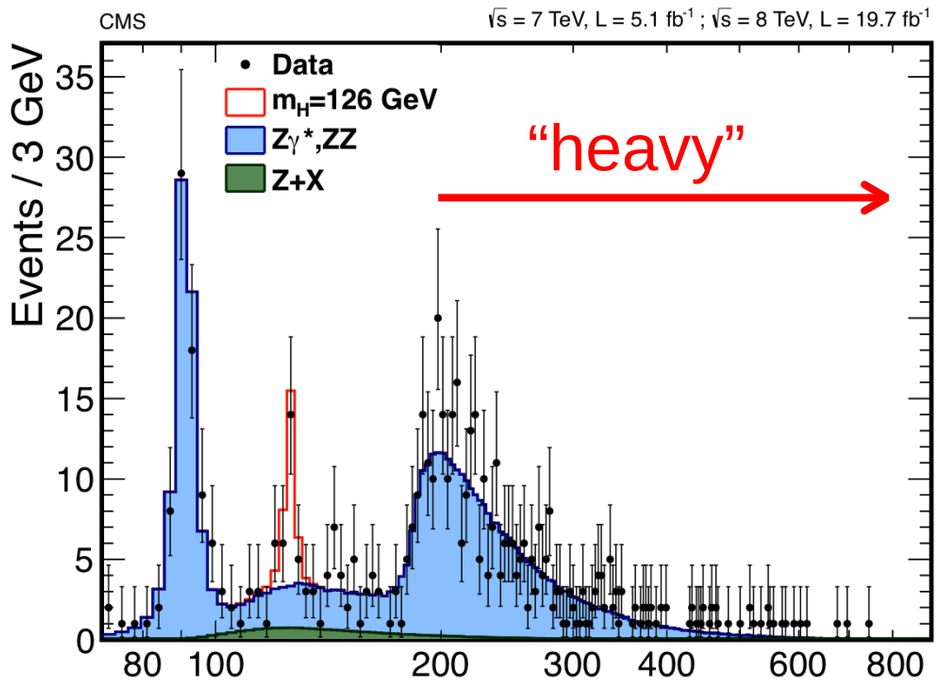
WIM 2015

Matthias Mozer
Institut für Experimentelle Kernphysik, Karlsruher Institut für Technologie

Why even look for that?

- The Higgs boson has been found, and it’s light
- Higgs Mechanism minimal solution for particle masses



Phys. Rev. D 89 (2014) 092007

- If there’s one, why not more?:
  => extended Higgs sector in SUSY scenarios
  => mixing with sterile scalar states
  => technicolor like models
- Extended Higgs sectors well defined after H(125) discovery

  => Go search!

2HDM

- Inspired by SUSY Higgs sector:
  => additional complex doublet

- Impose CP conservation => realize states of definite CP
  => two scalar bosons h,H
  => one pseudoscalar boson A
  => two charged bosons $H^{\pm}$

- Distribute SM Higgs couplings among new doublet:
  Type I: ϕ_2 has all fermion couplings
  Type II: ϕ_1 : down type + leptons ϕ_2 : up-type
  flipped: ϕ_1 : up type + leptons ϕ_2 : down-type
  lep. spec.: ϕ_1 : leptons ϕ_2 : quarks

- Important parameters:
  $\tan\beta = v_1/v_2$:rotation angle to get one scalar with zero vev
  α :rotation angle to obtain h/H mass eigenstates from $\phi_{1/2}$
  Higgs potential parameters => fix mass spectrum

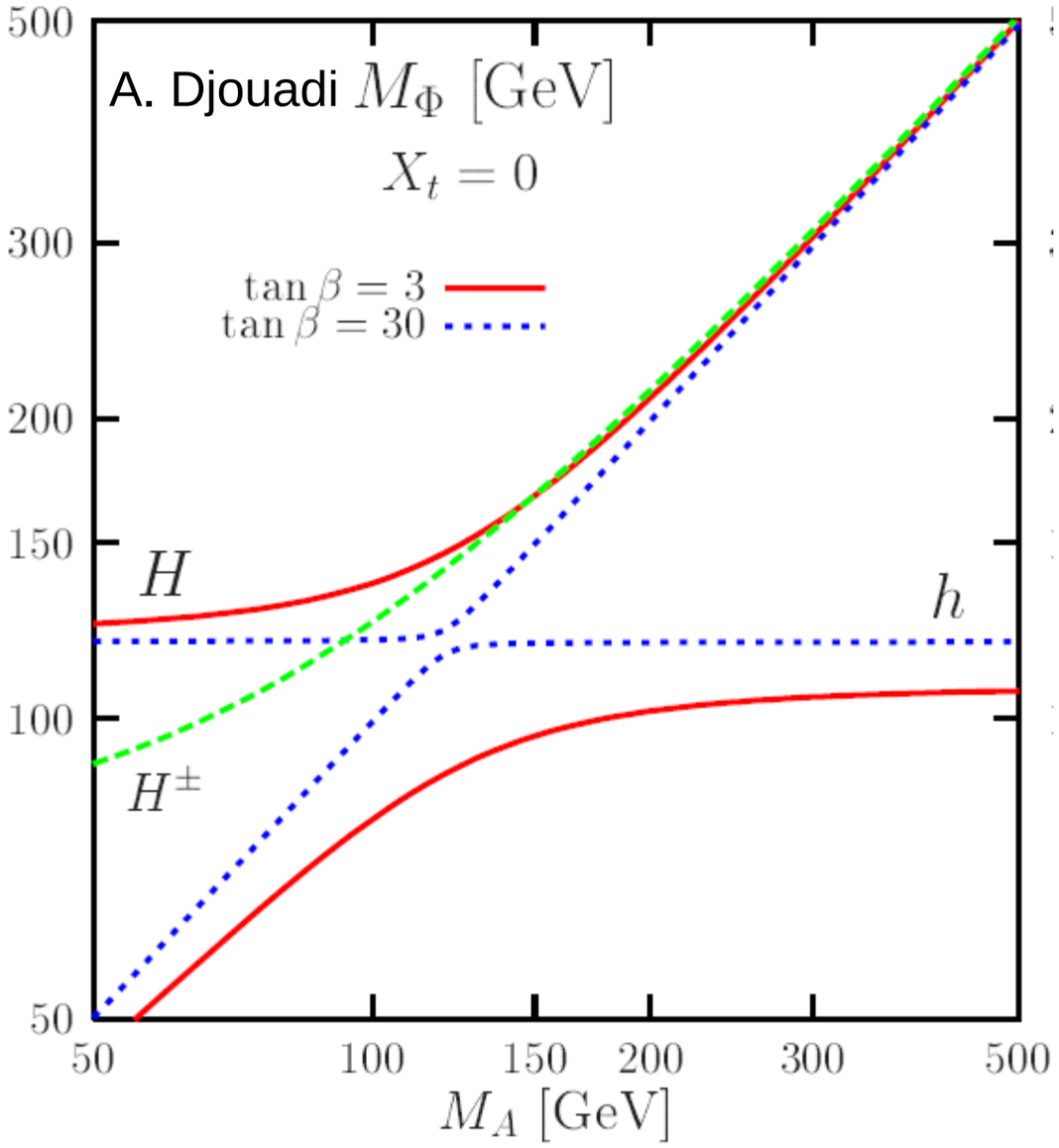
2HDM Spectrum

- h/H couplings to W/Z modified by sin(α-β) and cos(α-β)
  => constrain α-β from H(125) measurements
  => but direct search can be more sensitive

- Fermion couplings modified dependent on type of model

- Very rich phenomenology large variations of couplings with model parameters
  => fermiphobic, leptophobic…

- For high mass searches, assume h = H(125)



Eur.Phys.J.C59:389-426,2009

2HDM: Searches

- Rich phenomenology => look for many channels
- Neutral boson decays:

=> $A \to \tau\tau$	JHEP 10 (2014) 160*, JHEP11(2014)056**
=> $A \to Zh \to \gamma$ + leptons	Phys. Rev. D 90 (2014) 112013*
=> $A \to Zh \to ll/\nu\nu + \tau\tau/bb$	arxiv:1504.04710*
	Phys. Lett. B 744 (2015) 163**
=> $A \to ZH \to llbb, ll\tau\tau$	CMS-HIG-15-001
=> $H \to hh \to \gamma\gamma$ bb	CMS-HIG-13-032, PRL 114, 081802**
=> $H \to hh \to 4b$	arxiv:1506.00285**
=> $H \to hh \to \gamma$ + leptons	Phys. Rev. D 90 (2014) 112013*
=> $H \to AA \to \mu\mu\tau\tau$	arxiv:1505.01609**
=> $H \to ZA \to llbb, ll\tau\tau$	CMS-HIG-15-001

*:CMS **:ATLAS

2HDM: h/H/A → ττ

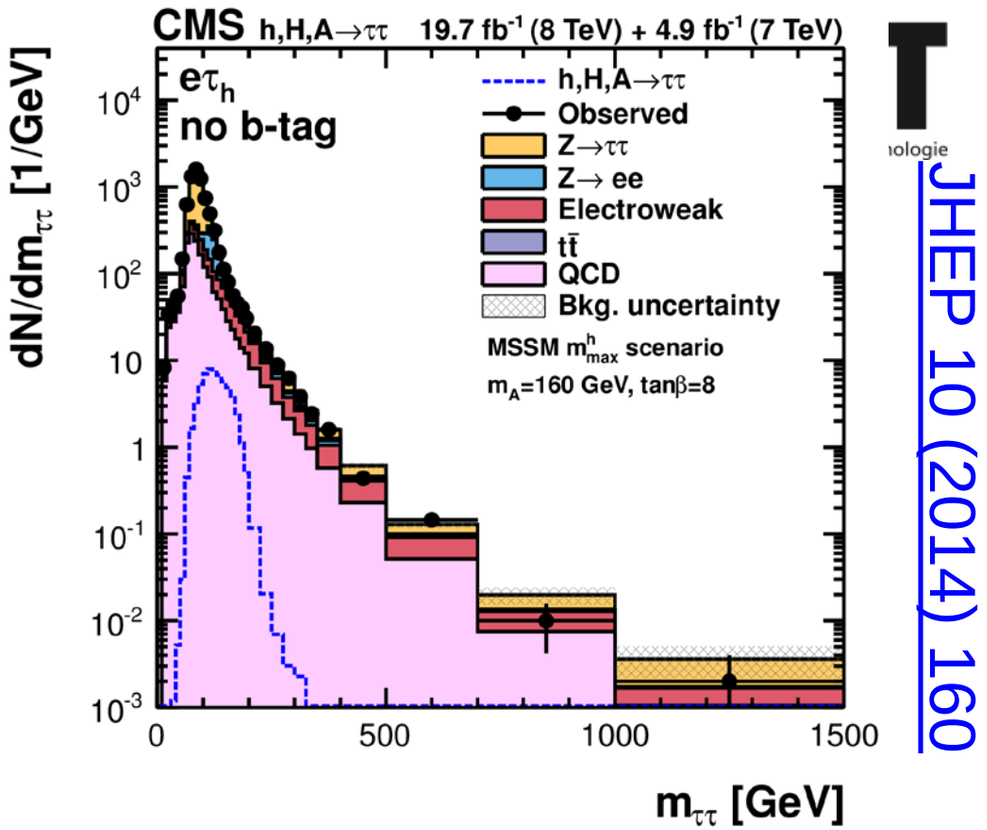
- SUSY inspired search
  => type II 2HDM

- Large tanβ
  => enhanced bb ττ
  => large b-associated production xsec
  => use b-tag to suppress background

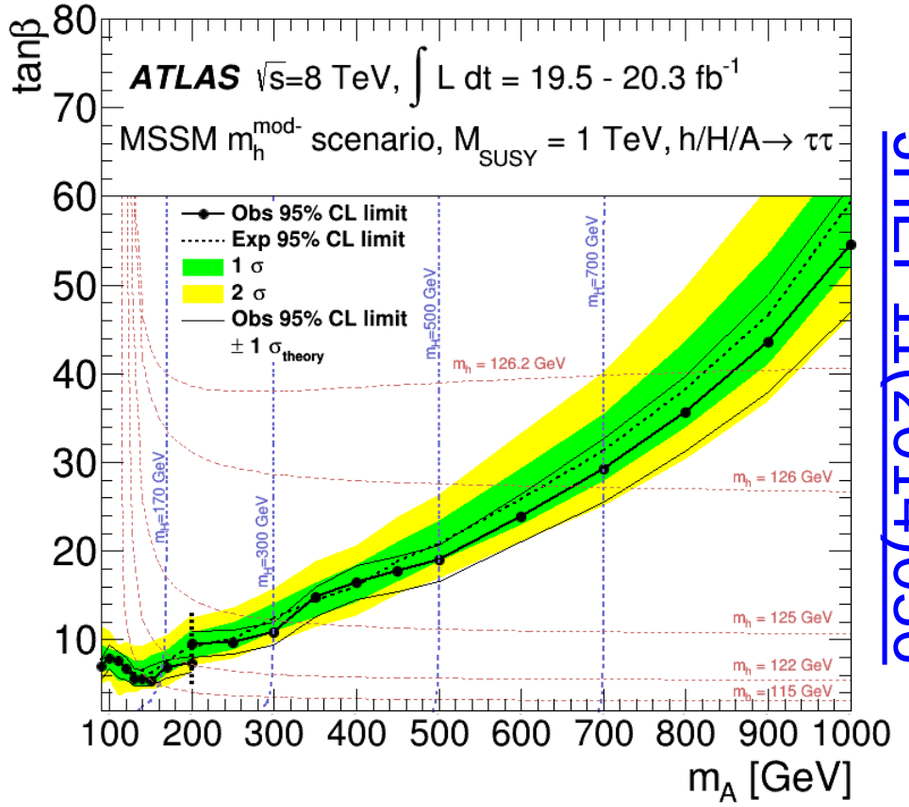
- Search in ττ more promising
  => hadronic τ reco. is key

- Tricky mass reconstruction due to nteurinos

- Search for A/H simultaneously



JHEP 10 (2014) 160



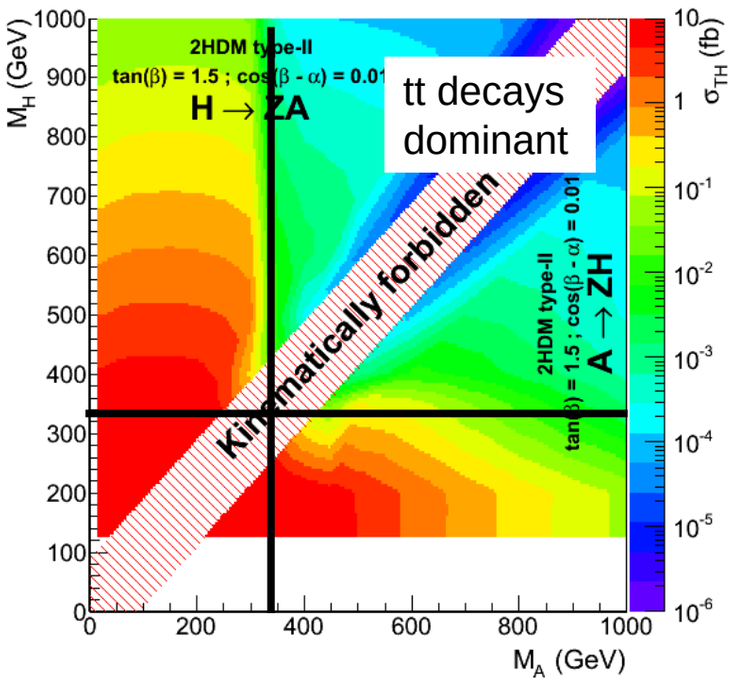
JHEP11(2014)056

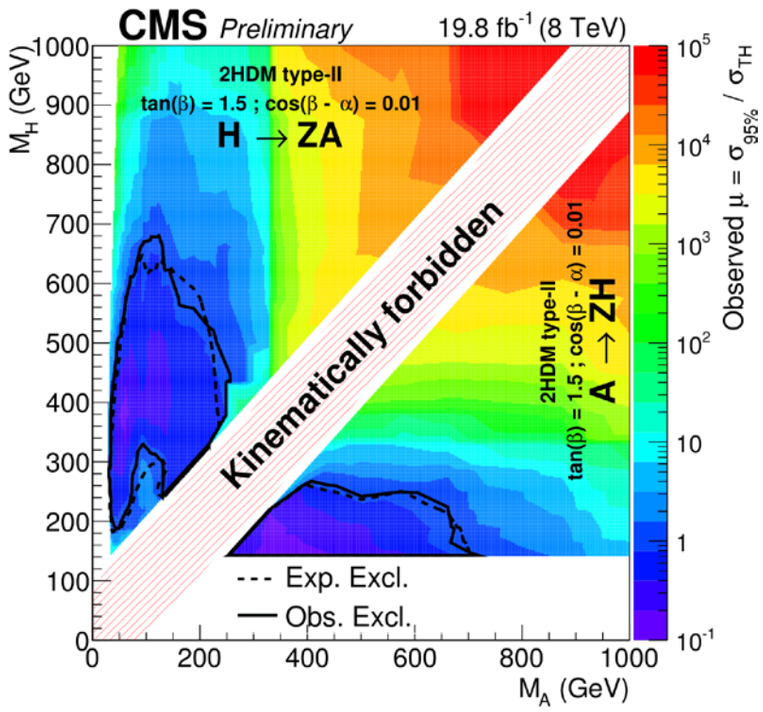
2HDM: Bosonic Decays

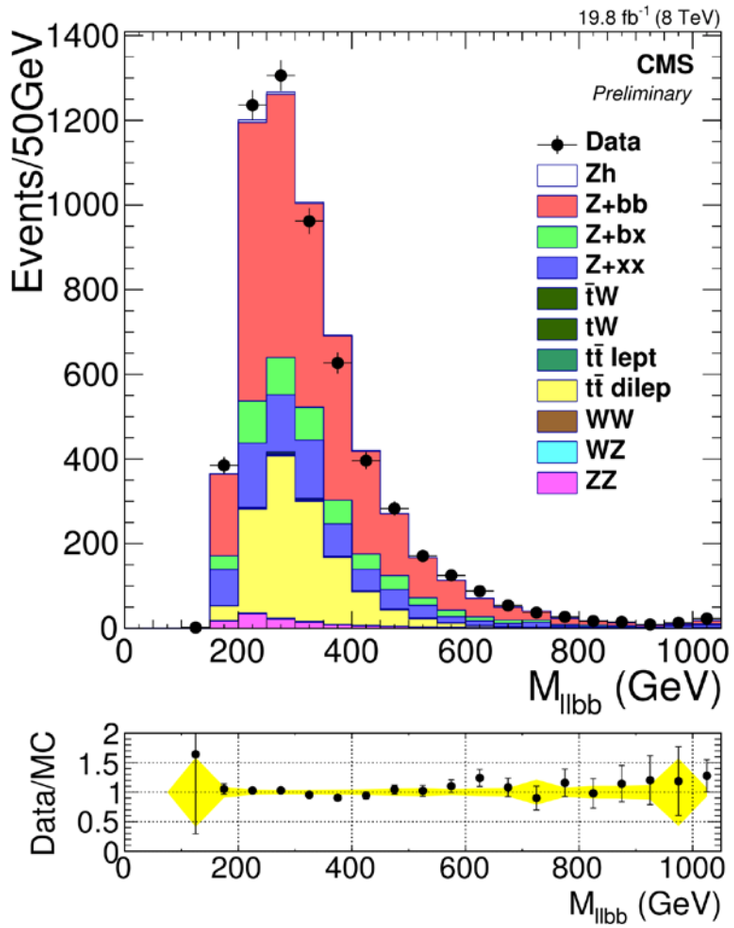
- Assume aligned scenario: $\cos(\alpha-\beta)\approx 0$ or $\sin(\alpha-\beta)\approx 0$
  => light Higgs has SM properties

- Don't use detailed kinematic properties:
  => sensitivity over wide range of parameters space

- Simultaneous search for
  $A \rightarrow ZH \rightarrow llbb, ll\tau\tau$
  $H \rightarrow ZA \rightarrow llbb, ll\tau\tau$





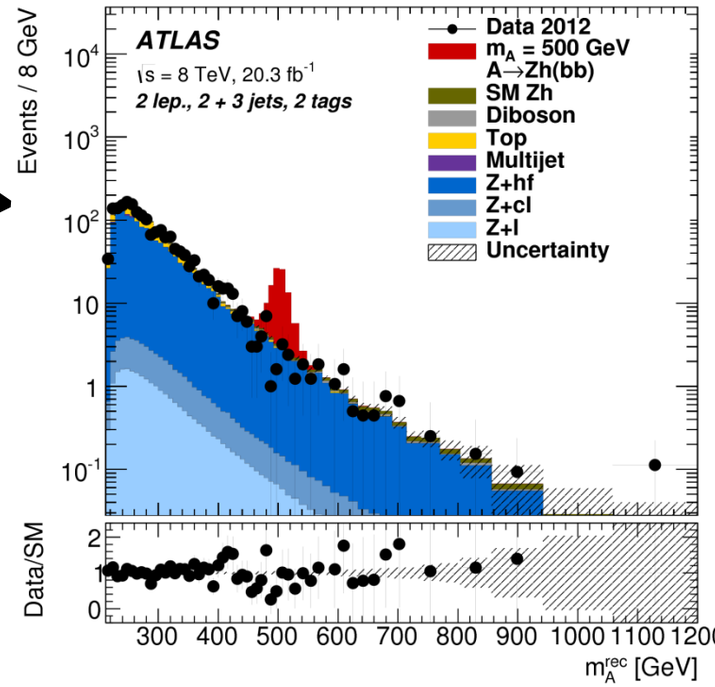


CMS-HIG-15-001

2HDM: Bosonic Decays

- $A \rightarrow Zh \rightarrow$ ll bb
  ll ττ
  νν bb

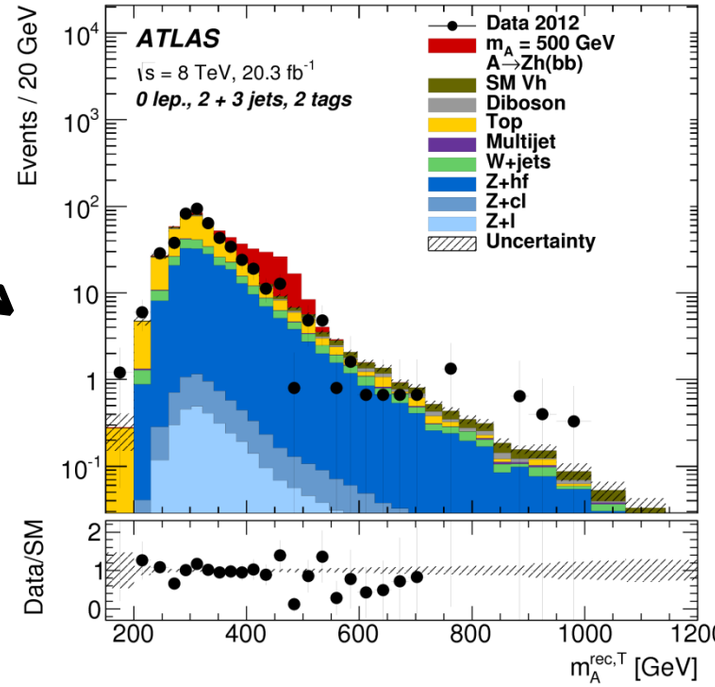
Good resolution
Low background
Low branching ratio

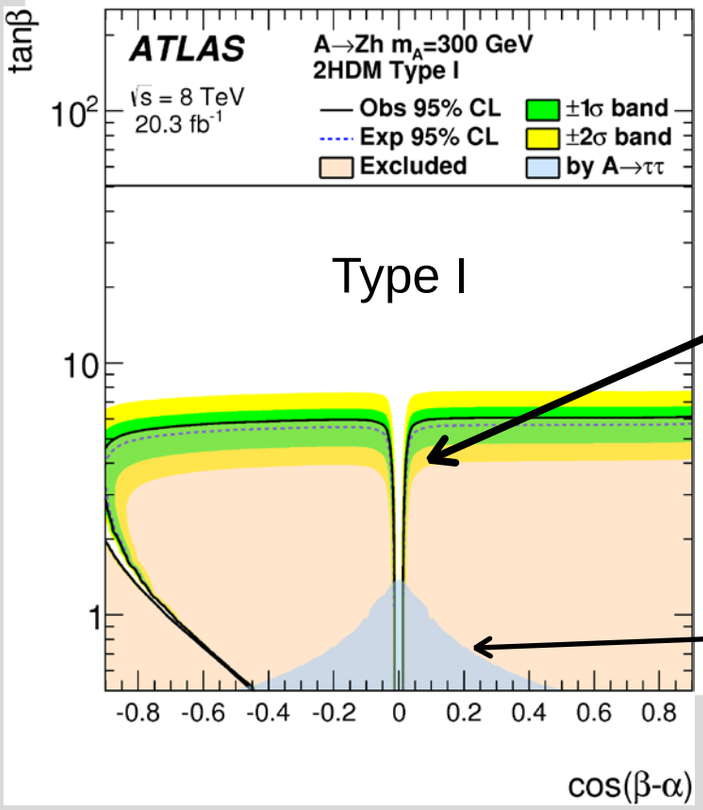


- Parallel analysis to maximize accessible Branching fraction

poor resolution
higher background
higher branching ratio

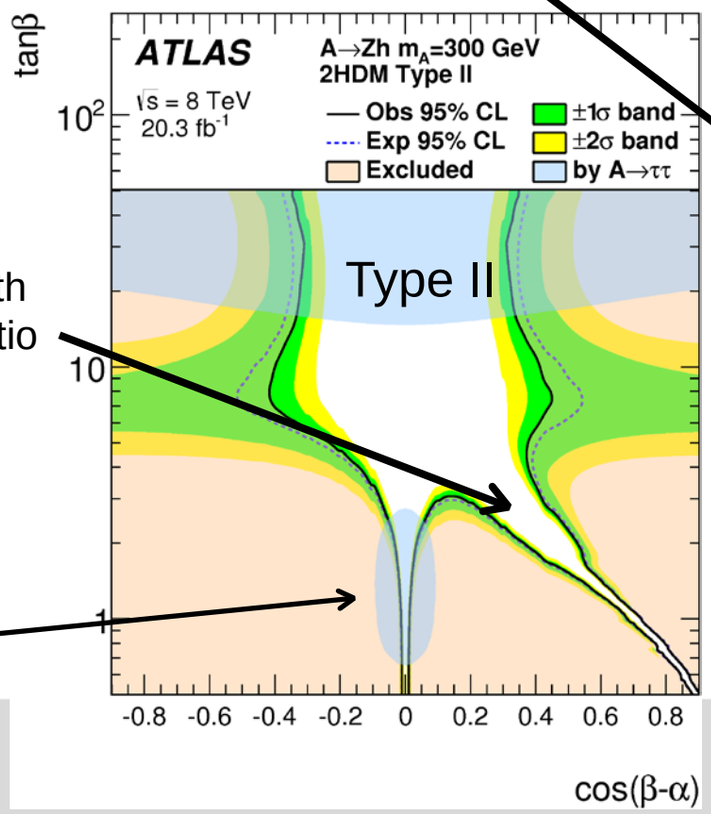
- Not sensitive when 2HDM parameters conspire





Small regions with low branching ratio $h \rightarrow bb / \tau\tau$

$X \rightarrow \tau\tau$ results

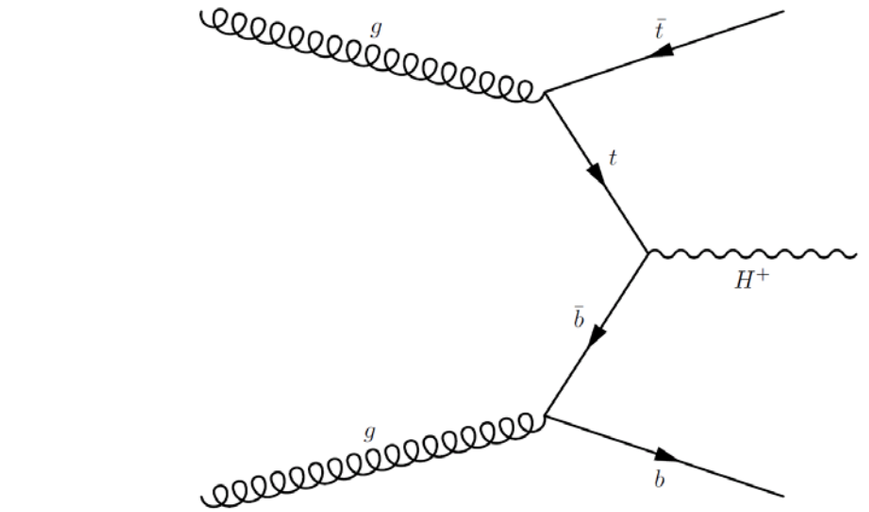


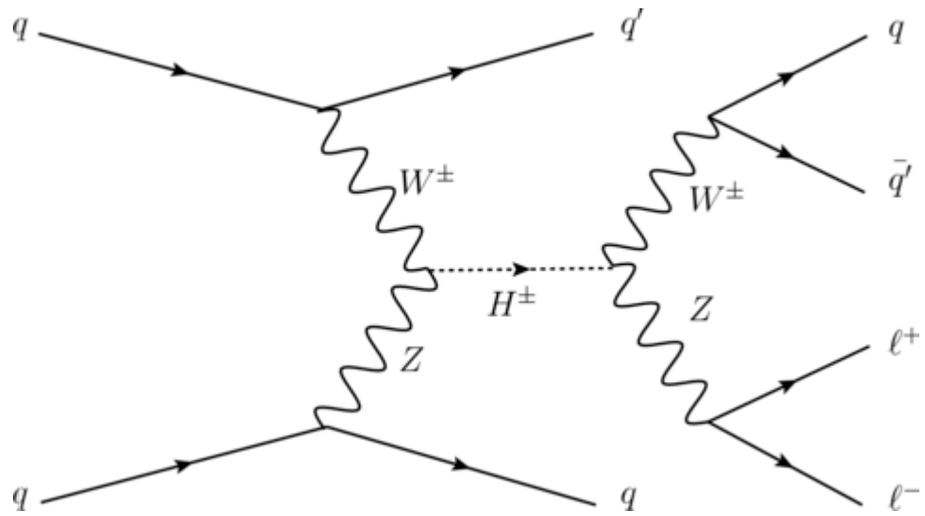
[Phys. Lett. B 744 (2015) 163]

2HDM: Charged Bosons

- Low mass searches in top → $H^{\pm}$b decays
- High mass analysis split into fermionic and bosonic analysis
- Fermionic channels:
  production in top-associated production
  leptonic (e,μ,τ→l,tb leptonic) decays
  => CMS-HIG-13-026

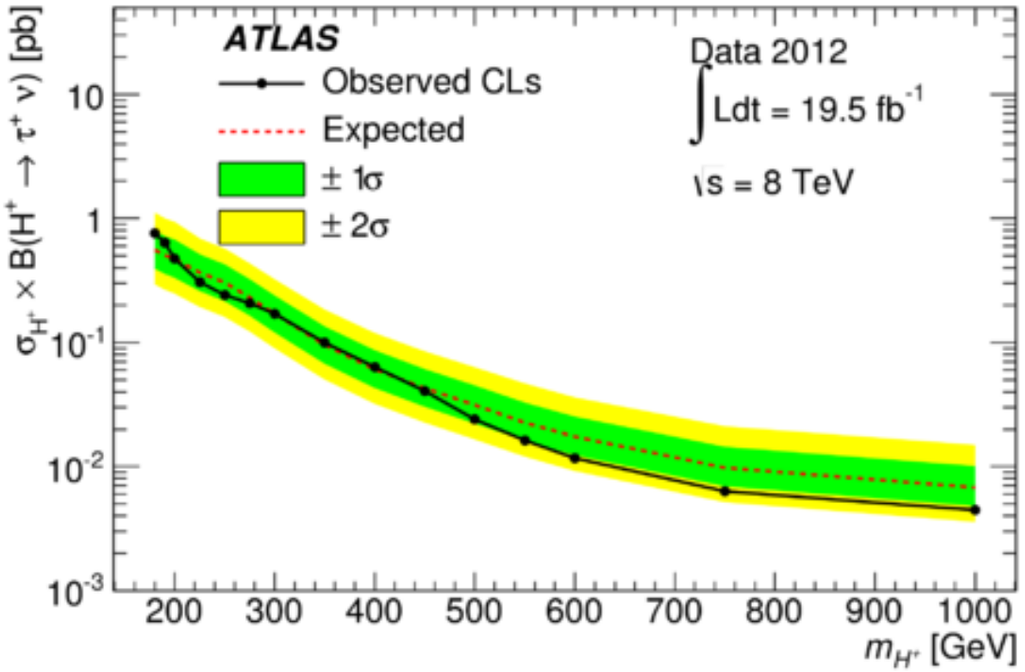
  hadronic decays (τ→had)
  => CMS-HIG-14-020
  => JHEP03 (2015) 088 (ATLAS)
- Bosonic channels:
  production in VBF
  decay to WZ→lljj
  => ATLAS-HIGG-2014-13



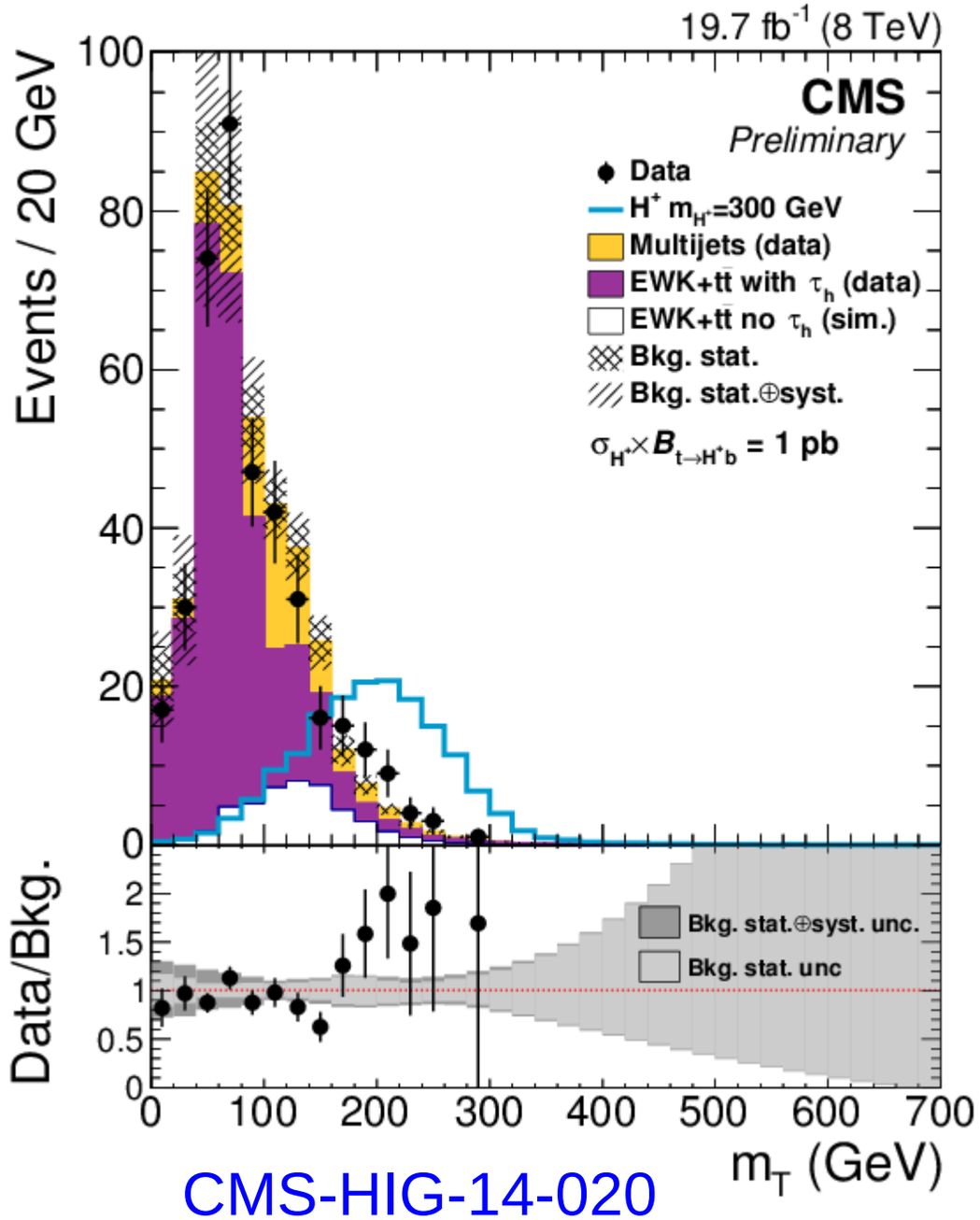


2HDM: $H^{\pm}$ fermionic ($\tau\nu$)

- Search in transverse masse spectrum
- Use additional jets to tag expected top associated production
- Dominant background have real τ
- Low backgrounds at high masses
  => few SM processes with very high MET



JHEP03(2015)088

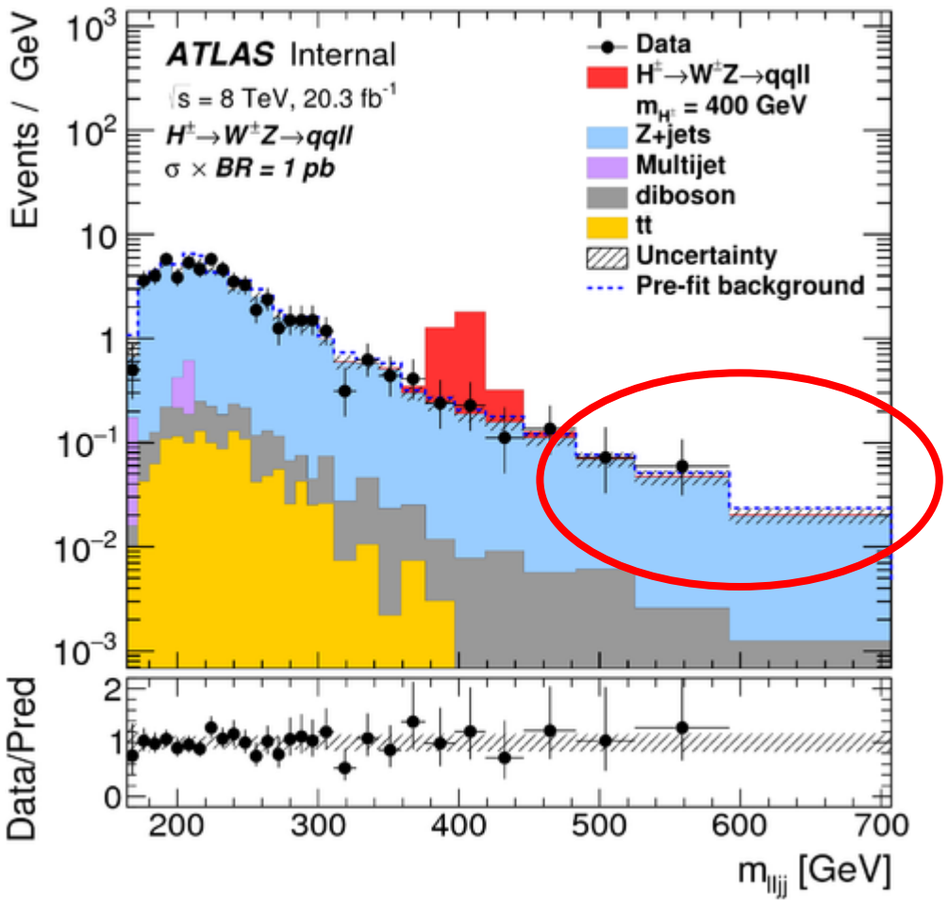


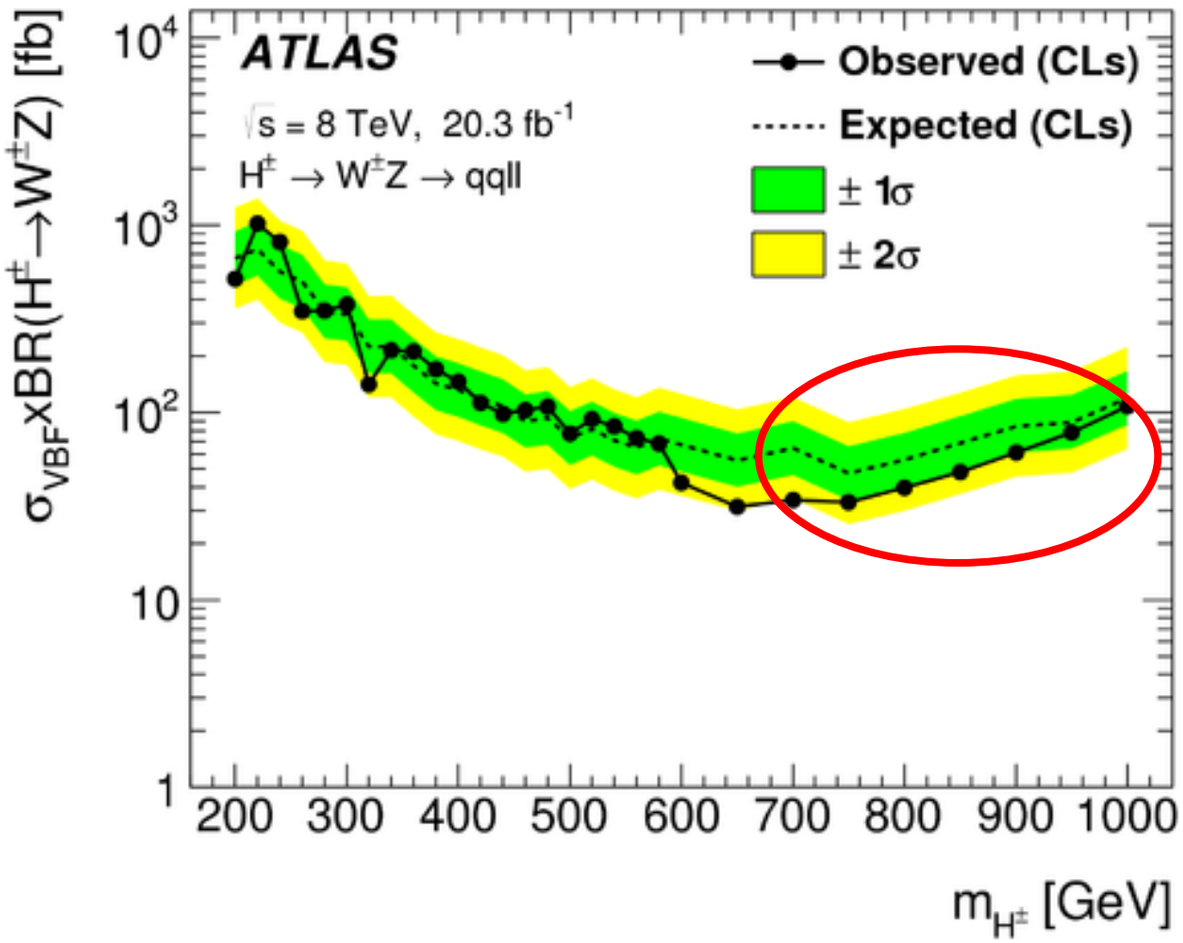
CMS-HIG-14-020

2HDM: $H^{\pm}$ bosonic

- Low cross sections => use one hadronic boson decay

- Look in WZ semileptonic decays
  => No neutrinos => good mass resolution
  => larger branching fraction than all leptonic





ATLAS-CONF-2014-13

Acceptance limited by jet merging at high masses

Other Searches

- 2HDM not the only possibility

- Electroweak singlet:
  additional sterile scalar, mixing with H(125)
  => properties similar to H(125), but lower couplings
  => derive limits already from H(125) coupling fits
  => arxiv:1504.00936 (CMS, H $\rightarrow$ WW/ZZ)

- generic spin 0 models:
  => H $\rightarrow \gamma\gamma$ at high mass
  => not really a model, but can be reasonably reinterpreted
  => CMS-HIG-14-006 (H $\rightarrow \gamma\gamma$)
  => Phys. Rev. Lett. 113, 171801 (2014) (ATLAS, H $\rightarrow \gamma\gamma$)

- technicolor / SU(4) chiral sym. Breaking
  => JHEP 1010:086,2010 (theory Ref.)
  => CMS-HIG-14-031 (H $\rightarrow Z\gamma$)

CMS High Mass Mega-Combo

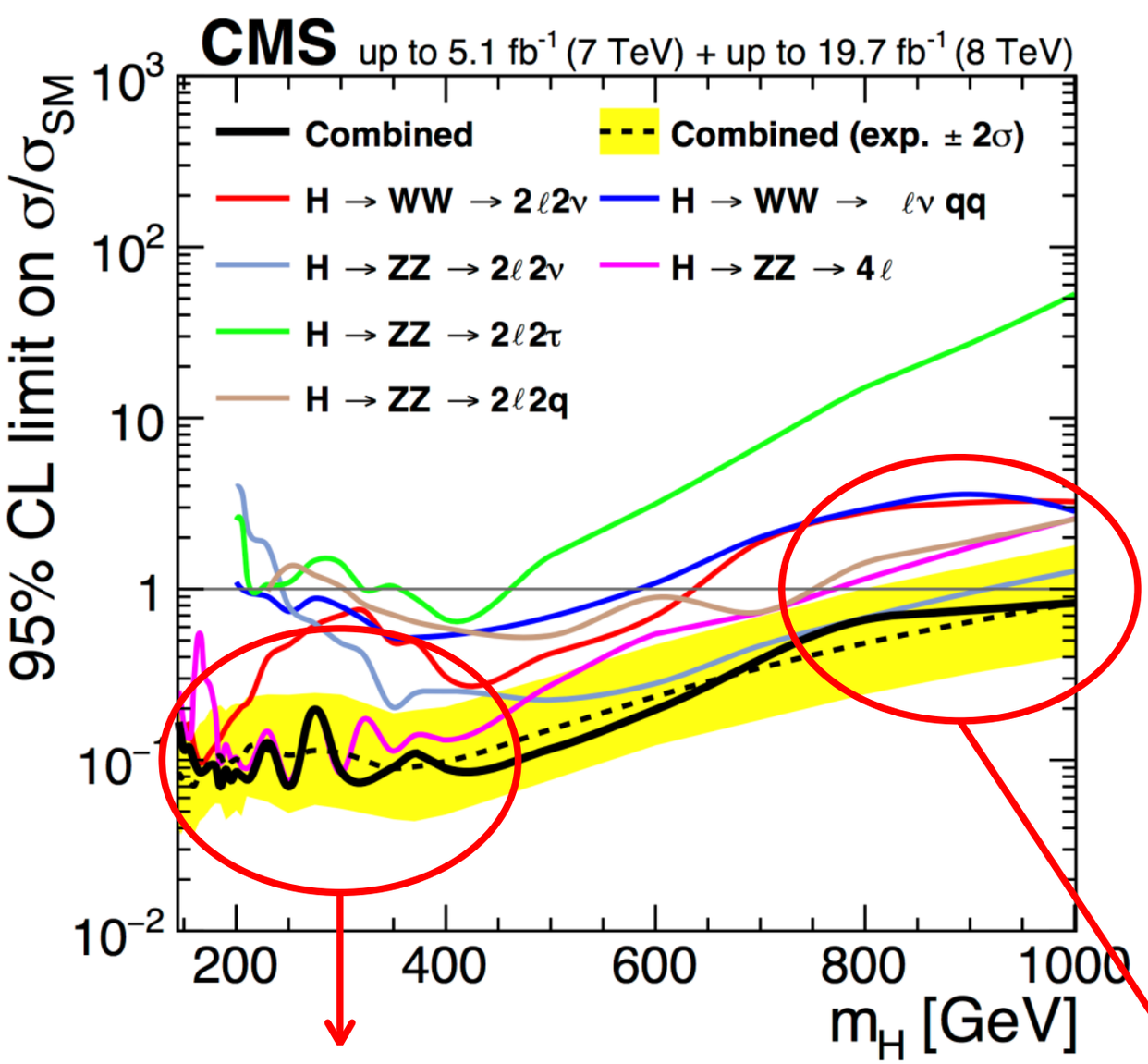
- arxiv:1504.00936/CMS-HIG-13-031:
  Additional Higgs boson in WW and ZZ decays

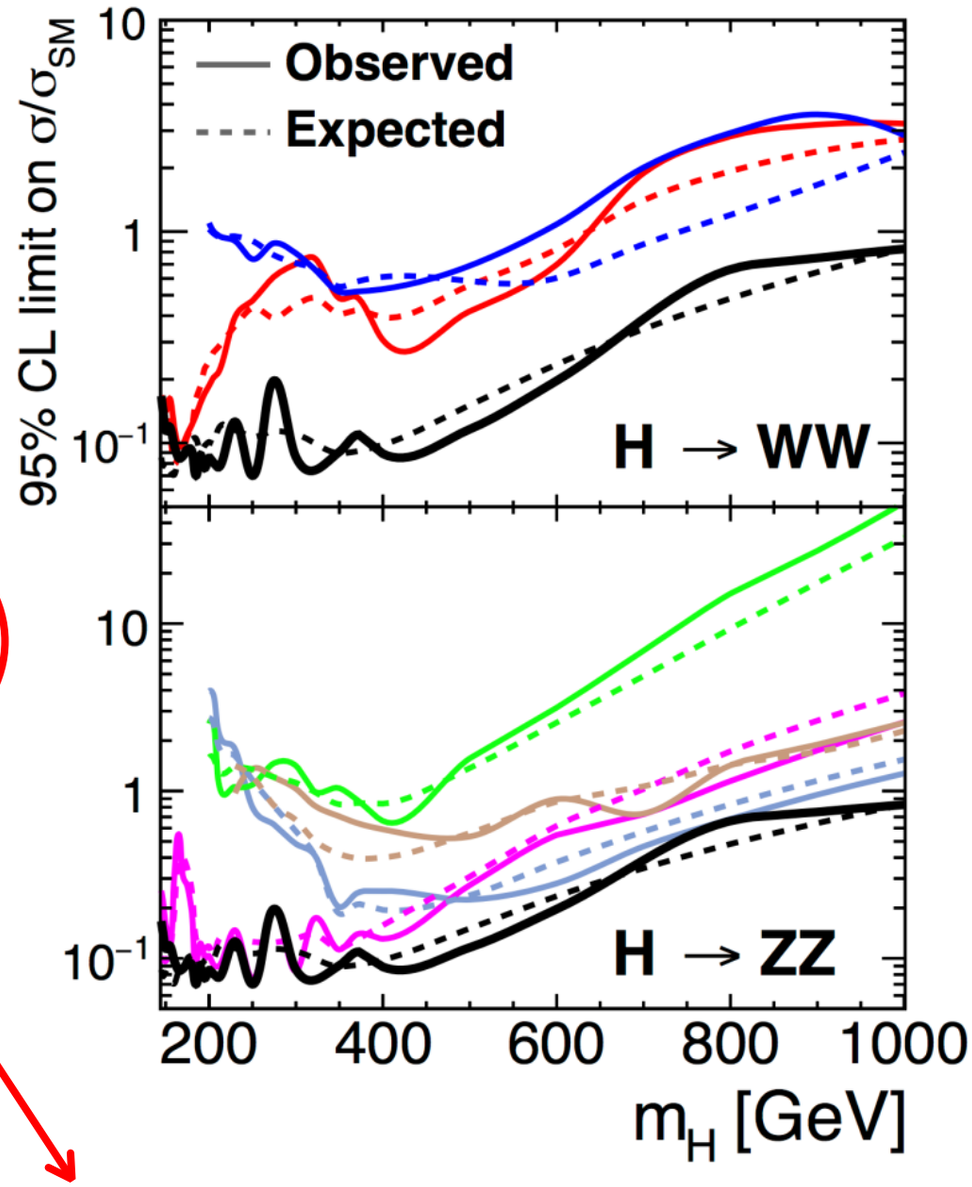
- Large number of WW/ZZ channels combined:
  $ZZ \rightarrow 4l$
  $ZZ \rightarrow 2l2q$ extra info: CMS-HIG-14-007
  $ZZ \rightarrow 2l2\nu$ extra info: CMS-HIG-13-014

  $WW \rightarrow 2l2\nu$
  $WW \rightarrow l\nu qq$ extra info: CMS-HIG-14-008, -13-027

- Advanced features
  => angular discriminants
  => boosted hadronic decays
  => subjet b-tagging
  => VBF vs gluon fusion tag
  => τ decays included in 4l channel

Singlet Interference: WW/ZZ





CMS-HIG-13-031

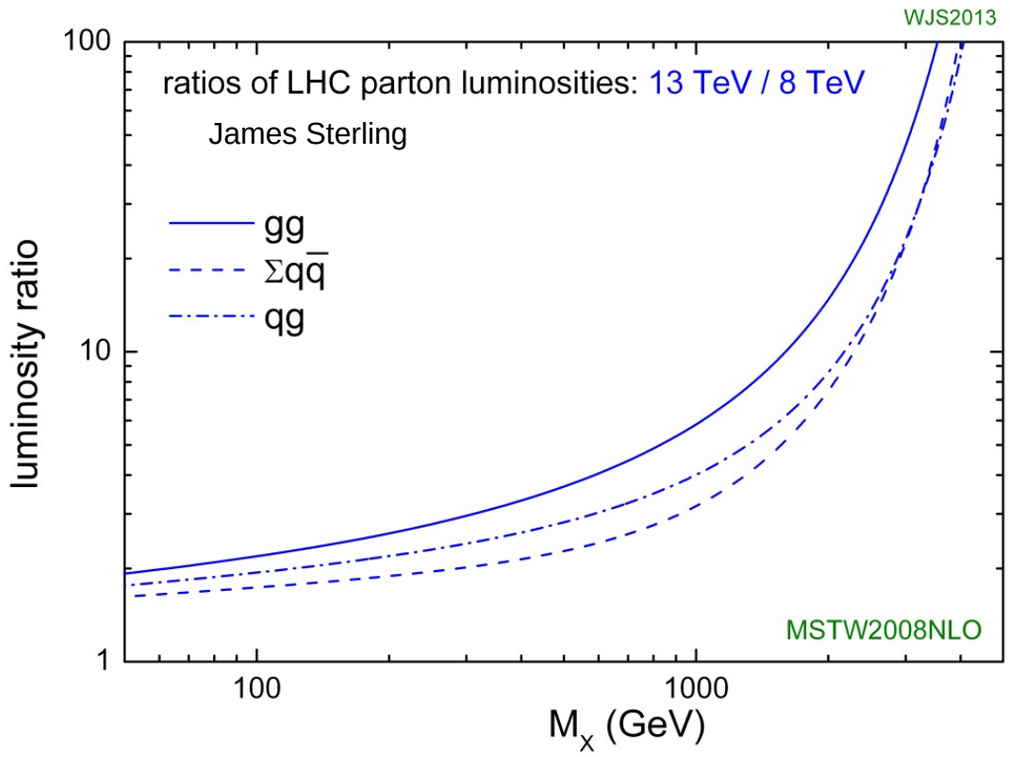
Lower mass: background important

Highest mass: BR important

Prospects I

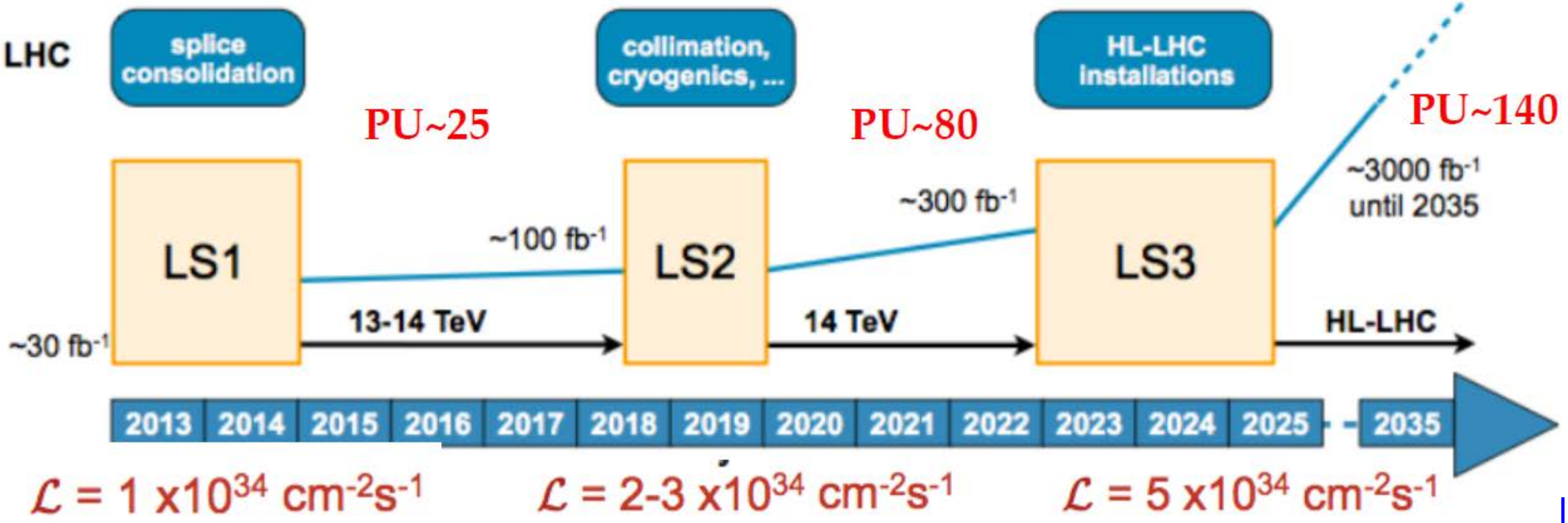
- Run I:
  => repurposed Higgs searches
  => no systematic coverage
  of parameter space

- Run II:
  => increased parton lumi
  => dedicated program
  => enable coherent effort

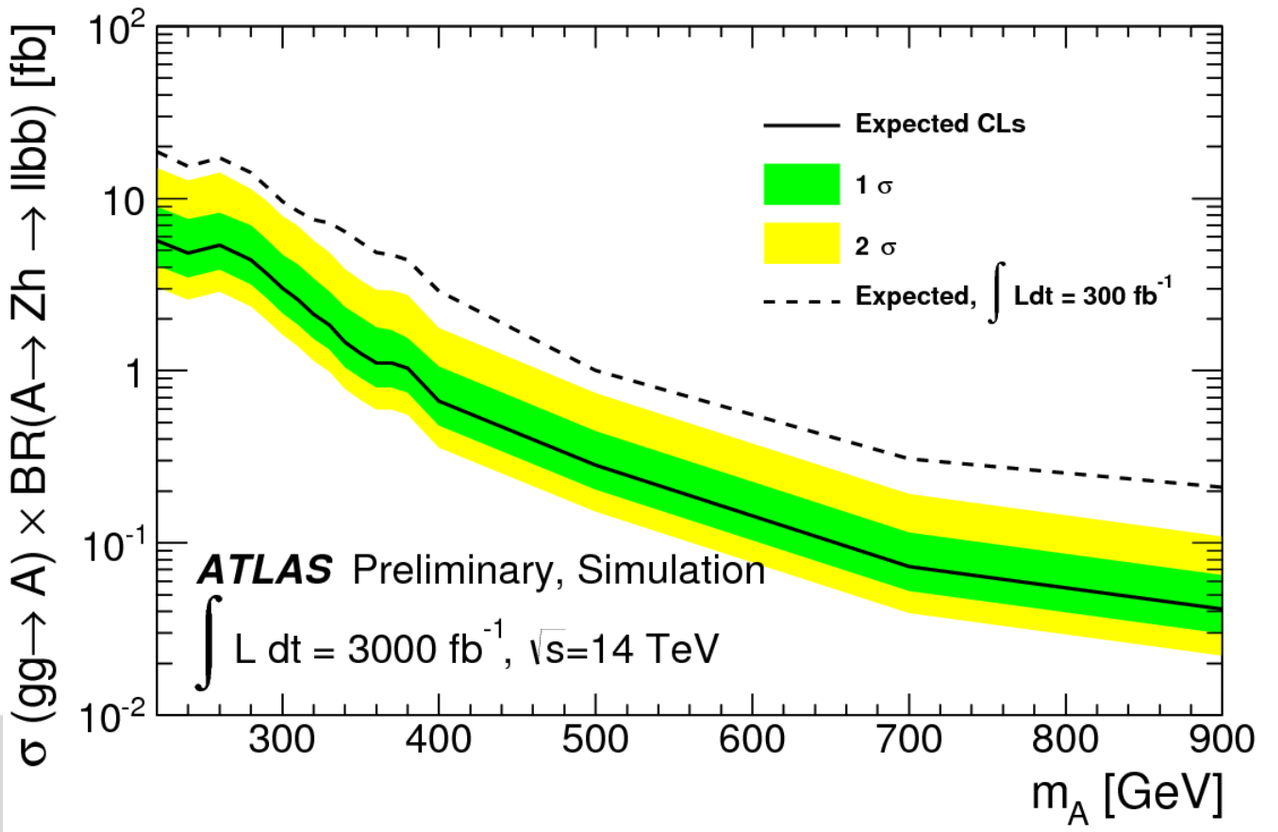


- Coordination with EXO group:
  currently rough division HIG < 1TeV, EXO > 1TeV
  HIG analysis use more model specific optimizations
  EXO analysis more often for generic narrow resonances
  => improve coordination

HL-LHC



- Beam-energy to remain roughly the same
- Major lumi upgrade
- Requires major detector overhauls
- Gives access to very rare processes
  => may be necessary if
  α/β conspire for low xsec



ATL-PHYS-PUB-2013-016

015

Conclusion

- Discovery of H(125) opens investigations of extended Higgs sector
  => 2HDM (SUSY-like) most prominent
  → very large spectrum of possible signatures
  => but also others:
  → Electroweak singlet
  → technicolor-like / compositeness
  → …

- Results so far: no significant excess observed

- Looking forward to run II
  => higher lumi
  => higher parton lumi
  => more coherent search program