H?

QMUL - NExT
9th November 2011

- What do know about it?
- Is the LHC closing in?

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Why do we need the Higgs?

Fermions | **Gauge Symmetries** → **Bosons, Interactions**

families,
with leptons

$$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}, \nu_R, e_R$$

and quarks

$$\begin{pmatrix} u_L \\ d_L \end{pmatrix}, u_R, d_R$$

U(1)$_Y$: $\psi(x) \rightarrow \exp\left[i \frac{g'}{2} Y_\psi \omega(x)\right] \psi(x)$

SU(2)$_L$: $\psi_L(x) \rightarrow \exp\left[i \frac{g}{2} \vec{\sigma} . \vec{\theta}(x)\right] \psi_L(x)$

SU(3)$_c$: $\psi_q(x) \rightarrow \exp\left[i \frac{g_s}{2} \lambda_a \theta^a(x)\right] \psi_q(x)$

γ : QED

Z, $W^\pm$: Weak

$$\tan \vartheta_W = \frac{g'}{g}$$

gluons : QCD

A mass term couples L & R
and would violate SU(2)$_L$

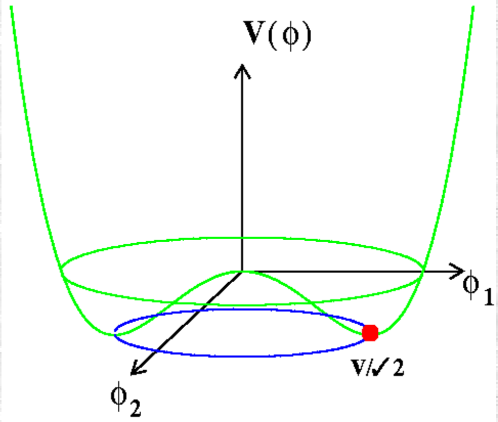
solution: The Higgs Mechanism

What is Higgs' mechanism?

- **Doublet of $SU(2)_L$, $\Phi=(\Phi_1,\Phi_2)$**
- **Potential respects $SU(2)_L$**

  But Vacuum does not!

$$V(\Phi)=\frac{\lambda}{3!}\left\{\overline{\Phi}\Phi-v^2/2\right\}^2$$



Fermions:

Interact with Higgs field slows them down → generates mass

Bosons:

$SU(2)_L$ interact, gain mass

$U(1)_\gamma$ and $SU(3)_c$ do not, massless

3 degrees of freedom in Boson masses
4th becomes fundamental scalar

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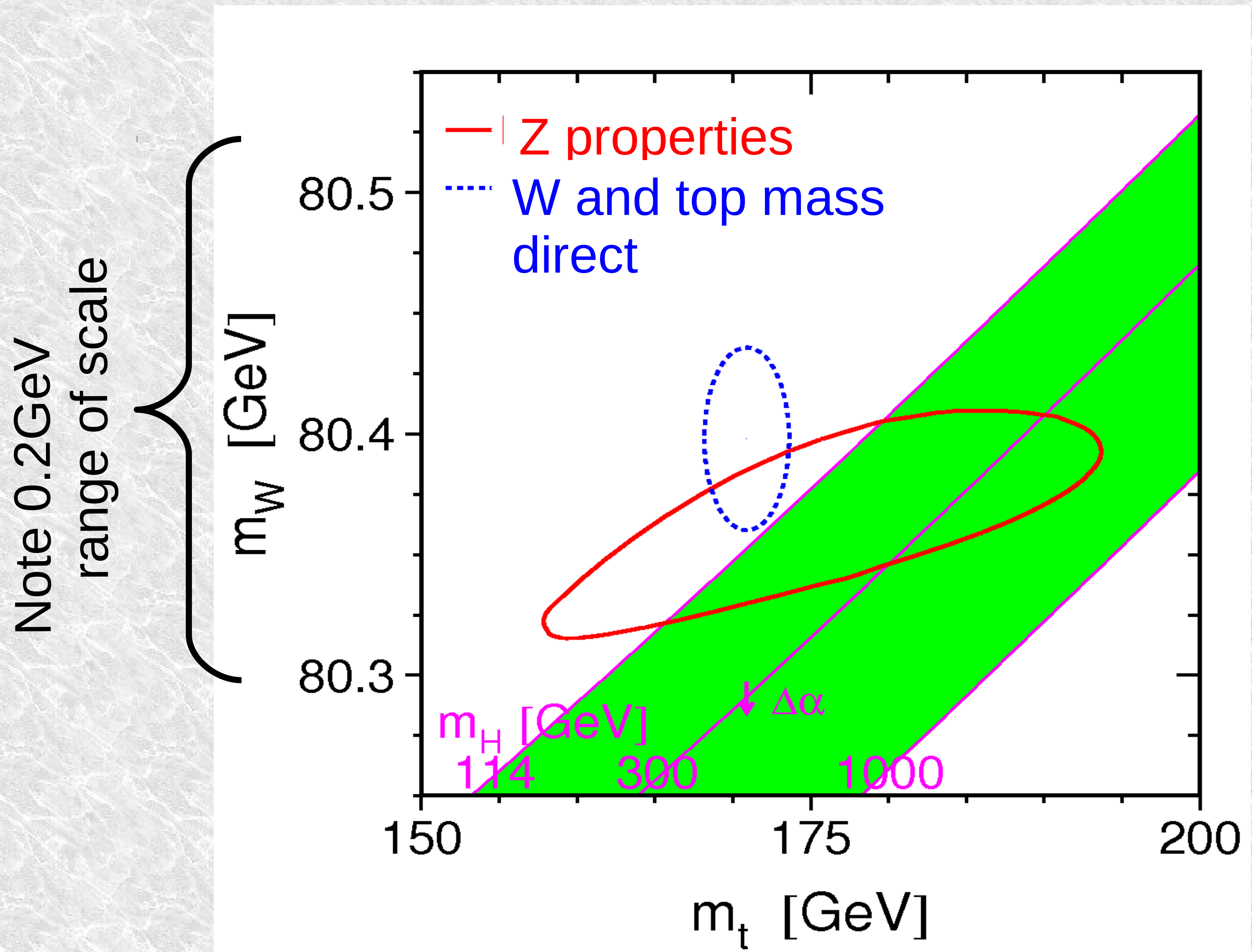
The W mass prediction



Green band is SM prediction
Red and blue measured

It all fits - if M_H<158GeV

This assumes no other unknowns

Hunting the Higgs Boson

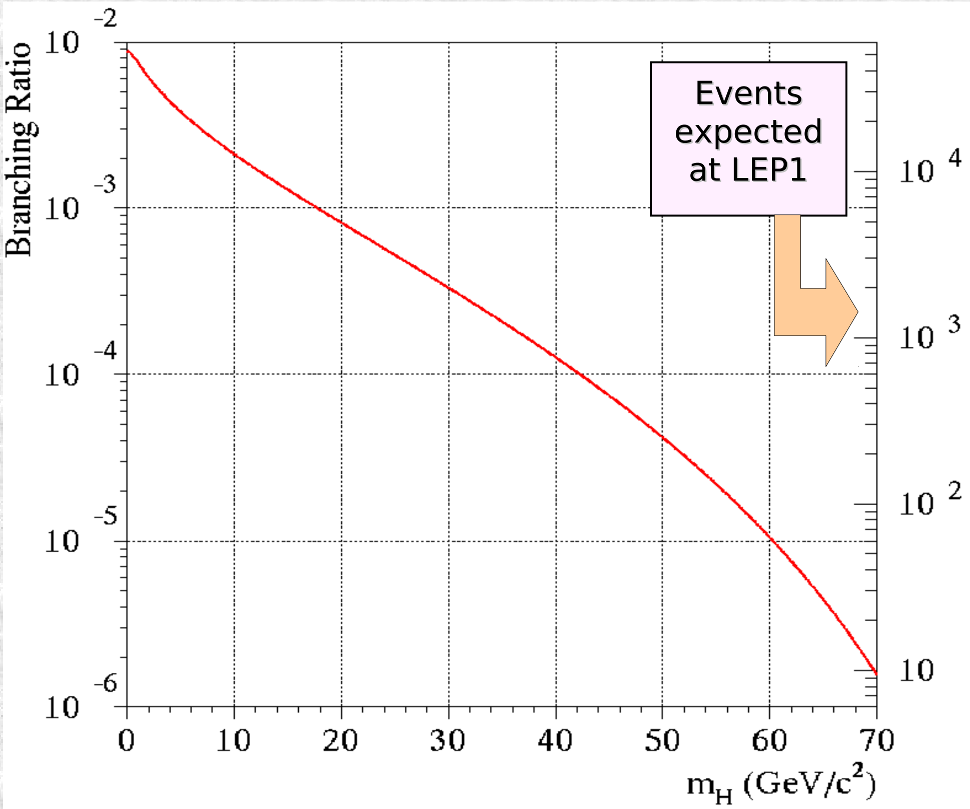
Search at LEP I: E=91GeV

- Great effort - which I have no time to describe
- Many modes:

    Stable,γγ,ee,μμ,ππ,ττ,bb

- Clean Z decays (ll, νν) used
- Prior to LEP only some patchy constraints

The mass range from 0 to ~65 excluded, no holes.

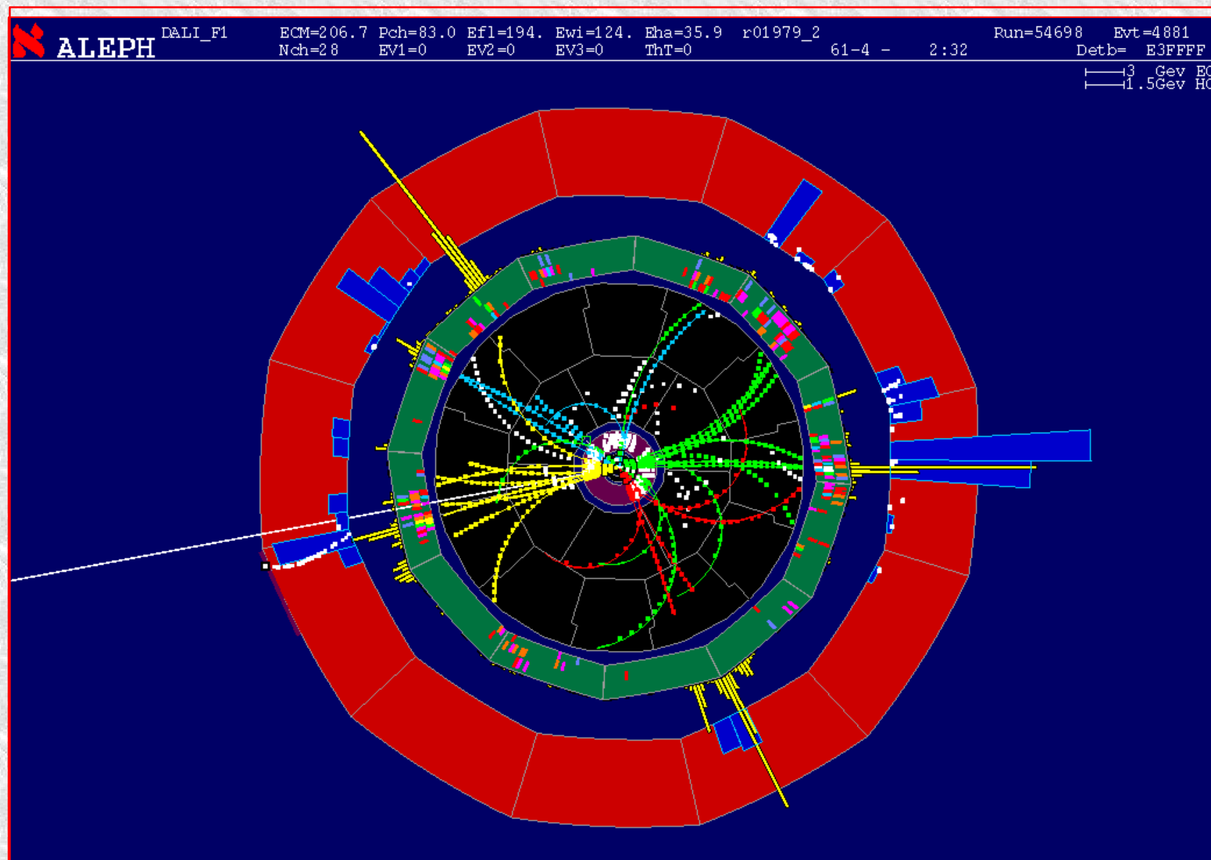


LEP II - high energy

- LEP at CERN ran until 2000
  - collided electron–positrons at up to 207GeV
  - It found a few possible Higgs candidates
- What is this?
- Four 'jets'
  - From 4 quarks
  - Could be ZH
  - Or ZZ
- No one knows

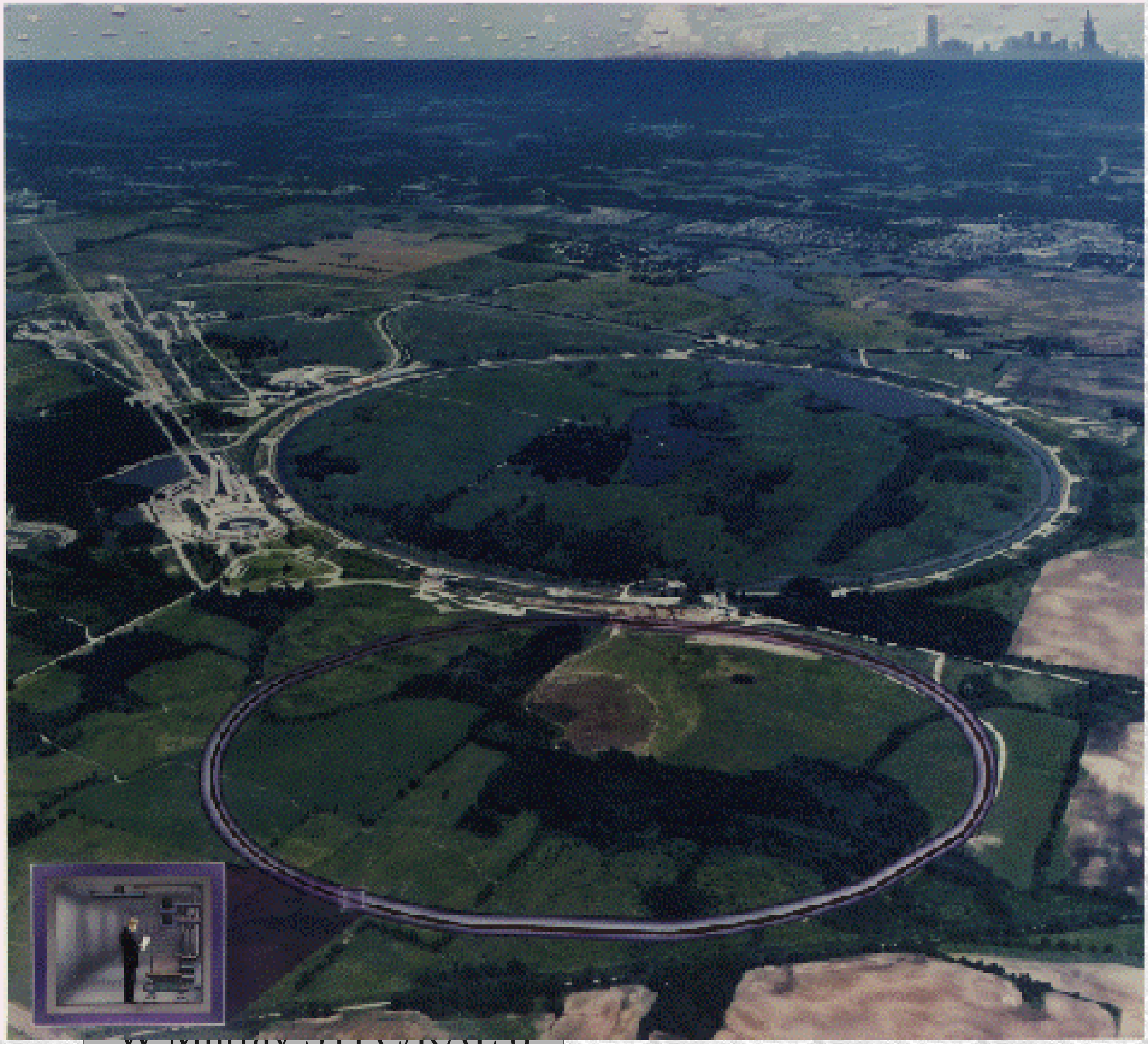
- Hint at 115GeV
- Lower limit:

m_H> 114.4GeV



The Tevatron

- 6km round
- Collided protons and antiprotons
  - Hard to get enough antiprotons
- Closed end of September
- ~$10fb^{-1}$ delivered to experiments
  - Not all analysed yet
  - Results overleaf



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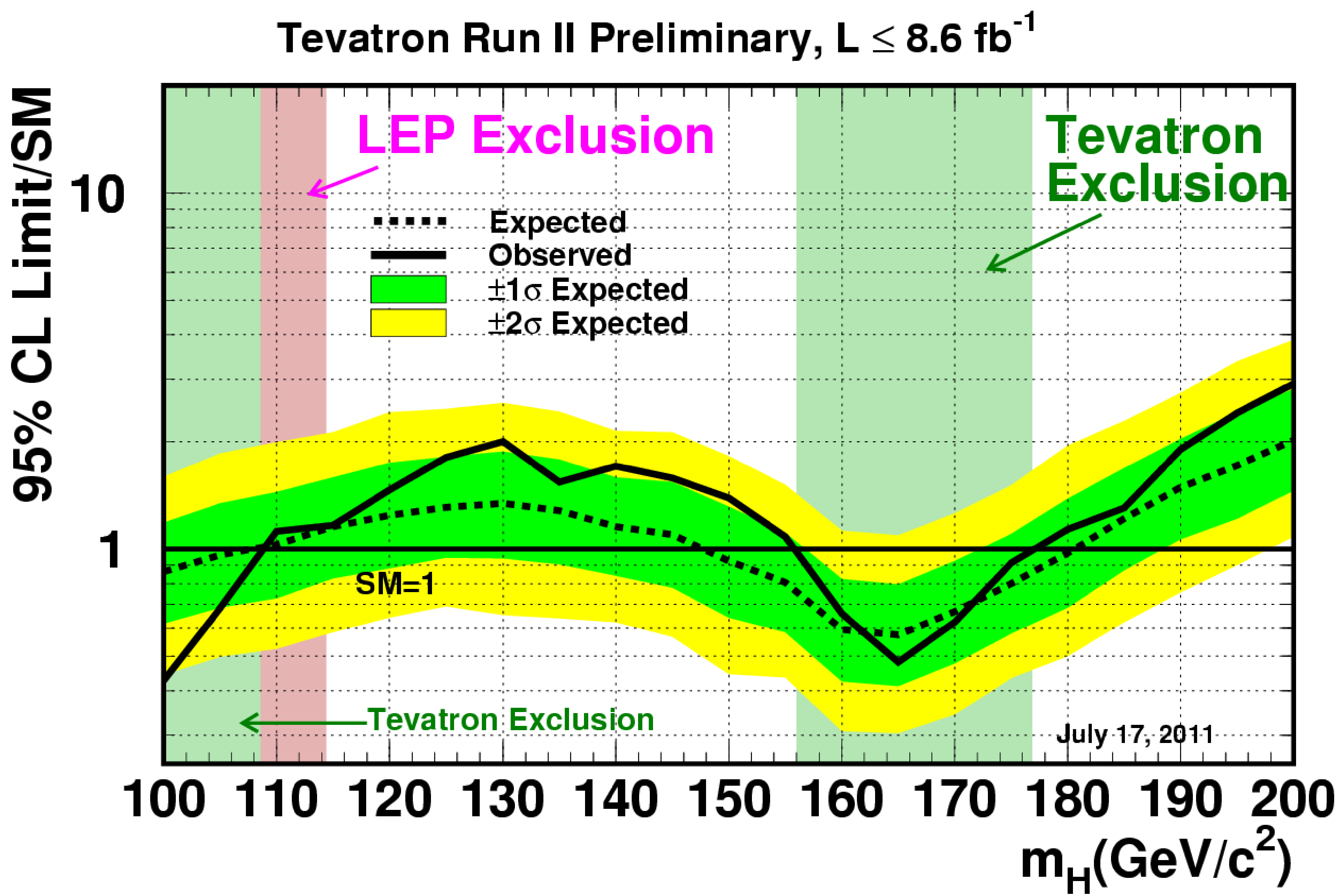
Tevatron Higgs Combination

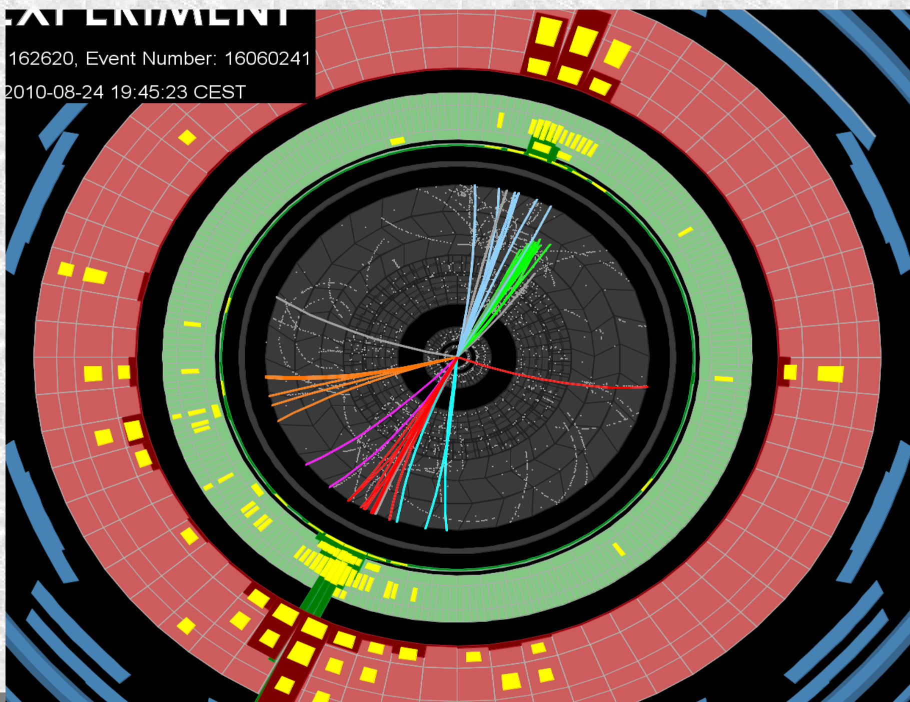


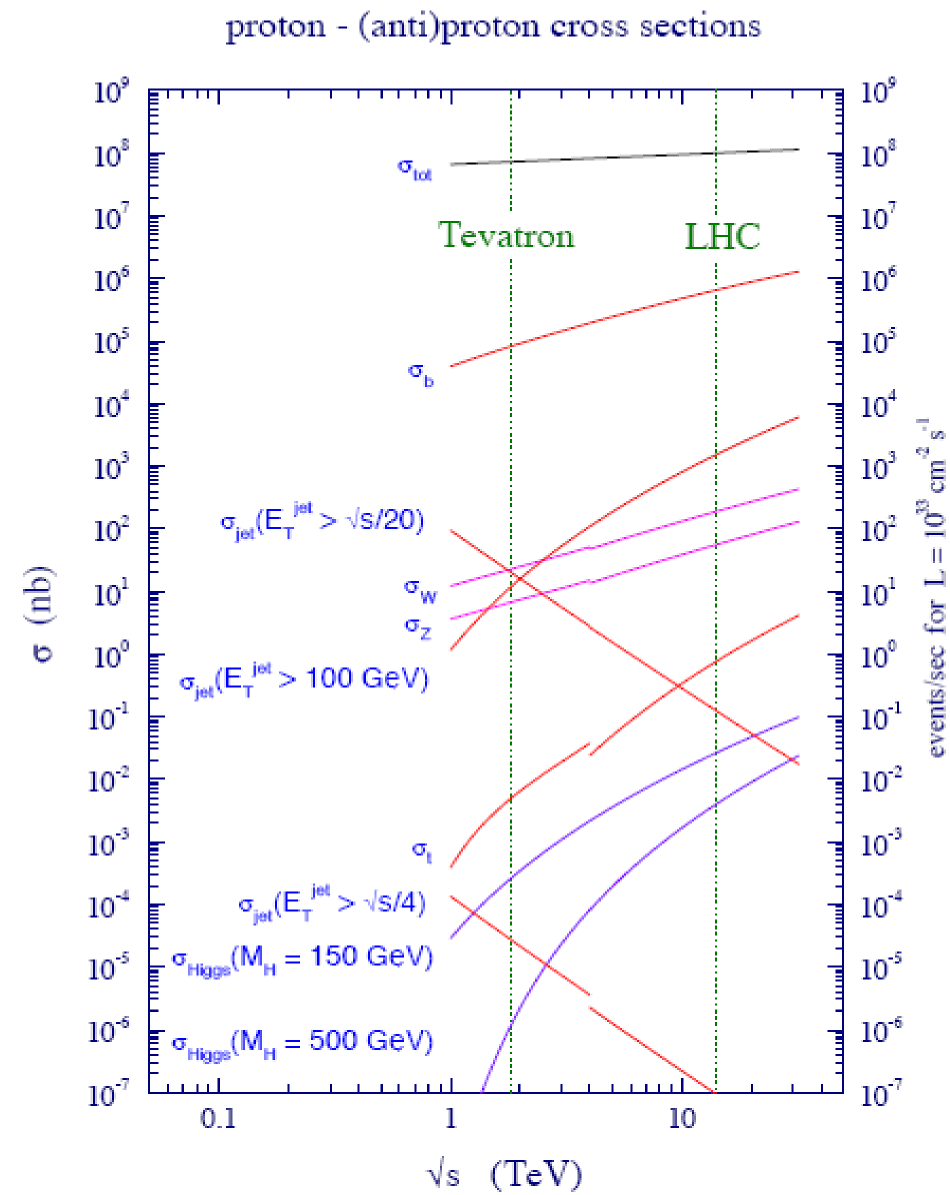
The Large Parton Collider

- Total cross-section 10^{11}pb
- Higgs cross-section 10pb

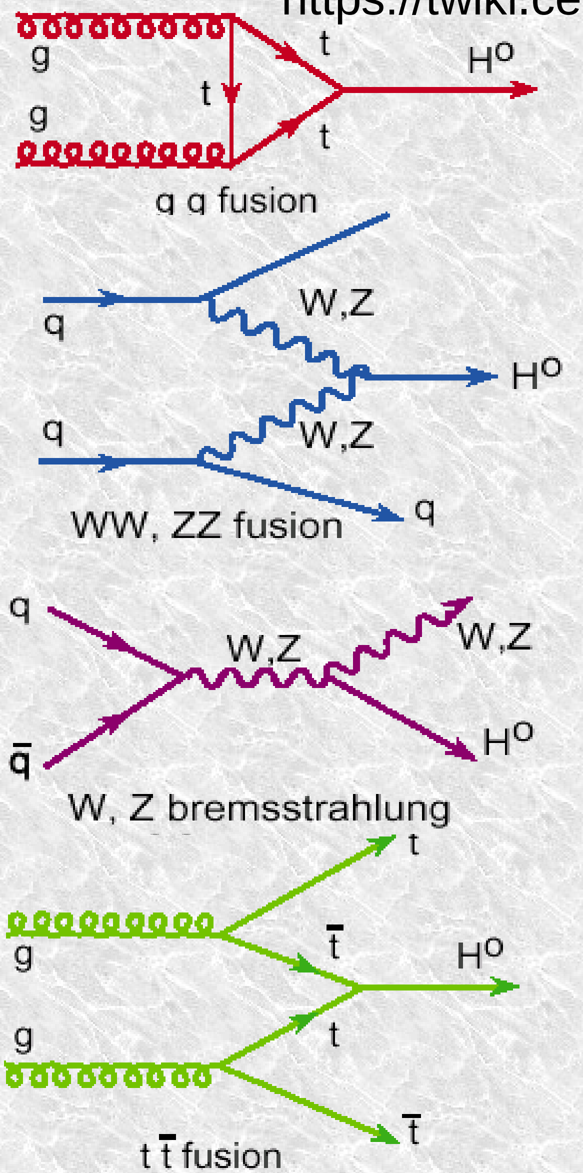
Every event at a lepton collider is physics; every event at a hadron collider is background

Sam Ting

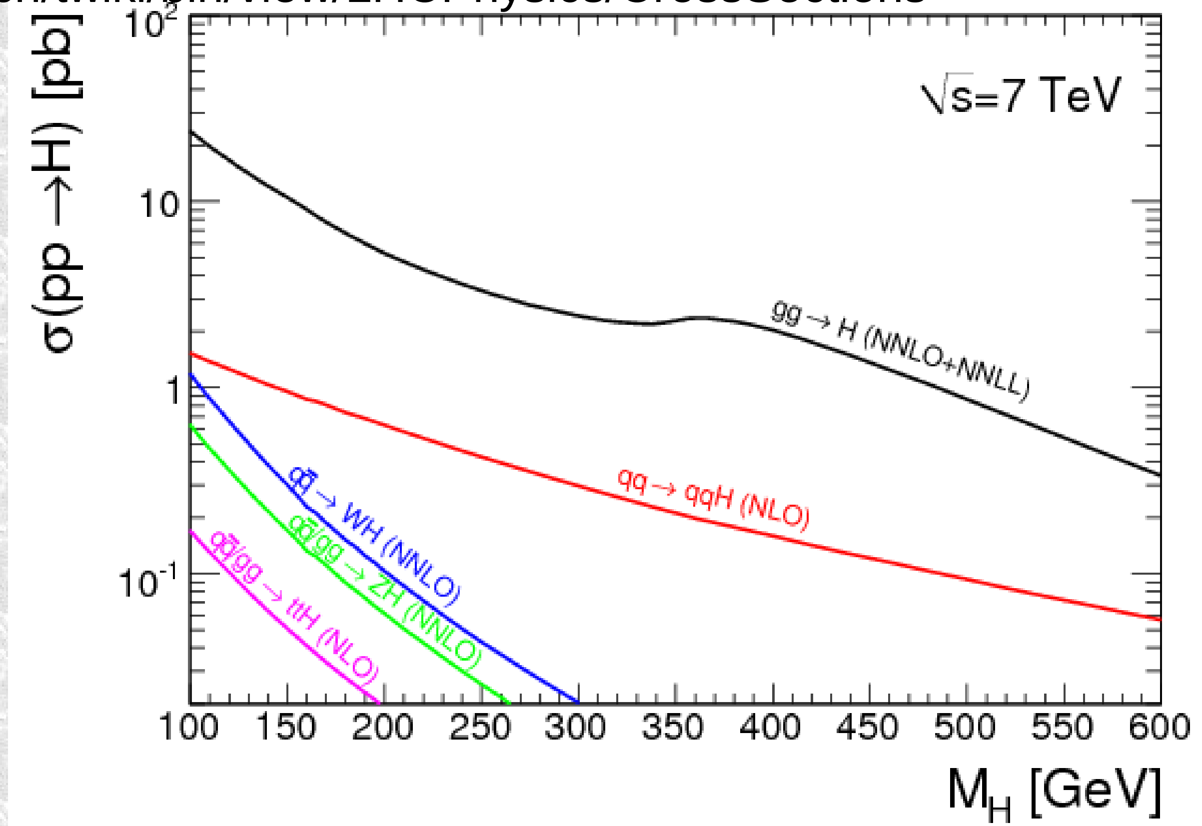




Higgs production



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections



- Fusion process much highest rate
- Others give extra 'tags'

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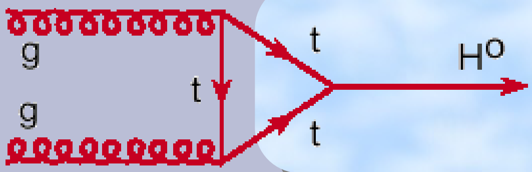
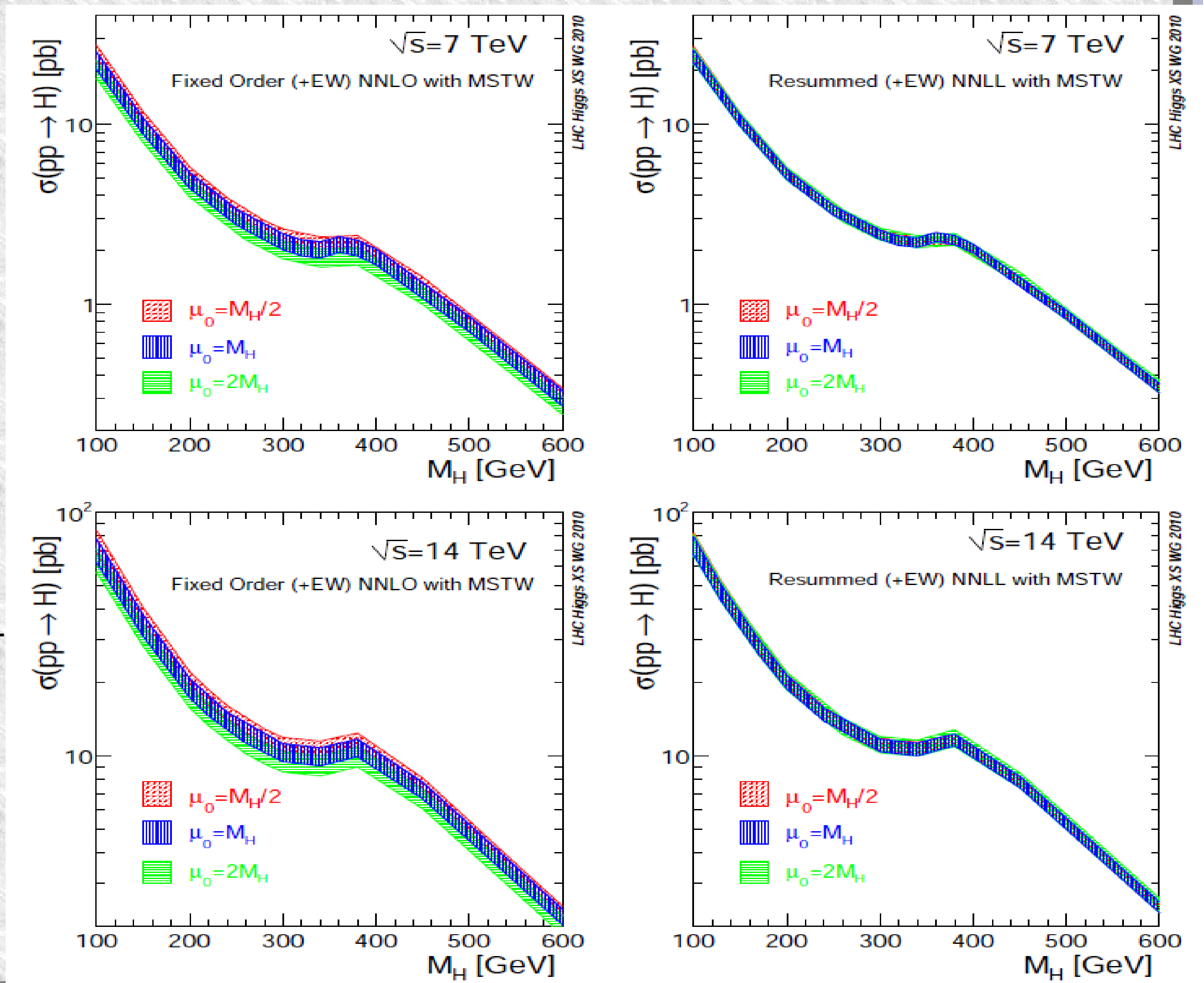


Cross-section in gg → H

arXiv:1101.0593

- The gluon-fusion process is calculated to NNLO+NNLL
  - Precision sounds impressive
  - But loop diagrams are tough
- Uncertainties from $\mu = m_H/2 \times 2^{\pm 1}$
- Gives ~10% from h.o.

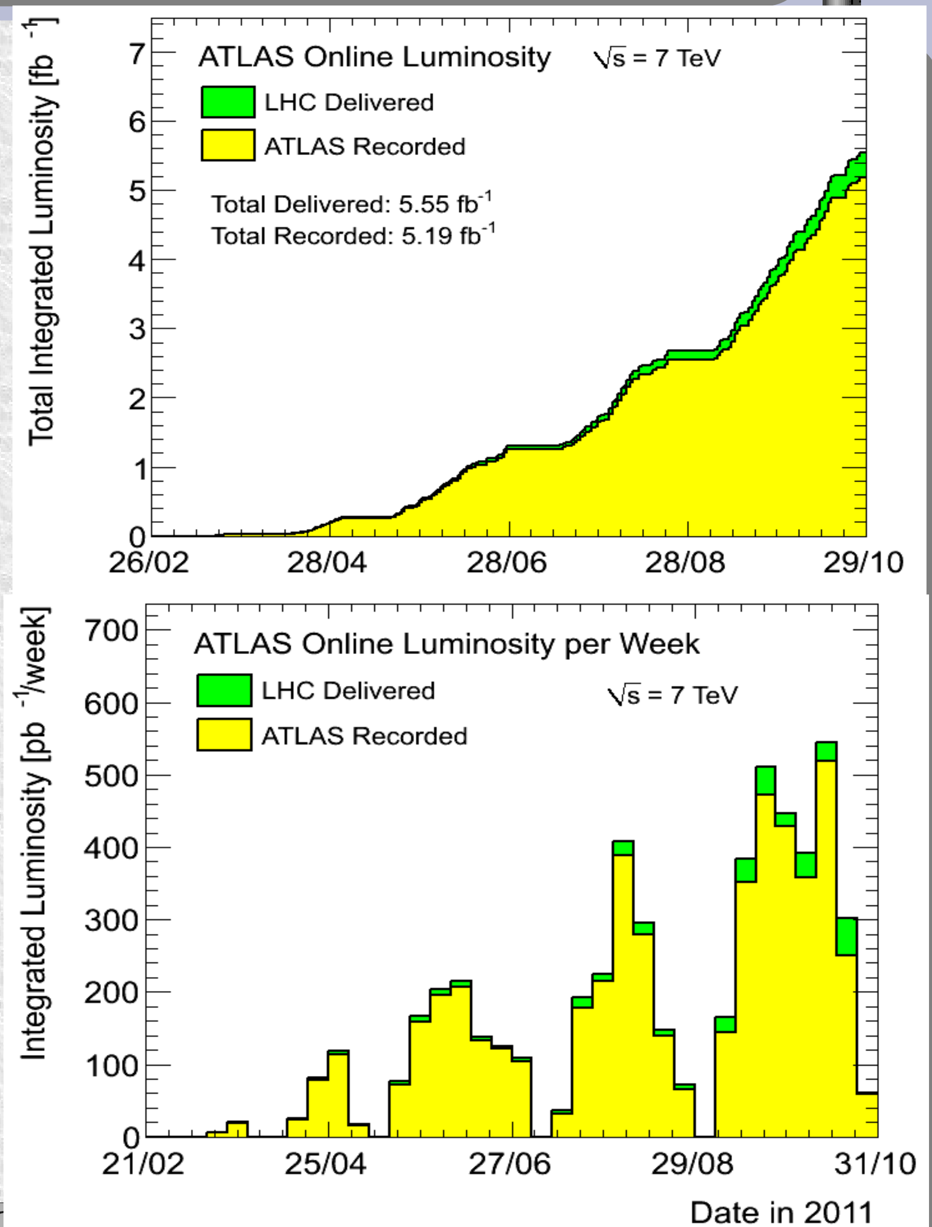


The controversy

- PDF uncertainties on gluon density give 3-4% errors
- How to combine with the scale uncertainty?
- Add them linearly?
  - Gives a safer error
  - Recommended by LHC Higgs cross-section working group
- Treat as independent
  - Correlations between processes PDF errors are accounted
  - Used by LHC Higgs combination group
- We need to fix this!

Luminosity this year

- 2010 was commissioning year
- 2011 devoted to physics
- We ran pp until the 29th of October
  - 5.6fb^{-1} delivered
  - Finally ~0.4fb^{-1} per week
- 1fb^{-1} gave major Higgs sensitivity by summer
- Luminosity in 2011 rising smoothly
  - Expect 10fb^{-1} in 2012
- Great effort by LHC team!



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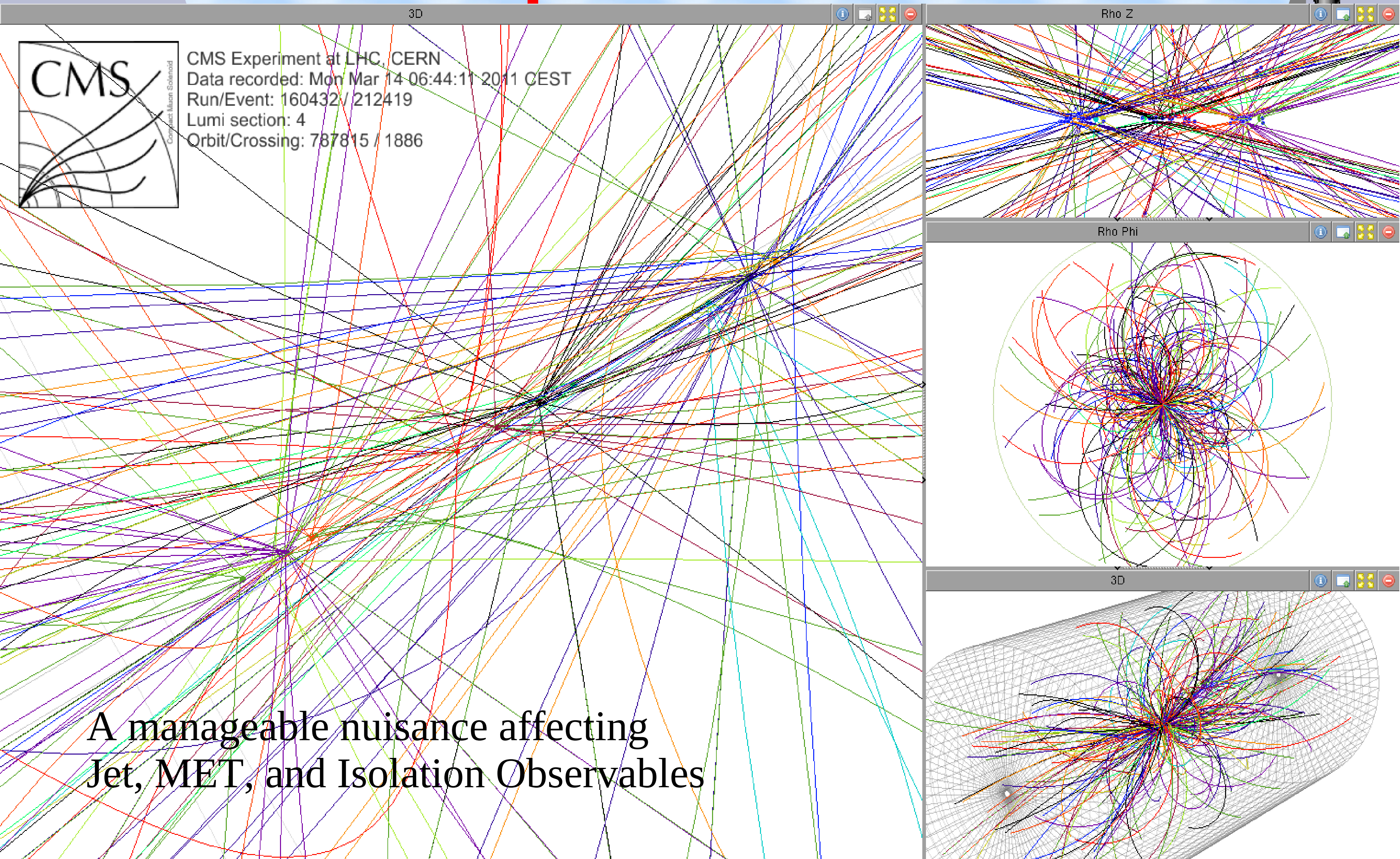
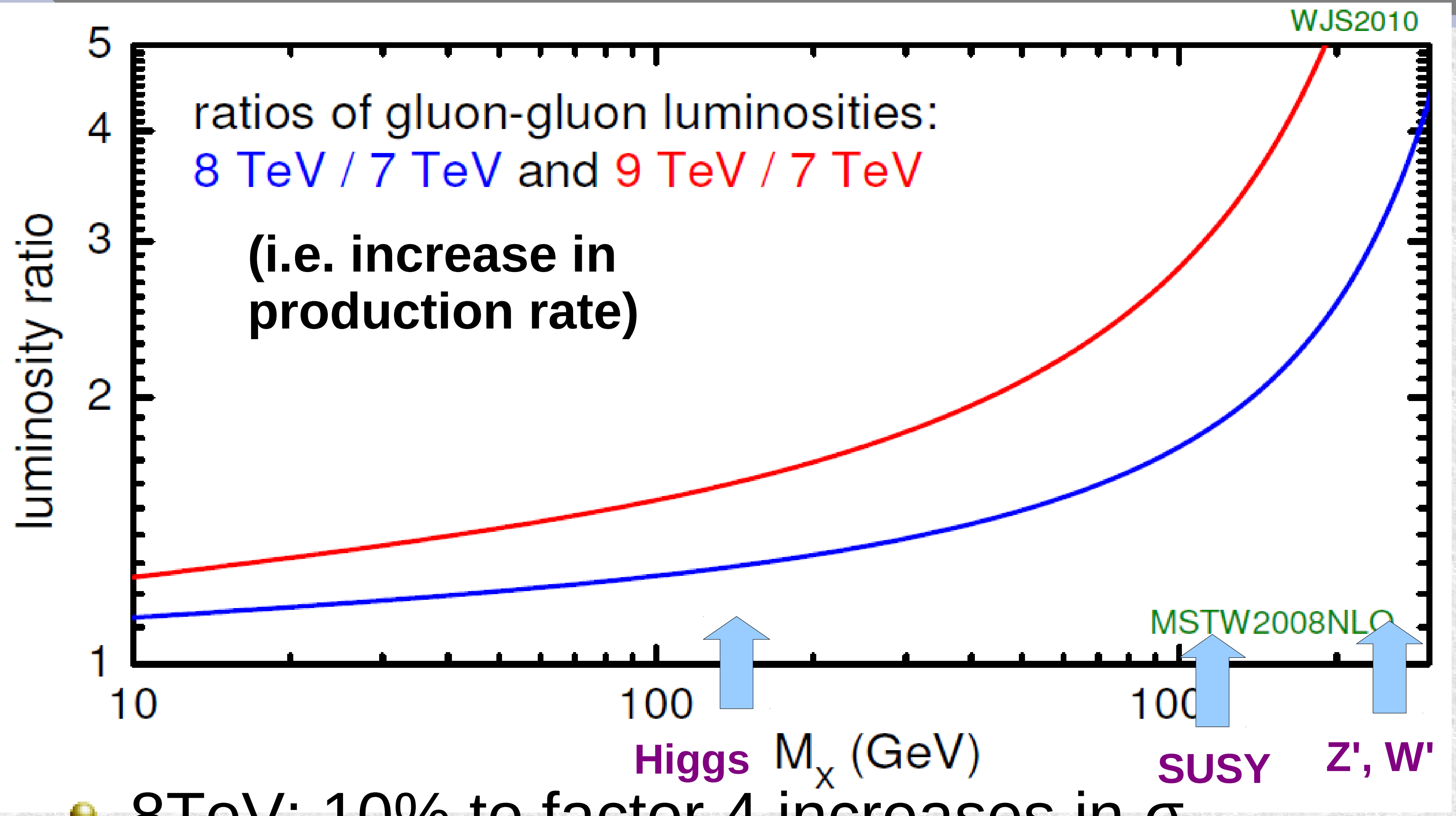
Pileup: 13 vertices



A manageable nuisance affecting
Jet, MET, and Isolation Observables

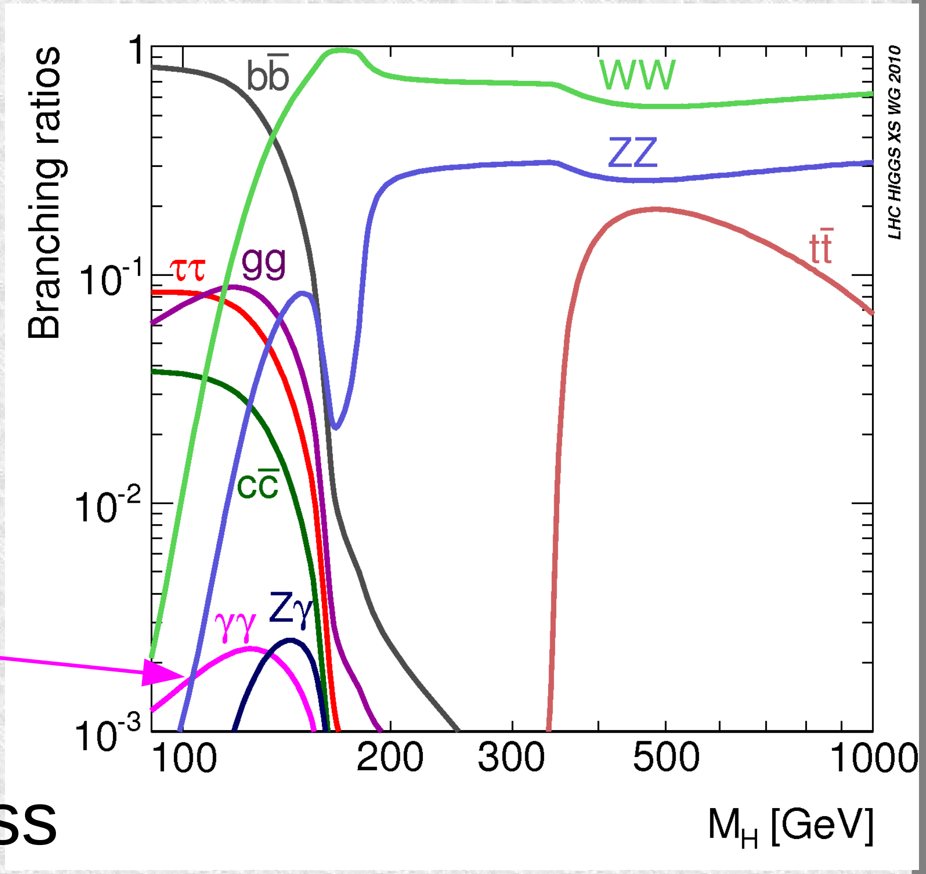
2011: 7 TeV or 8TeV?



- 8TeV: 10% to factor 4 increases in σ
  - Higgs increased by 30%
- Emittance shrinks by 8/7 as well
  - Luminosity may be slightly easier

Higgs branching ratios

- $H \to ZZ$
  - $ZZ \to llll$: Golden mode
  - $ZZ \to ll\nu\nu$: Good High mass
  - $ZZ \to llbb$: Also high-mass
- $H \to WW$
  - $WW \to l\nu l\nu$: Most sensitive
  - $WW \to l\nu qq$: highest rate
- $H \to \gamma\gamma$
  - Best for low mass
- $H \to \tau\tau$
  - Decent s/b in VBF, low mass
- $H \to bb$
  - $t\bar{t}H$, WH, ZH useful but hard



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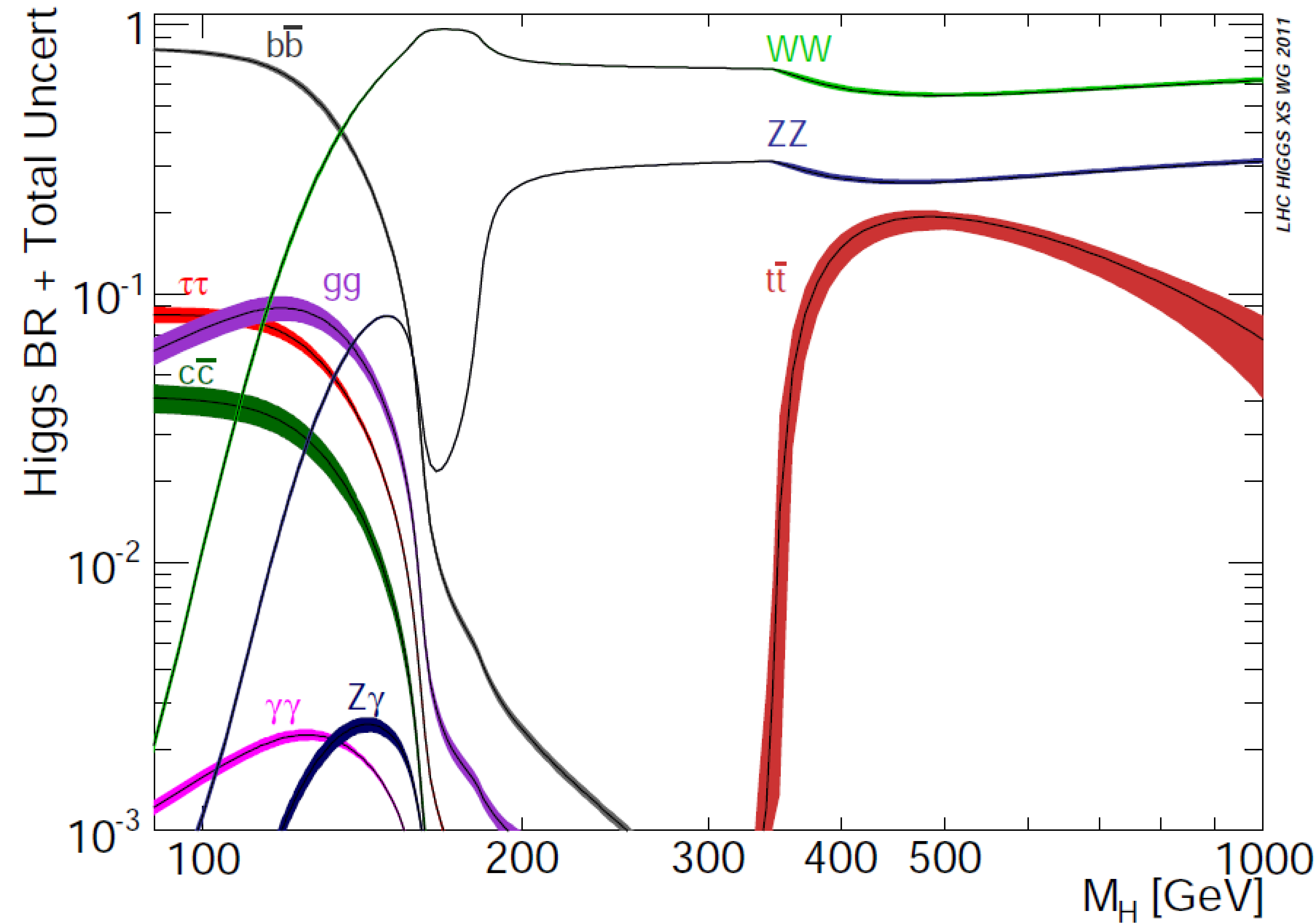
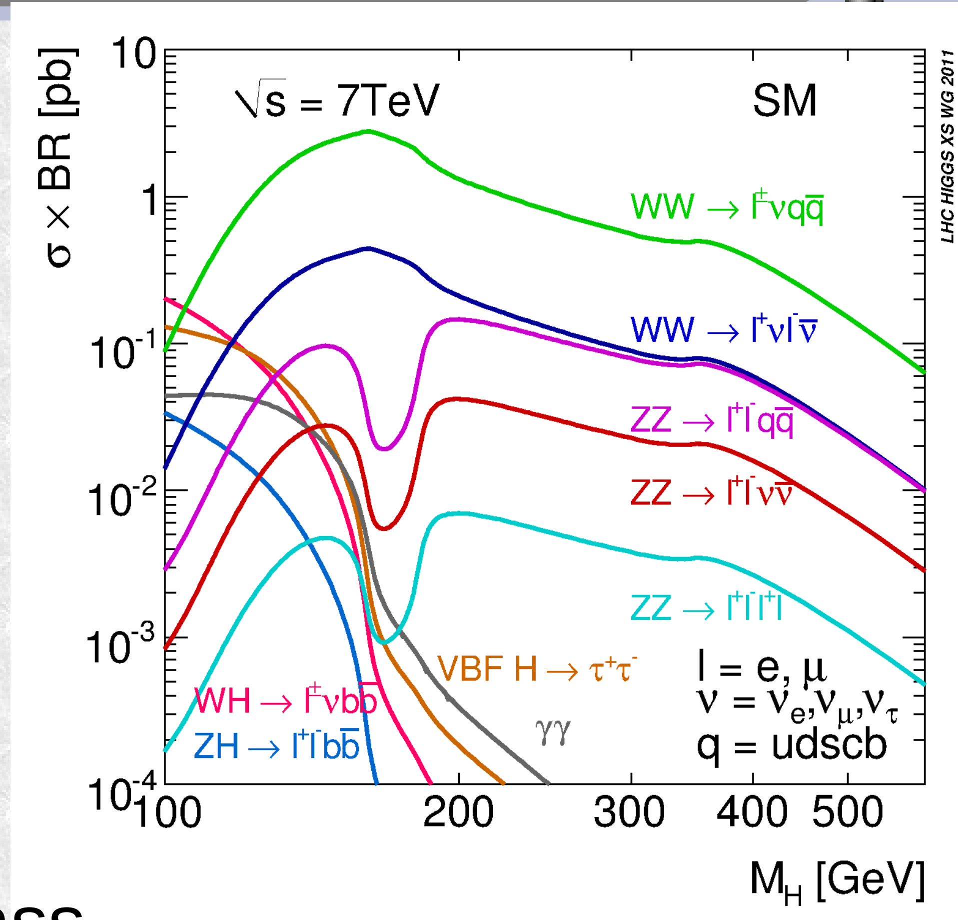
Branching ratio errors?



Higgs cross-sections

- H → ZZ
  - ZZ → llll: Golden mode
  - ZZ → llνν: Good High mass
  - ZZ → llbb: Also high-mass
- H → WW
  - WW → lνlν: Most sensitive
  - WW → lνqq: highest rate
- H → γγ
  - Best for low mass
- H → ττ
  - Decent s/b in VBF, low mass
- H → bb
  - $t\bar{t}H$, WH, ZH useful but hard



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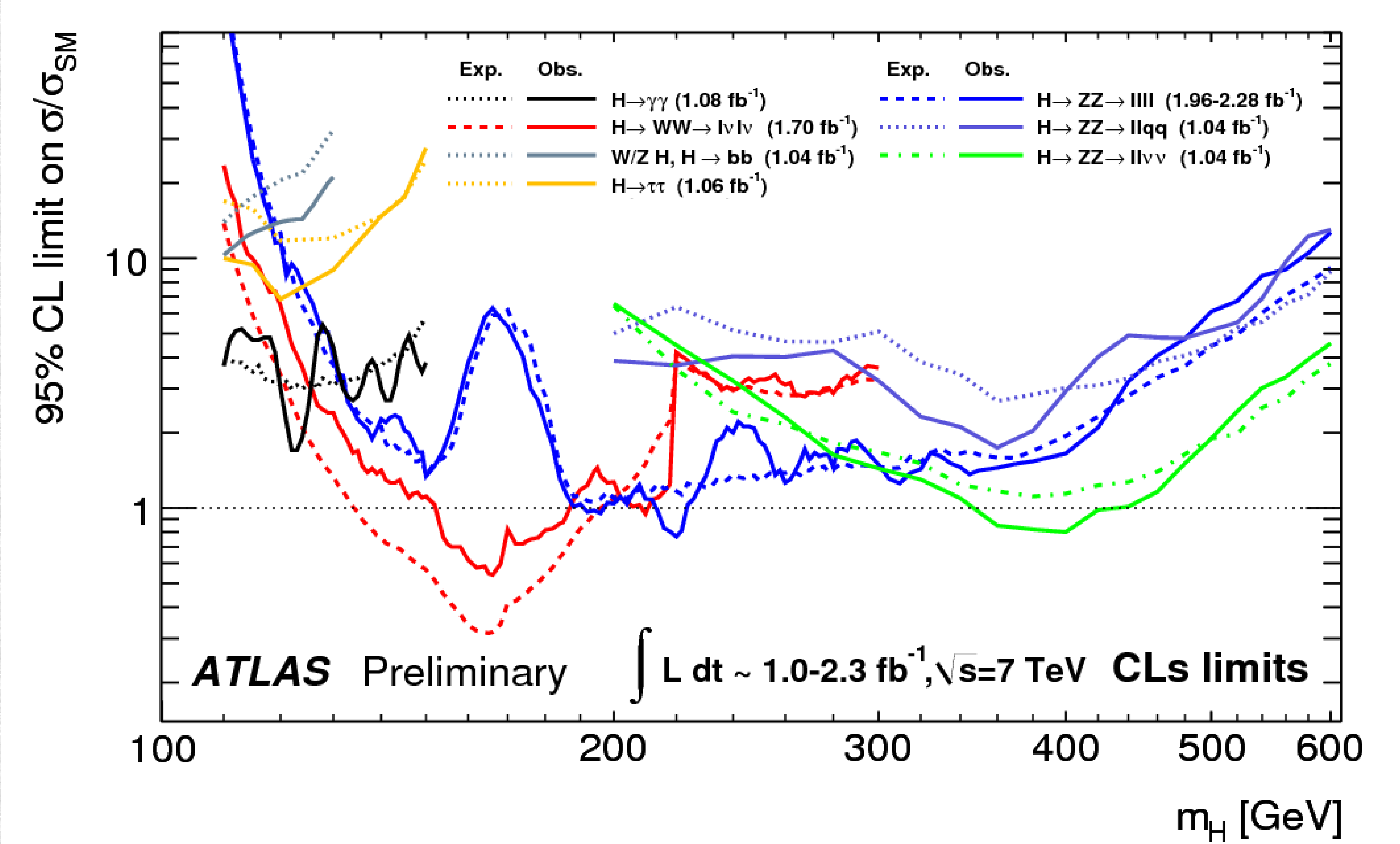
Impact by channel



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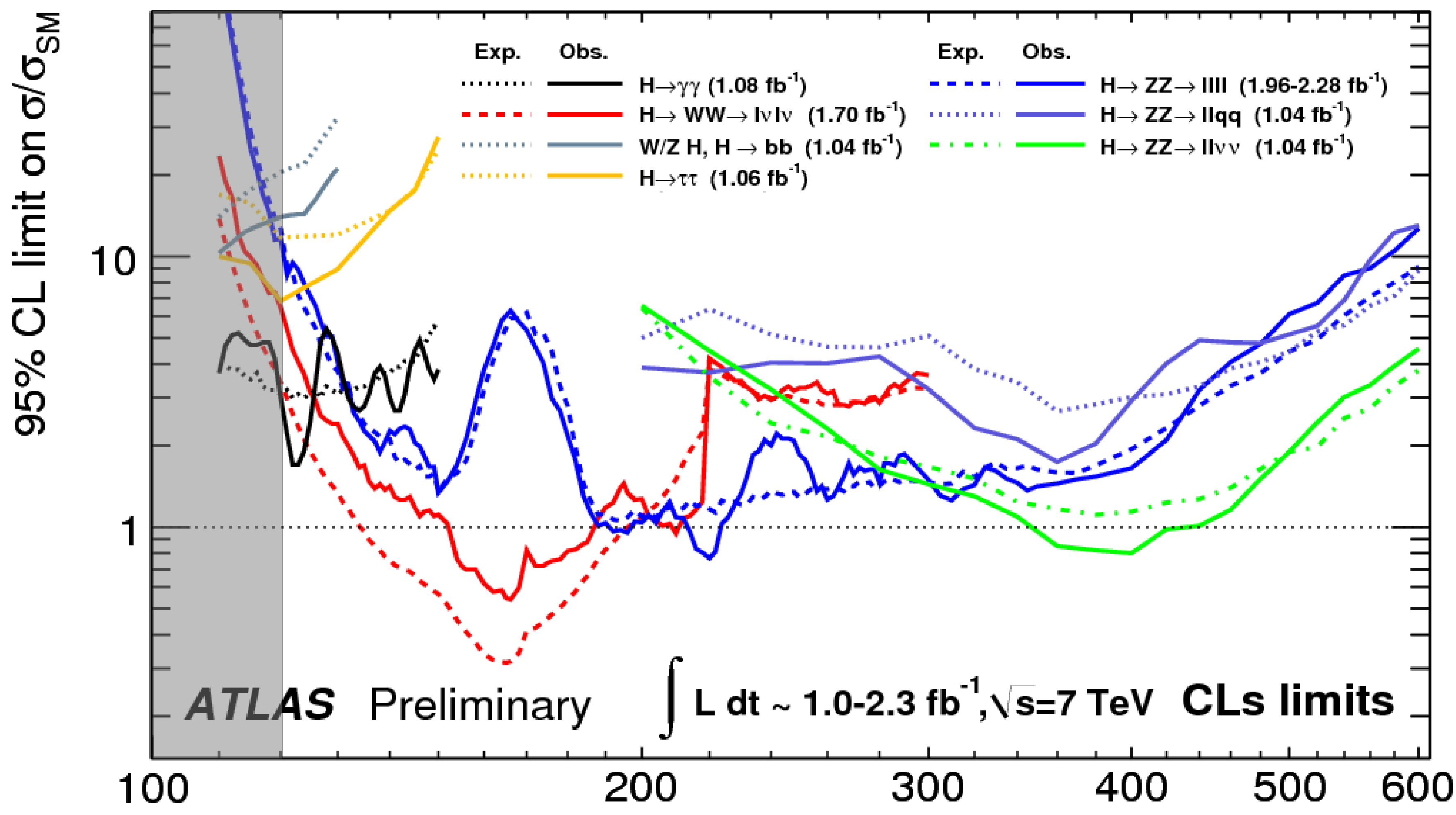
Low mass searches



γγ region, (plus ττ, bb)

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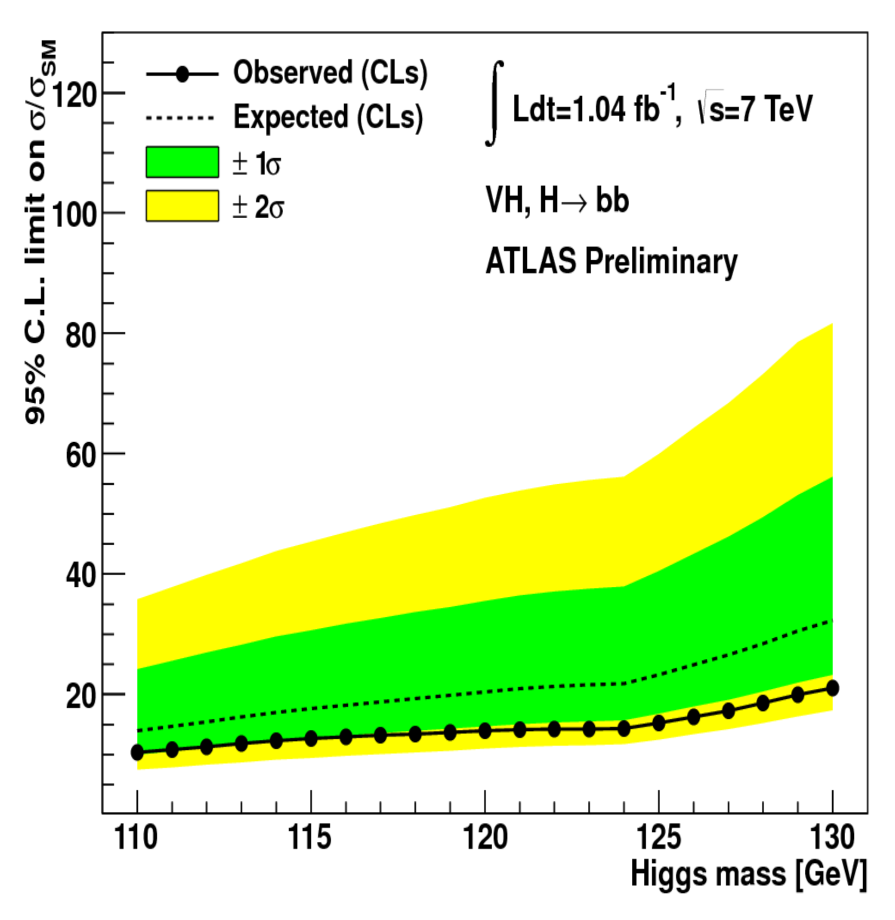
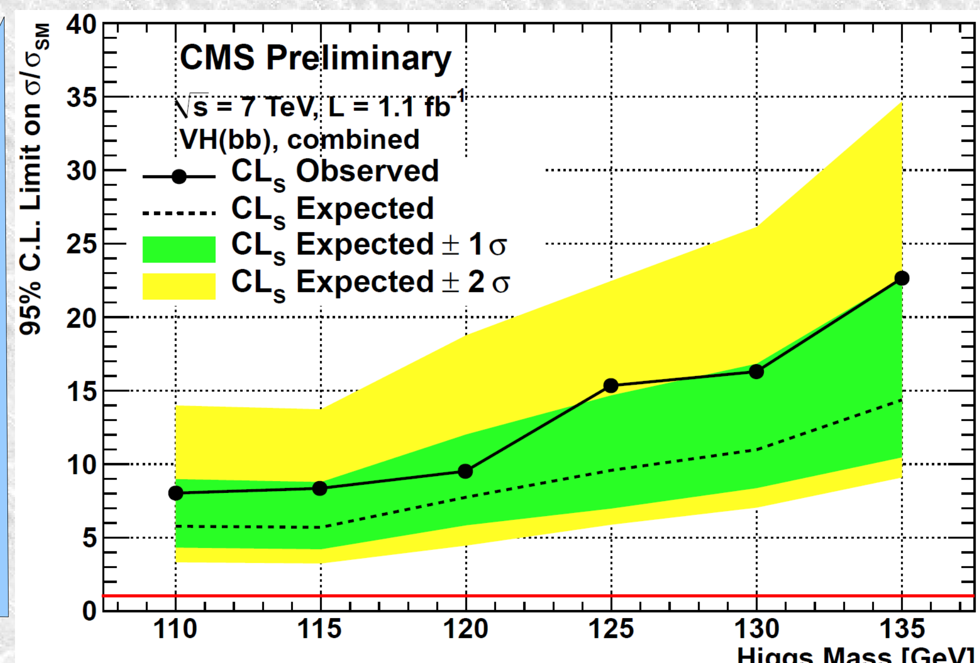
WH & ZH, H → bb

- Very different optimisations in ATLAS & CMS
  - Sensitivity is ~ 15xSM in ATLAS
  - 6xSM in CM
- Difference is due to inclusive/boosted +including ννbb by CMS





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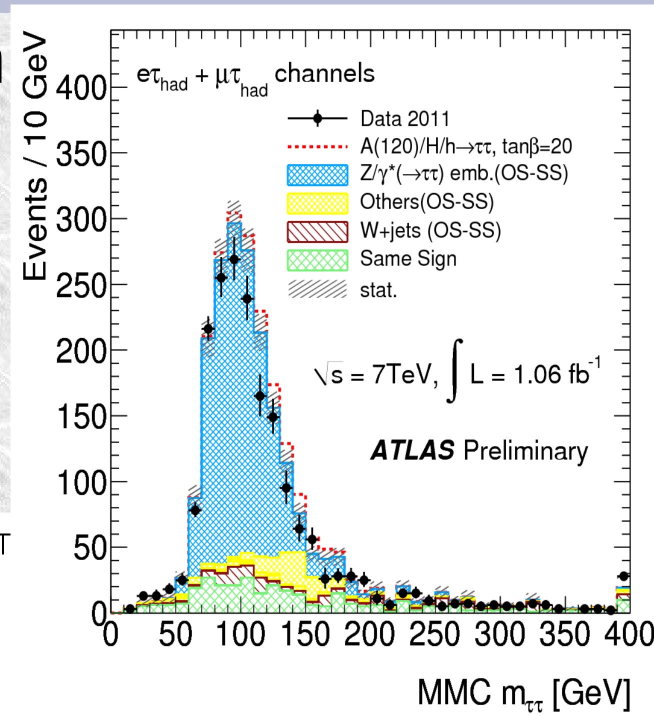
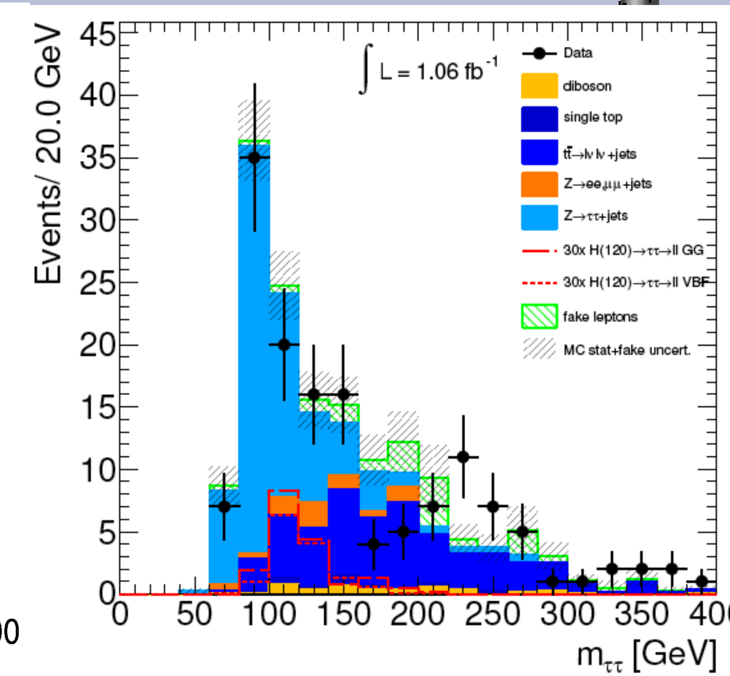
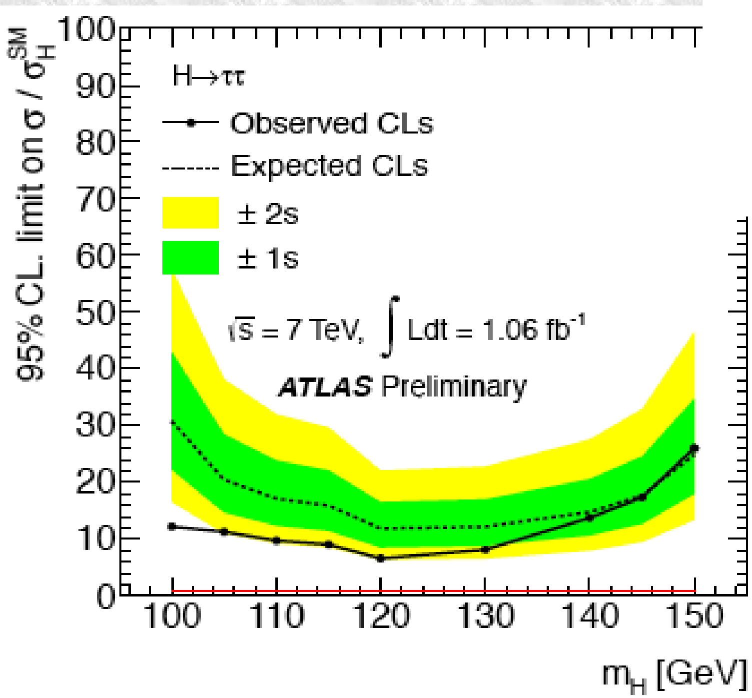
ATLAS H→ττ

- Inclusive H→ττ→lh
- Also use ll+jet
  - Sensitive to VBF process
  - Jet boosts ττ
  - Collinear mass







- Combined result shown to left
- Two sigma deficit at low m_H
- Sensitivity 15xSM, obs 10x

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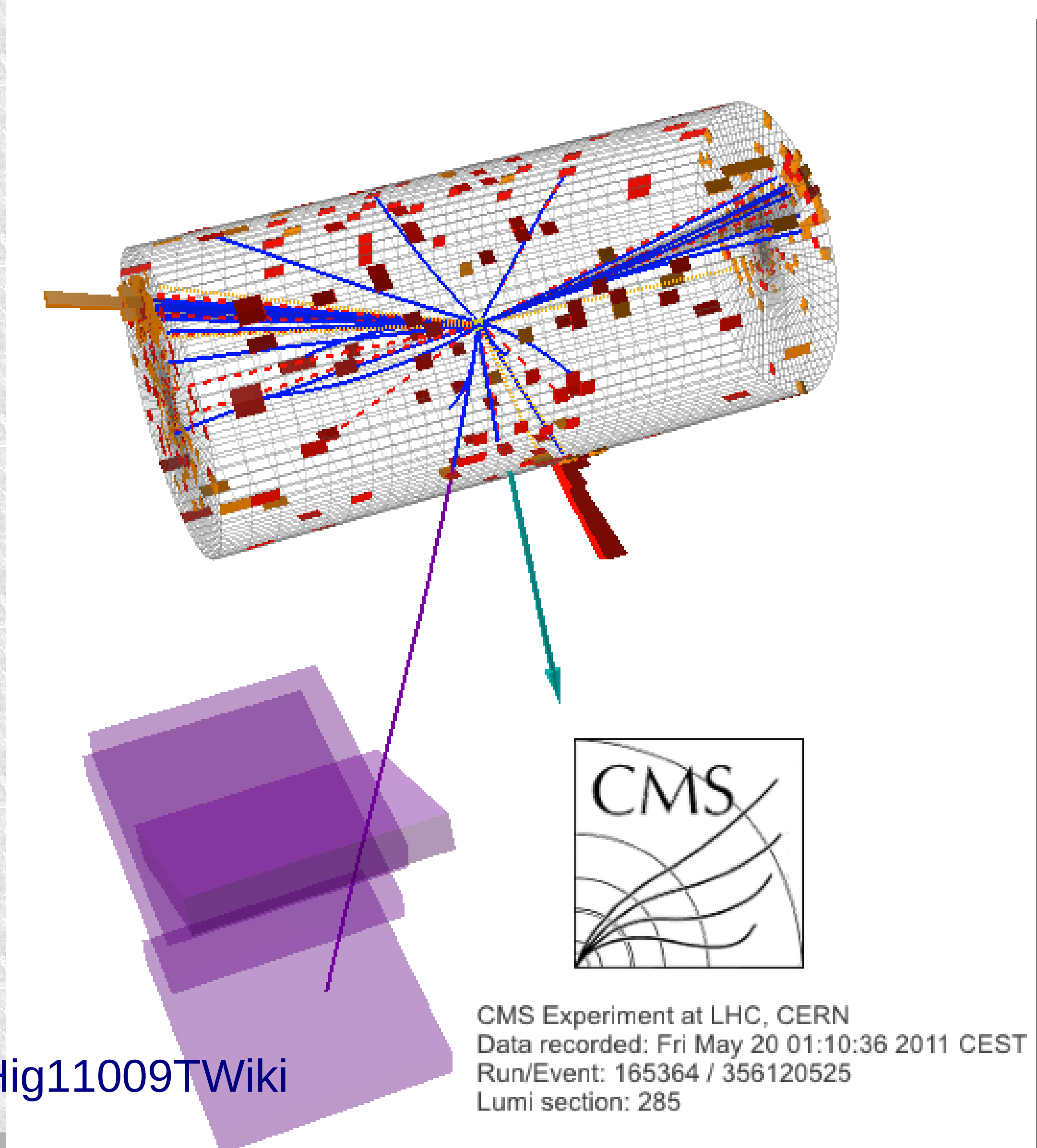
CMS H → ττ

- CMS have SM results
- Including VBF search
  - With a beautiful picture
    - μ-τ candidate
    - Two forward jets
      - Mass 580GeV
    - Little central activity
  - Looks just as advertised
- e-μ, μ-μ, μ-τ, e-τ channels studied
- Details are here:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig11009TWiki



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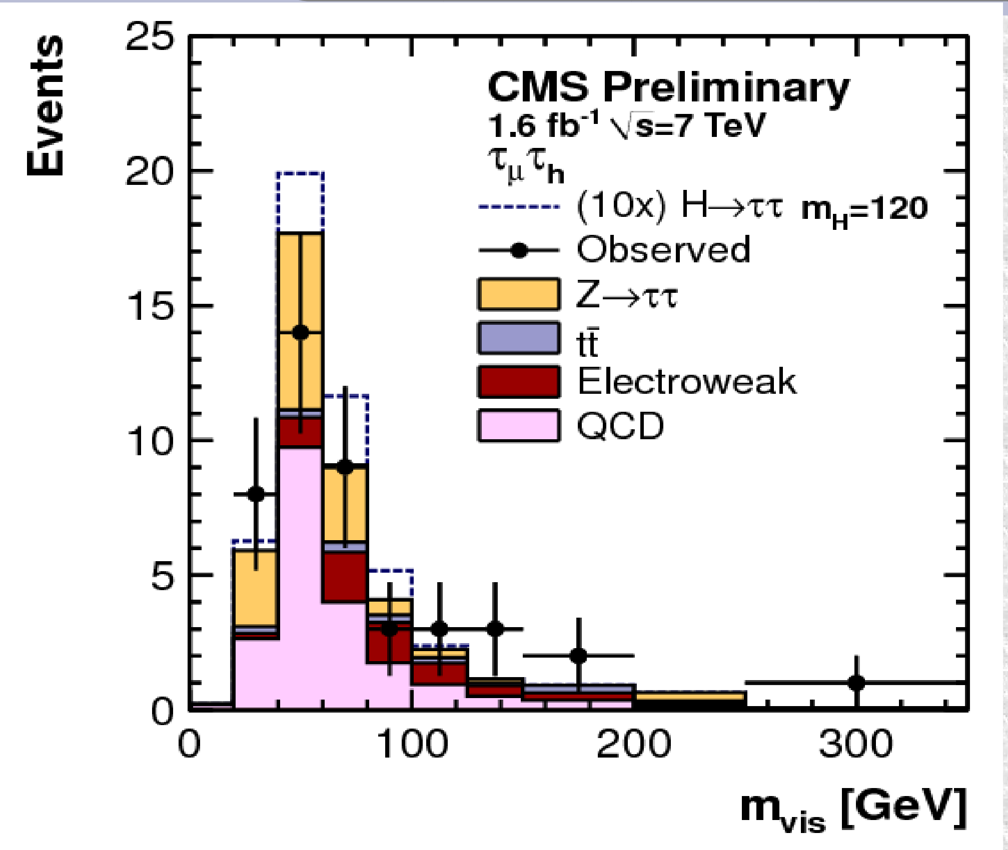
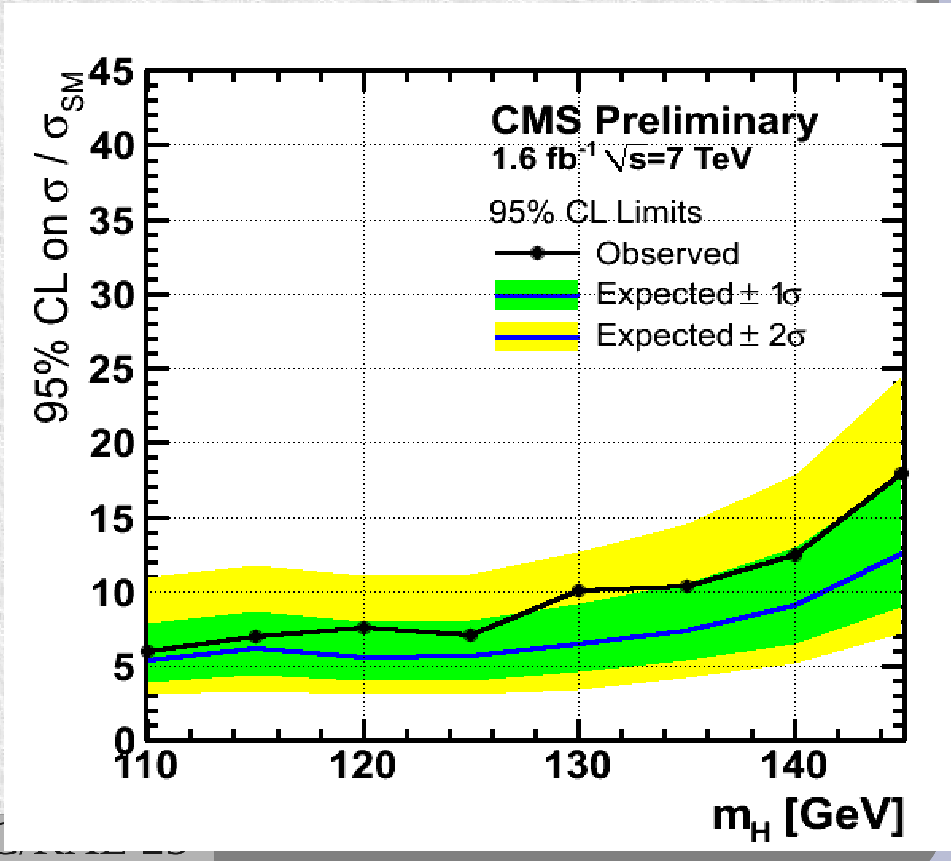
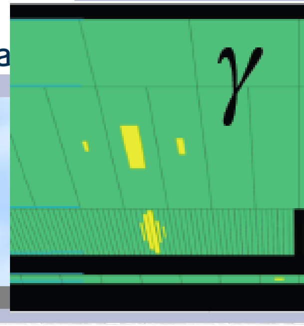
H → ττ results



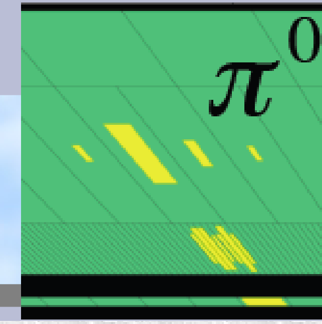
- CMS' μ-h VBF channel (left) is among best
  - e-μ, e-h VBF and all inclusive channels contribute

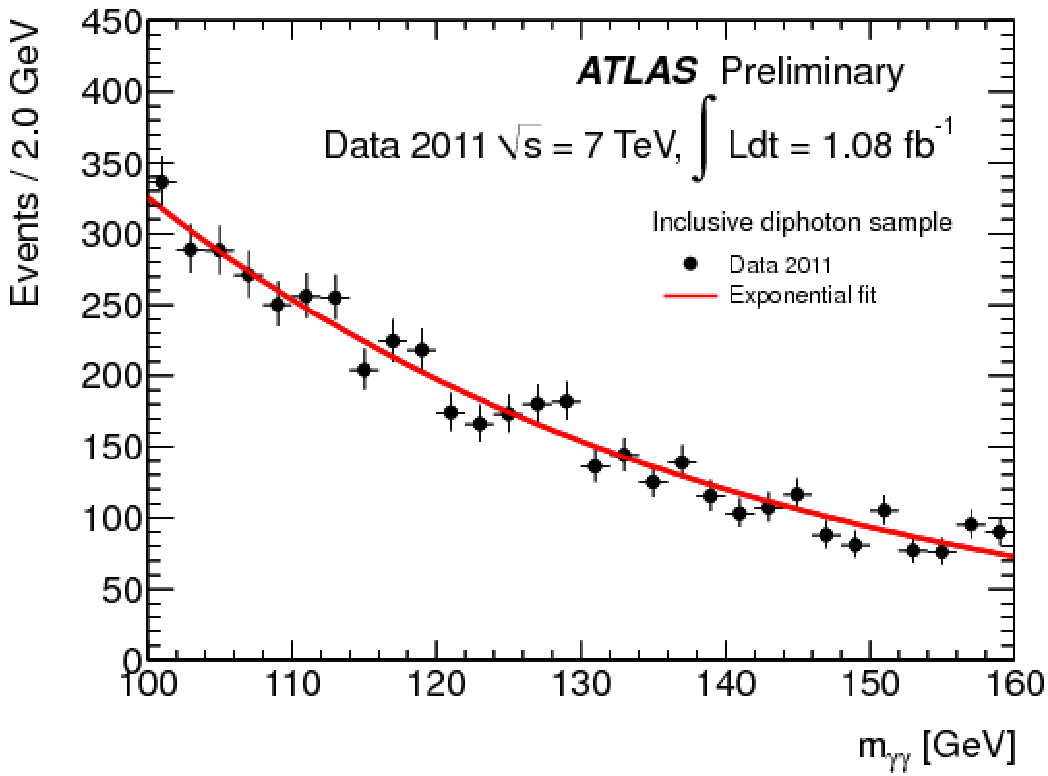


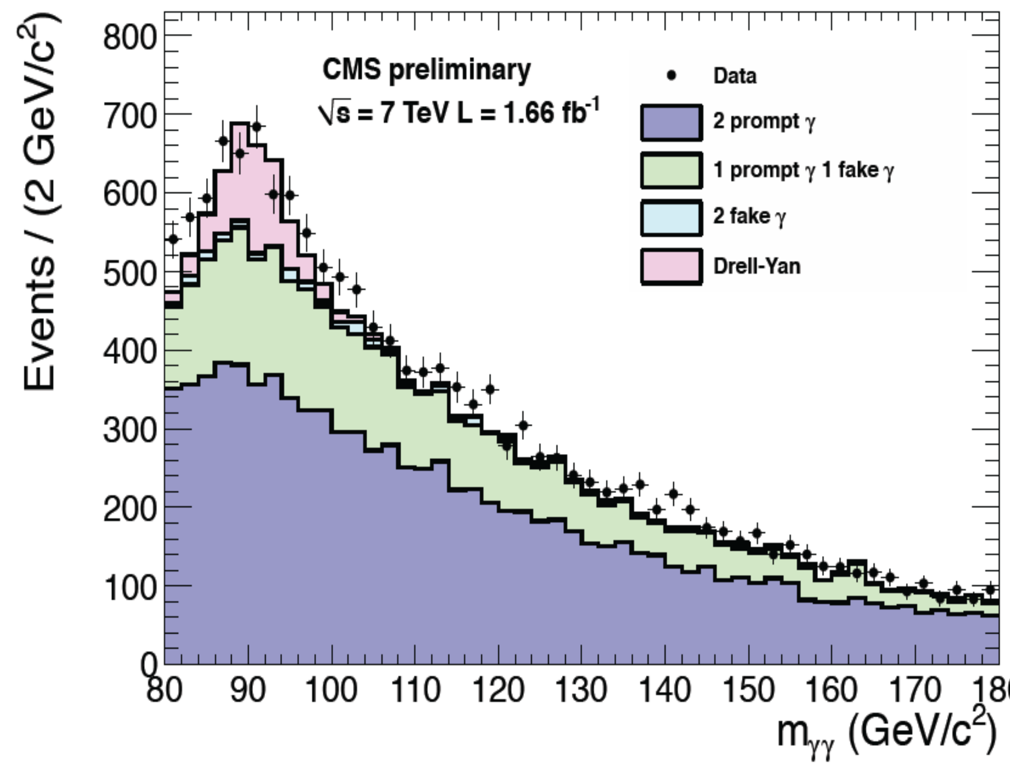
- Sensitivity around 6xSM
  - At 115-125 (where we need this most)



$H \rightarrow \gamma\gamma$

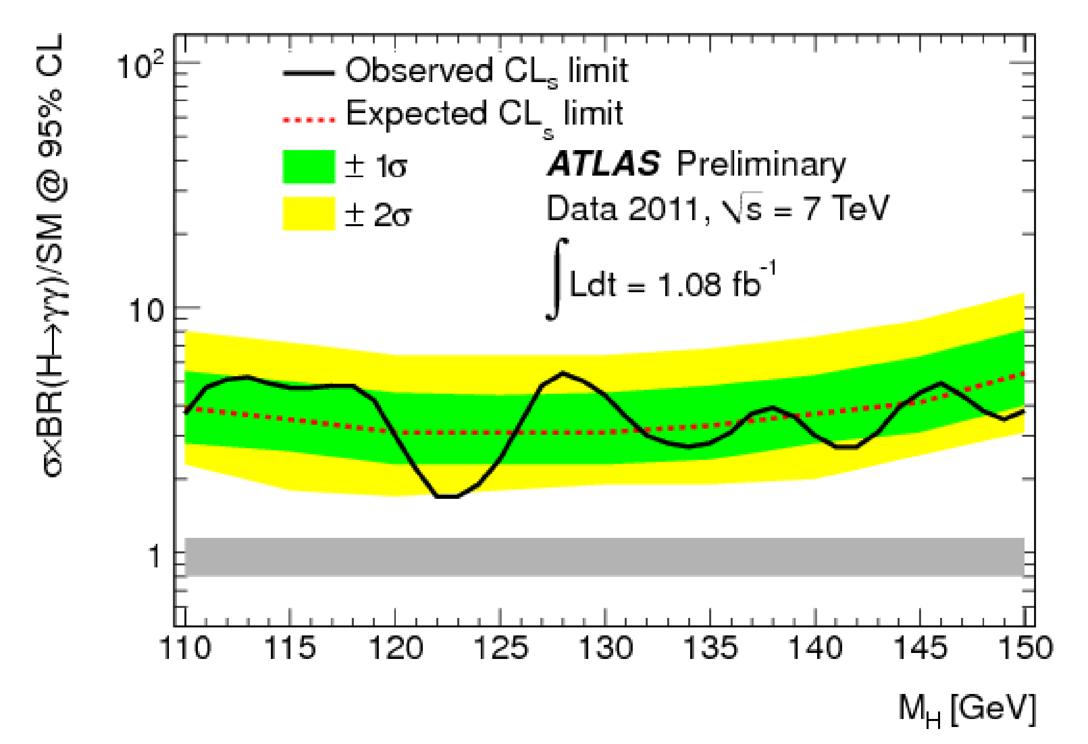


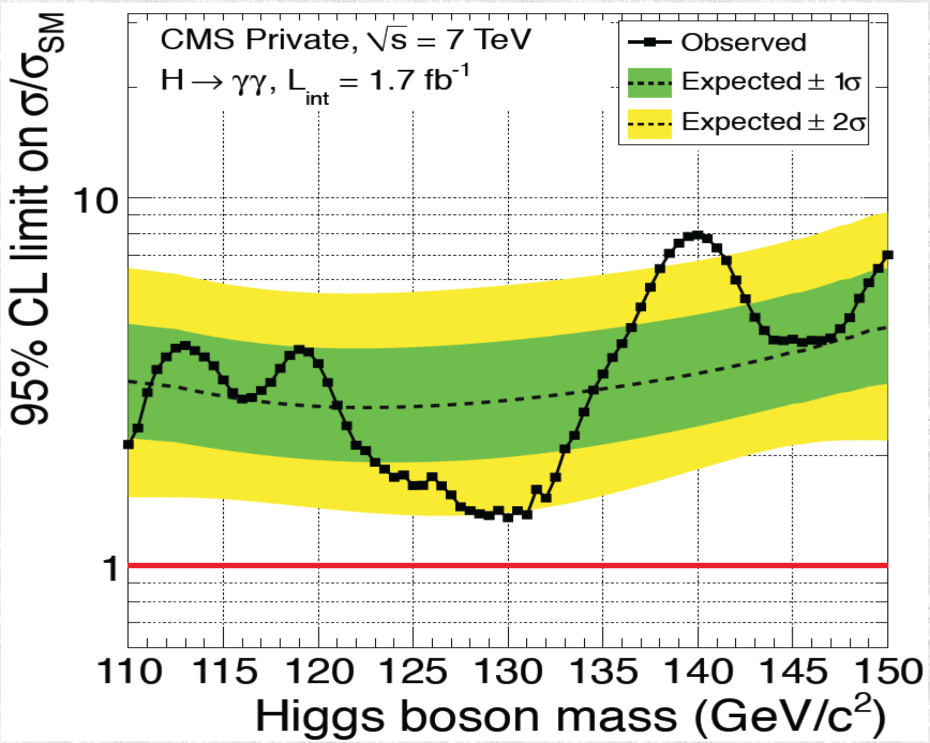




- Invariant mass spectra similar
  - Real $\gamma\gamma$ events dominant for both experiments
- Fit to this spectrum, looking for sharp peak
  - Both divide events into quality categories

H → γγ limits





- ATLAS (left) and CMS (right) sensitivity similar per fb^{-1}
  - CMS have used more luminosity
- Expected limits 2.5-4 x SM strength
  - Observed fluctuates down to1.5

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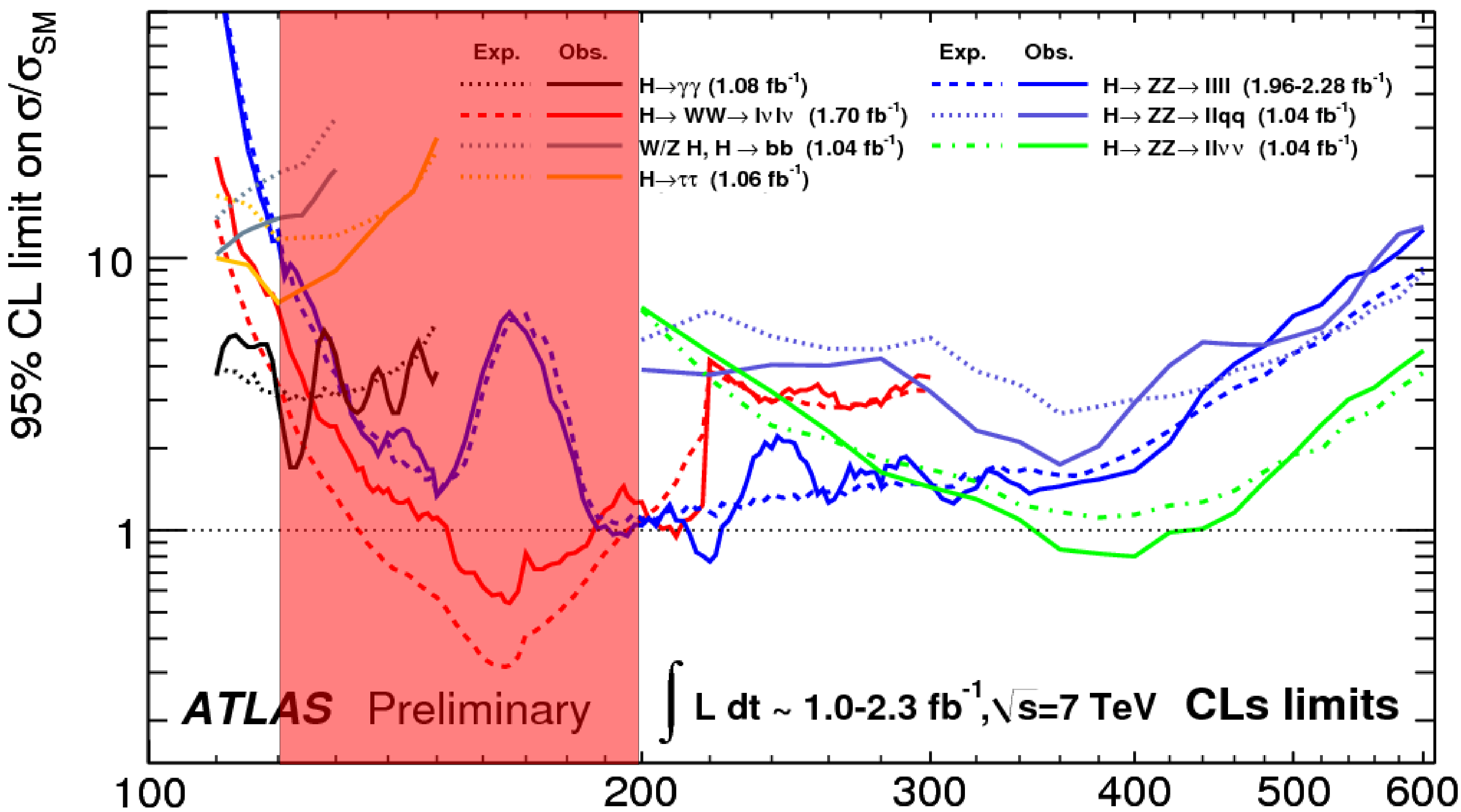
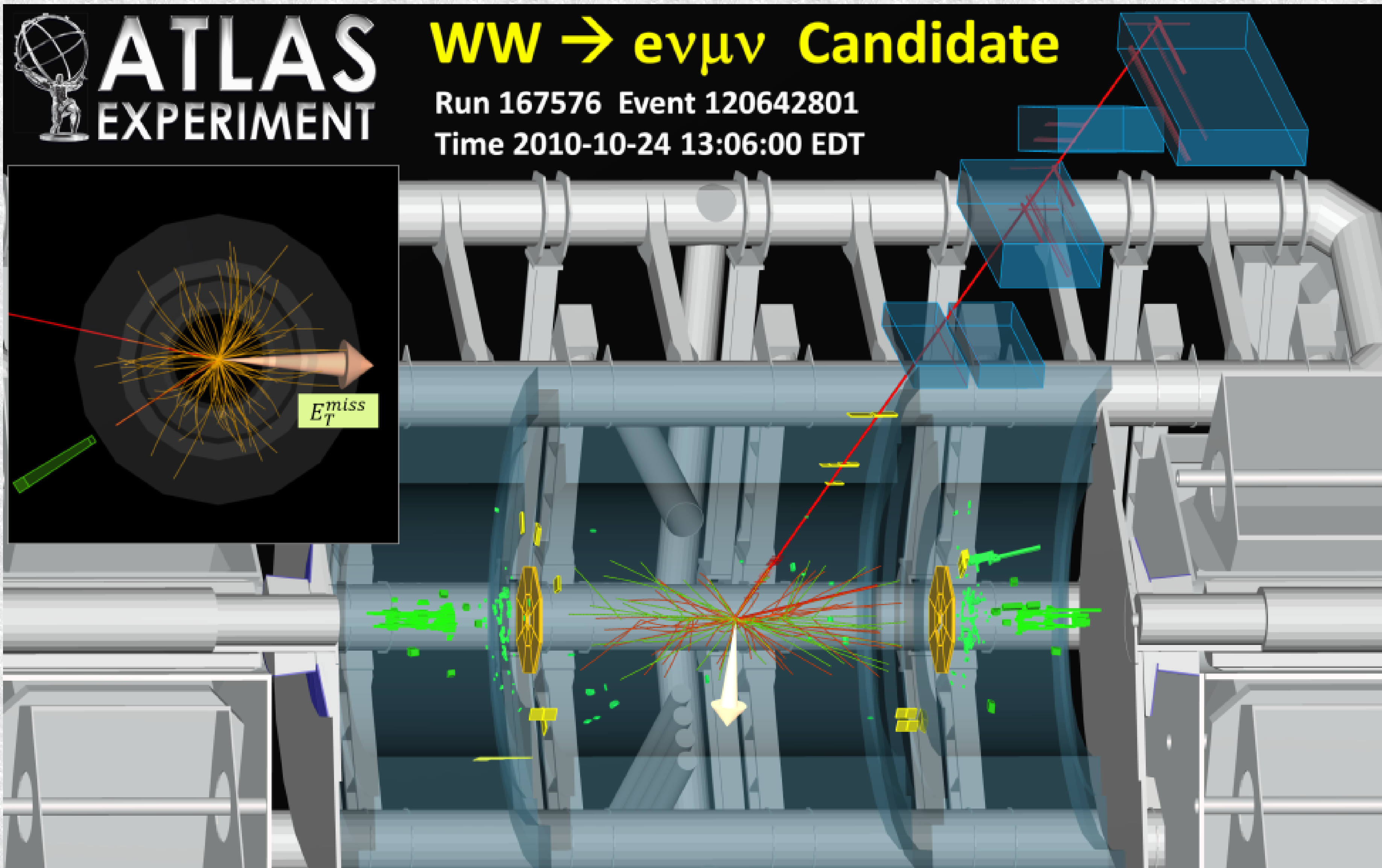
Intermediate searches



WW → lυlυ region (Plus ZZ → llll)

$H \to WW \to l\nu l\nu$

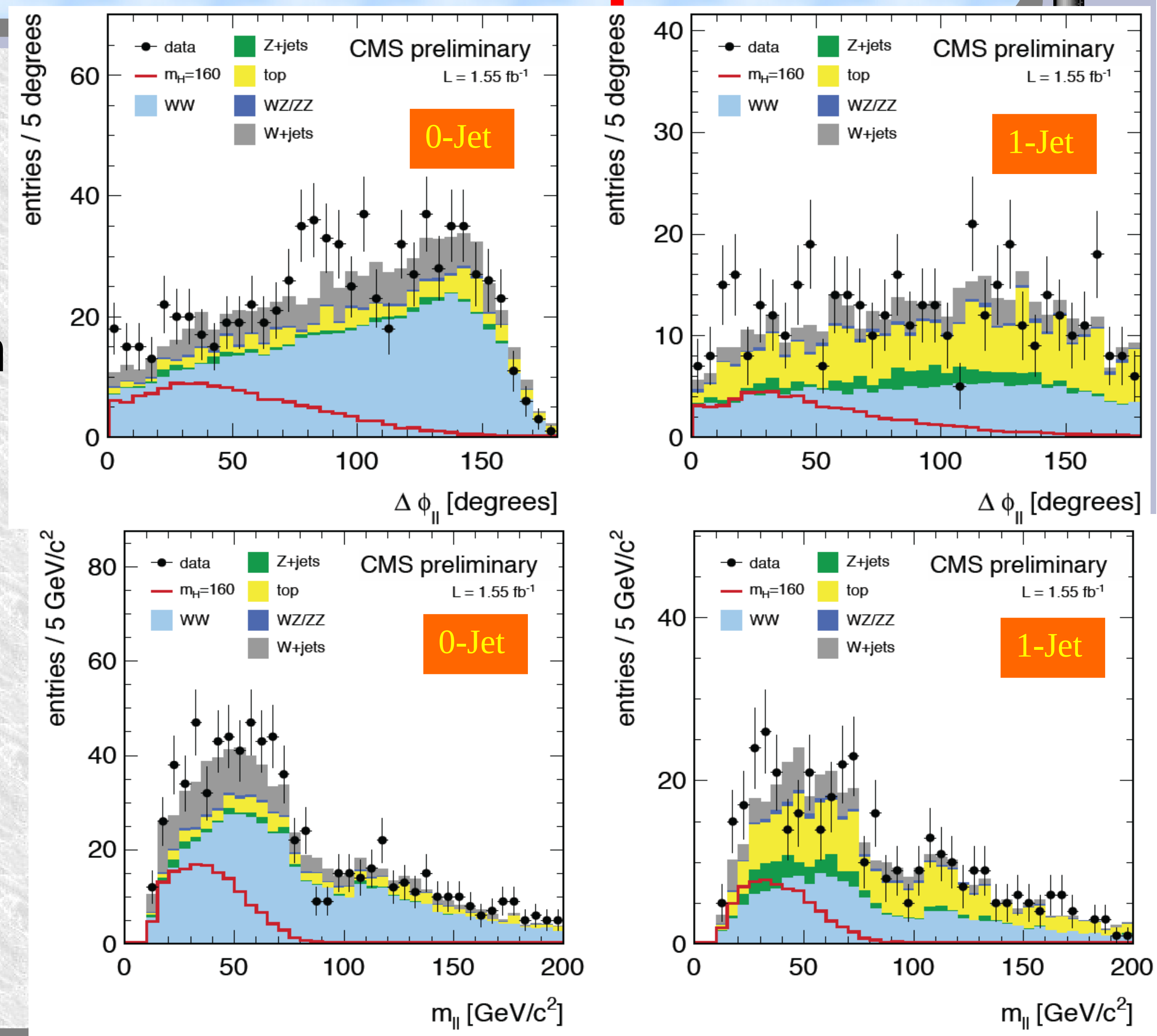


WW selection

- WW $\rightarrow l\nu l\nu$ many nice features
  - High branching ratio
  - Dilepton give clear separation from multijet
  - Good trigger
  - Missing energy makes events more distnctive
- But.....
  - Large non-resonant WW background
  - 2 neutrinos means mass not fully reconstructable
  - How do we distinguish it?
- RAL theory dept. to the rescue!
  - M. Dittmar and H. Dreiner, Phys. Rev. D55 (1997) 167.
  - Spin 0 Higgs means Ws aligned, so leptons aligned

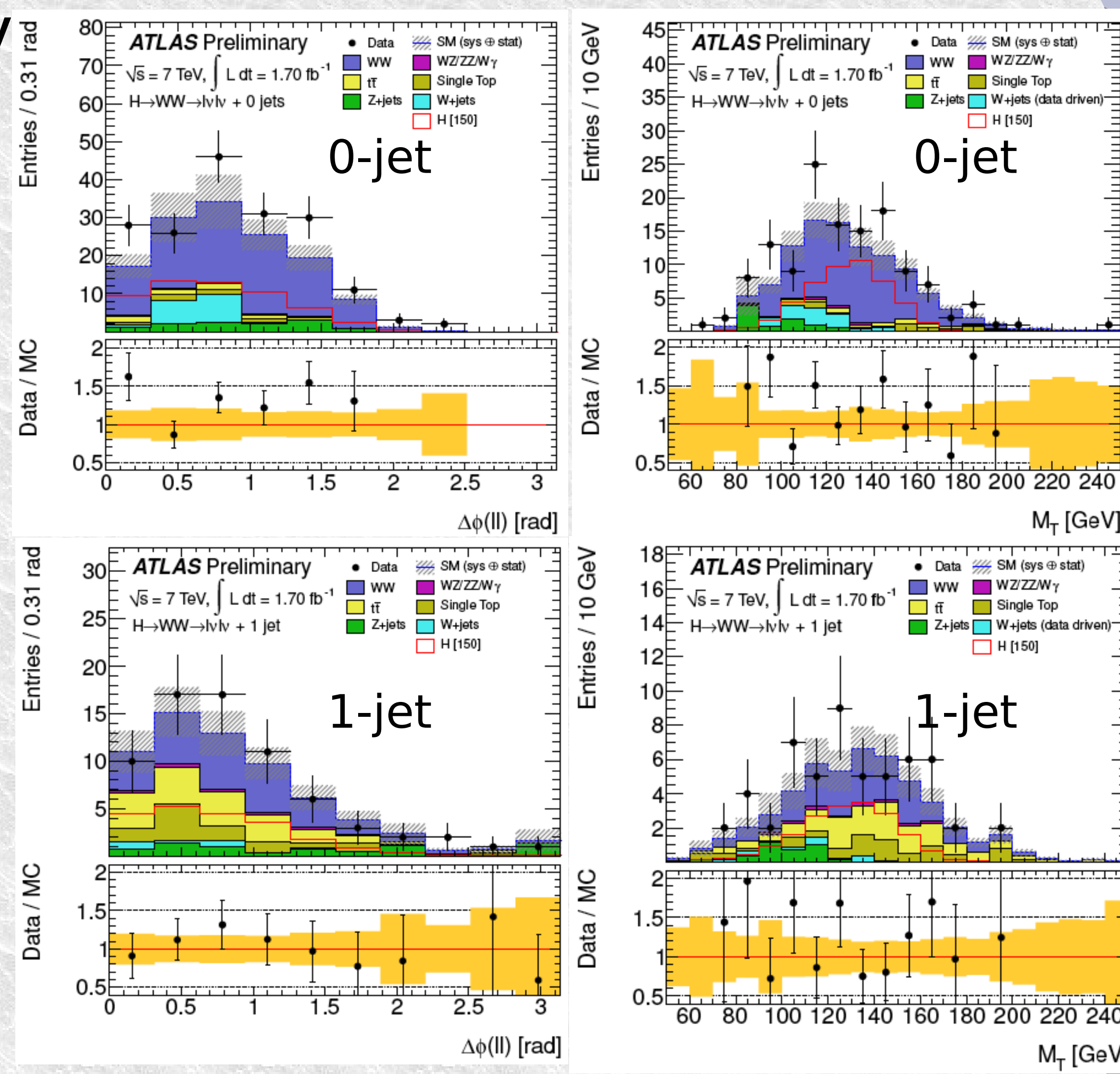
CMS WW sample

- The separation in $\Delta\Phi_{ll}$ is clear
  - Correlated to mass though
- Some excess in regions where signal expected
- Several backgrounds had to be understood in detail

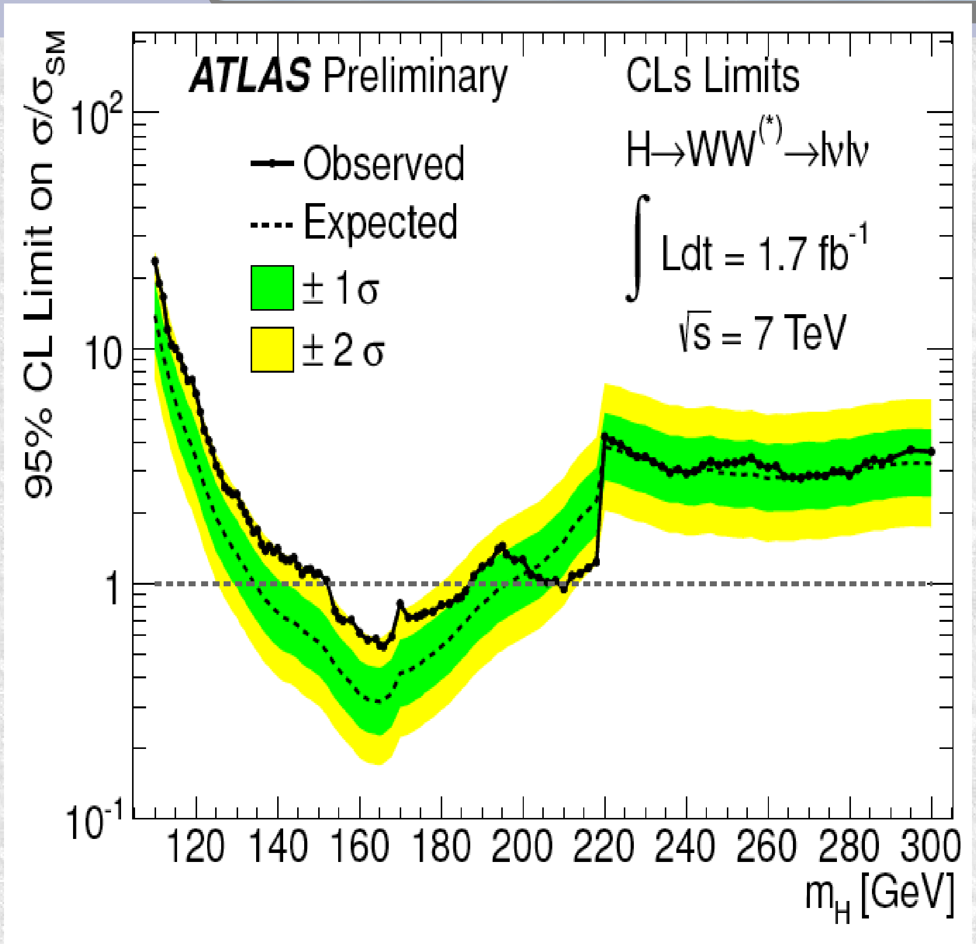


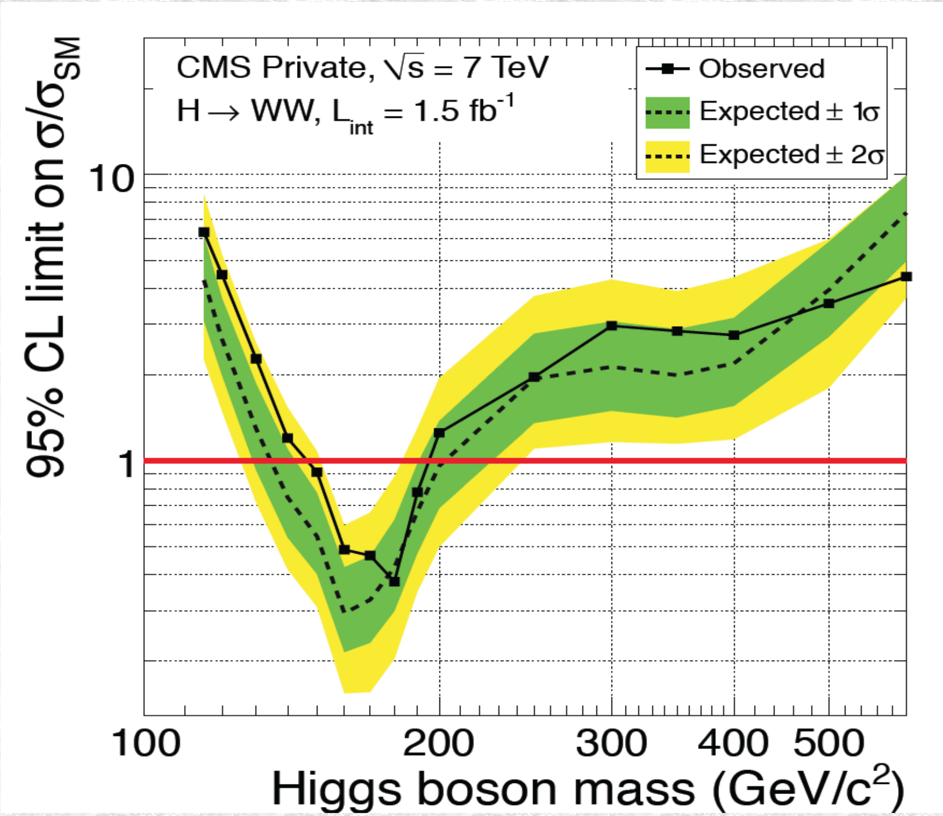
ATLAS WW m_T

- $1fb^{-1}$ (EPS) looked very exciting
- $1.7fb^{-1}$ excess much less pronounced
- 150GeV excluded...
  - But maybe a lower mass?



WW → lνlν





- ATLAS (left) exclude m_H 154-186 (exp: 135-196)
- CMS (right) exclude: m_H 147-194 (exp: 136-200)

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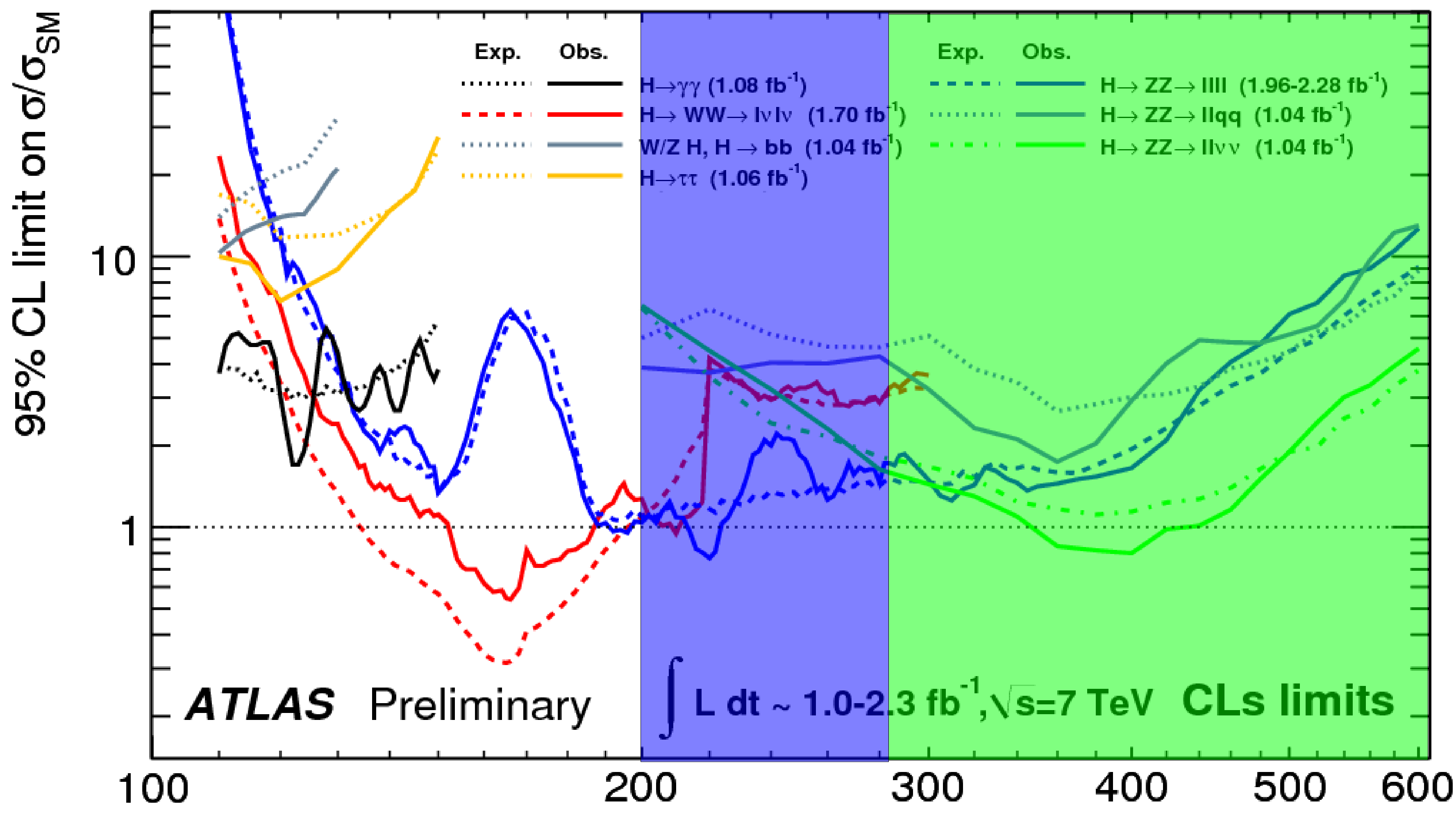
High mass searches



ZZ→llll, ZZ→llυυ (plus ZZ→llqq, WW→lυqq)

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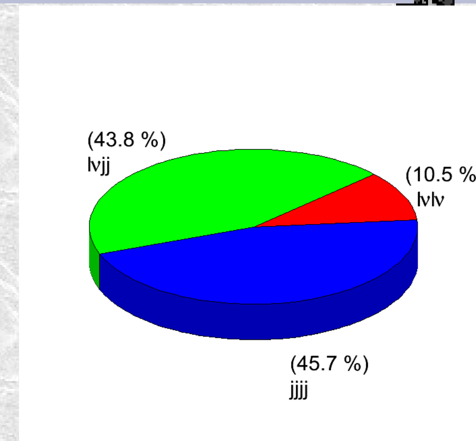
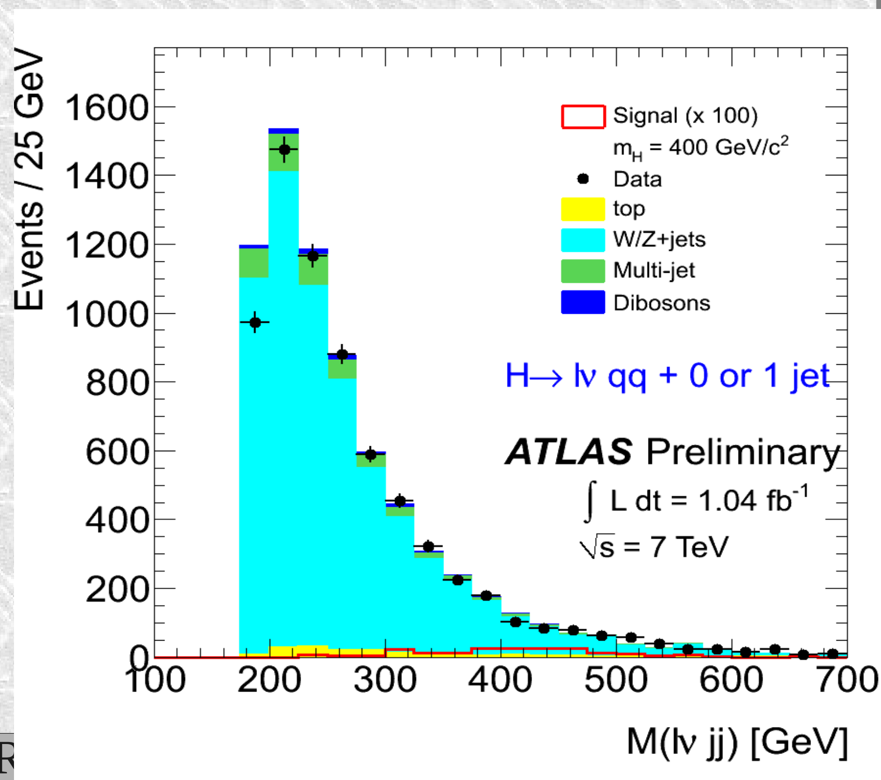
WW → lνqq

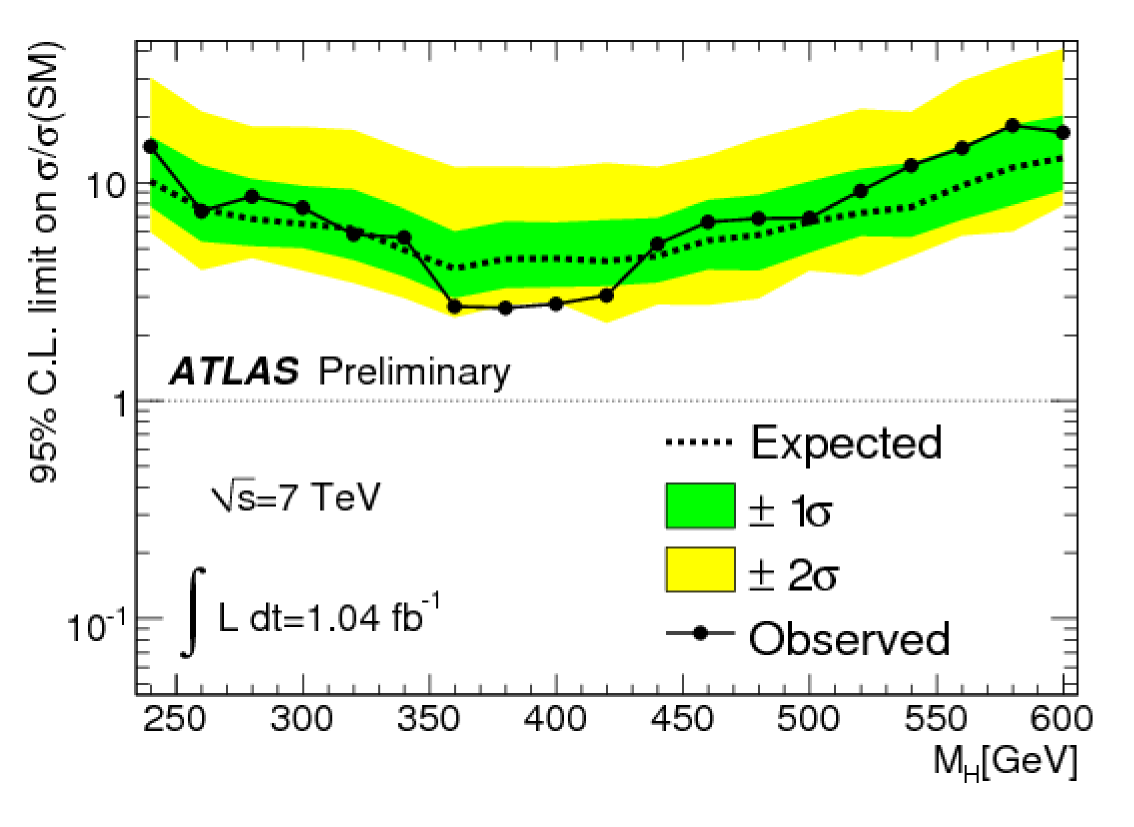
- Large Higgs BR for high mass
- Presence of charged lepton gives good QCD rejection
- But, like in $t\bar{t}$, semileptonic mode allows mass reconstruction
- Suffers from LARGE background from W+jets
  - But smooth background
  - Signal is a bump
  - Analysis is relatively straightforward



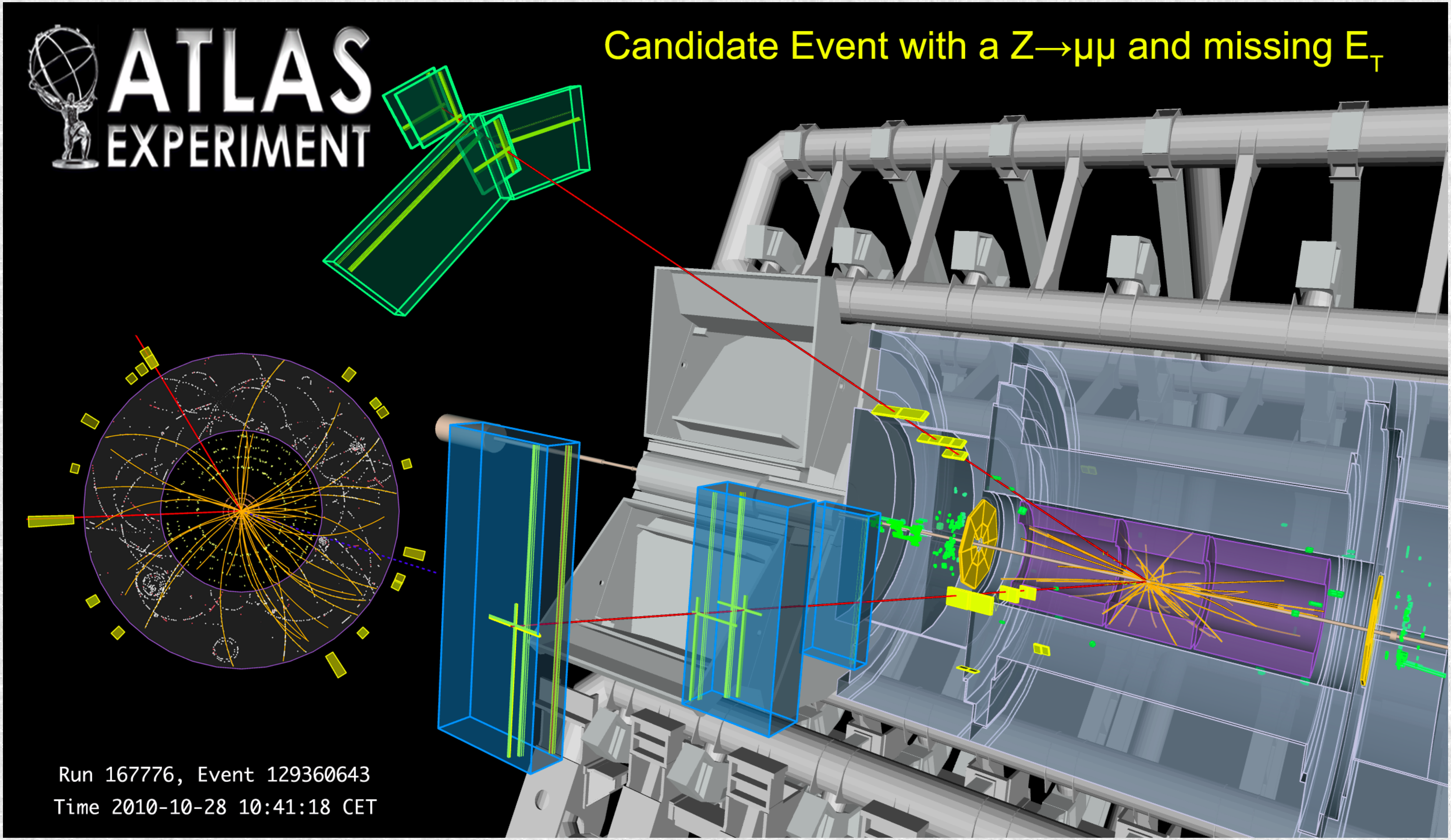


WW → lνqq

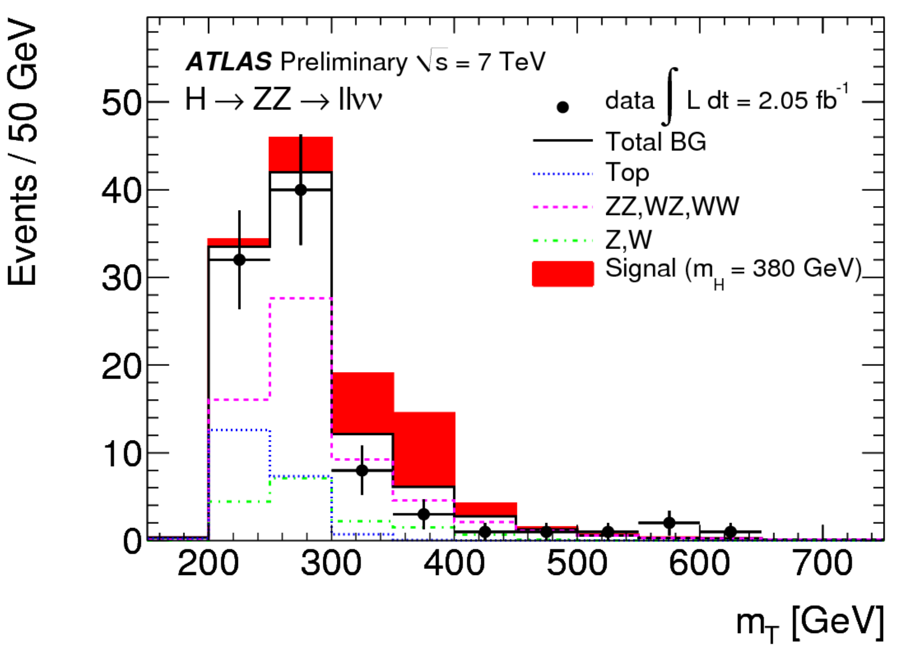
- Sensitive to five to ten times SM cross-section
- Limits 'lucky' around 400GeV
  - Exclude 2.5xSM
- No significant excess anywhere

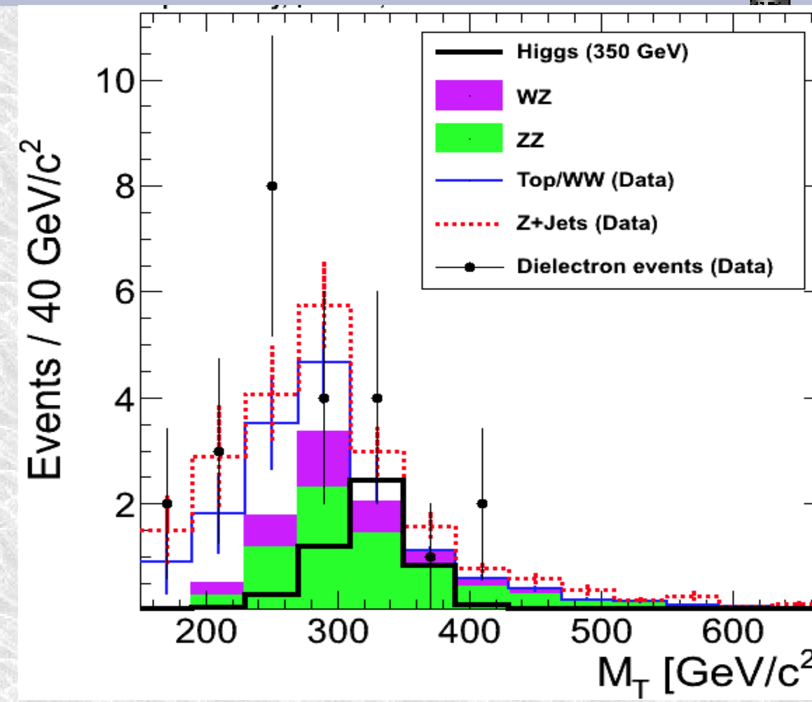


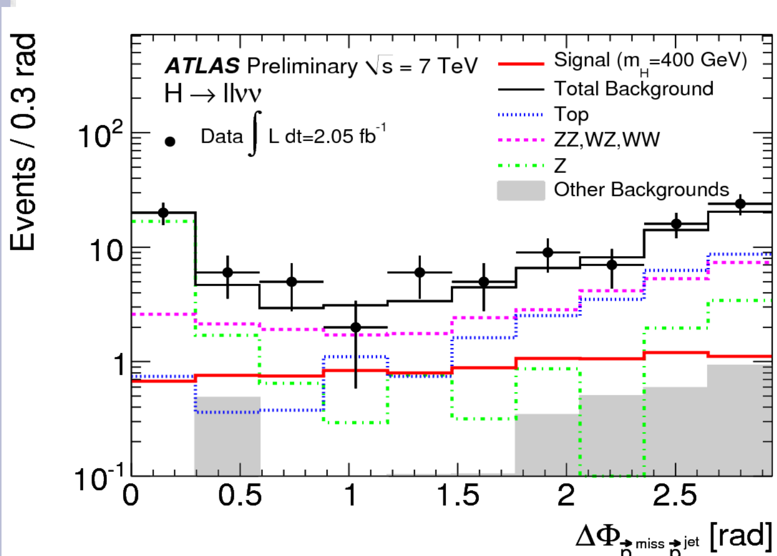
The H to llνν search



$ZZ \rightarrow ll\nu\nu$







- ATLAS (left) and CMS (right)
- Harder E_T^{miss} and $\delta\varphi$ cuts at high mass
- Each of these excludes the mass shown

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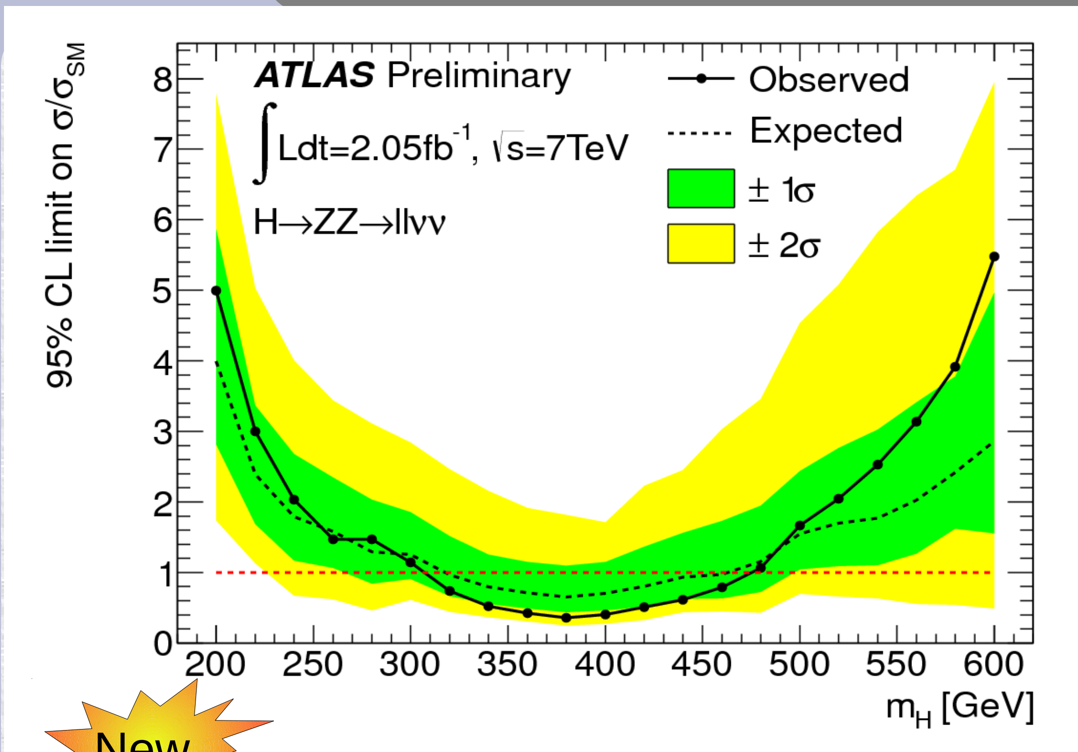
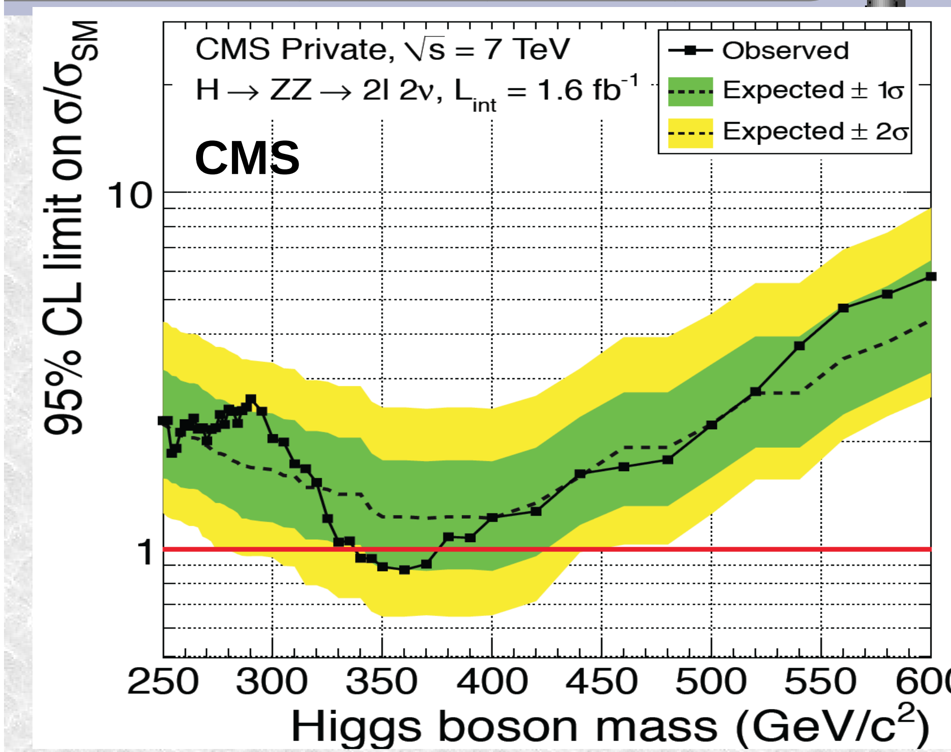
ZZ → llνν



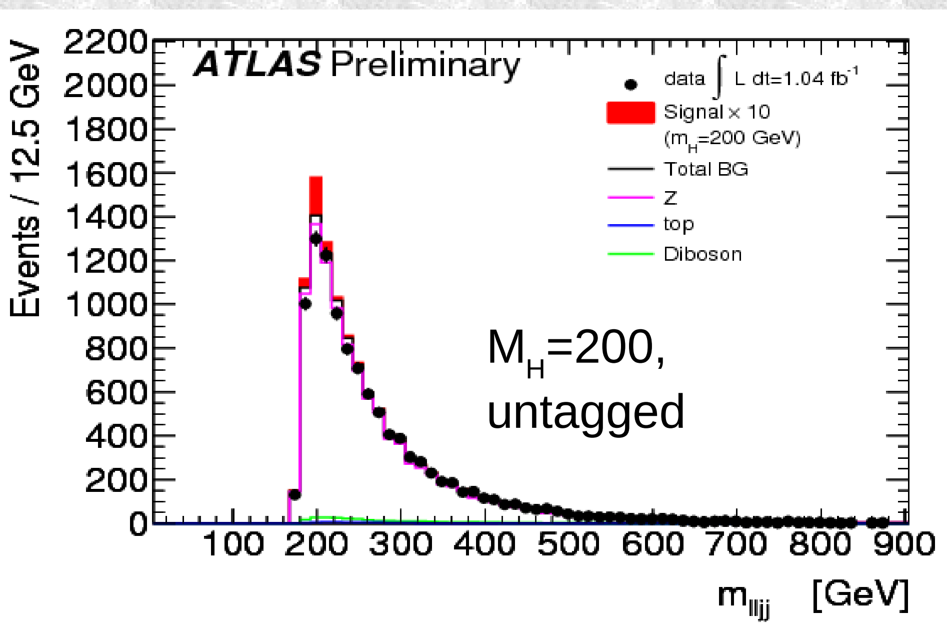


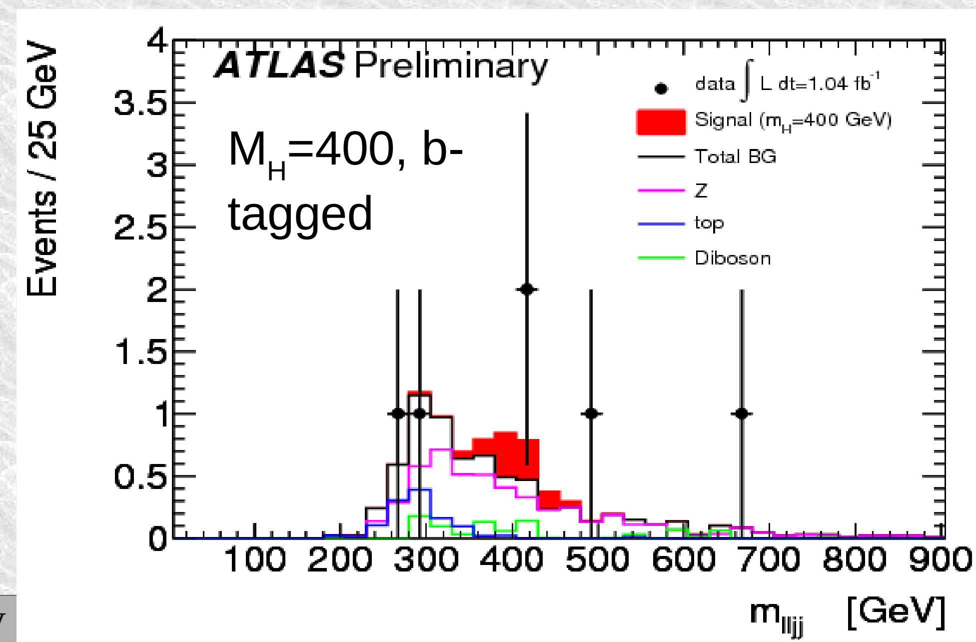
New

- ATLAS (left) and CMS (right)
  - ATLAS search excludes 150GeV wide region
  - This result is not in ATLAS combination ($1fb^{-1}$ only)
- Both searches best sensitivity ~1xSM
  - Both got lucky

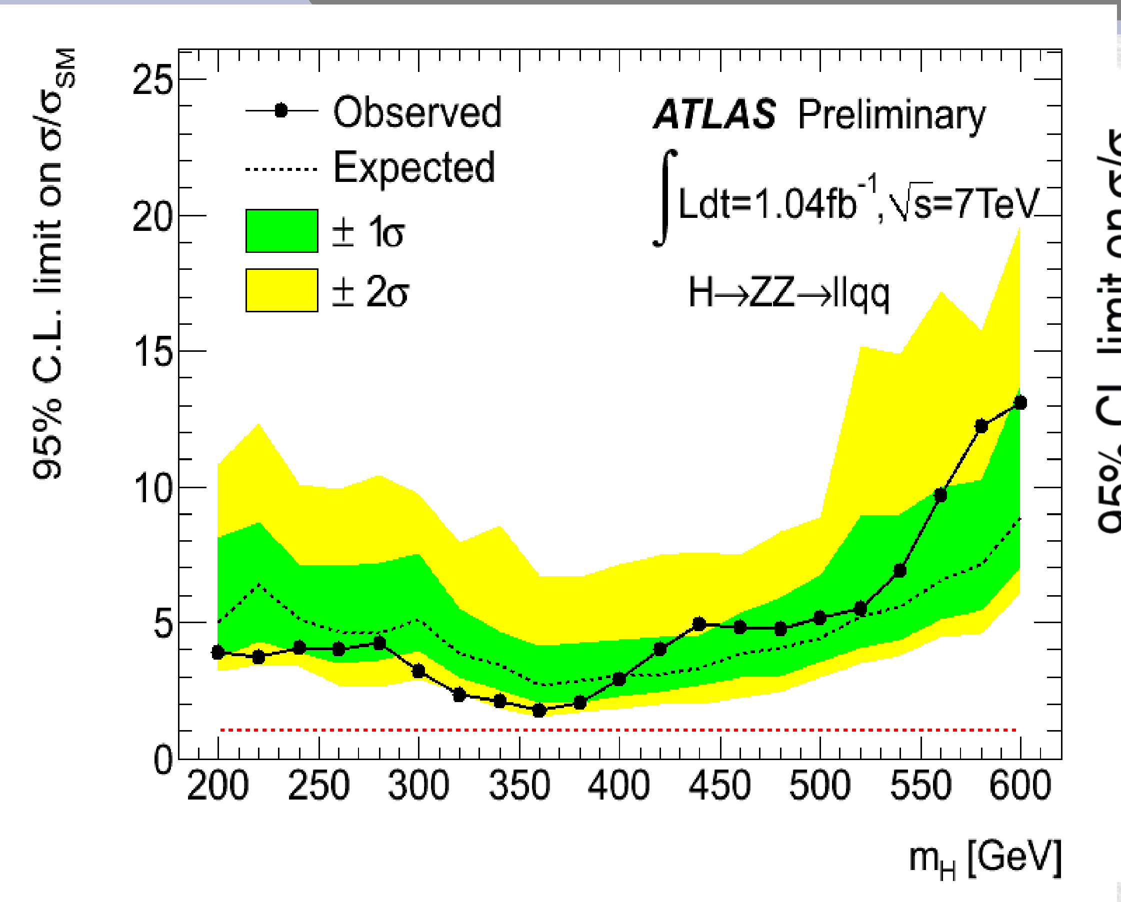
ZZ→llqq

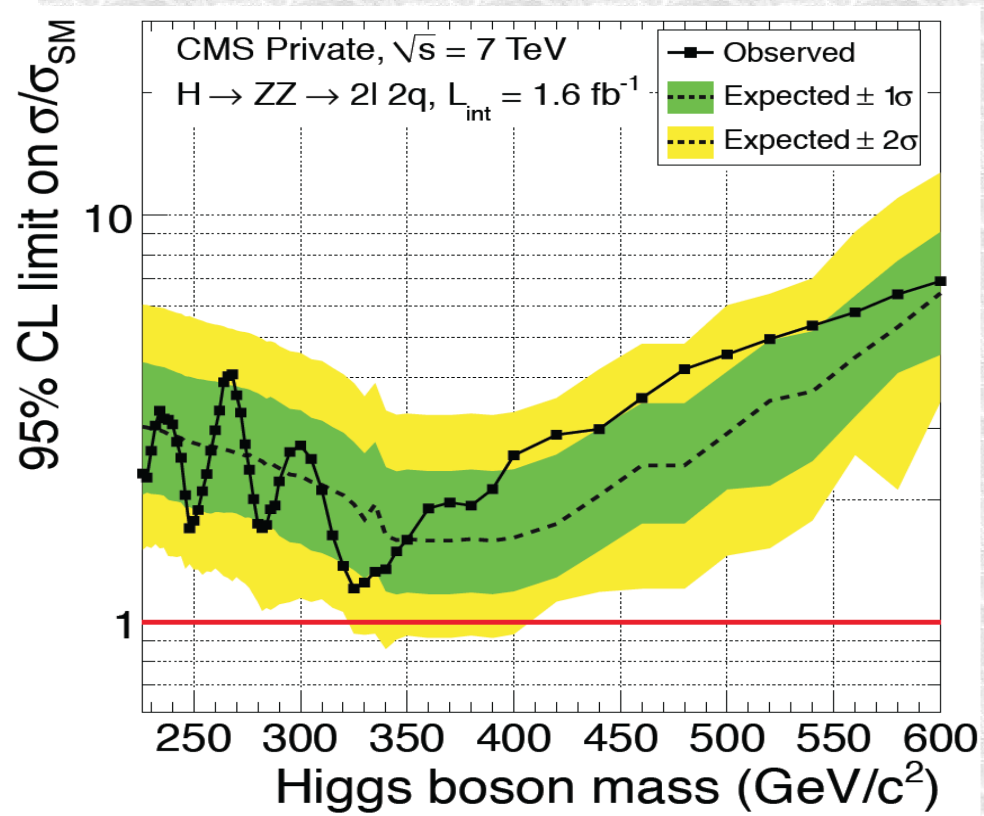
- Highest rate for a ZZ process
  - Good for Higgs boson mass over 200GeV
- Use 2 or 3 subchannels:
  - Z to light quarks (inclusively)
    - CMS use quark/gluon tagging to enhance signal
  - Z to b quarks
- CMS use decay angles explicitly





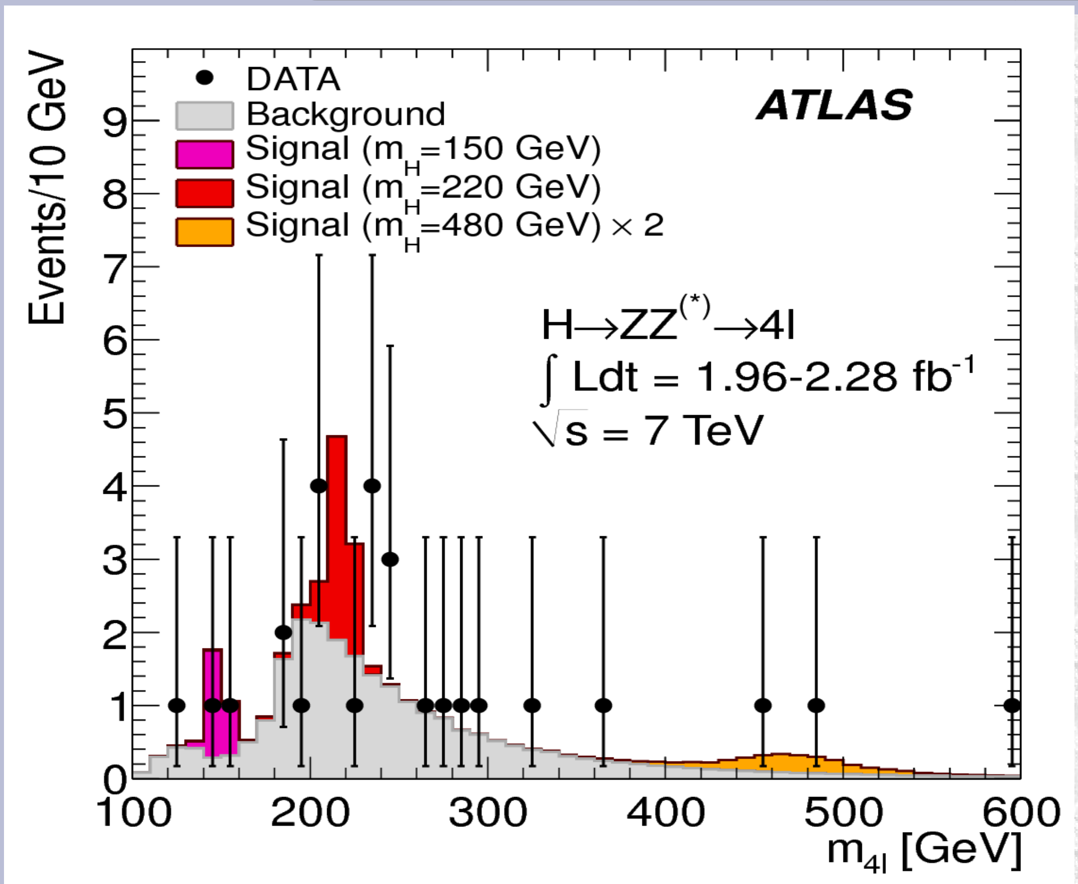
llqq

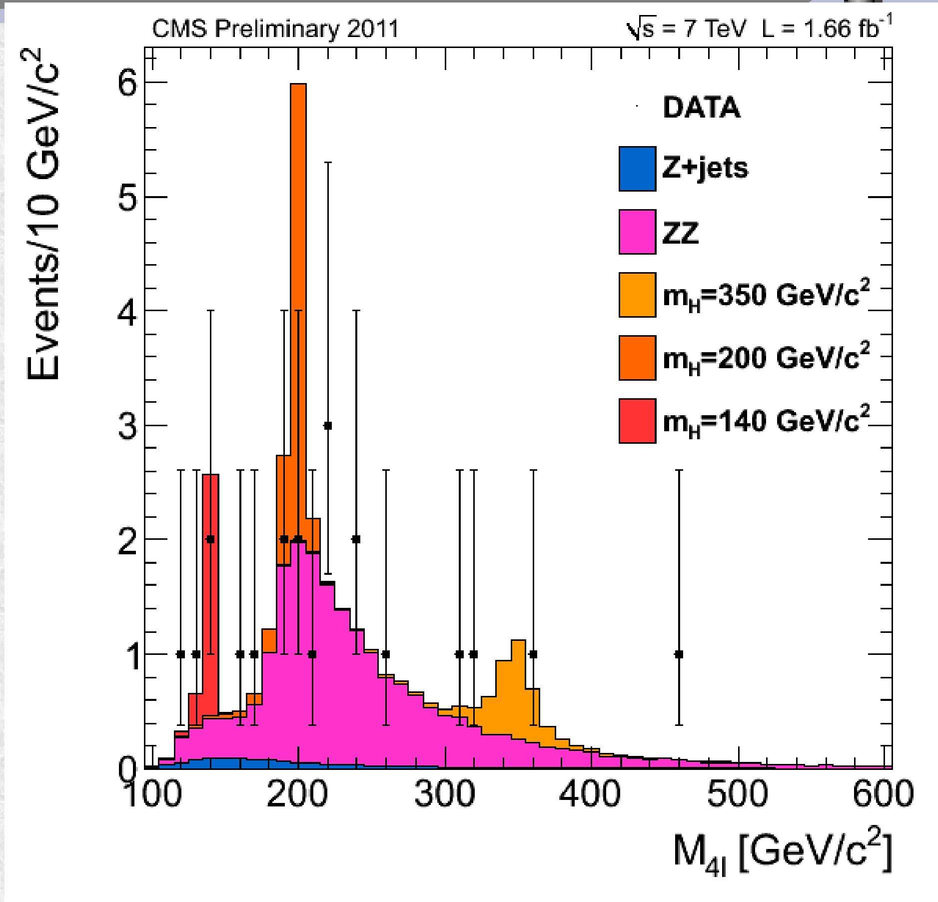




- CMS sensitivity 2xSM, ATLAS 3xSM at 350-400
- Fluctuations never up to 2σ

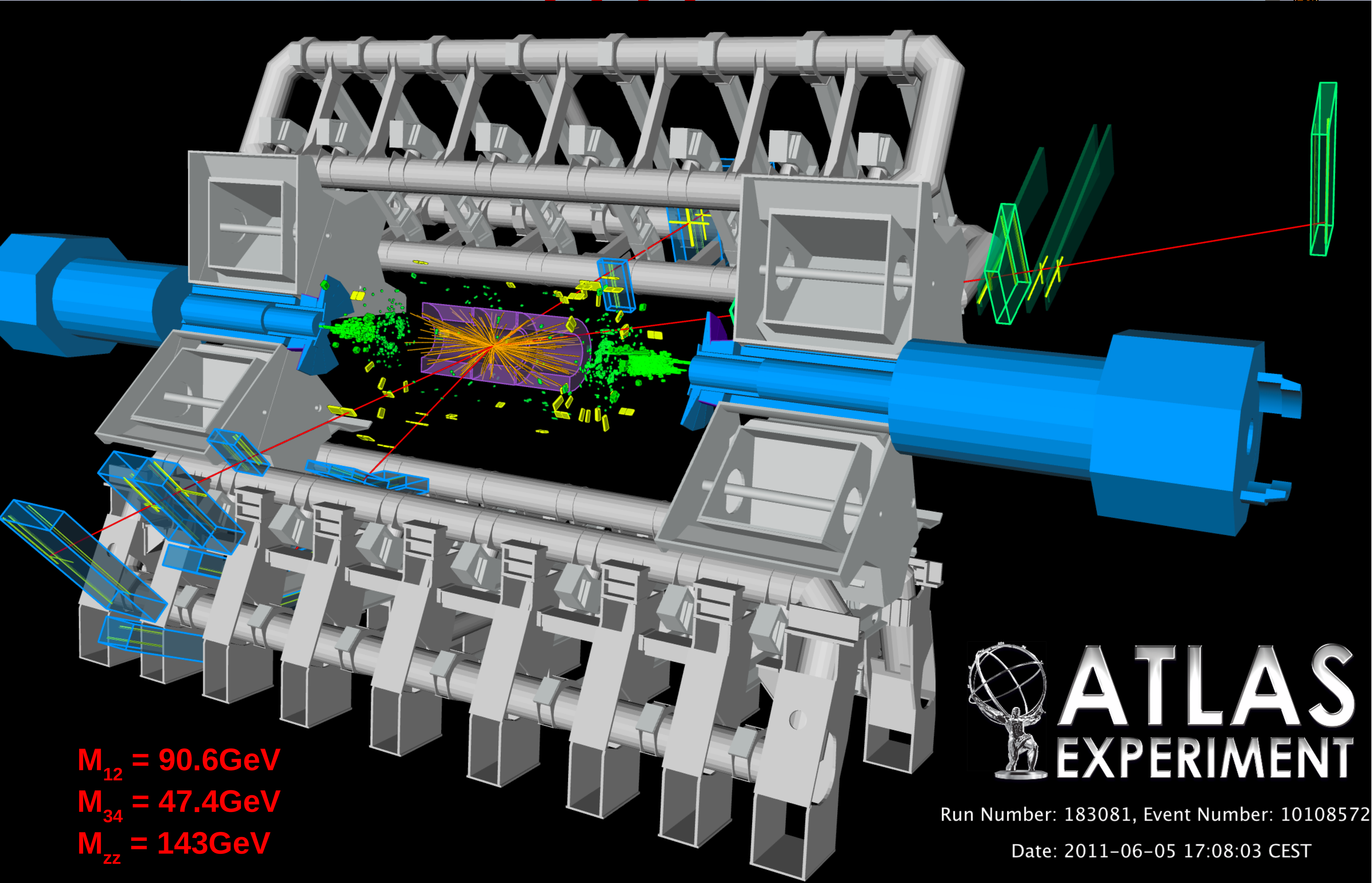
$ZZ^{(*)} \rightarrow llll$





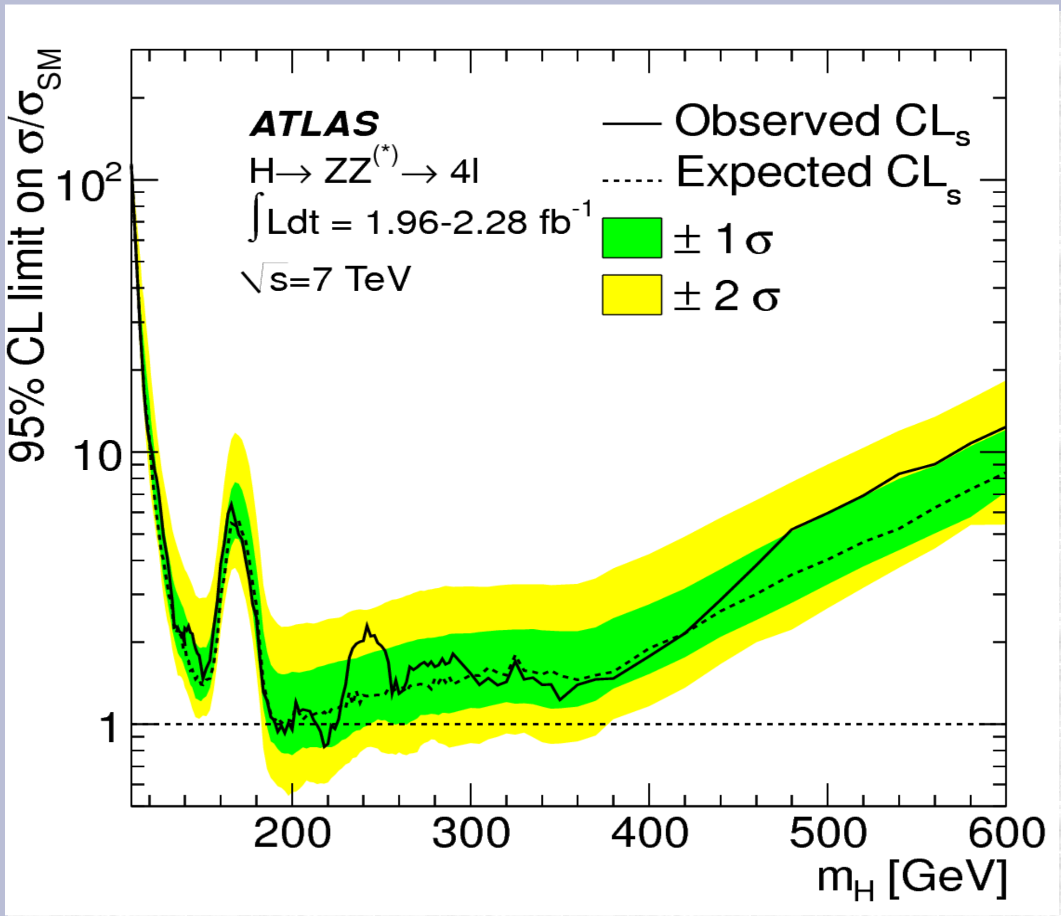
- Both experiments have local excesses
- But all 6 candidates below 150GeV were in first fb^{-1}

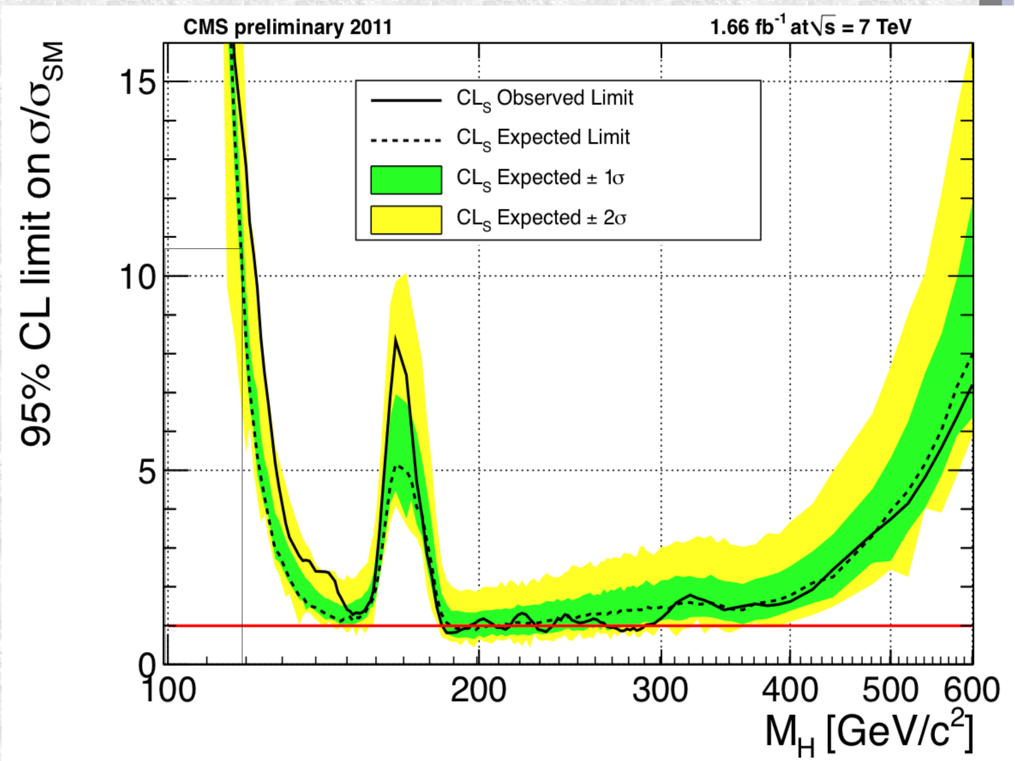
$ZZ^* \rightarrow \mu\mu\mu\mu$ candidate



M_{12} = 90.6GeV
M_{34} = 47.4GeV
M_{zz} = 143GeV

$ZZ^{(*)} \rightarrow llll$





- Both experiments have small exclusions
- Soon this channel will have large ones
  - Some small differences in detailed comparison

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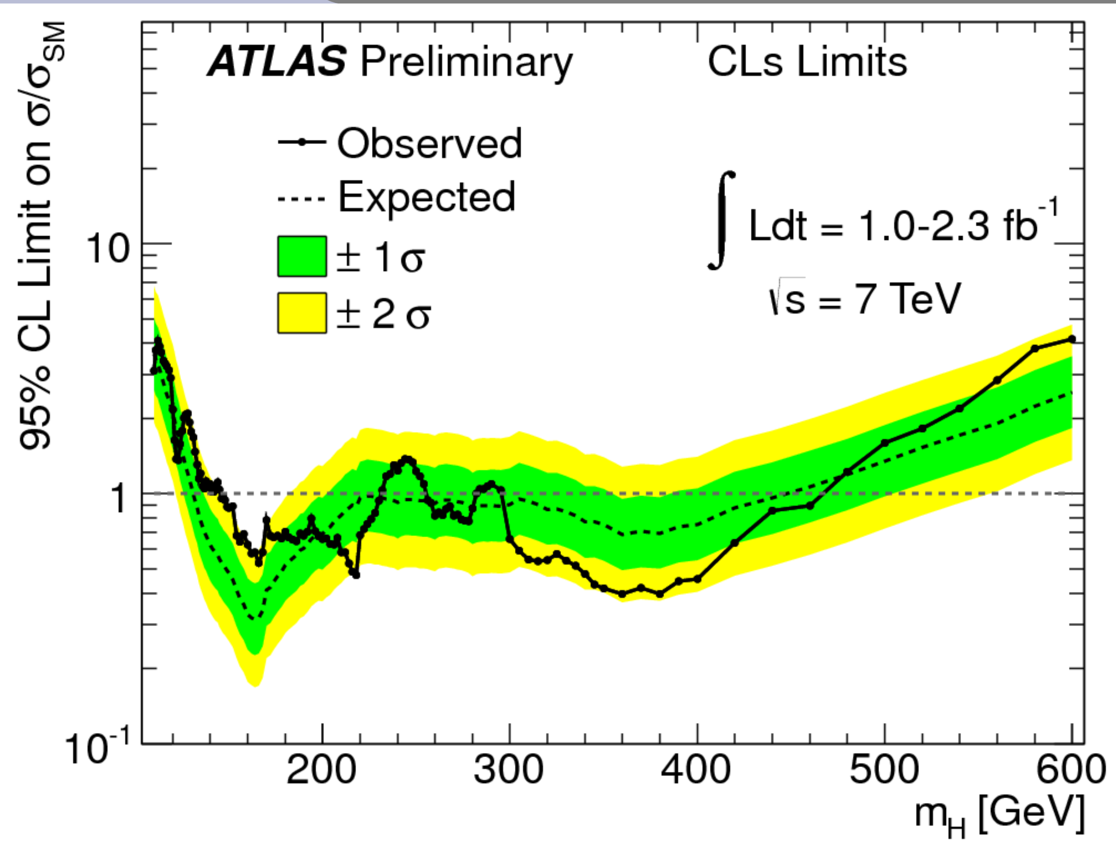
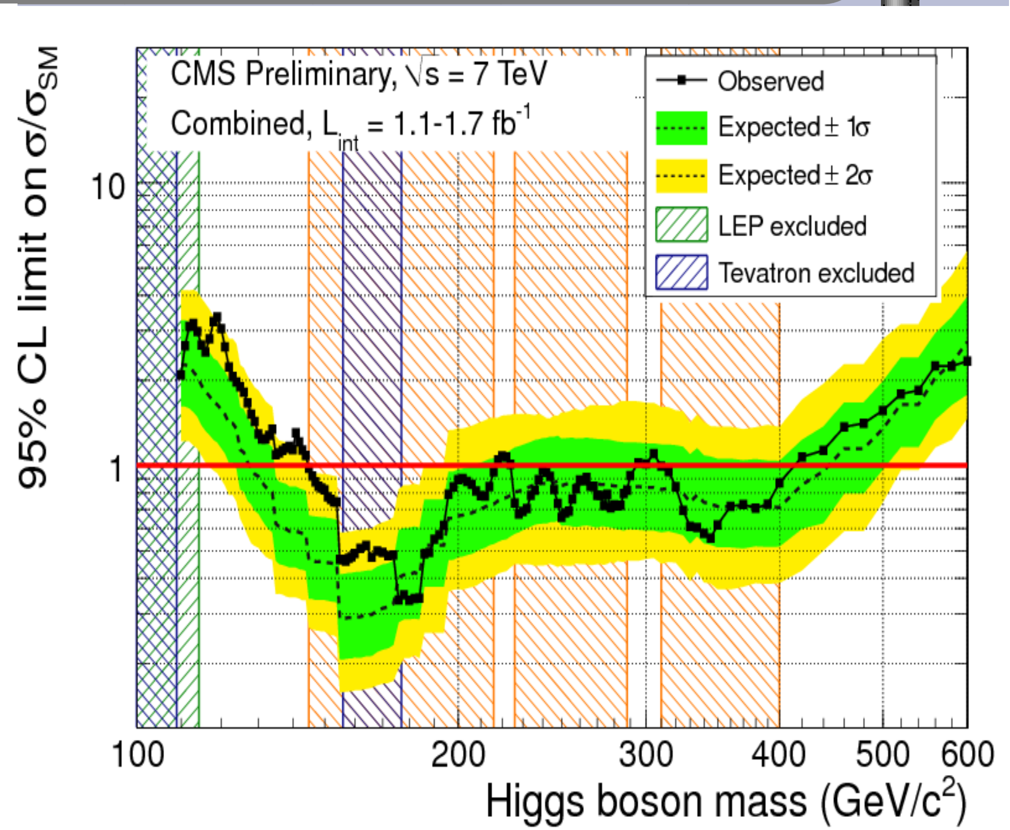
ATLAS / CMS combinations

- The SM Higgs is a very well-defined thing
  - Tell us the mass and we know the rest
- So we know what to expect in all these channels
  - We put them together for optimal sensitivity.
- Needs precise understanding of the theory
  - LHC cross-section working group did a great job
  - We have an agreed set of rates to work with
    - There is .... discussion about systematics
- So what do the combinations look like?

The Combined Results

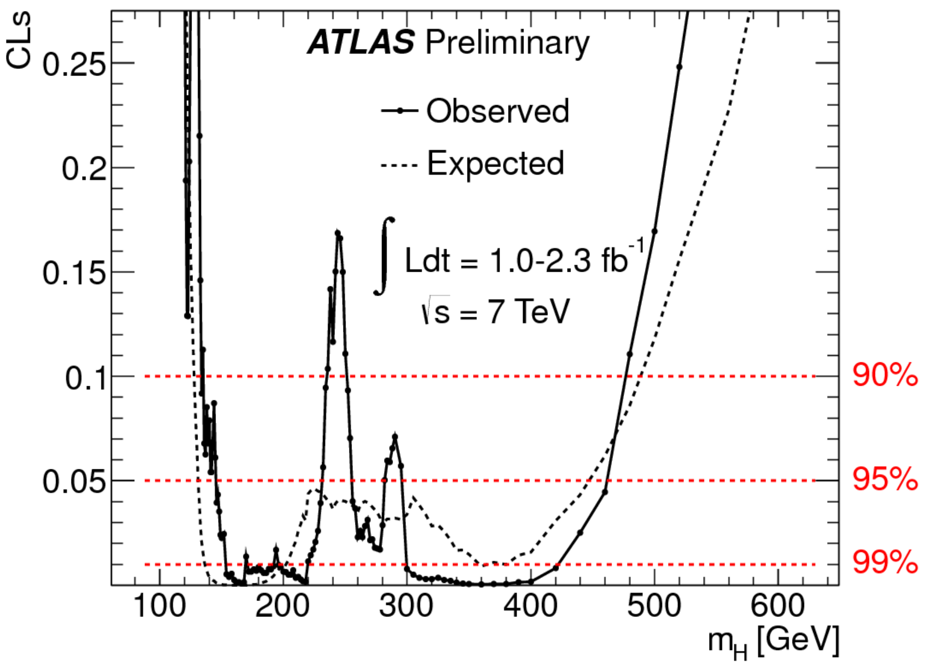
The Standard Model

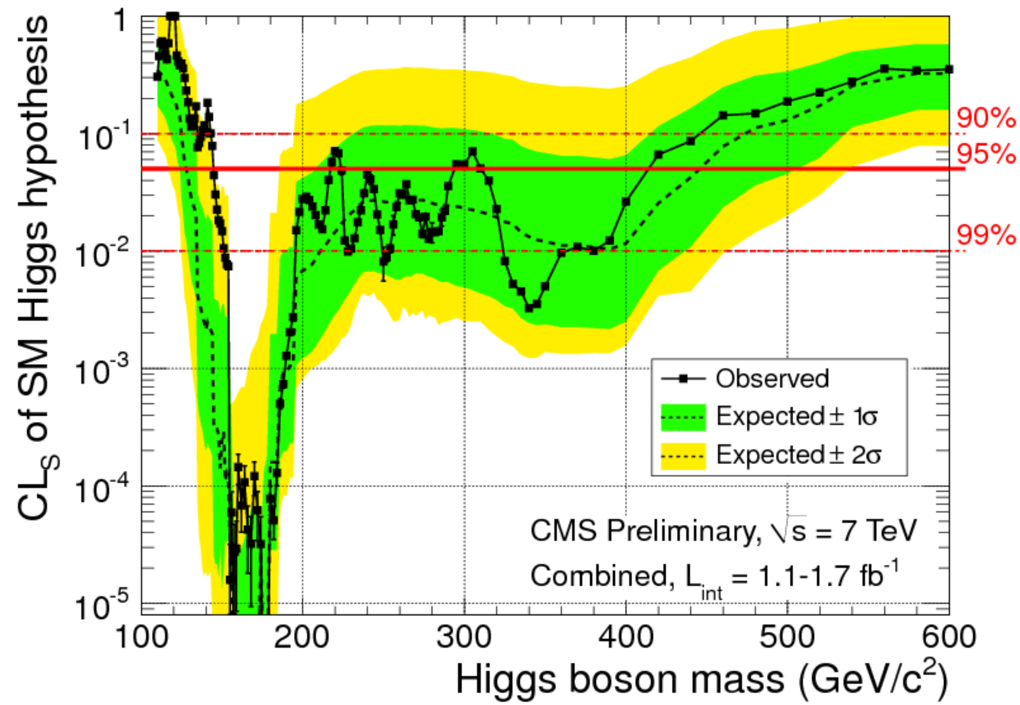




- ATLAS and CMS exclude 145 to 460GeV together
  - Islands (e.g. 300) not formally excluded, but are close
- Focus on 114-145GeV

How well excluded?





- All m_H 140-500 disfavoured by both experiments
  - Need a combination to know how strongly – HCP meeting
  - But the 'islands' seem to be in trouble
- Much is excluded at 99% or better
  - Soon, I guess, this will apply to a very wide region

High mass Higgs?

- Exclusion goes up to 460GeV
  - There is in fact an excess beyond this in ATLAS
- This could be where the Higgs boson lies
  - Somewhat easier to get to 600GeV than to 114GeV
  - Doable with $5fb^{-1}$, combining two experiments probably needed
- But theory is becoming tricky
  - Lineshape become badly predicted
  - Four-fermion interference is not properly treated
  - The electroweak fits of course raise problems

Low Mass

- The focus is now on the region below 145GeV
  - i.e. 114-145GeV
- The lower the mass the harder it is at LHC

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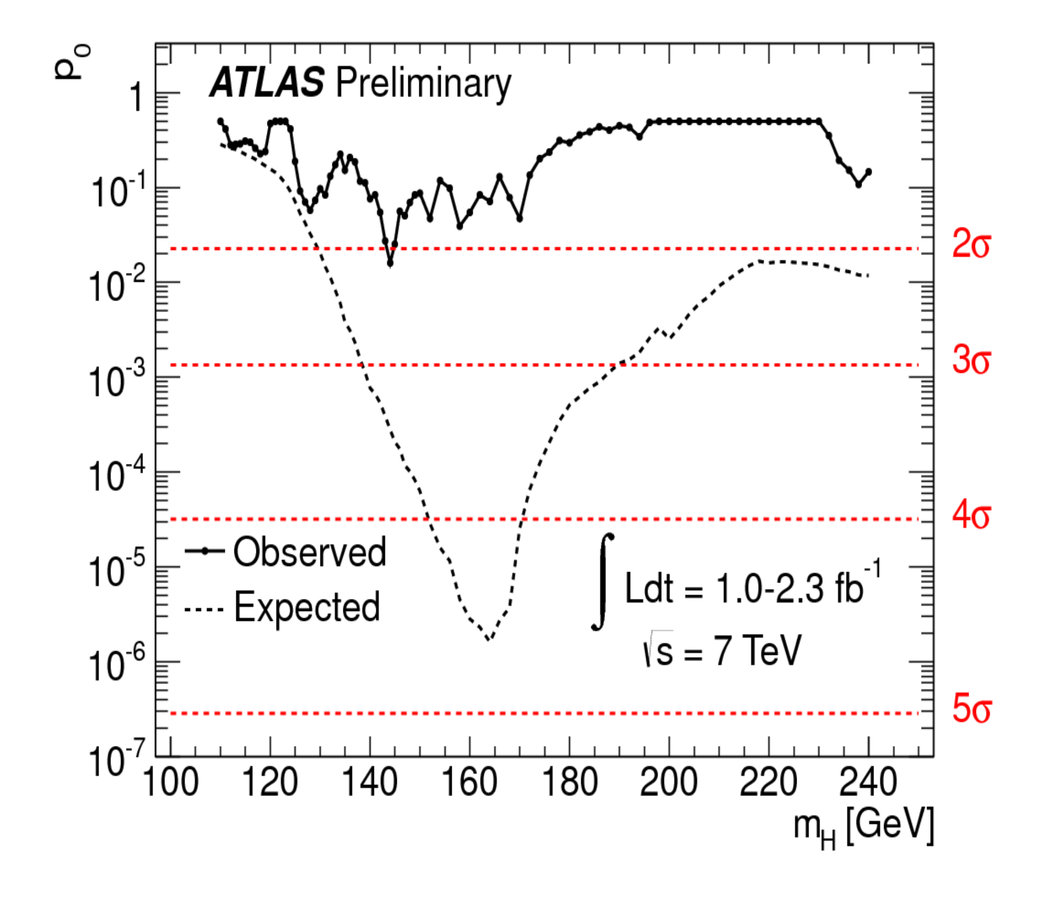
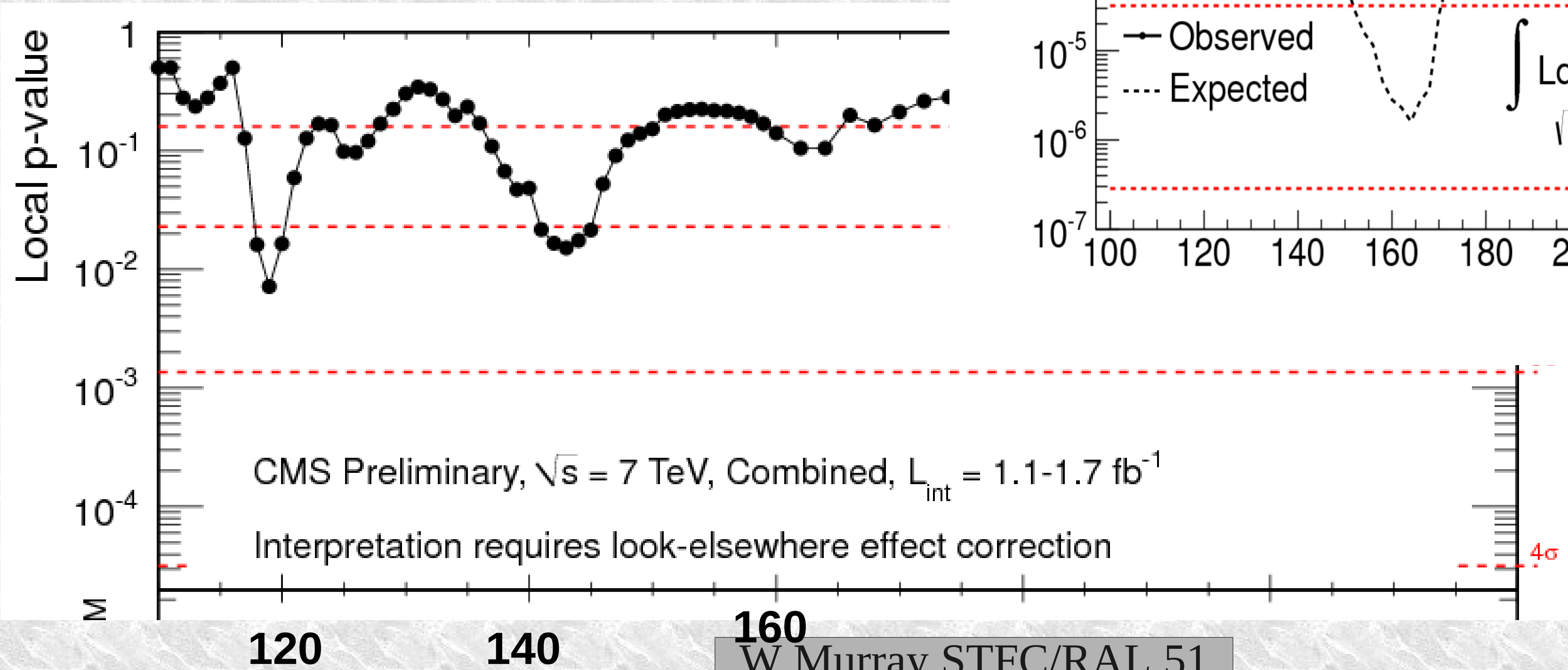
Where might it be?

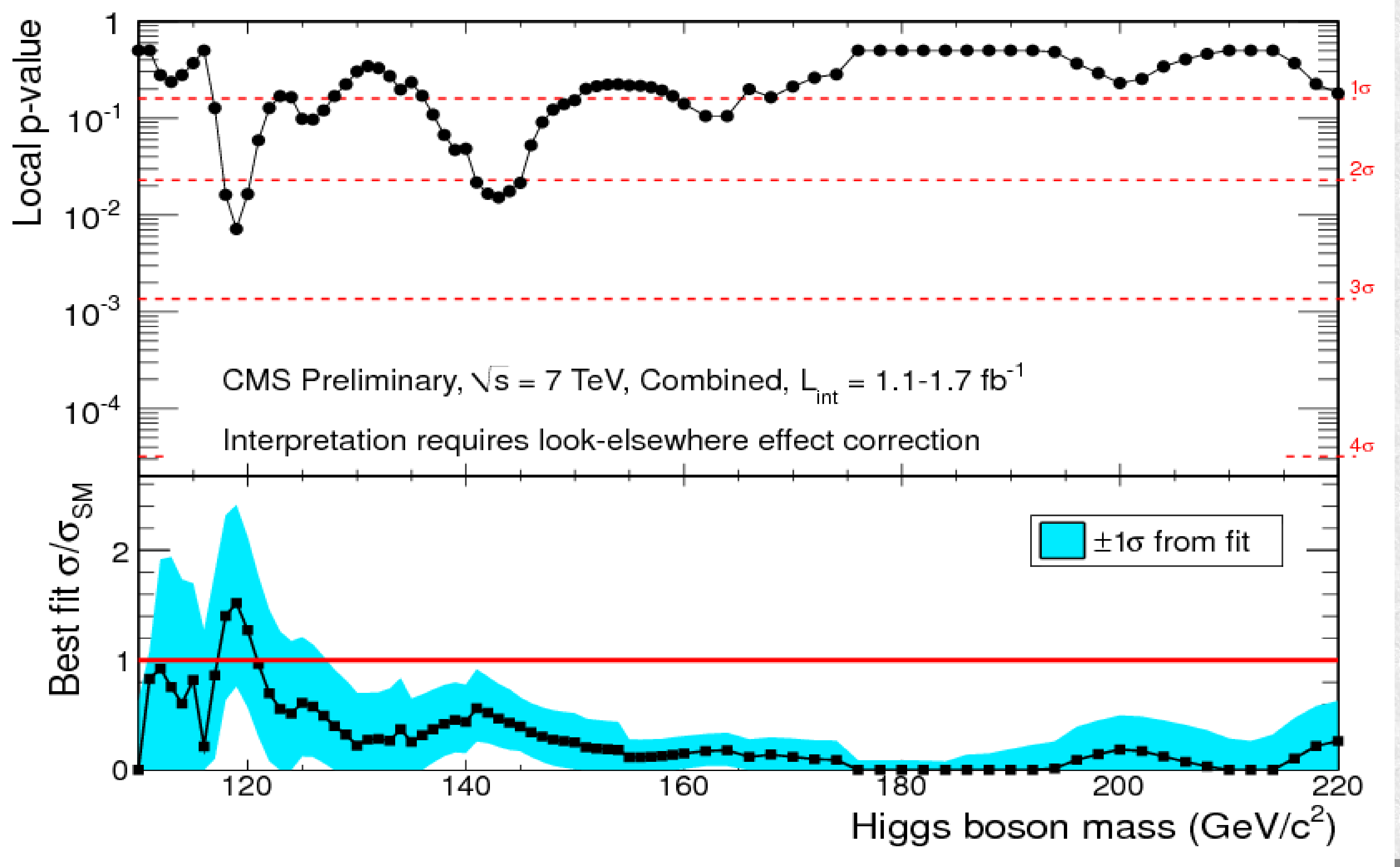
- Small excesses everywhere
  - 114 to 144 both ATLAS+CMS
- With more data any point might look interesting
  - But...





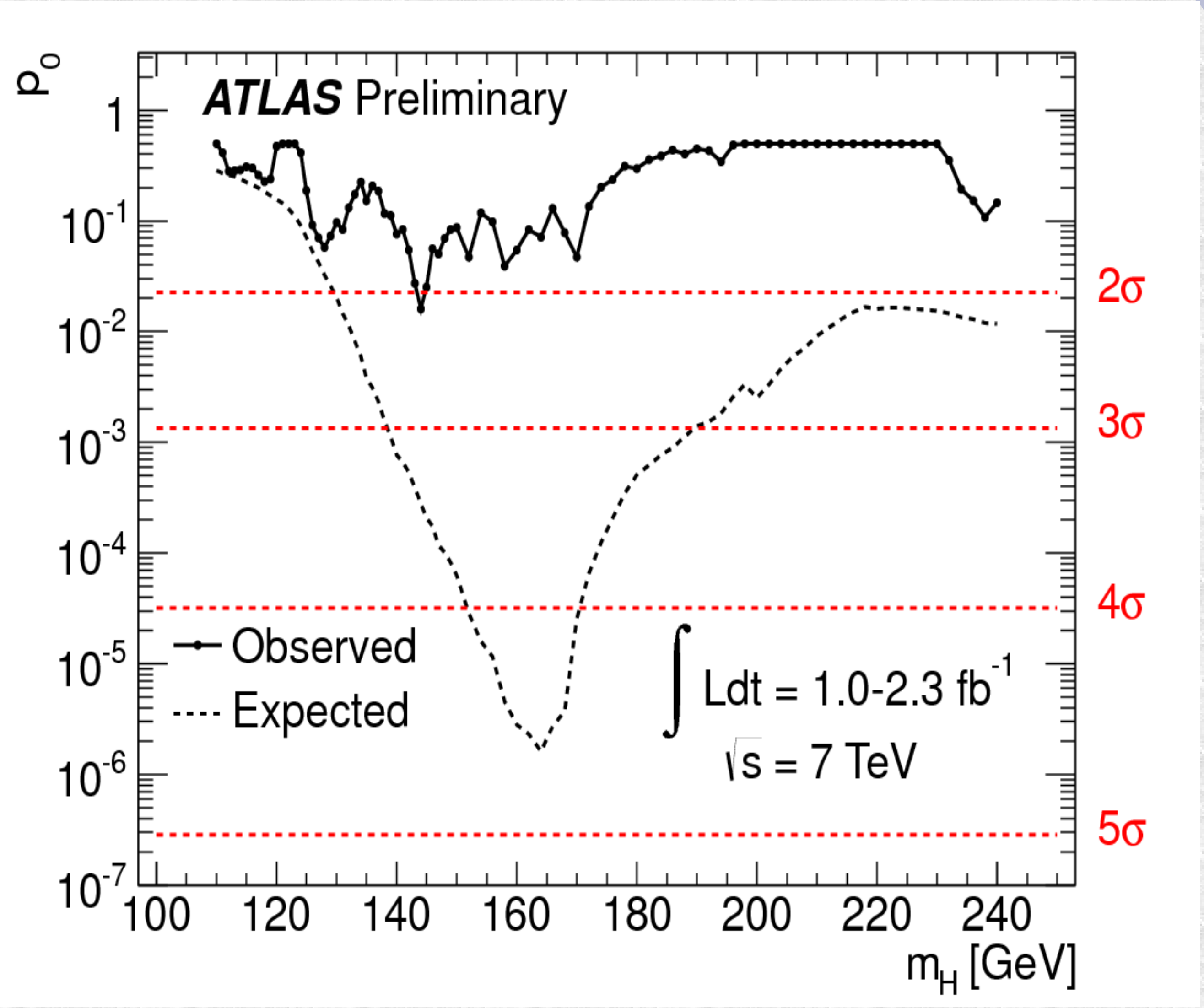
Where is Higgs hiding?

- CMS have significance below expected for m_H>125 ..



Where is Higgs hiding?

- ATLAS has a deficit c/f SM Higgs for almost all masses
- Not a lot, but 'unlucky'



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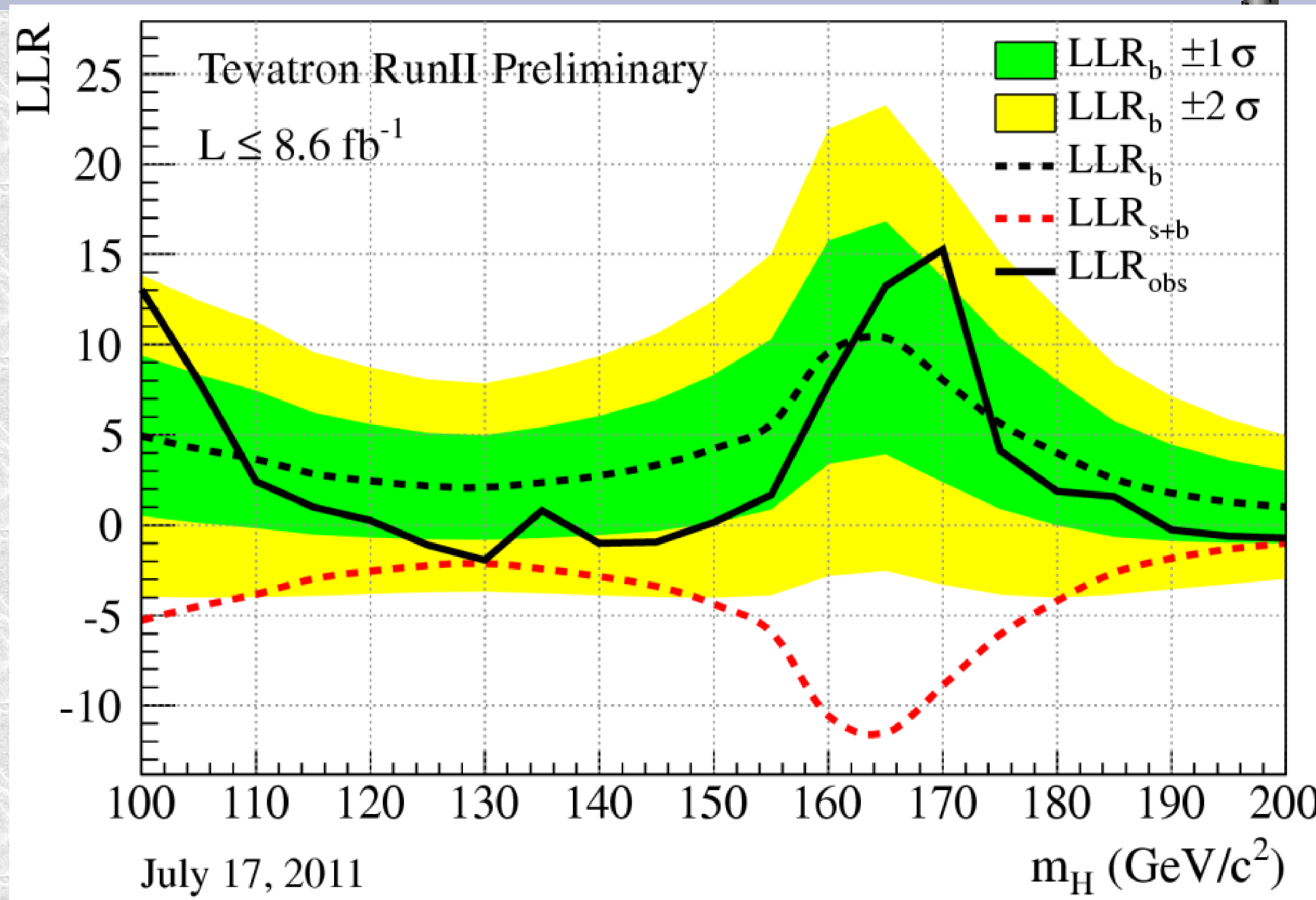
Where might it be?

- What about the Tevatron?
- Also less signal than would be expected at all masses

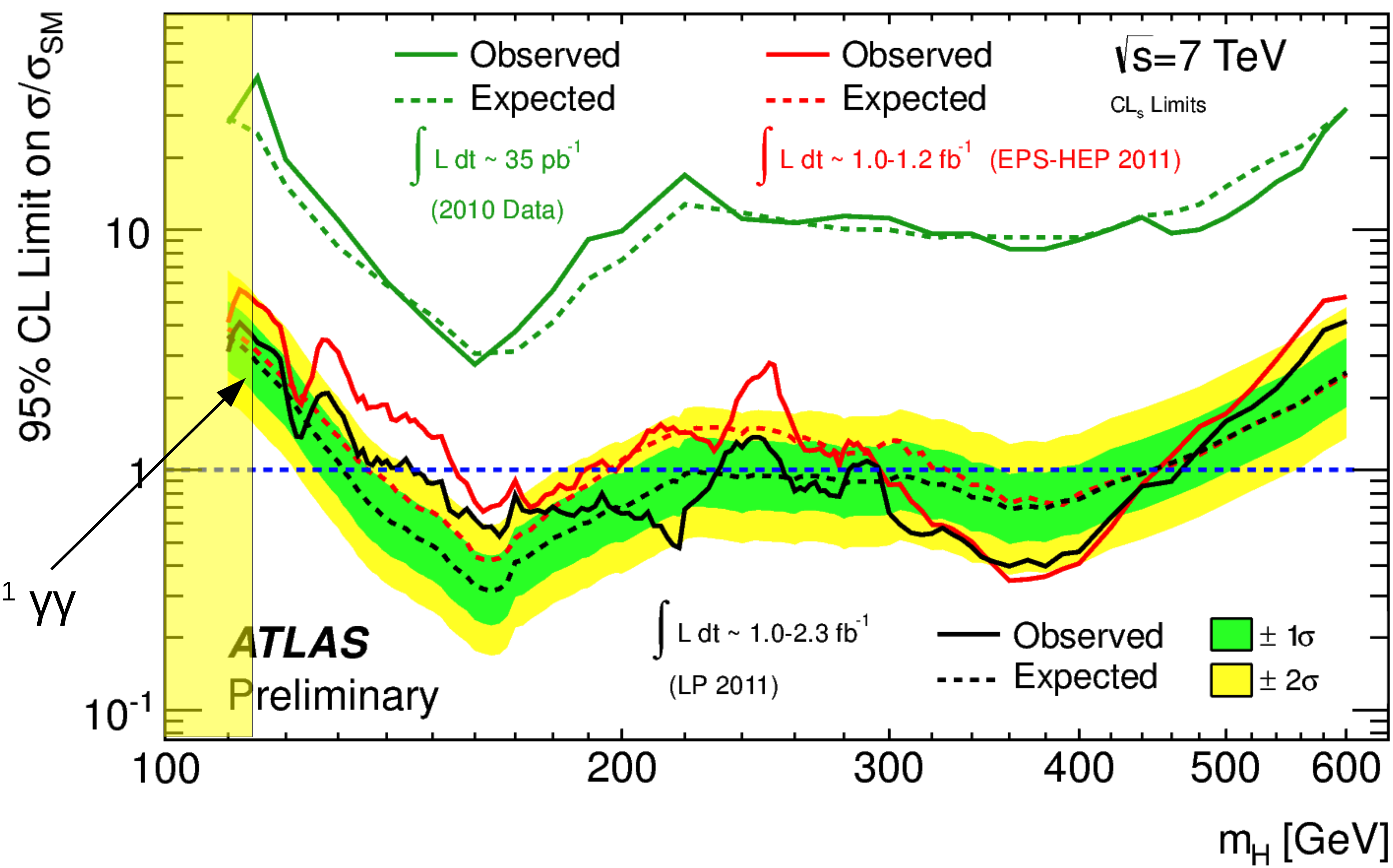


So where is the boson?

- The first fb^{-1} showed big excess over background
- The second fb^{-1} had little sign of anything
- The 3rd, 4th and 5th are keenly awaited

- We have a lot of possibilities, and we should take nothing for granted.

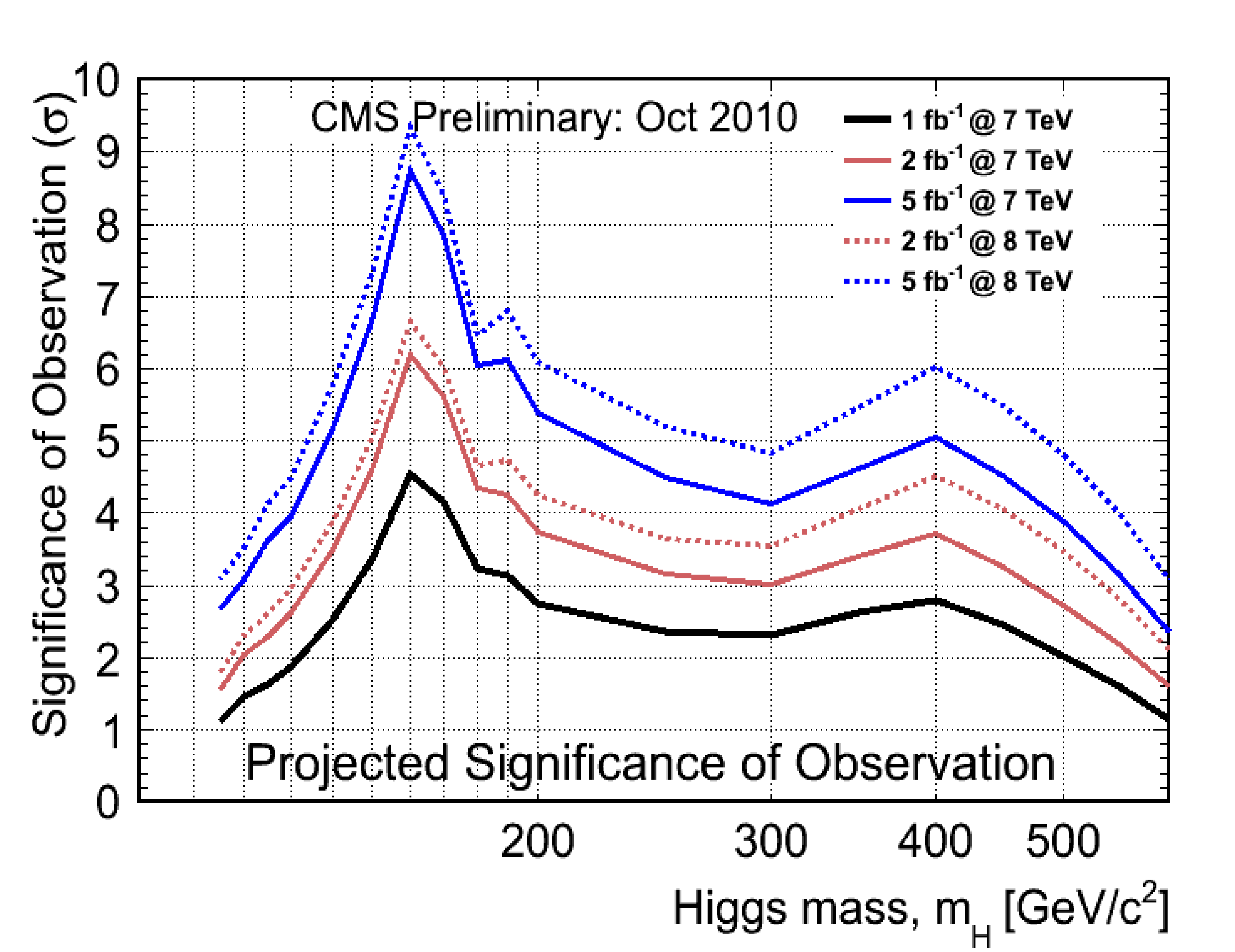
How do we progress?



$1fb^{-1}$ γγ

Signal significancee

- $5fb^{-1}$ has large sensitivity in each experiment
- Projections slightly optimistic at 115
  - Need γγ resolution!
  - Or SM cover needs combination



Signal significancee

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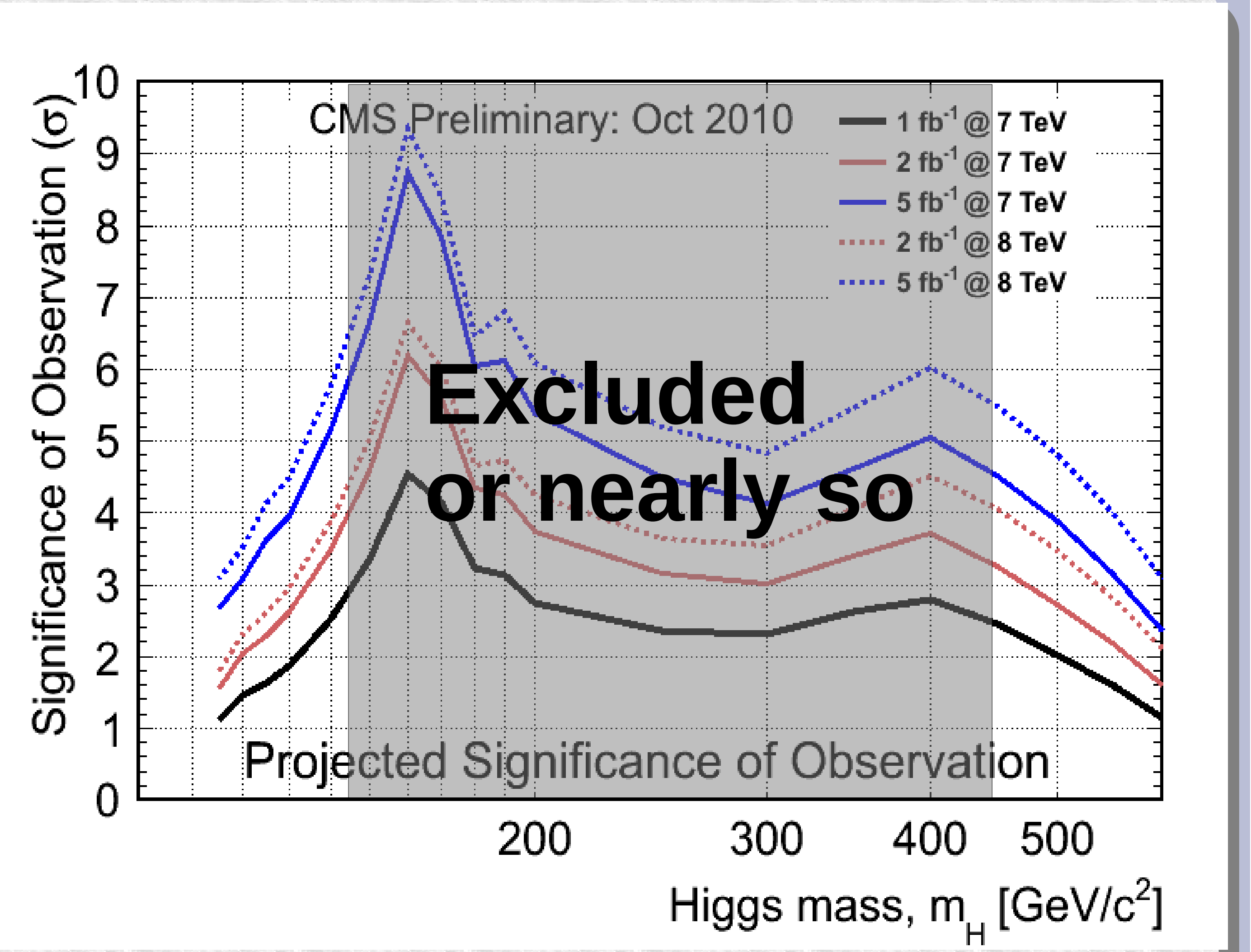
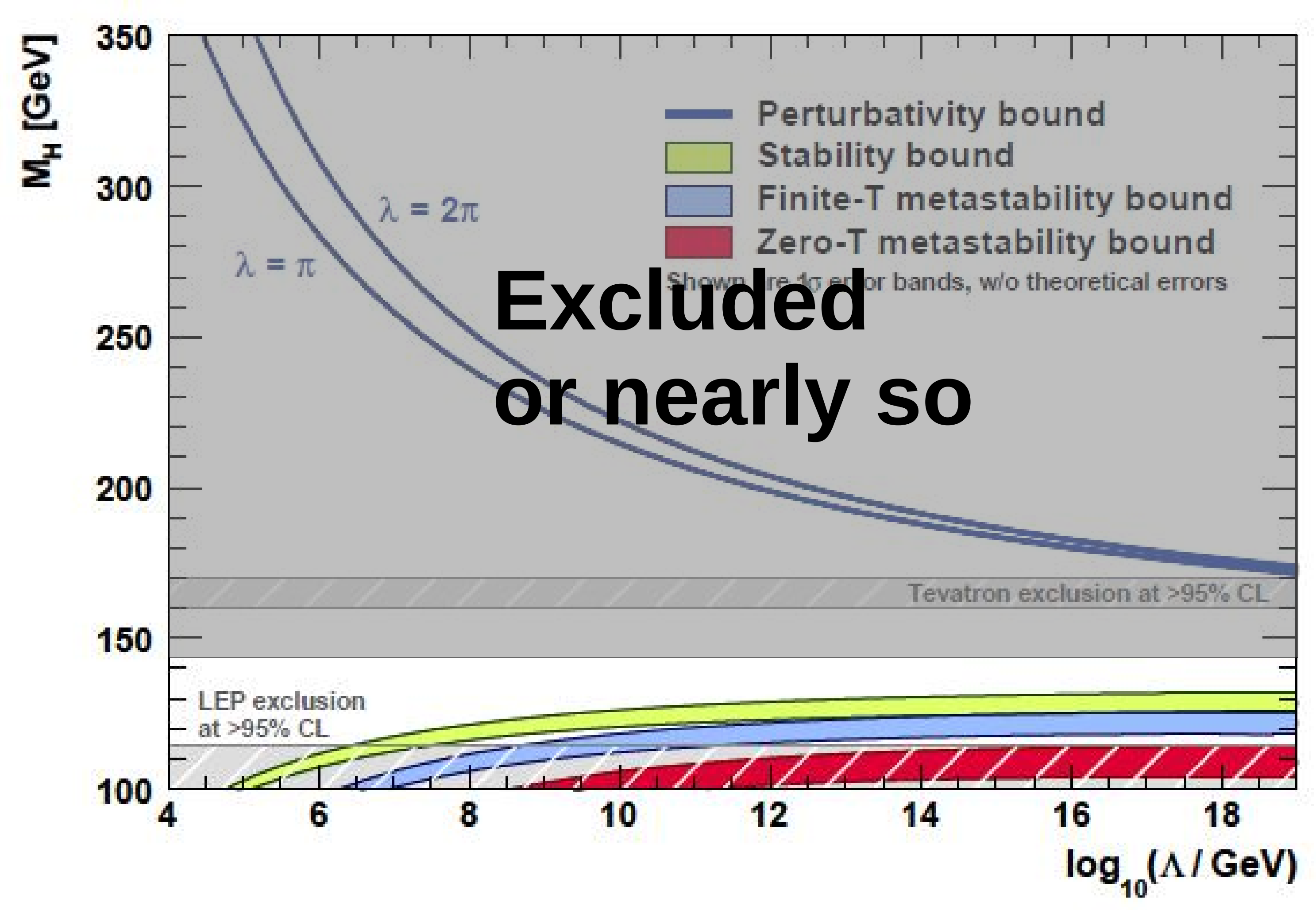


Higgs Stability

- Only small stable region left
- Are we heading into region where Higgs demands new physics?
- Know very soon!



Excluded or nearly so

What happens if we find it?

- Many channels contribute to low mass discovery
  - $H \rightarrow \gamma\gamma$
    - Gluon fusion, VBF, vector boson associated
  - $H \rightarrow ZZ$
    - Gluon fusion
  - $H \rightarrow WW$
    - Gluon fusion, VBF
  - $H \rightarrow \tau\tau$
    - VBF
  - $H \rightarrow bb$
    - Vector boson/top associated
- Measurements studies follow discovery fast
  - Checking the Higgs properties will be possible
    spin, parity, Br....

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Summary

- In 2011 LHC has produced $5.5 fb^{-1}$
  - 5x the amount promised
  - Record luminosity $3.6 \times 10^{33} cm^{-2} s^{-1}$
- The SM Higgs range has been massively reduced
  - 145 GeV to 460GeV has only small islands
    - 90% of the region explored already
  - Thanks to the LHC people who made it possible
- $5 fb^{-1}$ at 7TeV should give ATLAS/CMS over 2σ Higgs evidence COMBINED for any mass
  - 3σ for all bar 115
- The CERN DG has requested updates for December council

Summary 2012

- Running in 2012…
  - Assumed order of 15fb^{-1}
- LHC combination will offer 5σ sensitivity to many SM Higgs
  - Unless m_H=115; then maybe only 3.5σ+
- Convincing evidence for absence?
  - In which case we have many exciting avenues to explore

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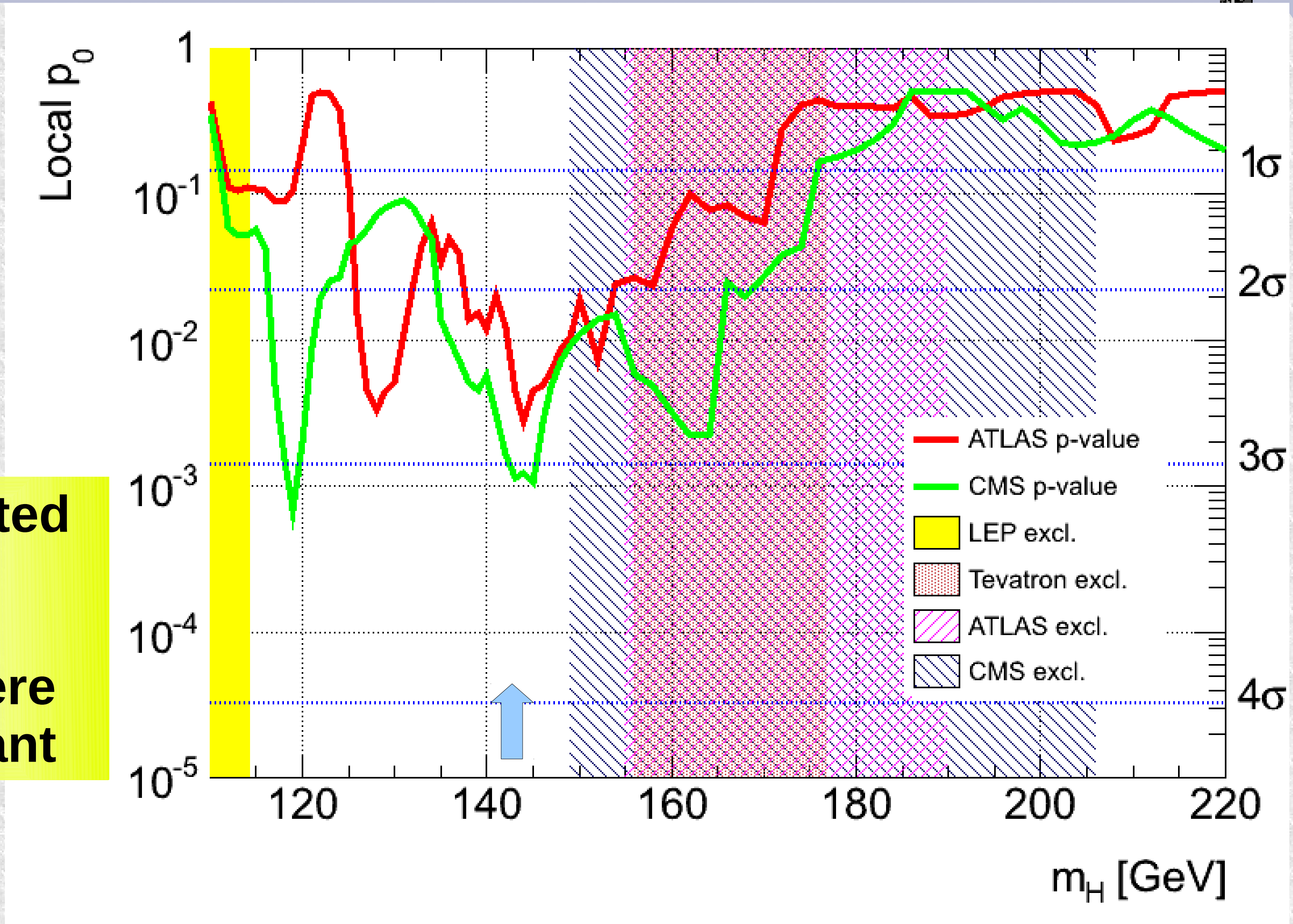
P-values at low mass

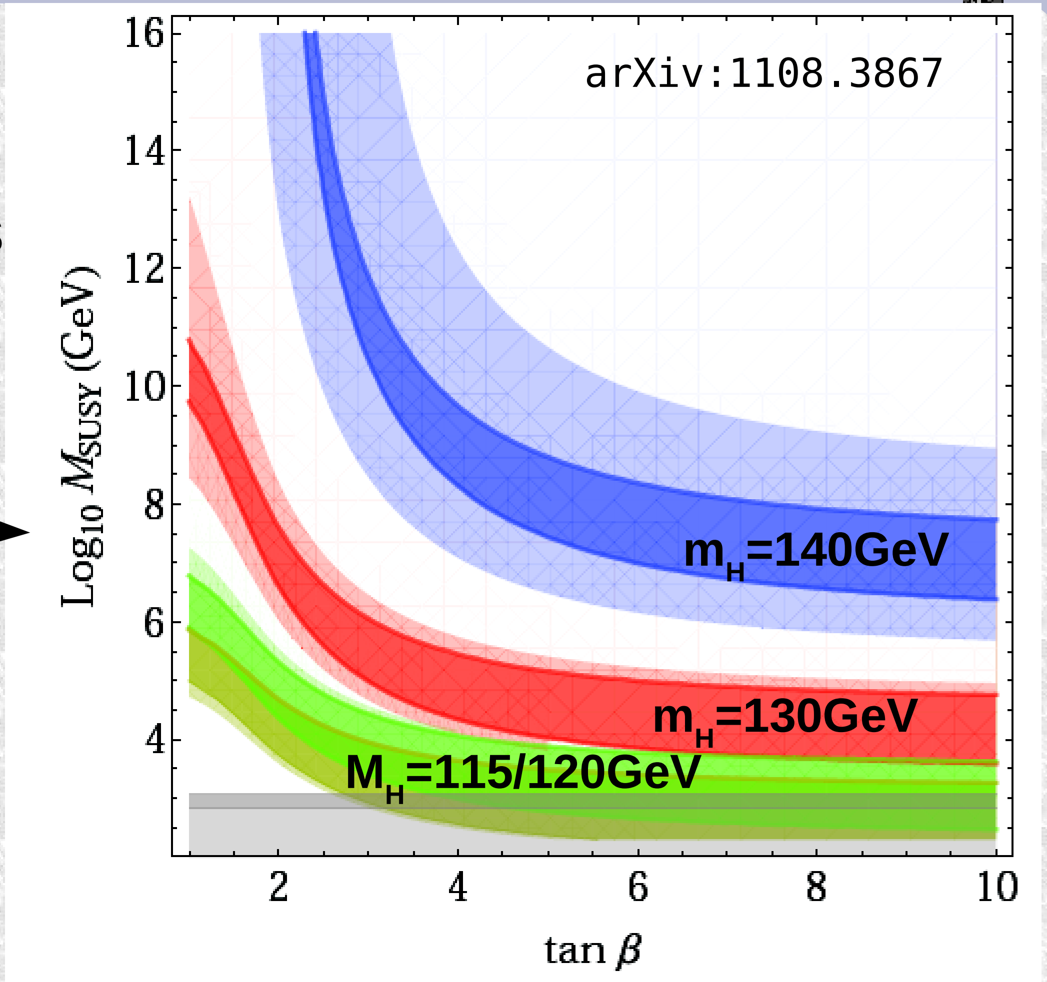


Some correlated uncertainties

Look-elsewhere effect important

Upper bound on M_{SUSY}

- The lighter MSSM scalar is below m_Z
  - Before radiative corrections
  - from m_{top}
  - and M_{SUSY} ($\approx m_{STOP}$)
- Implications for M_{SUSY} from measuring m_H are shown
- Grey band is search limit
- M_H=130GeV or above does not exclude SUSY – but it makes it experimentally inaccessible



High mass Higgs?

- Exclusion goes up to 460GeV
  - There is in fact an excess beyond this in ATLAS
- This could be where the Higgs boson lies
  - Somewhat easier to get to 600GeV than to 114GeV
  - Doable with $4fb^{-1}$, combining two experiments probably needed
- But theory is becoming tricky
  - Four-fermion interference is not treated
    - This gets messy...advice here?
  - The electroweak fits of course raise problems
- Will briefly discuss this option

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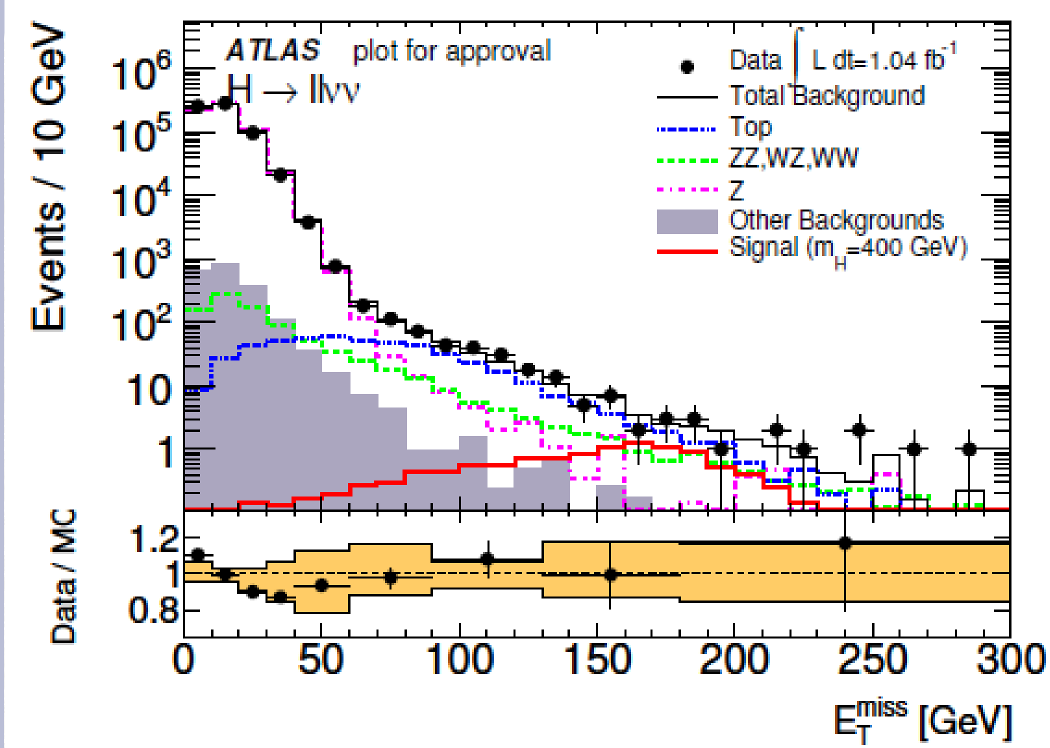
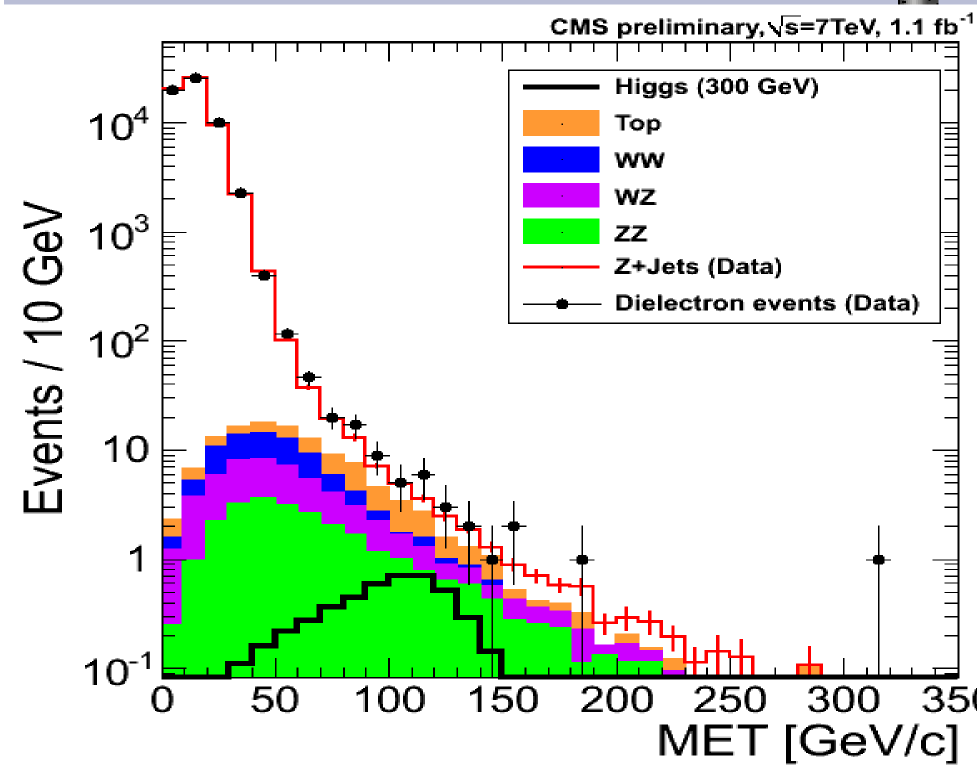
ZZ→llνν missing E_T

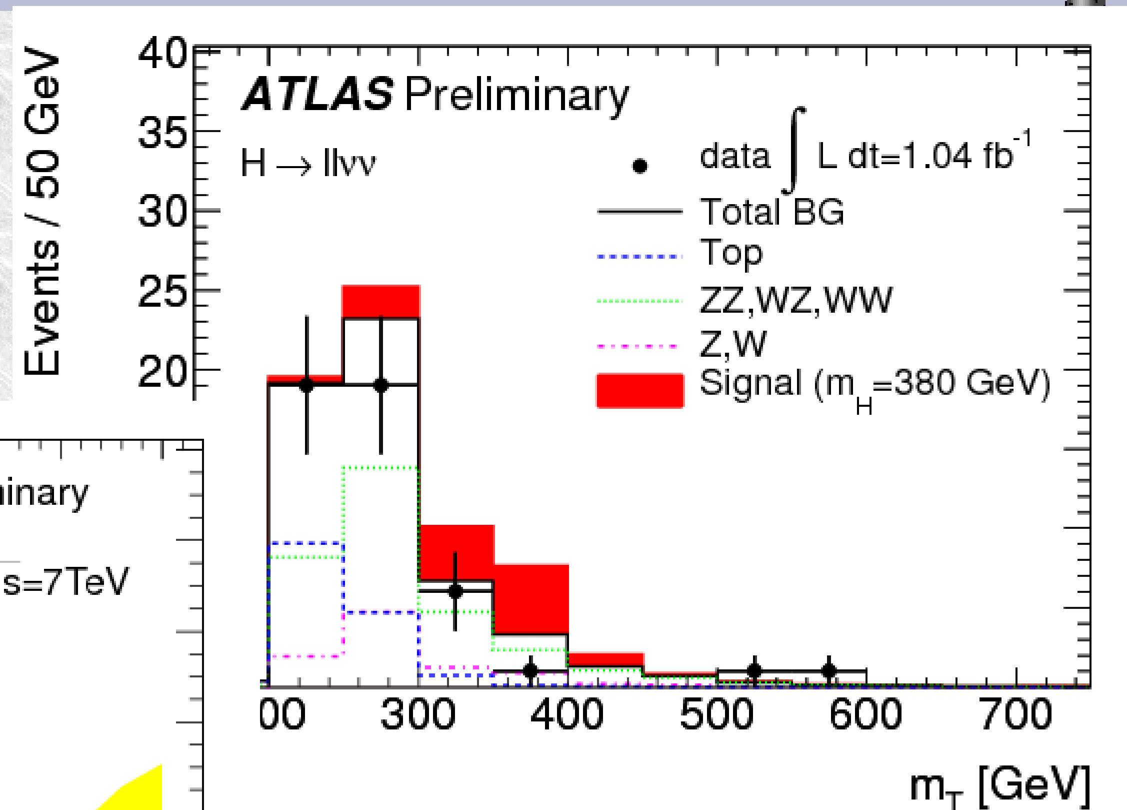


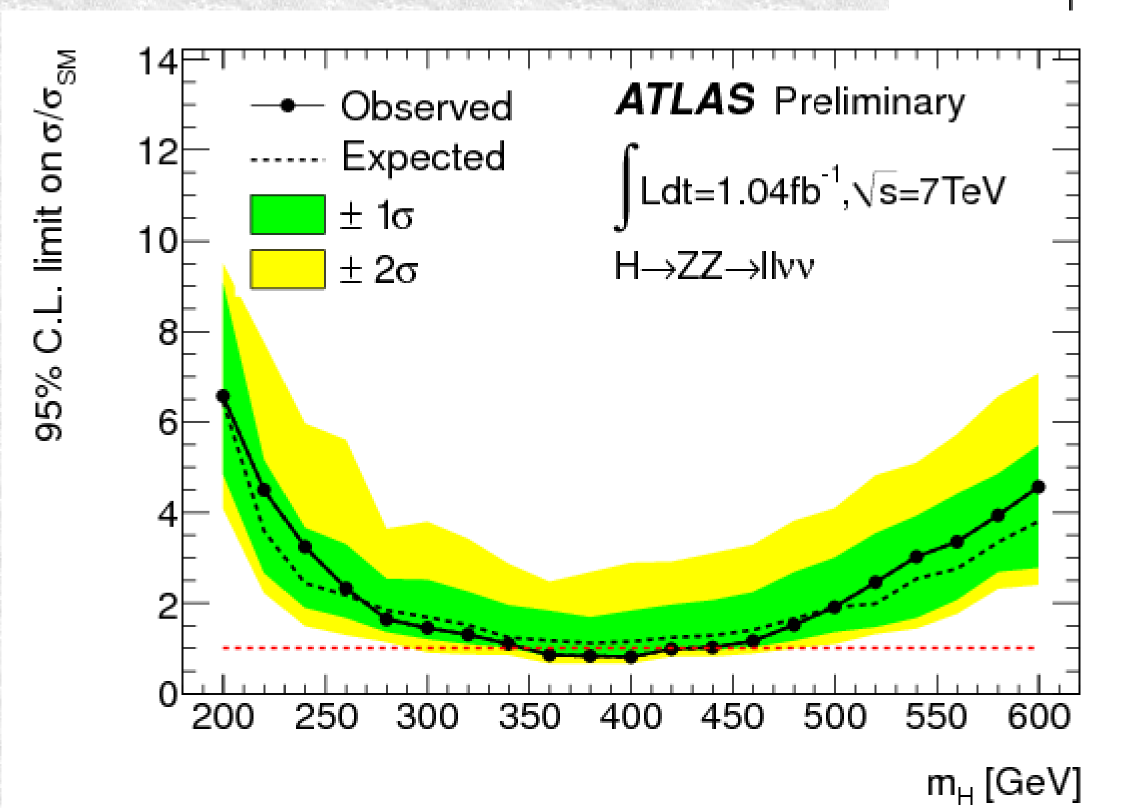


- For 150GeV ATLAS find Z with MET is minor
  - But ATLAS take this from simulation
- CMS have larger Z with MET component
  - Taken from gamma plus MET studies

$H \rightarrow ZZ \rightarrow 2l\ 2\upsilon\ (l = e,\mu)$

- ATLAS & CMS best channel for m_H>300
- High mass almost background free





- Scaling faster than $1/\sqrt{l}$
- Should extend to 550+ by end of 2011

Low Mass

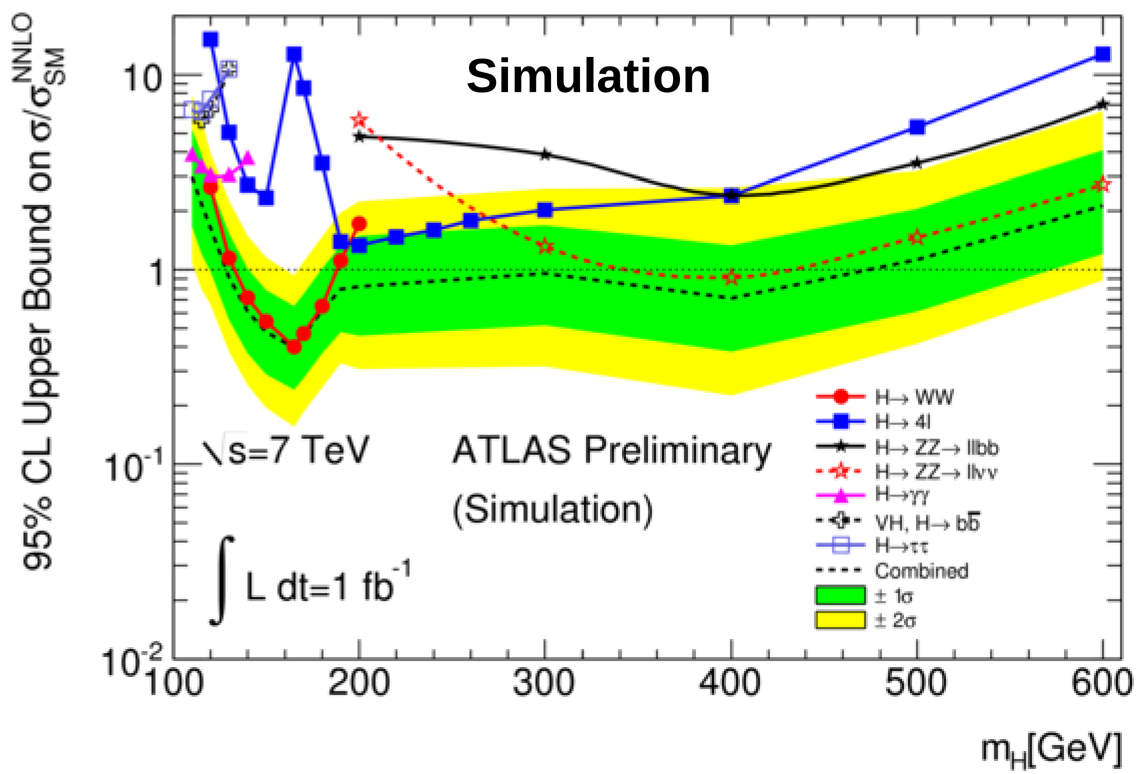
- The focus is now on the region below 145GeV
  - i.e. 114-145GeV
- The lower the mass the harder it is at LHC
  - Will look at 114 as example

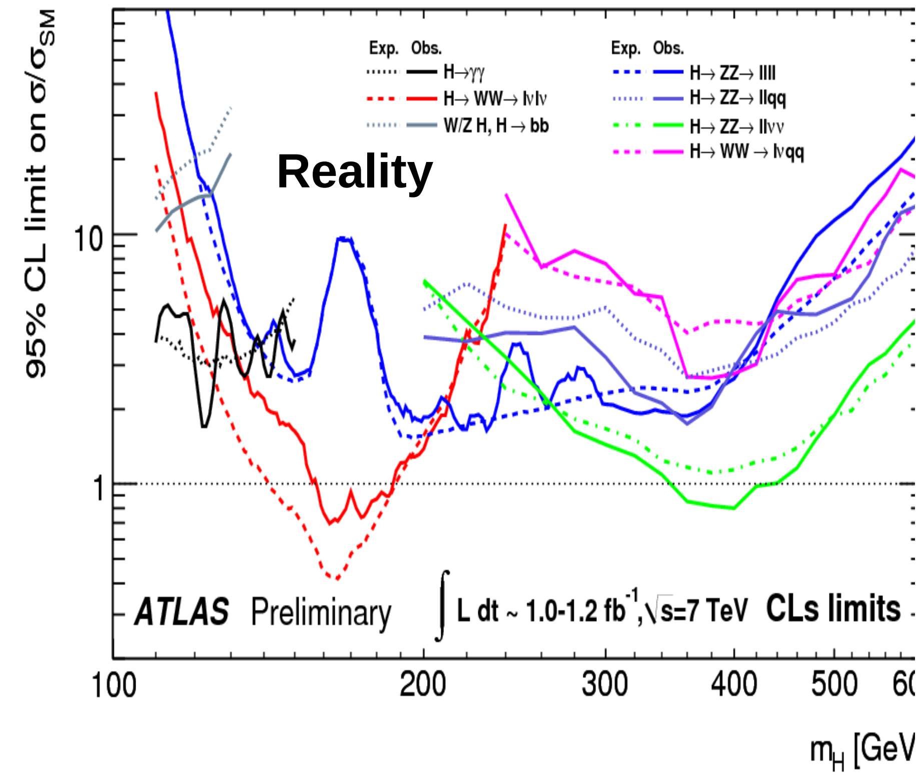
So where is the boson?

- The first fb^{-1} showed big excess over background
- The second fb^{-1} had little sign of anything
- The 3rd and 4th are an undiscovered country

- We have a lot of possibilities, and we should take nothing for granted.

Accuracy of projections





- Predictions very close – maybe 10% optimistic
  - H→bb here used non-boosted analysis
  - No VBF H→ττ from ATLAS yet
- CMS predictions similarly close

H to gamma gamma fits

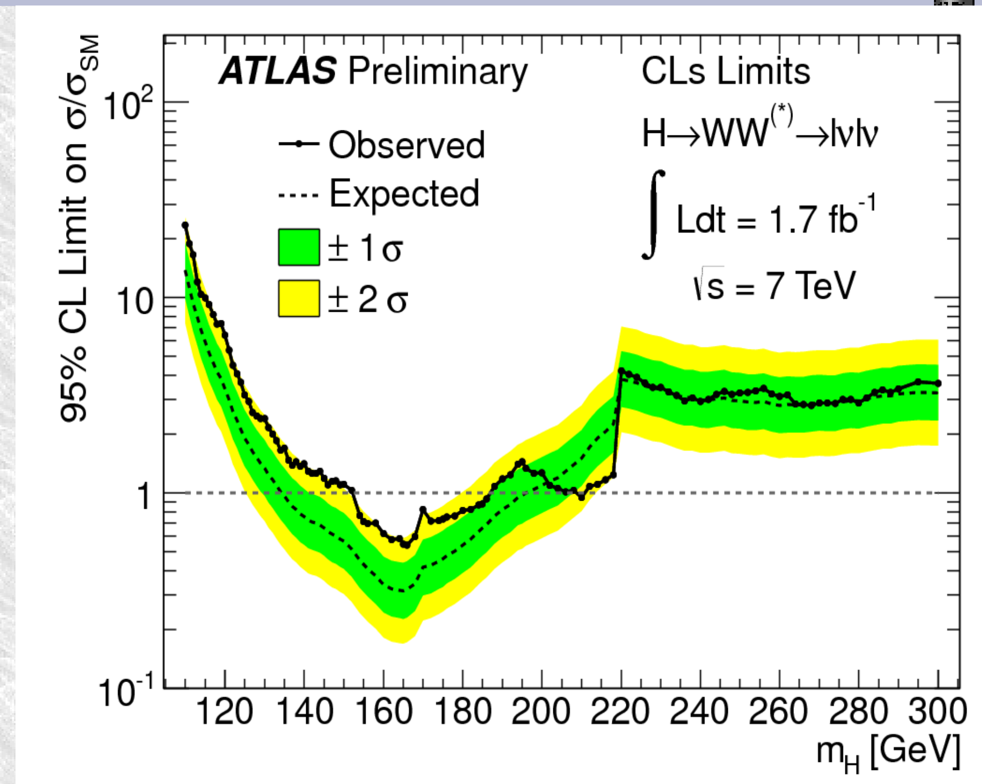
2010 slide

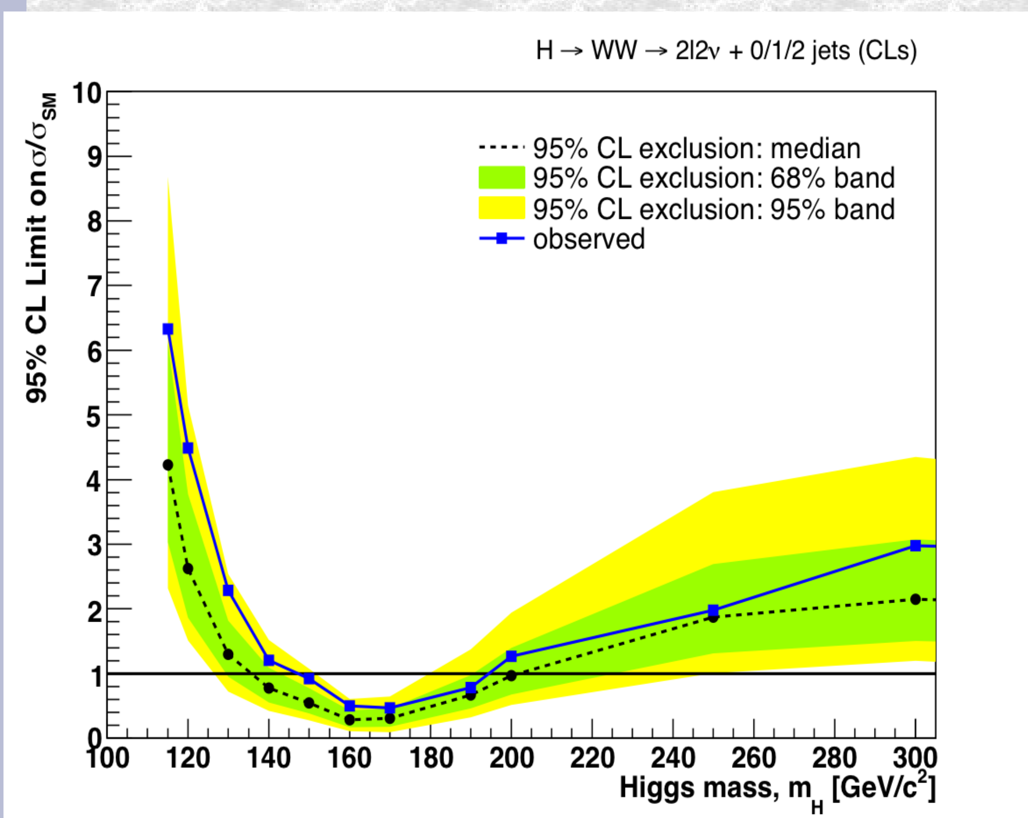
- 14TeV ATLAS study

Fit Variables	Categories	Significance
$m_{\gamma\gamma}$	-	2.31
$m_{\gamma\gamma}$	η	2.52
$m_{\gamma\gamma}$	η, conversions	2.58
$m_{\gamma\gamma}$	η, conversions, Jets	3.46
$m_{\gamma\gamma}$, cosθ*	η, conversions, Jets	3.83
$m_{\gamma\gamma}$, $P_{T,H}$	η, conversions, Jets	3.75
$m_{\gamma\gamma}$, $P_{T,H,}$ cosθ*	η, conversions, Jets	4.12

$H \rightarrow WW$

- CMS and ATLAS searches similar
  - Systematics important
- VBF not in ATLAS
  - Not critical for low mass





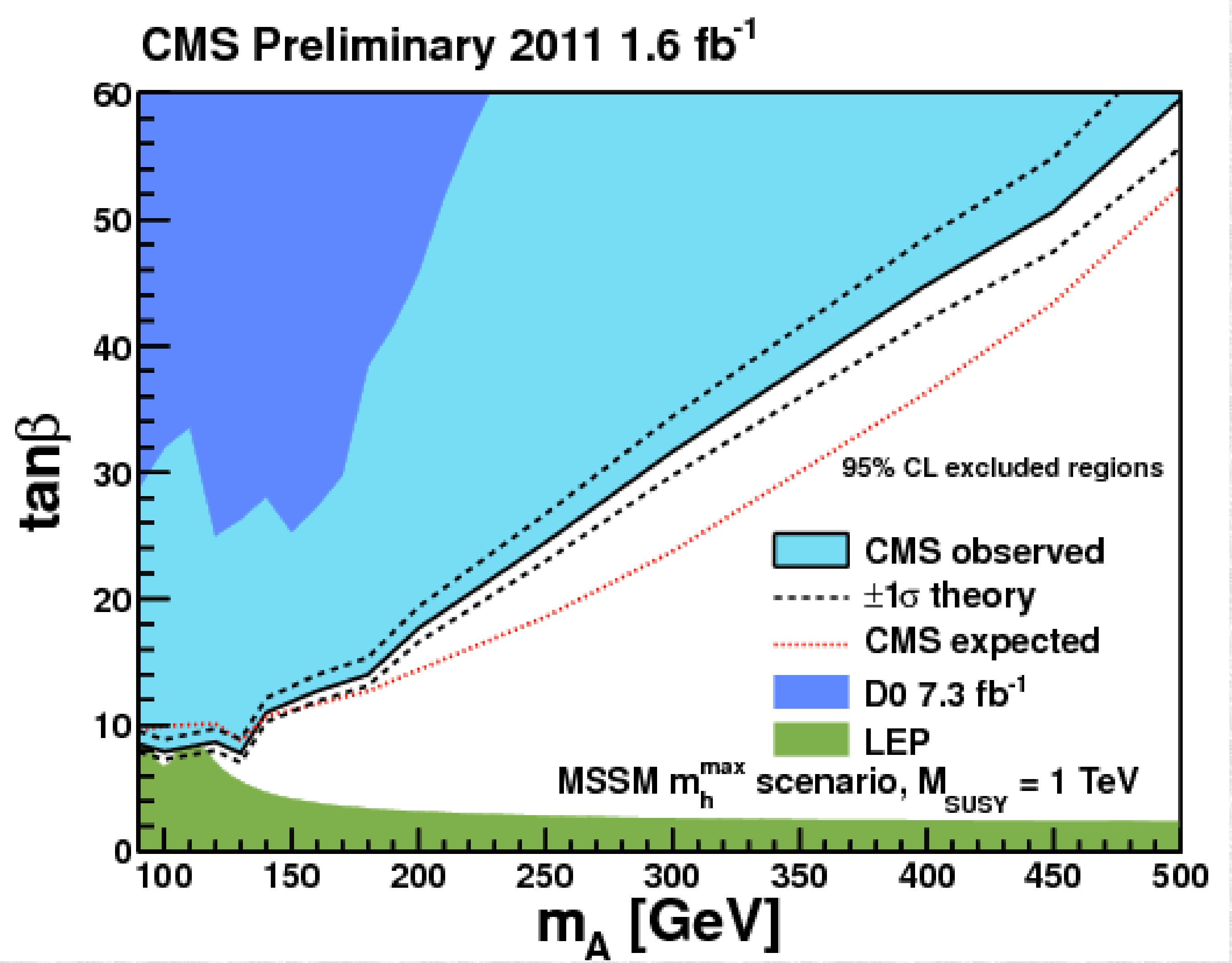
- CMS has lower p_T threshold
  - benefits 115GeV
  - ATLAS optimisation possible

Charged Higgs bosons

- Attention mostly on
  - $m_{H+} < m_{top}$
  - $H^+ \rightarrow \tau\upsilon$
- The first allows a large production rate via top decay
- The second is expected in high tan-β SUSY
- Both of these should be relaxed
  - ATLAS has studied $H^+ \rightarrow c\bar{s}$ – but only with $35 pb^{-1}$

Neutral MSSM Higgs

- Exclusions starting to get very interesting
- Meeting the LEP bounds for low m_H
- Starting to exclude two light Higgs doublets
  - Push to higher mass now



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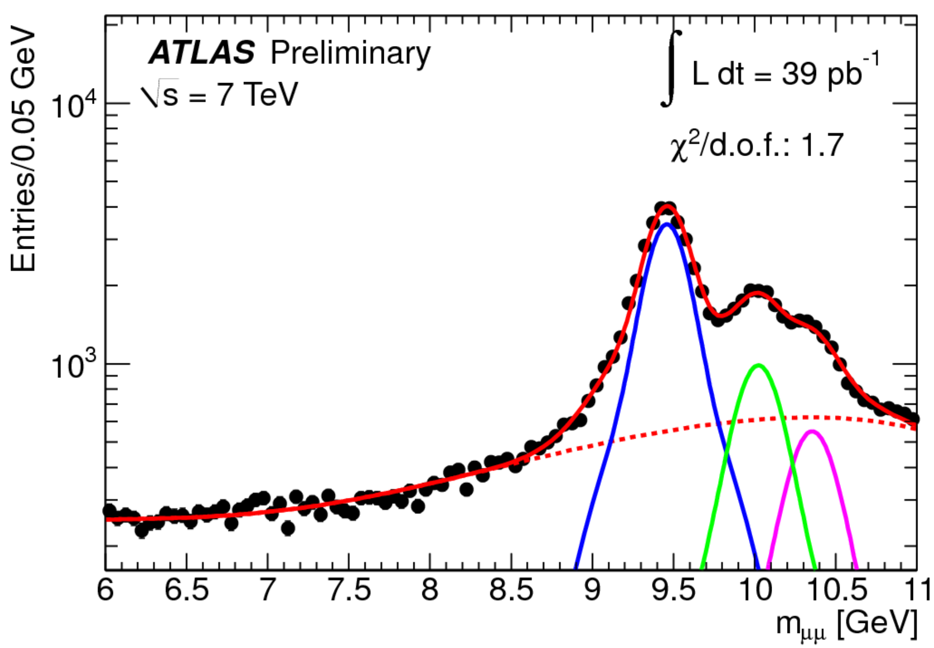
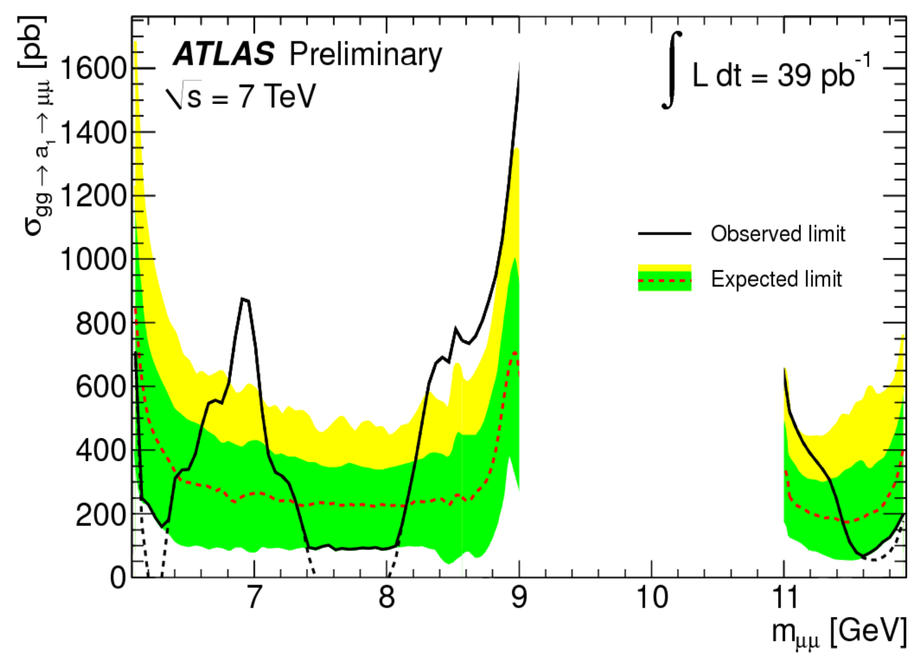
nMSSM a_1

- MSSM plus on scalar Higgs
  - Allows lightest Higgs to be very light.
  - 'ideal' Higgs near upsilon mass
  - ATLAS analysis misses difficult upsilon region
- If SM Higgs missing, such models will gain attention...





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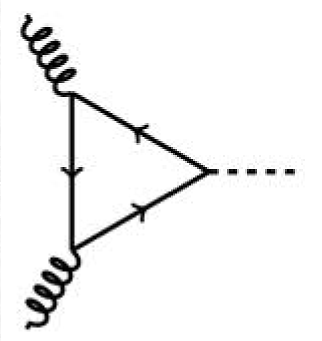
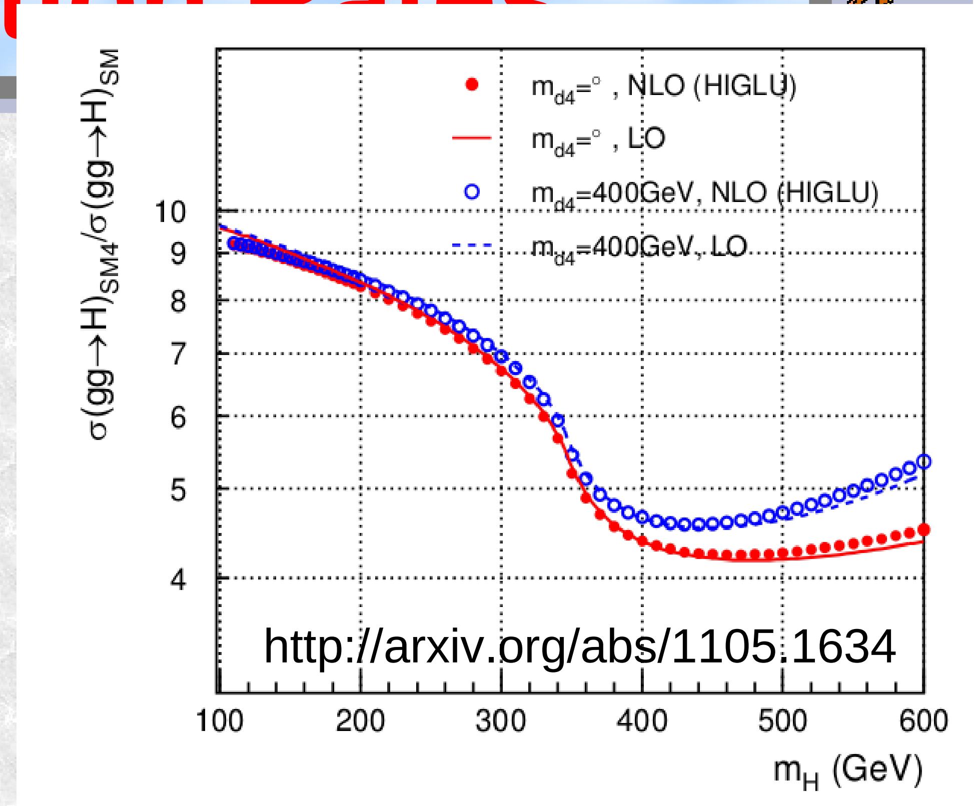
4^{th} Generation model

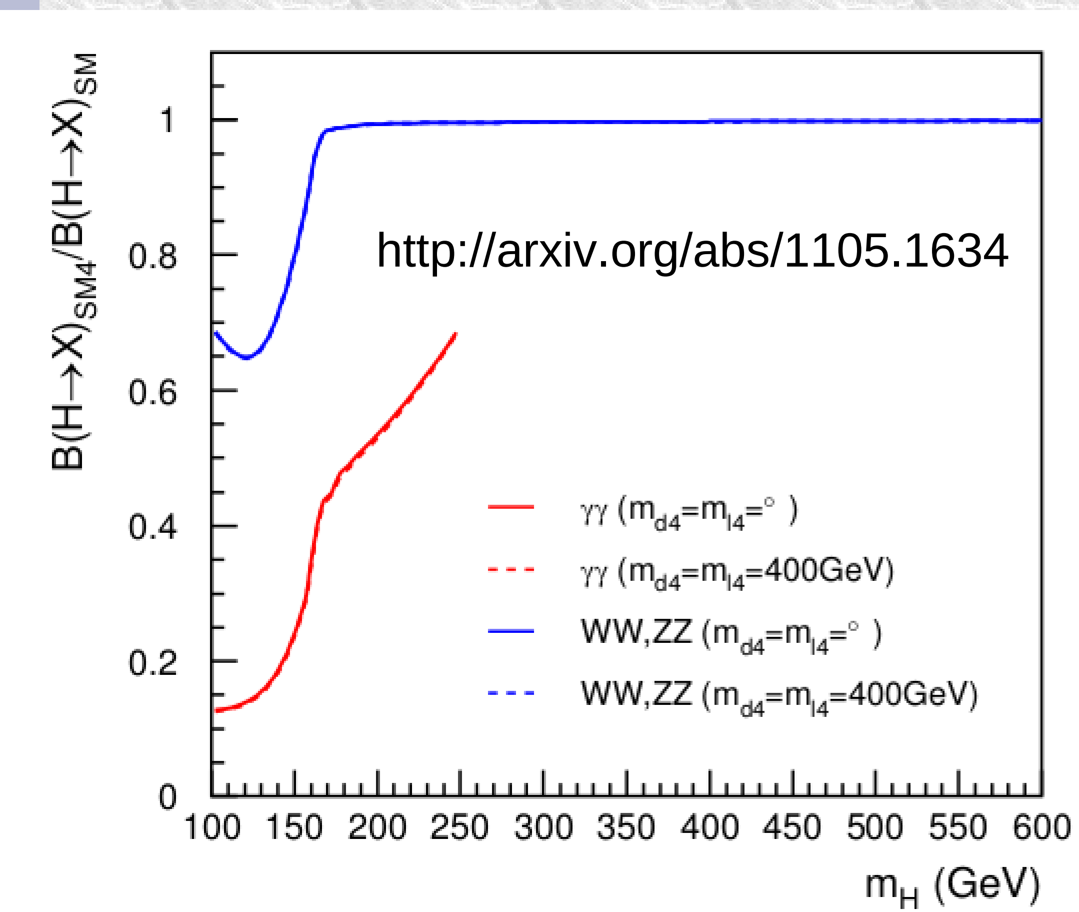
- Why?
  - Heavy particles enhance gluon fusion loop
  - Kinematics like 1/mass
  - Coupling to H like mass
  - Total is mass independent!
- Factor 4-9 enhancement from 4^{th} generation
  - Allowed if $m_\nu > 47$GeV
  - We require $m_\nu >> m_W$ - this removes $H\rightarrow\nu\nu$ decay
  - But photon decay is suppressed...
    - Interference and competition with gluons



4th Generation Rates

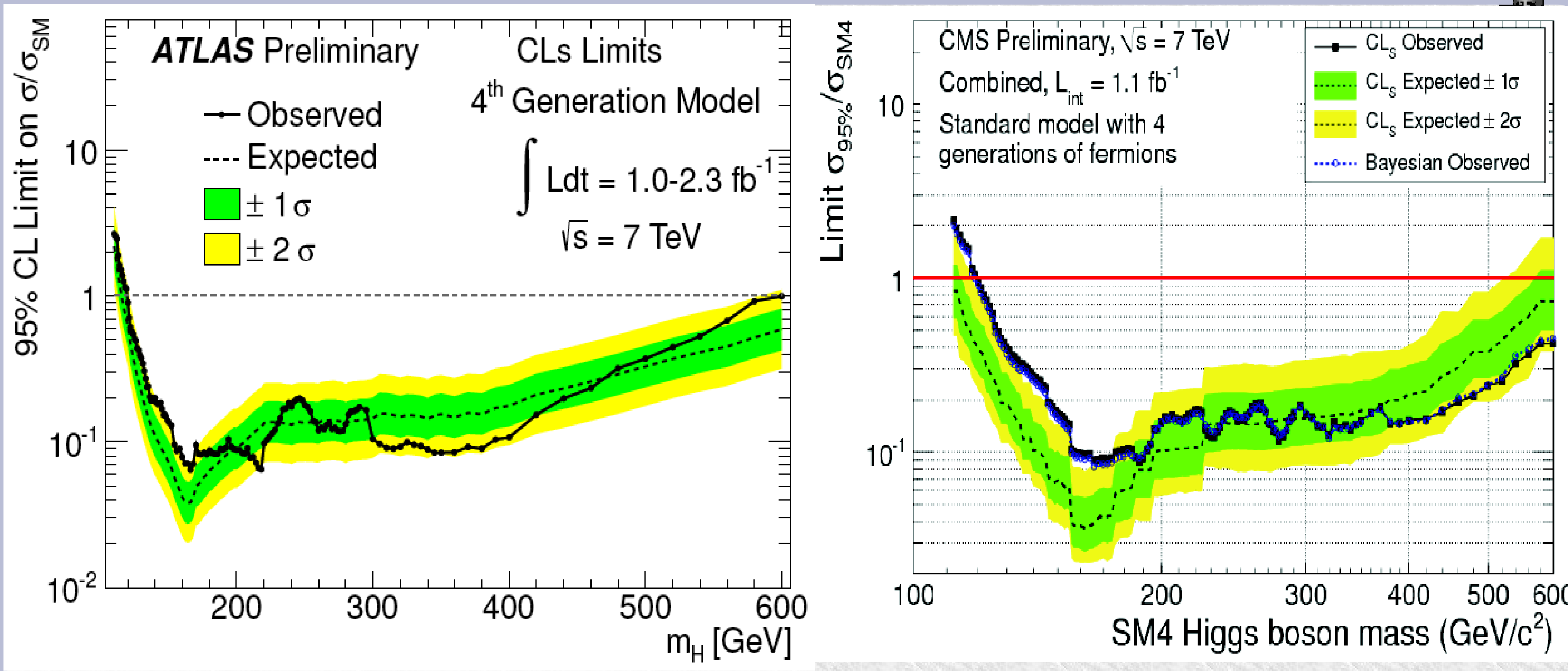
- Production rates enhance
- High mass -> minimum





- High-mass decay rates stable
- Low mass colourless decay suppressed

Higgs + heavy 4th Generation



- CMS and ATLAS exclude ~120GeV to 600GeV
  - ATLAS/CMS expected 116/112 to 600
- A combination would exclude ~all
  - But $47<m_\nu<80$ is a window

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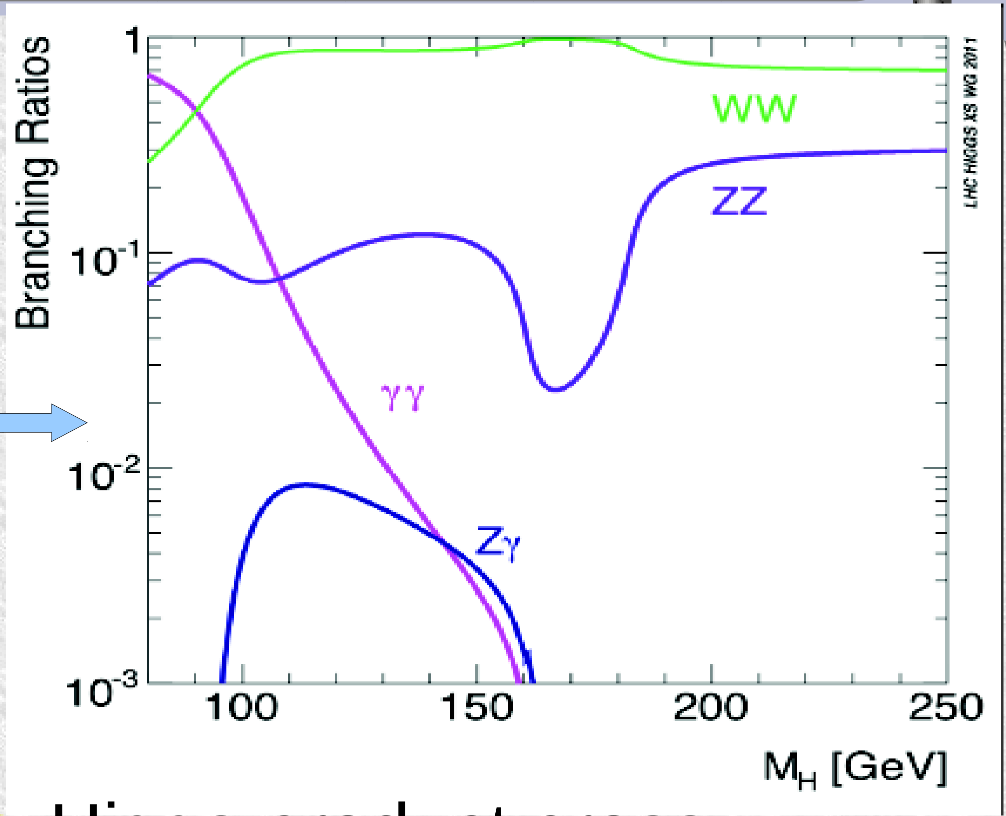
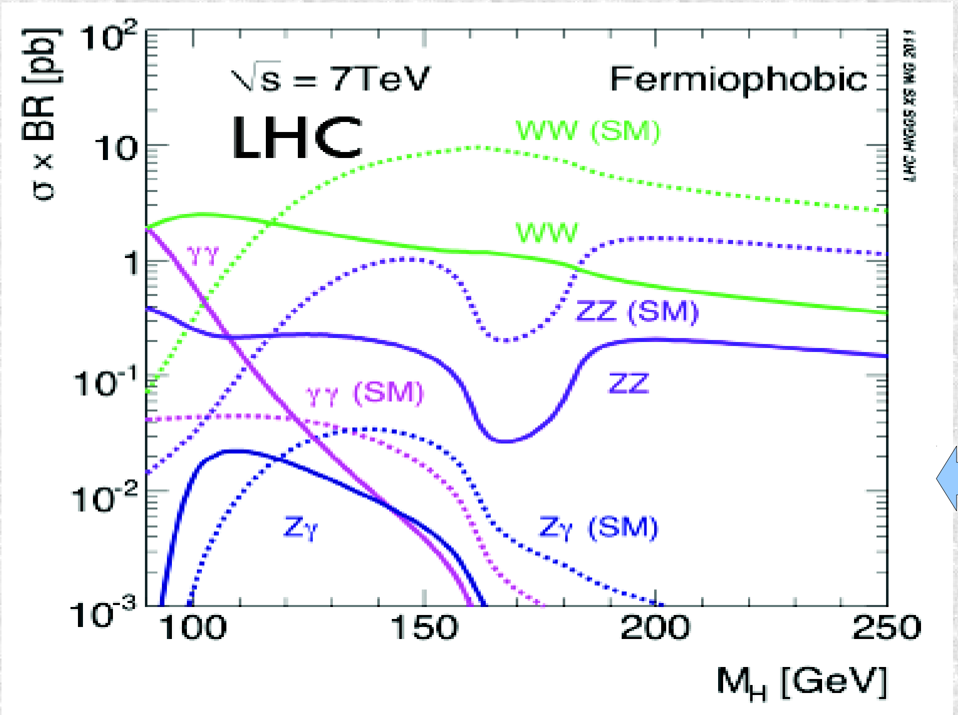
Fermiophobic

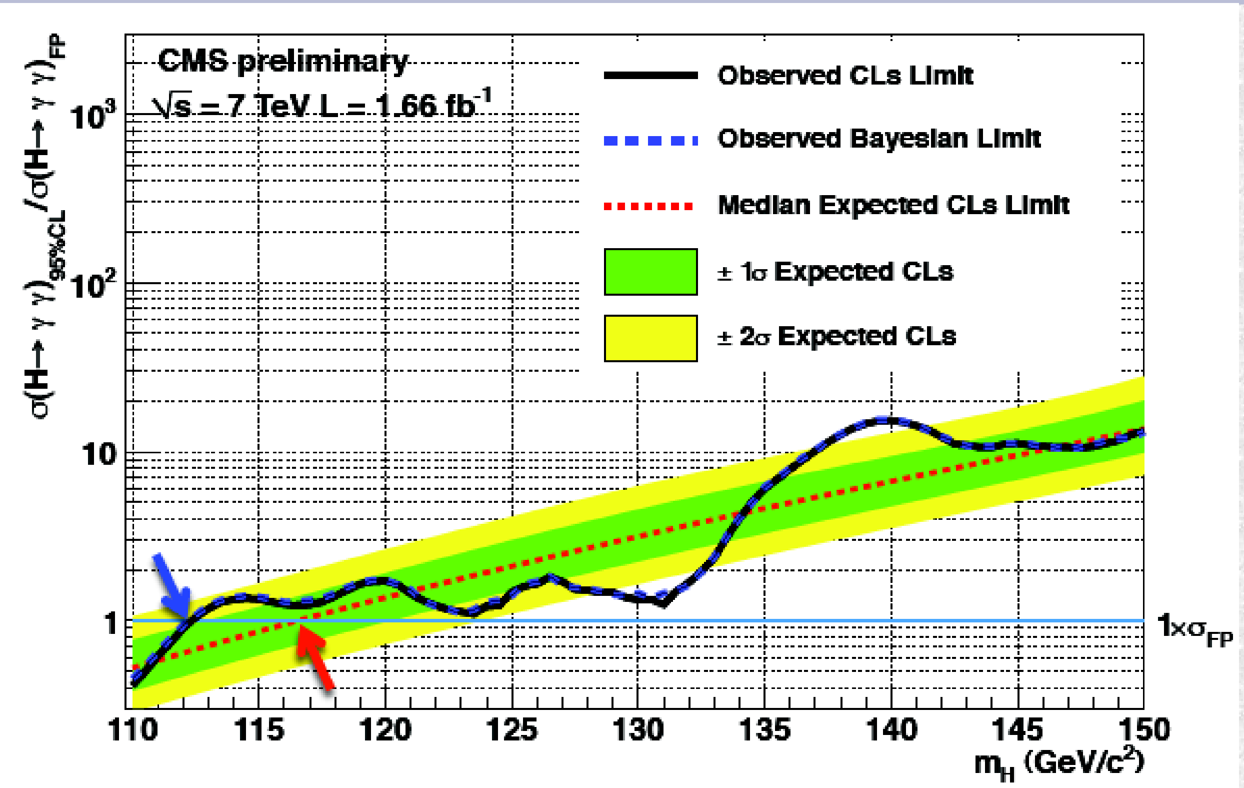
- Higgs produced in VBF or VH
  - No gluon fusion
- Higgs decay enhance γγ





- Higgs product cross-sections
  - Exceed SM < 120
  - Reduced above

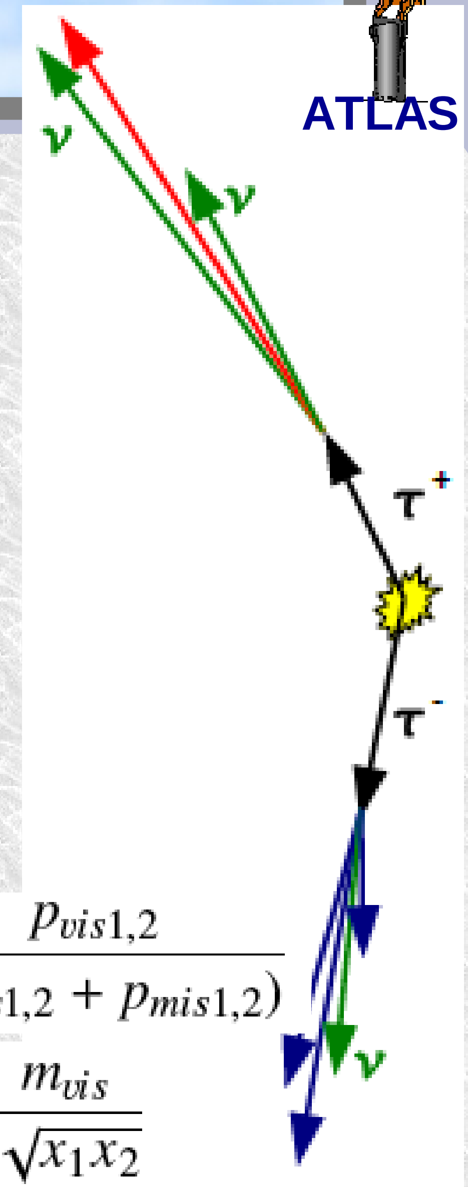
CMS FP search



- Expected CMS limit 116.5
  - actual CMS limit 112 due to excess
- CDF/Do expect 111/110.5
  - Actual CDF/D0 114/112.9GeV

ATLAS H→ττ

- Good for SM Higgs in the mass range mH=110-140 GeV
- Three classes of final states, depending on the τ-decay:
  - lepton-lepton, *ll*
  - lepton-hadron, *lh*
  - hadron-hadron, *hh*
- ATLAS has studied the *ll* and *lh* final states
- Most important backgrounds:
  - Z/γ* → ll + jets (→ττ is largely irreducible); W→lυ + jets; dibosons, ttbar and single top, QCD jets
- Selection for ll:
  - 2e, or 2μ or 1e1μ with pTe > 15 GeV |ηe|<2.47; pTμ > 10 GeV |ημ|<2.5; opposite charge required
  - At least 1 jet with pTj > 40 GeV |ηj|<4.5;
  - ETmiss > 30 GeV for 2e and 2μ, > 20 for 1e1μ
- *ll* finale state: reconstruct the tau momentum in the collinear approximation
- Apply dilepton invariant mass and topological cuts
- →Study the tau-tau invariant mass



$$x_{1,2} = \frac{p_{vis1,2}}{(p_{vis1,2} + p_{mis1,2})}$$

$$m_{\tau\tau} = \frac{m_{vis}}{\sqrt{x_1 x_2}}$$

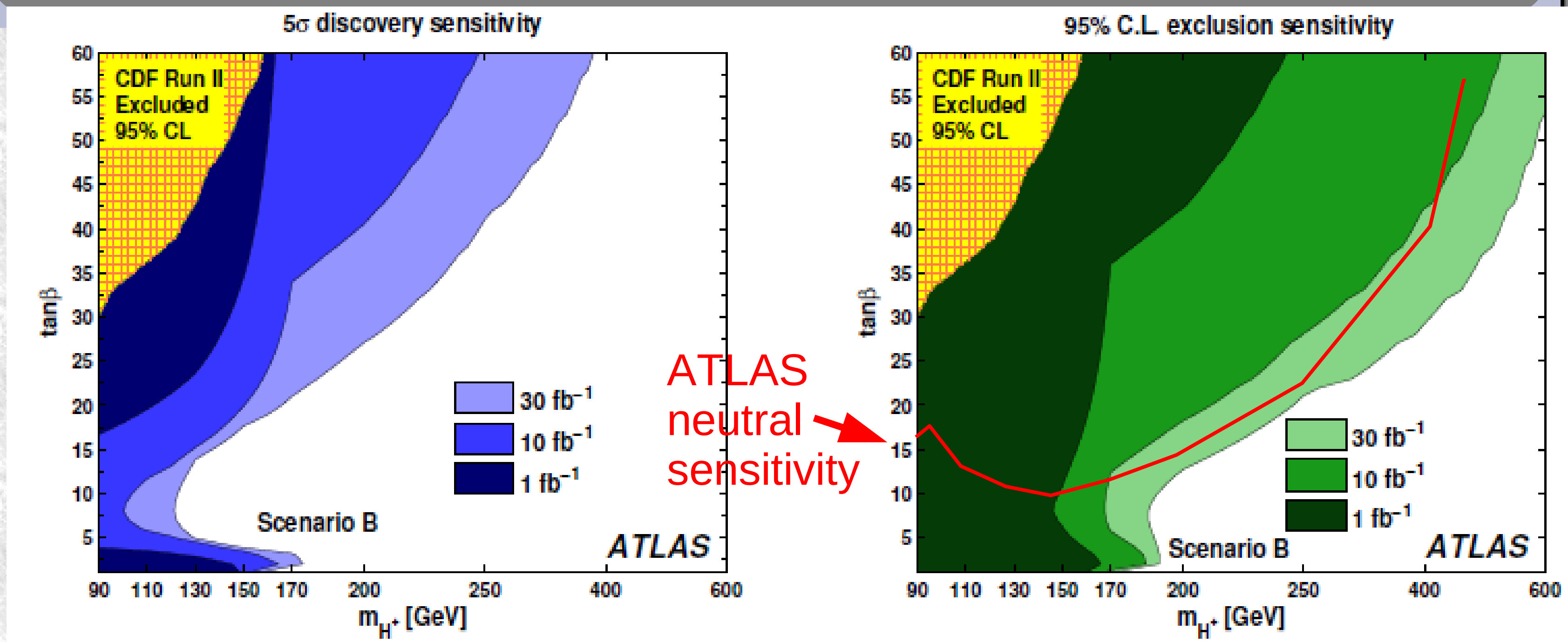
Collinear approximation

MSSM Higgs

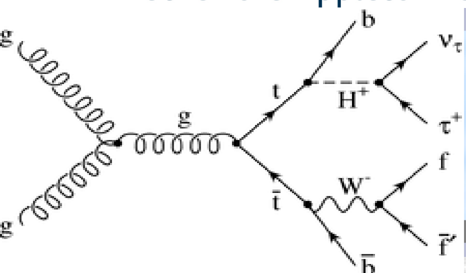
Charged Higgs bosons

- Attention mostly on
  - $m_{H+} < m_{top}$
  - $H^+ \rightarrow \tau\upsilon$
- The first allows a large production rate via top decay
- The second is expected in high tan-β SUSY
- Both of these should be relaxed
  - ATLAS has studied $H^+ \rightarrow c\bar{s}$ – but only with $35pb^{-1}$

H^+ (at 14TeV)

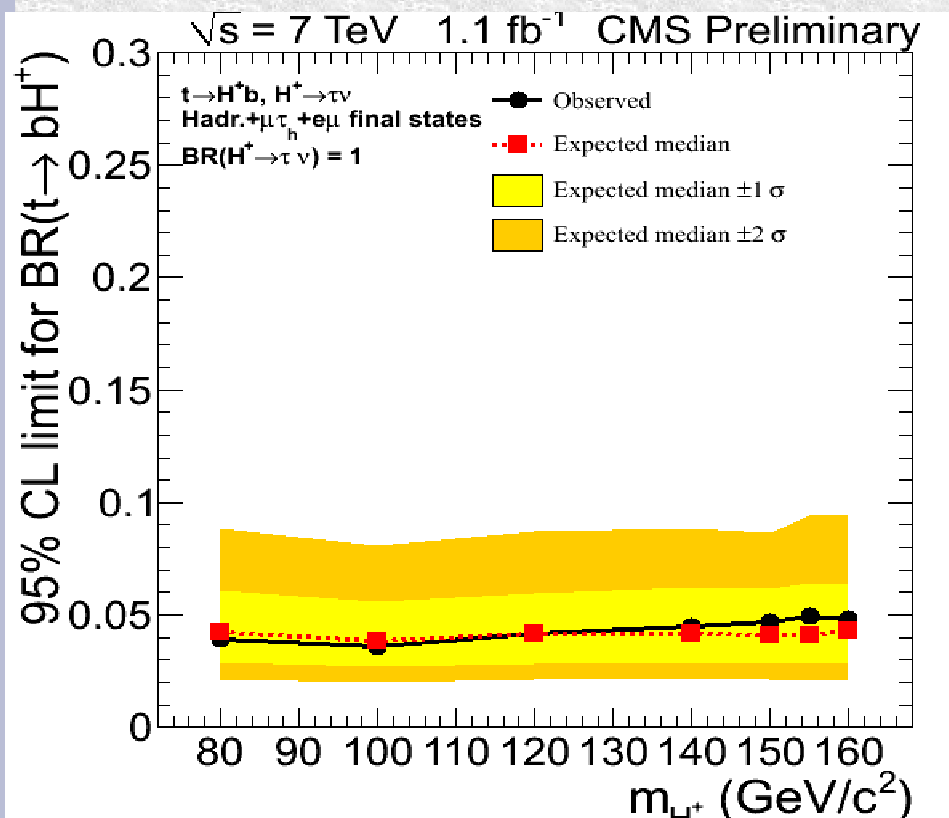


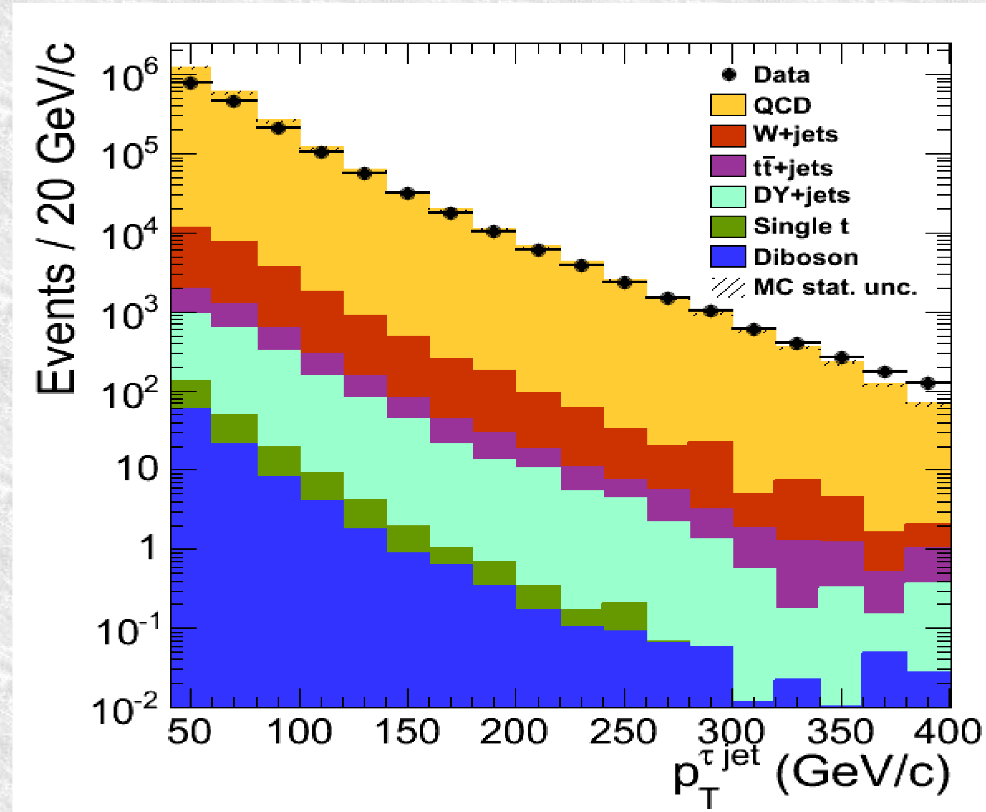
- ATLAS study @ 14TeV
  - Good for $m_H<m_{top}$
  - Lags behind H/A $\rightarrow\tau\tau$ *in MSSM* for $m_H>m_{top}$
    - Pair production is relatively weak
    - ATLAS sensitivity from $1fb^{-1}$ to H/A is added
  - But experimentally charged Higgs very conclusive



Charged Higgs to τν

- CMS search for top to H^+b, H^+ to τν for $1fb^{-1}$
- Background is mostly $t \rightarrow W+b$



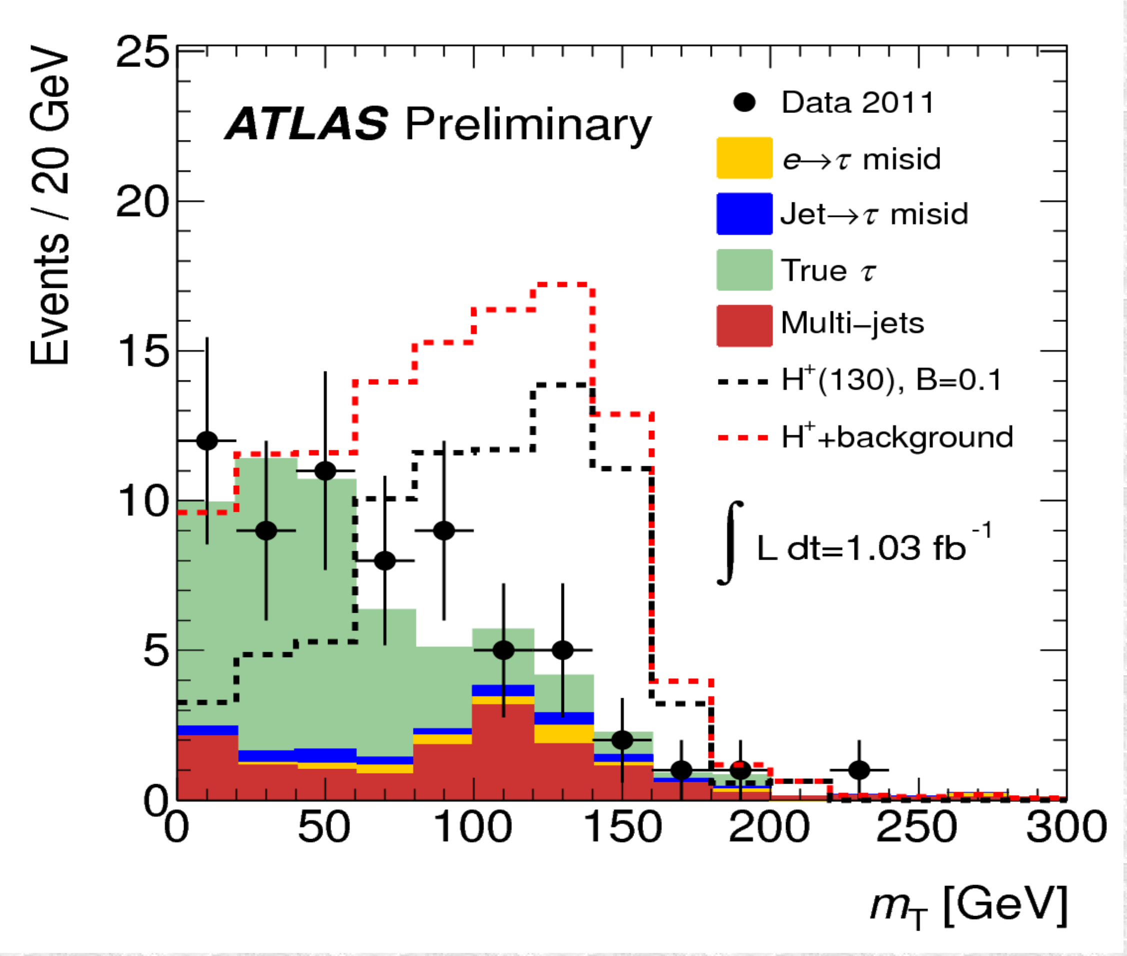


- No evidence so far
- Limits BR(t-H+b) ~4%
  - Far surpassing previous results

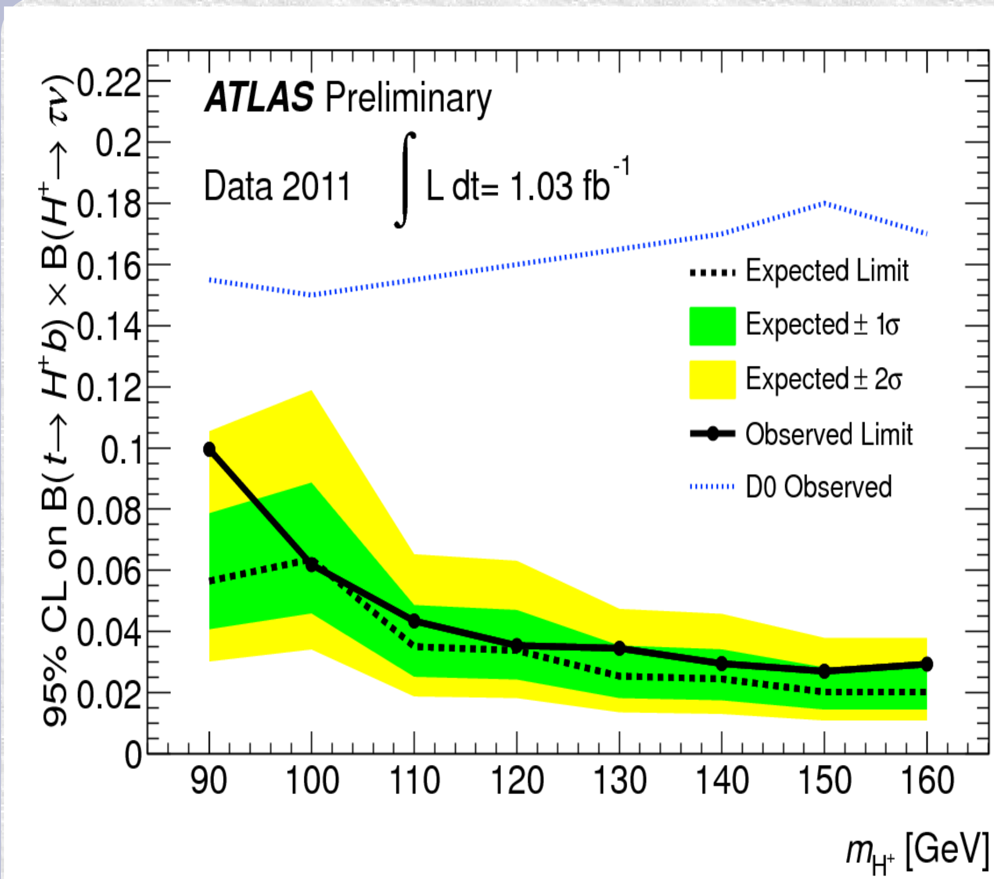
Just out: More H+, ATLAS

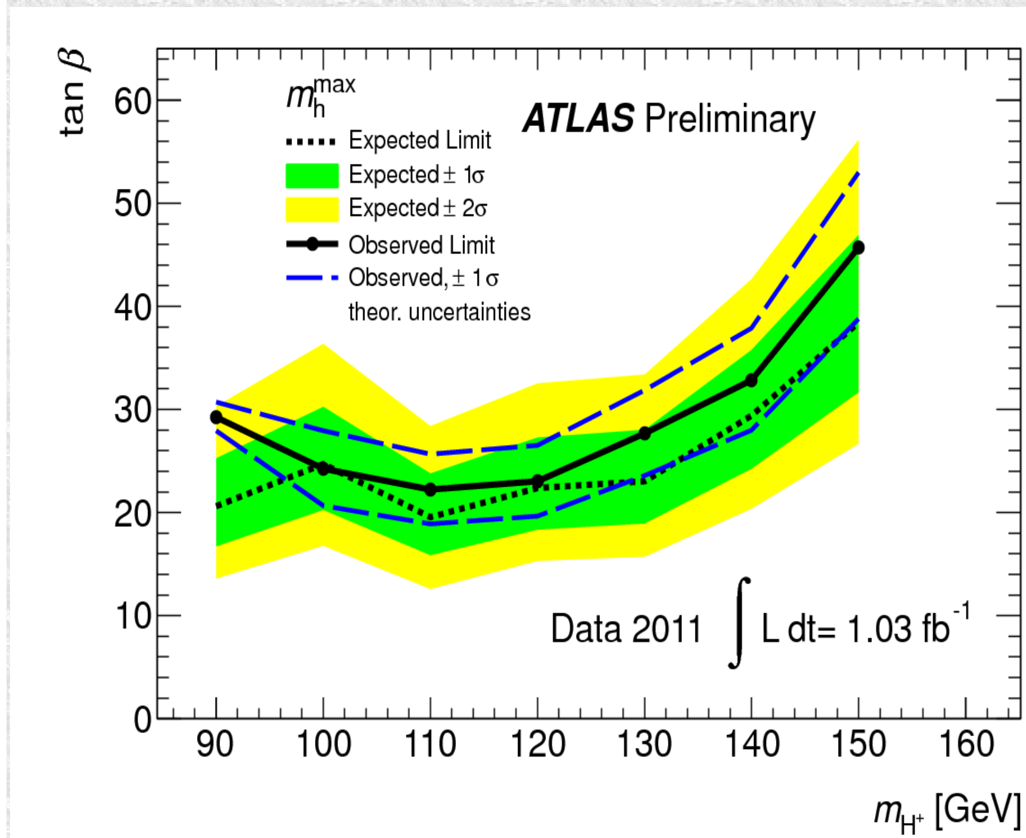
Https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-138/

- H+ is fully hadronic mode
  - Only 1 neutrino
  - Find m_T distribution
- QCD from data
  - Normalised by fit to MET
- τ distributions from embedding method
  - Normalised m_T<40
- Fit m_T>40 for signal



H+ limits





- Most sensitive result for m_{H+} > 120GeV
  - Further progress will benefit form similar techniques

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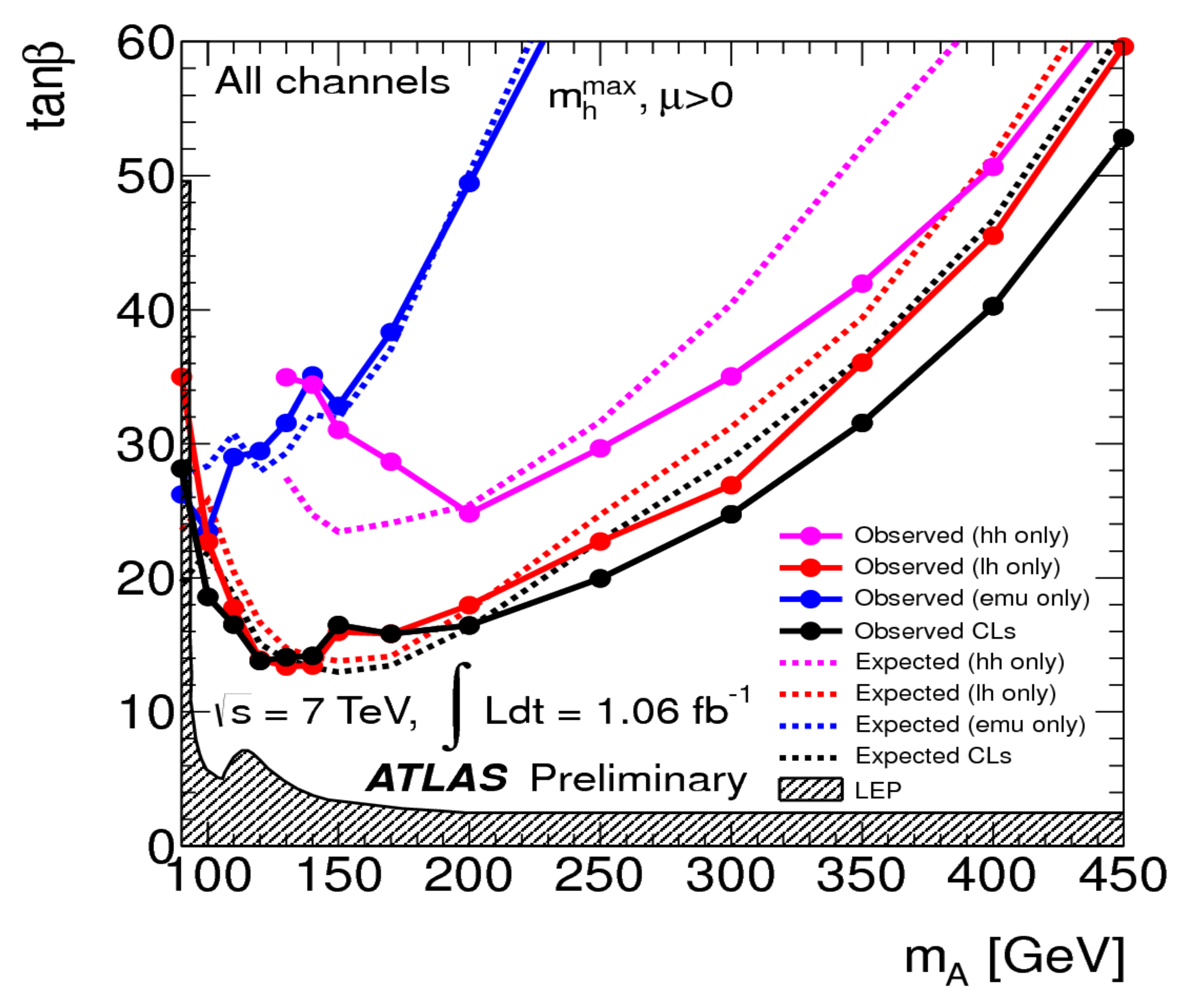
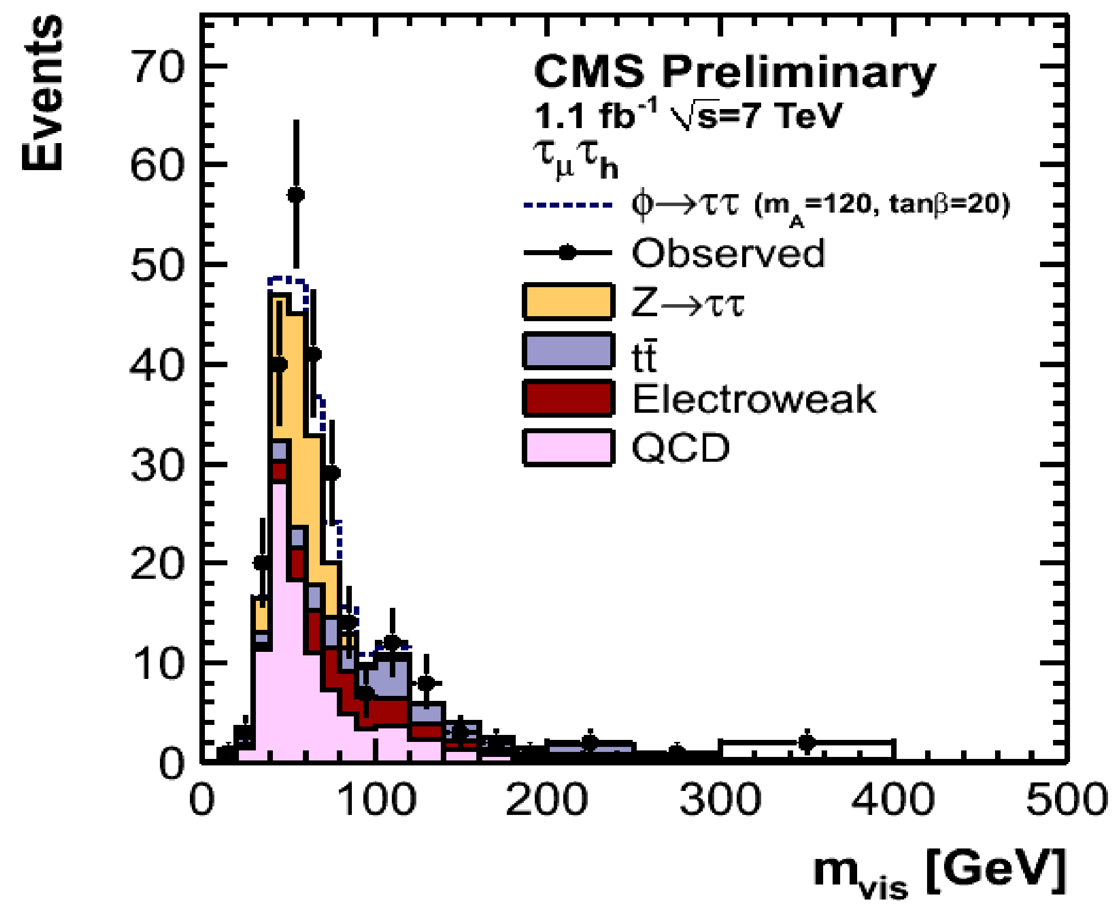
ATLAS $H \rightarrow \tau\tau$ by mode

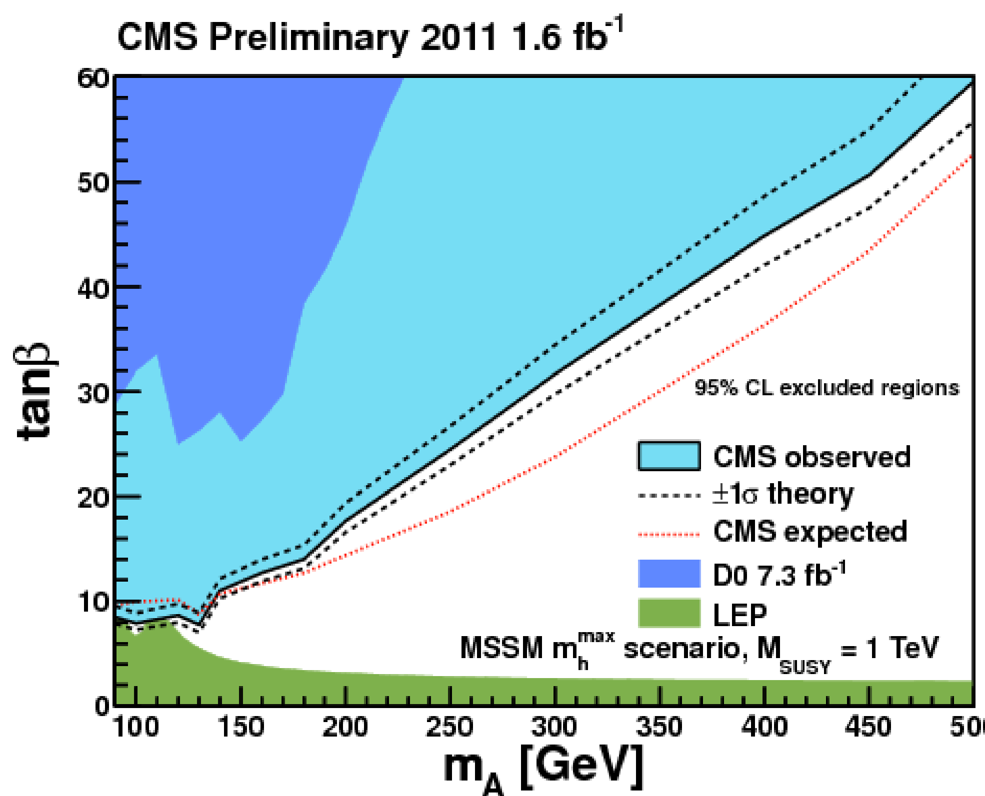
- lh generally most sensitive
- ll mode best when degenerate with Z
  - Mass resolution doesn't help
- hh importance rises with mass



CMS H/A → ττ

- Φ → ττ 2011 CMS
- eμ, $\mu\tau_h$, $e\tau_h$
- Inclusive, b-tag, VBF
- Very nice results





- Exclusion meeting LEP bound
  - As re-interpreted