Higgs Status and combinations

HPC November 2011

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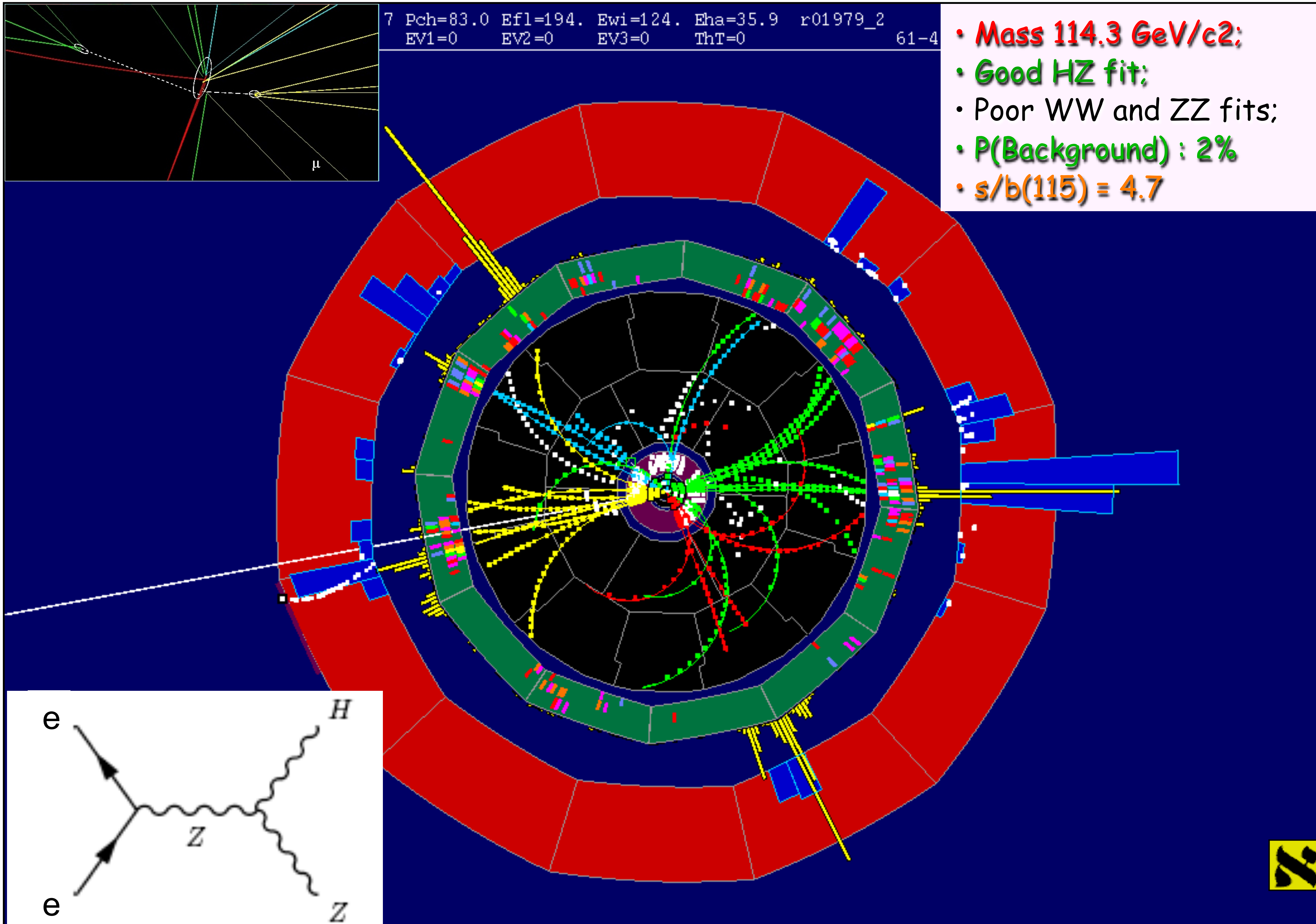
CERN and Scuola Normale Superiore , Pisa

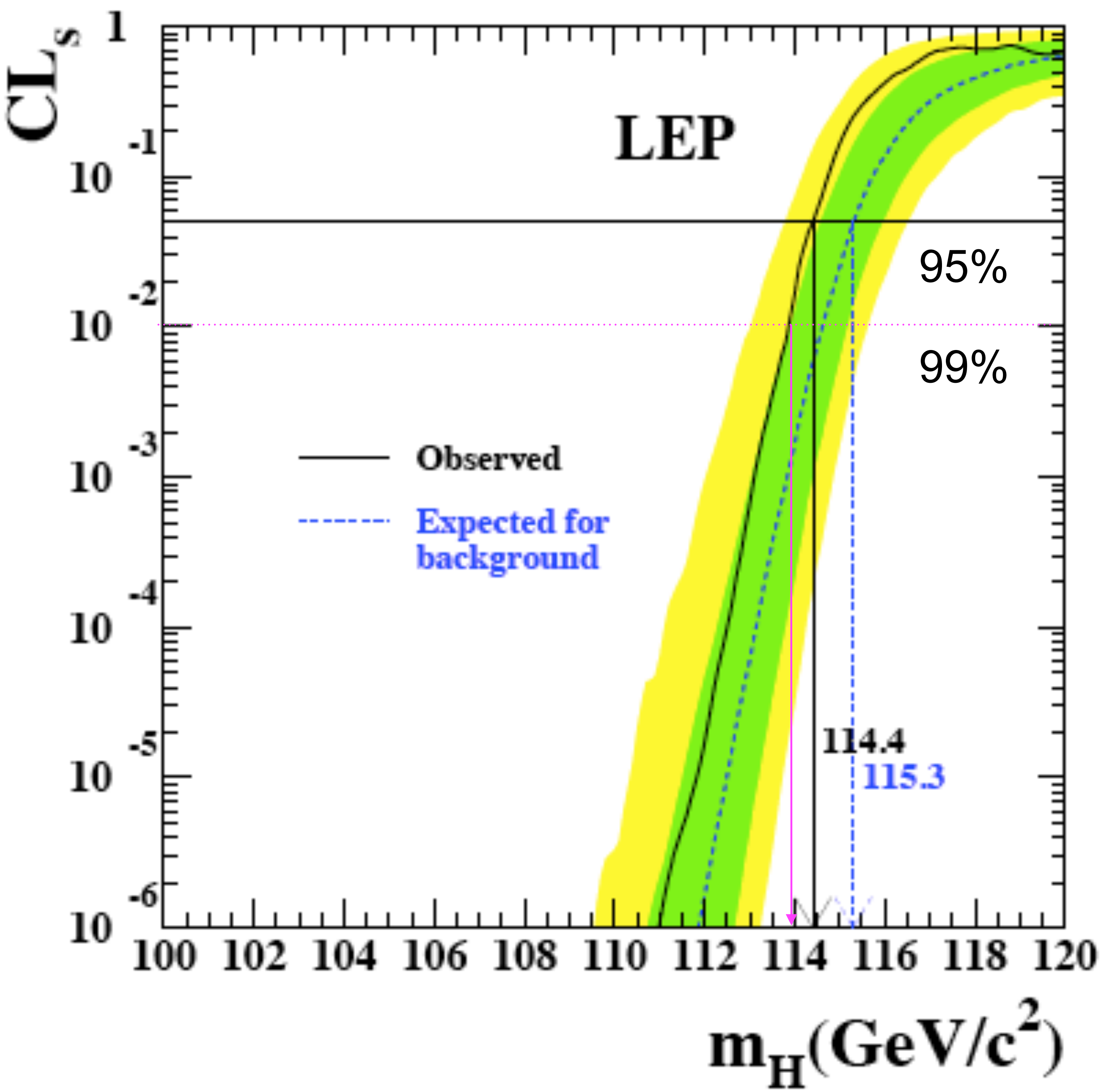
Acknowledgements: Giovanni Petrucciani for his help and many ATLAS, CDF, CMS and D0 Colleagues

Higgs Search at LEP



- Mass 114.3 GeV/c2;
- Good HZ fit;
- Poor WW and ZZ fits;
- P(Background) : 2%
- s/b(115) = 4.7

LEP Limit



± 1σ background only hypothesis

± 2σ background only hypothesis

2.4 fb^{-1} $\sqrt{s}$> 189 GeV

0.5 fb^{-1} $\sqrt{s}$> 206 GeV

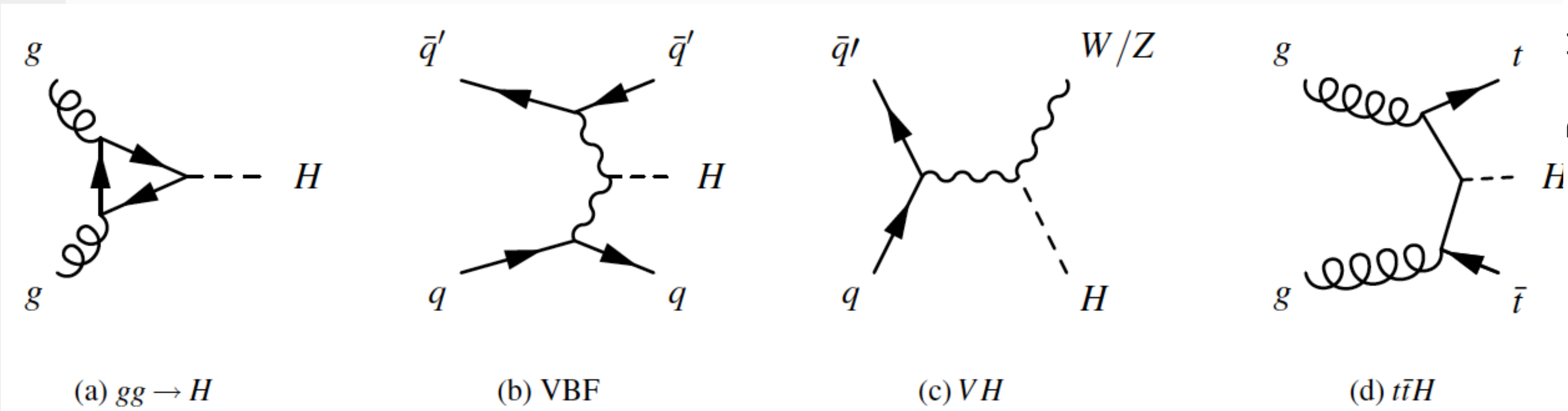
(sum of the 4 experiments)

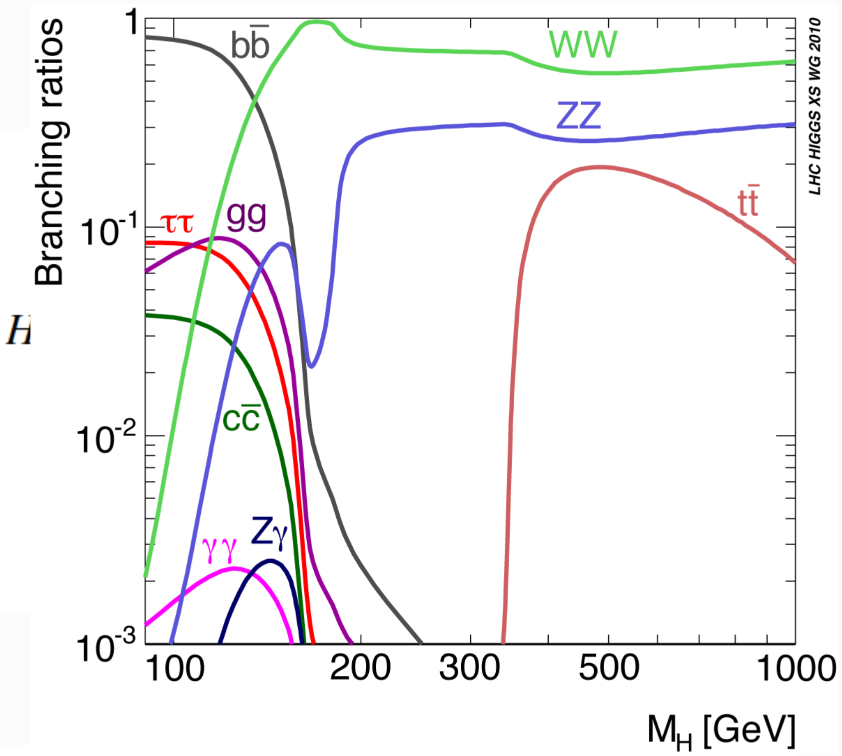
Limit on M_H at the kinematical limit ~ $\sqrt{s}-M_Z$

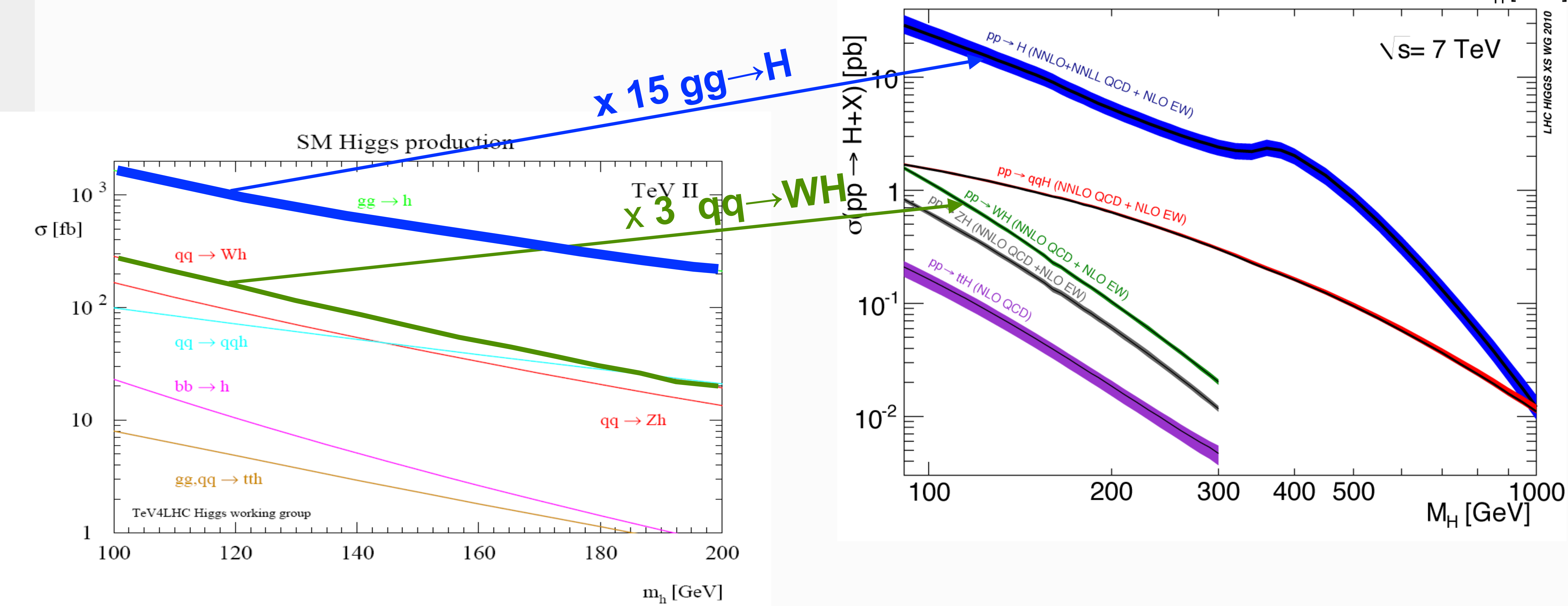
Observed exclusion 95% CL < 114.4 GeV

Expected exclusion 95% CL < 115.3 GeV

Higgs production $p\bar{p}$@2TeV vs pp@7Tev

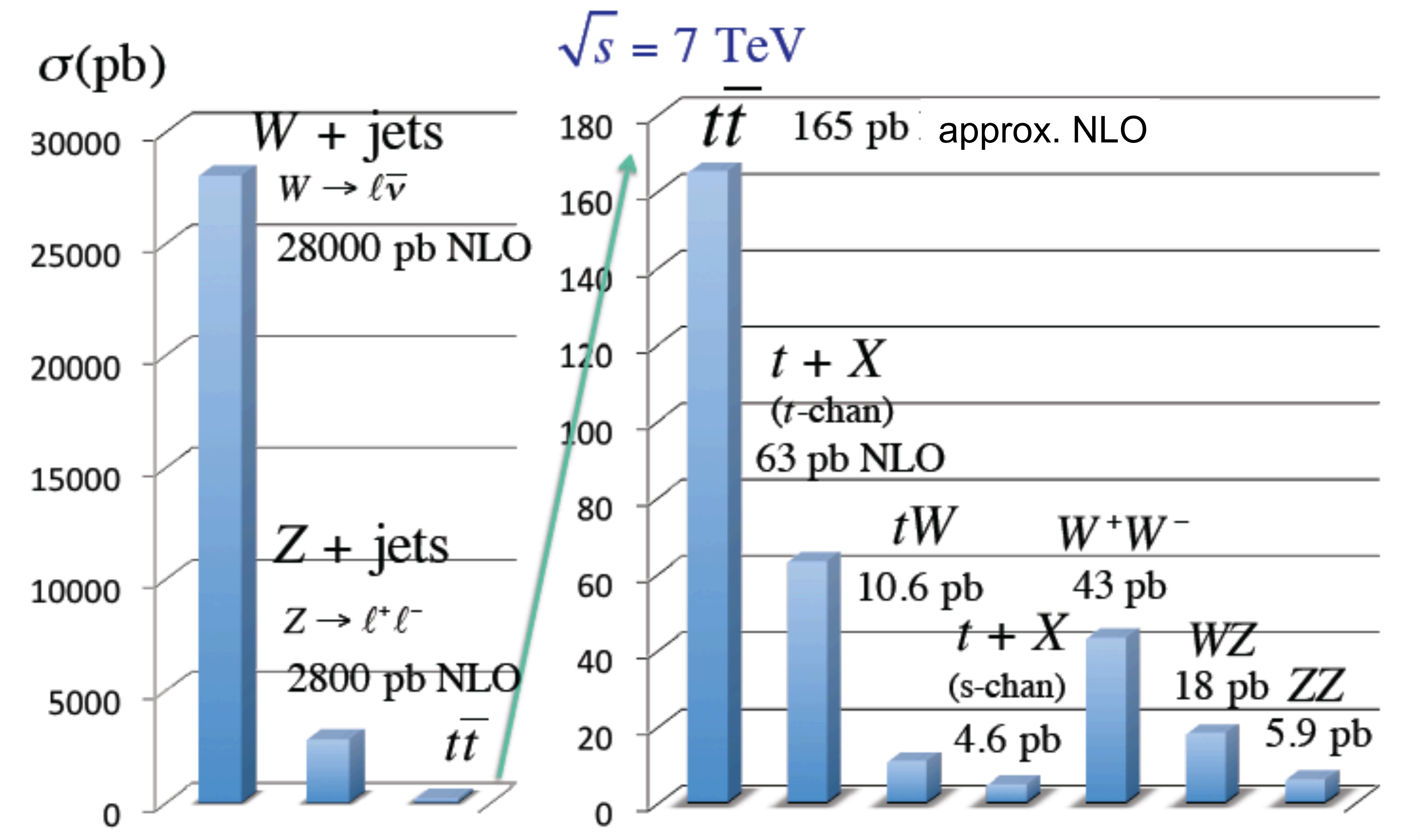






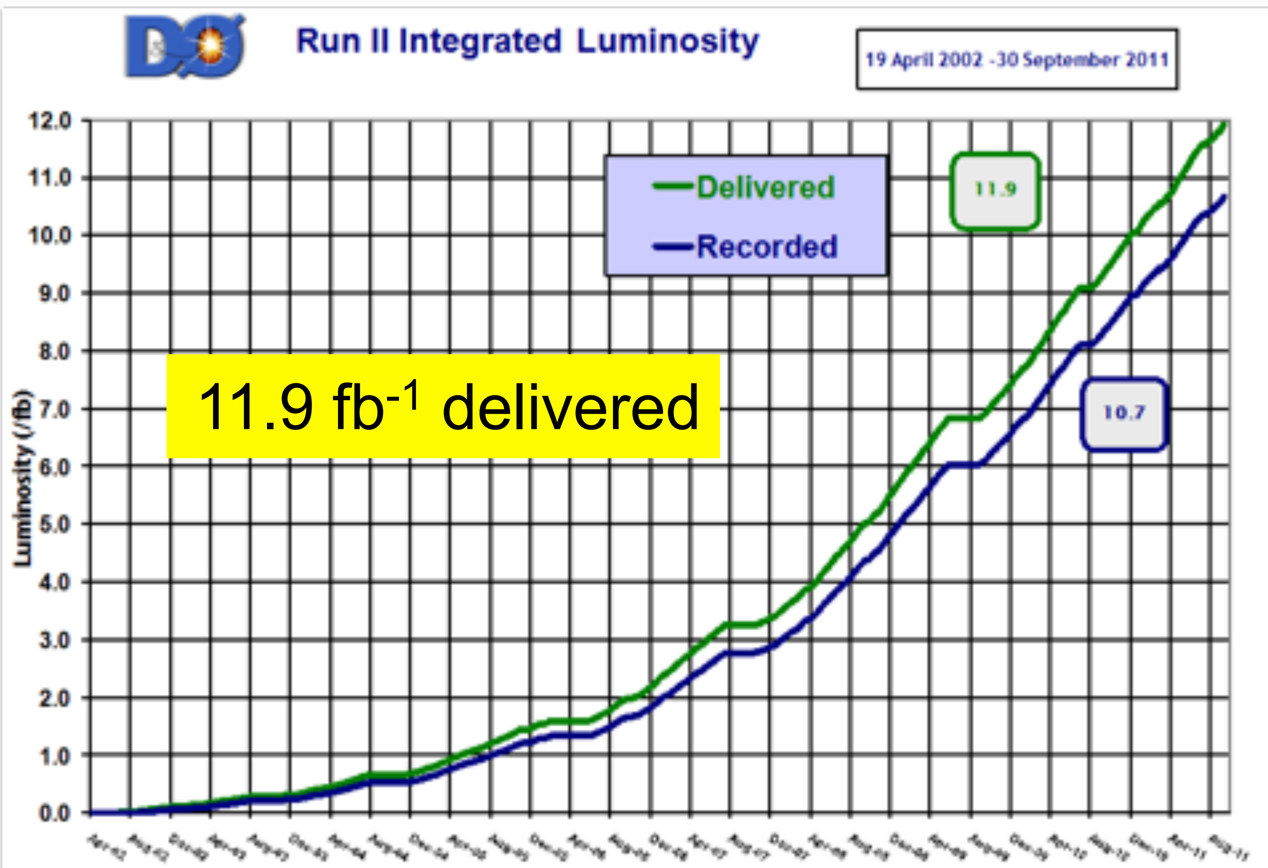
Key SM Background processes

AT LHC

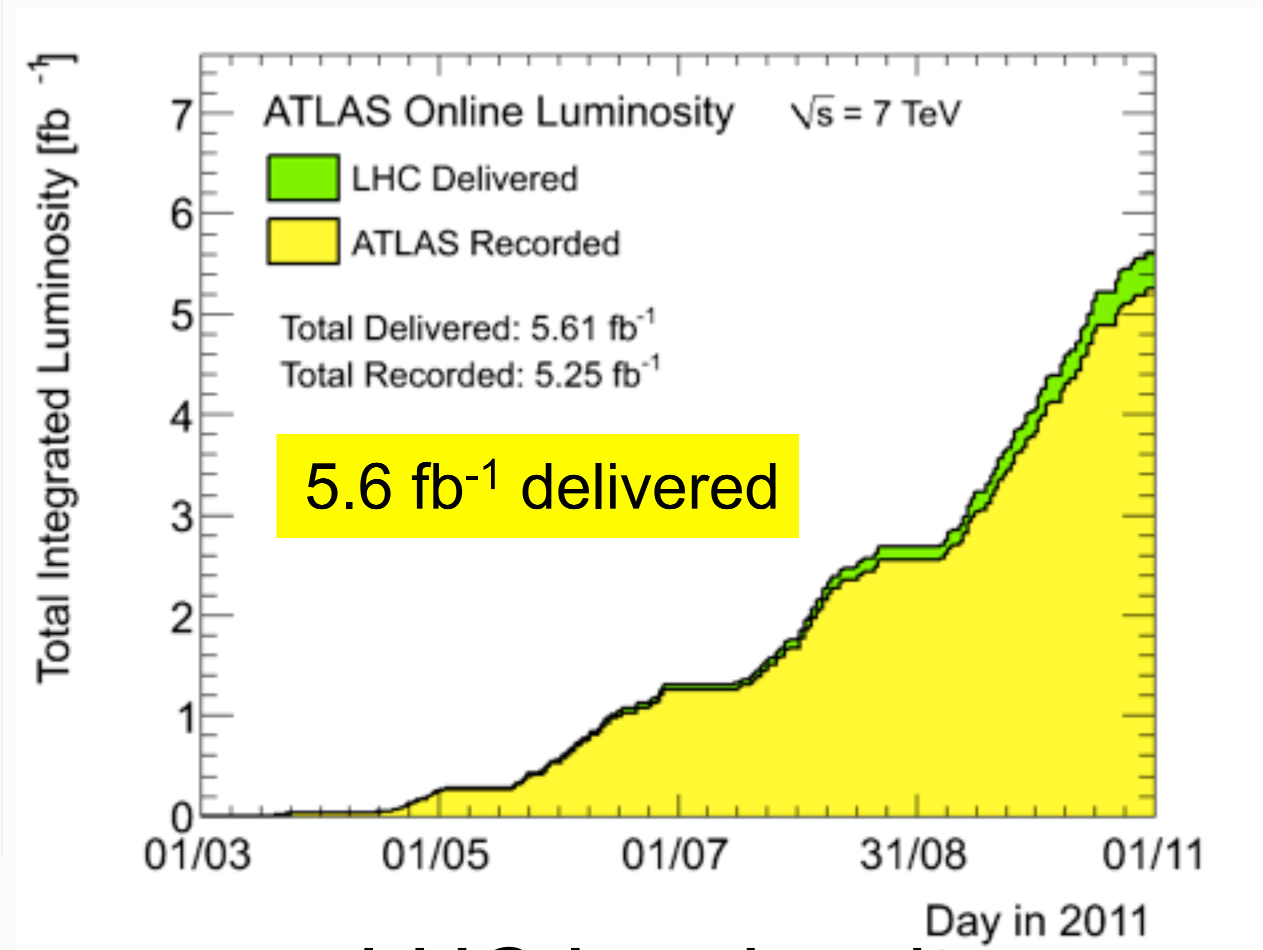


V. Sharma

Data sets for Higgs Searches



Tevatron Luminosity

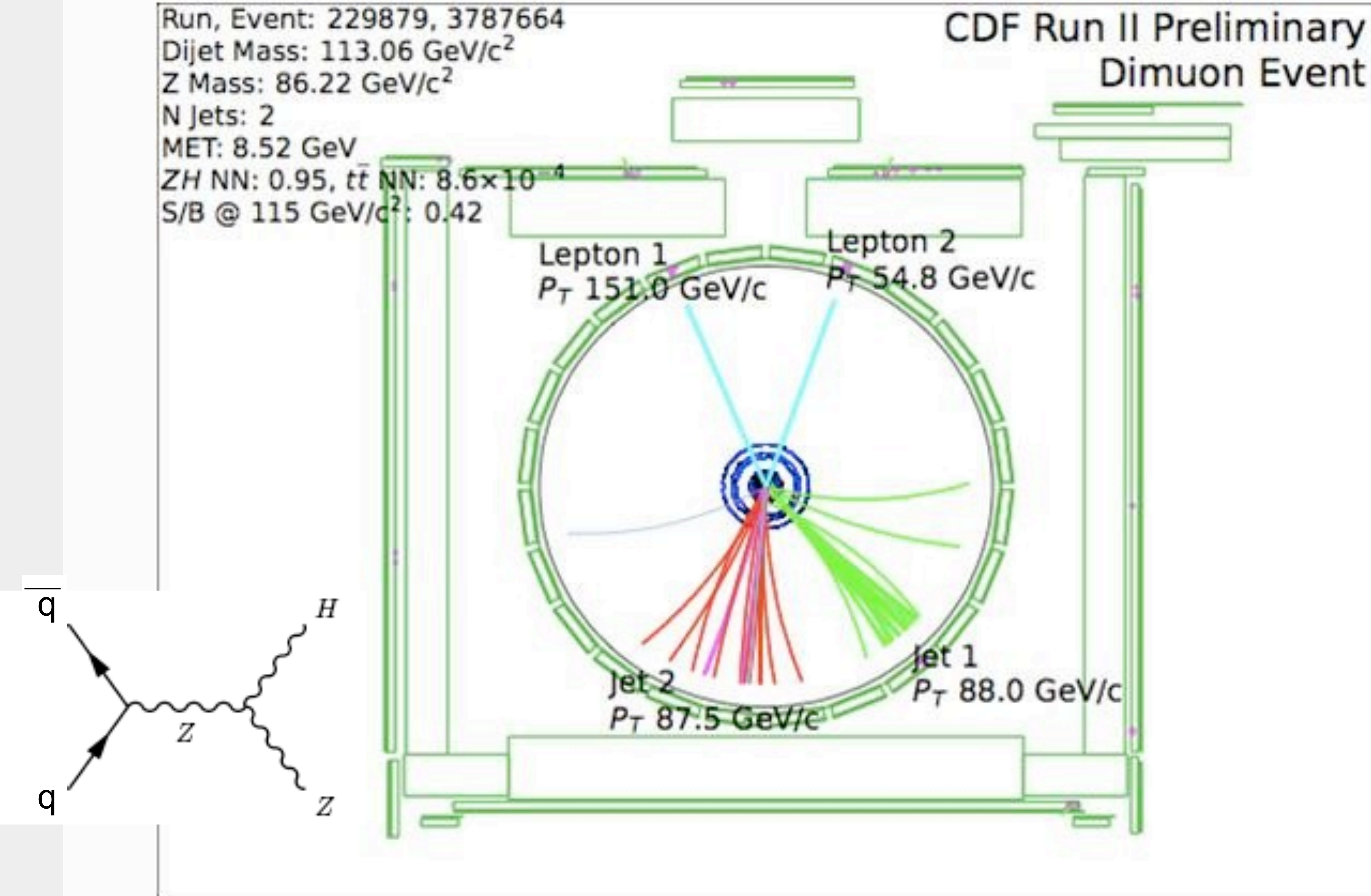


LHC Luminosity

HCP2011 analyses <8.6 fb^{-1}

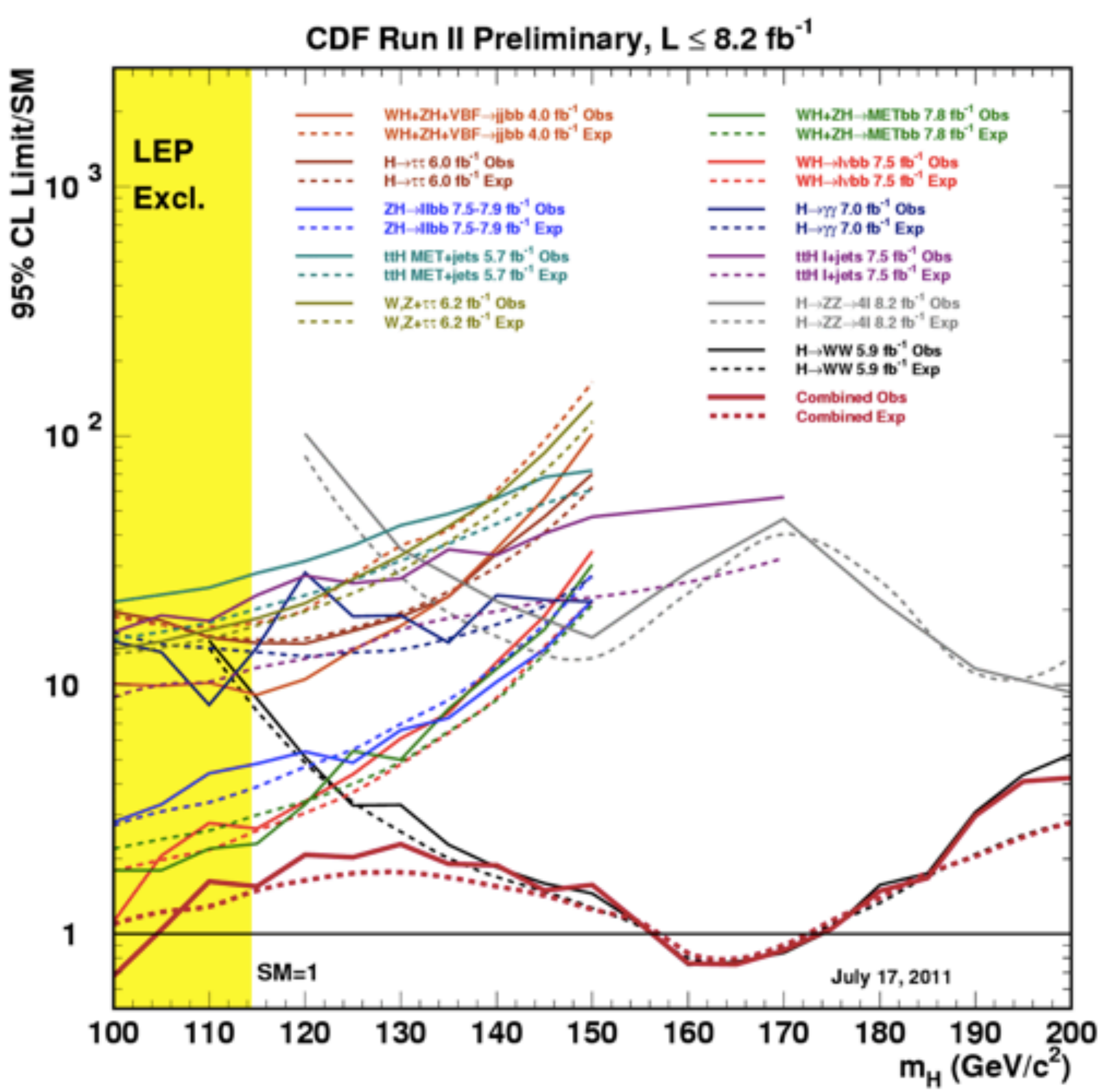
HCP2011 analyses < 2.3 fb^{-1}

Higgs Search at the Tevatron



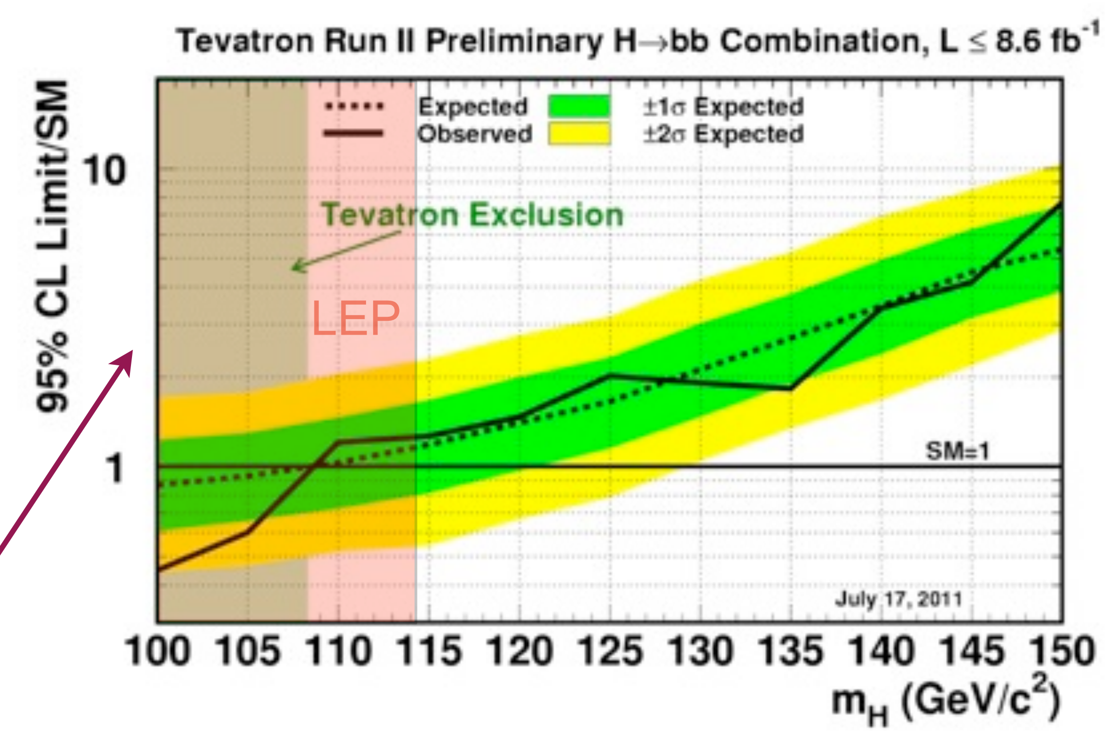
Tevatron results

talks by: Petridis/Sforza/Yao



Best sensitivity obtained by combining many channels.

VH→Vbb is the most sensitive channel for M_H~115 GeV



μ_{up} expected/observed upper limit on the signal strength modifier, $\mu = \sigma/\sigma_{SM}$,

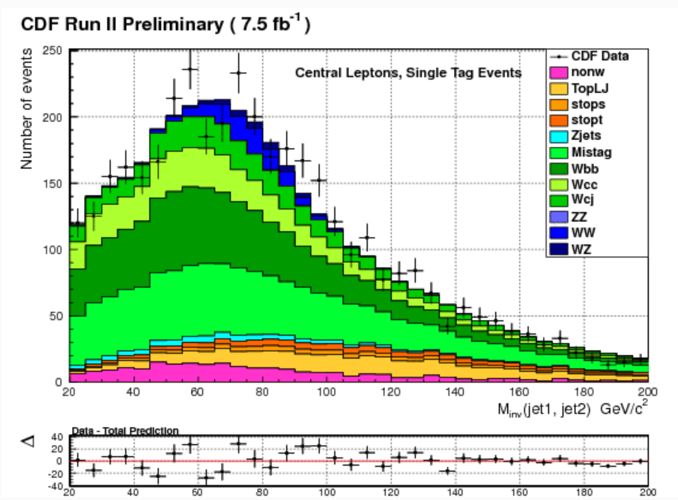
LHC expected limit H→bb@1 fb^{-1} ~ 5 x SM

Dibosons searches as proxy for VH→Vbb

talk by Grivaz

For MH=115 GeV, VH→Vbb is 46 fb , while VZ→Vbb is 202 fb.
The cross section for diboson production is 4.5 times larger than for VH. But the background situation at lower mass is more difficult.

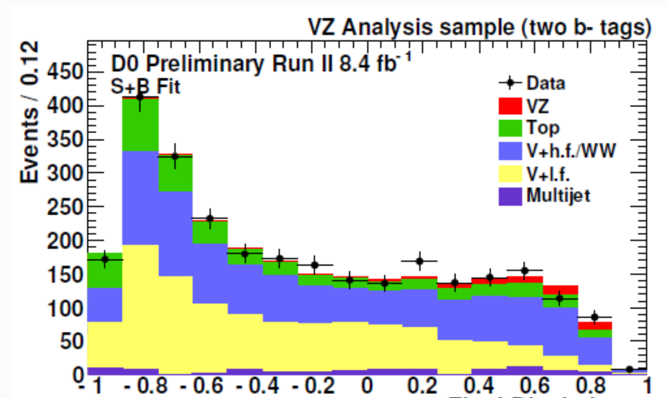
WW+WZ in lν+HF

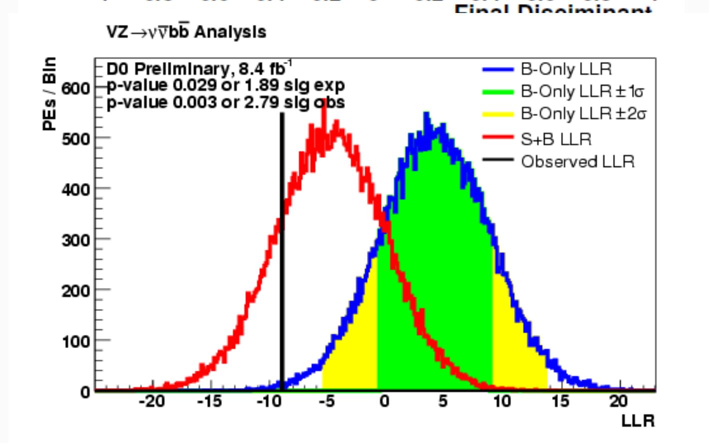


WW/WZ ratio fixed as in the SM
Large contribution from WW→lνcs
3.0 σ from the B-only hypothesis
(3.0 expected)
Good agreement with S+B:
σ (WW+WZ) = (1.1 +0.3 -0.4) **σ_SM**

CDF

WZ/ZZ in MET + HF





2.8 σ from the B-only
(1.9 expected)
σ(WZ+ZZ) = (1.5 ± 0.5) σ_SM
Sensitivity shared by ZZ and WZ

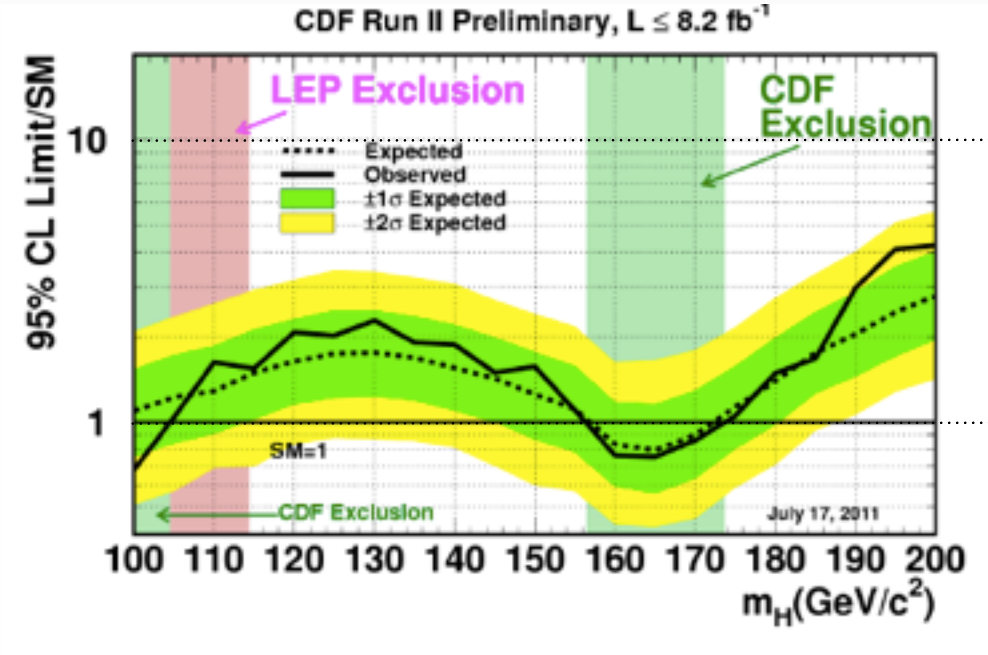
The combination of these searches has been done using the same technique as for the Higgs.

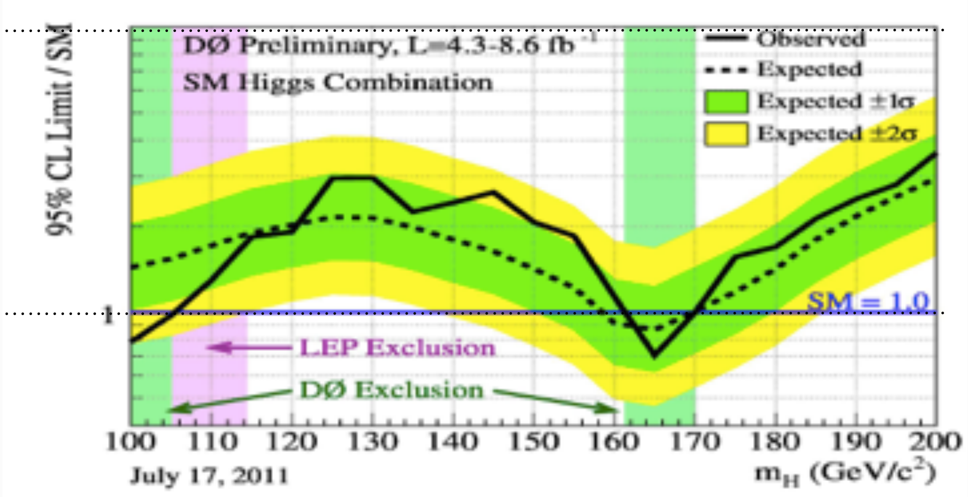
3.3 σ evidence
for WZ+ZZ combined
(2.9 expected)

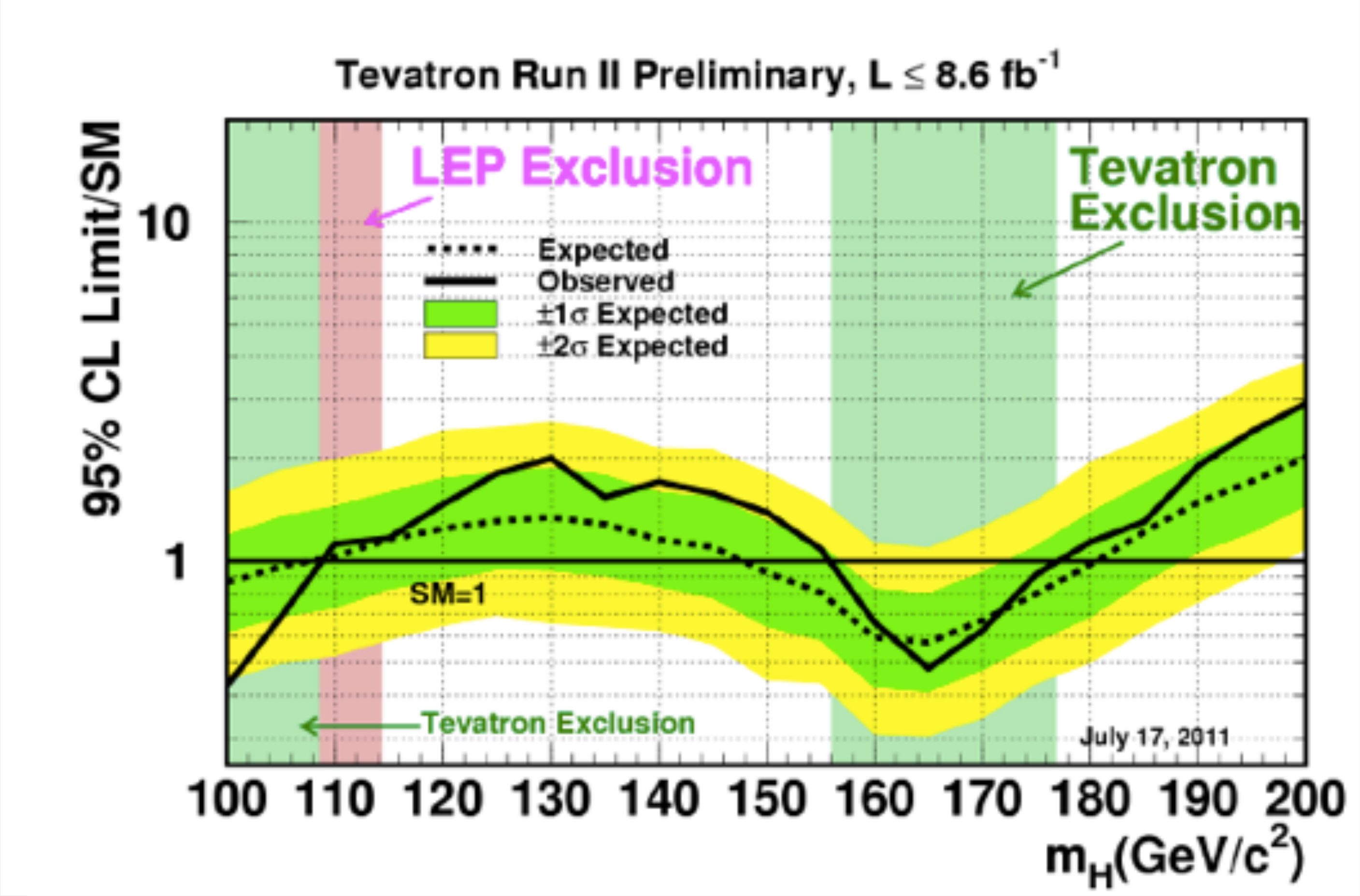
Good agreement with S+B:
σ(WZ+ZZ) = (1.13 ± 0.36) σ_SM

D0

Tevatron Limits



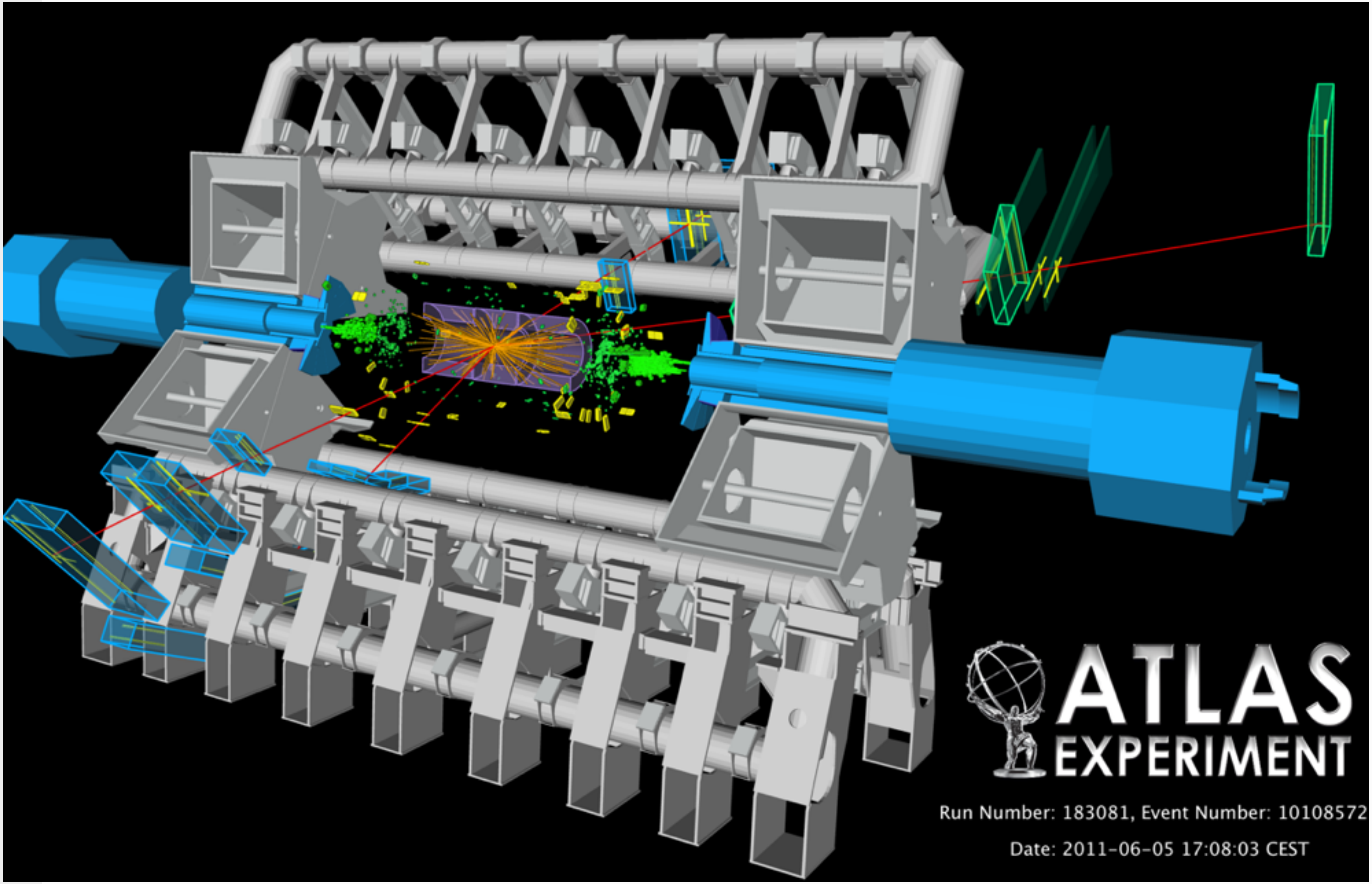




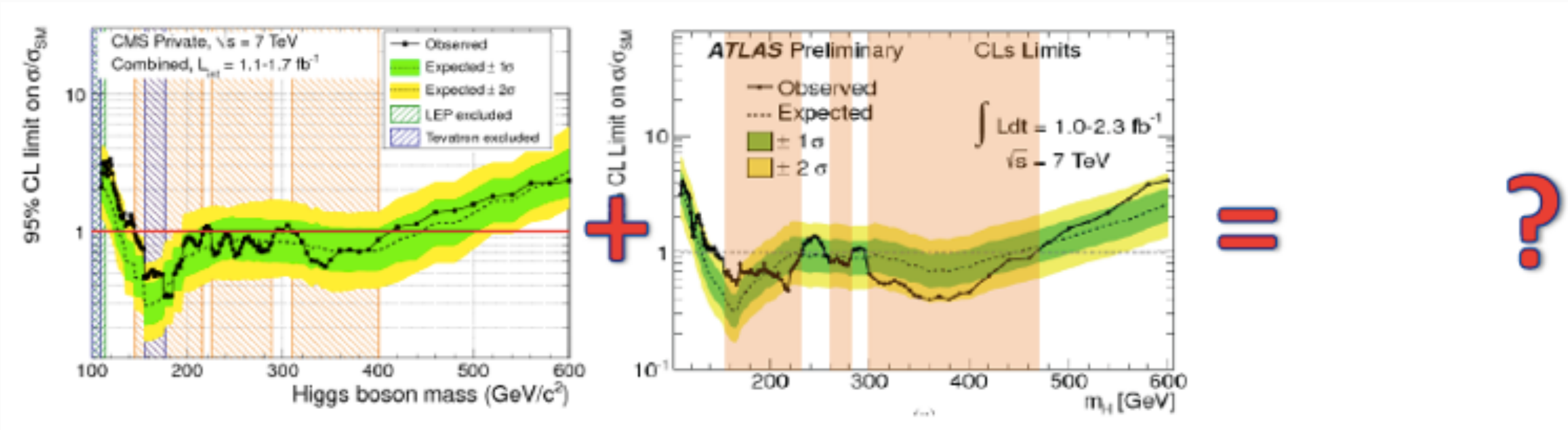
Observed exclusion 95% CL
100-109 156-177 GeV

Expected exclusion 95% CL
100-108 148-181 GeV

Higgs Search at LHC



LHC Combination SM Higgs searches



Performed by LHC Higgs Combination Group

- Combining the results presented at Summer Conferences

- All ATLAS and CMS analyses entering in the combination are documented

- Consistent treatment of the systematic errors in the two Collaborations
- Careful (conservative) attention to correlations

ATLAS-CONF-2011-157 - CMS-PAS-HIG-11-023

Channels entering in the combination

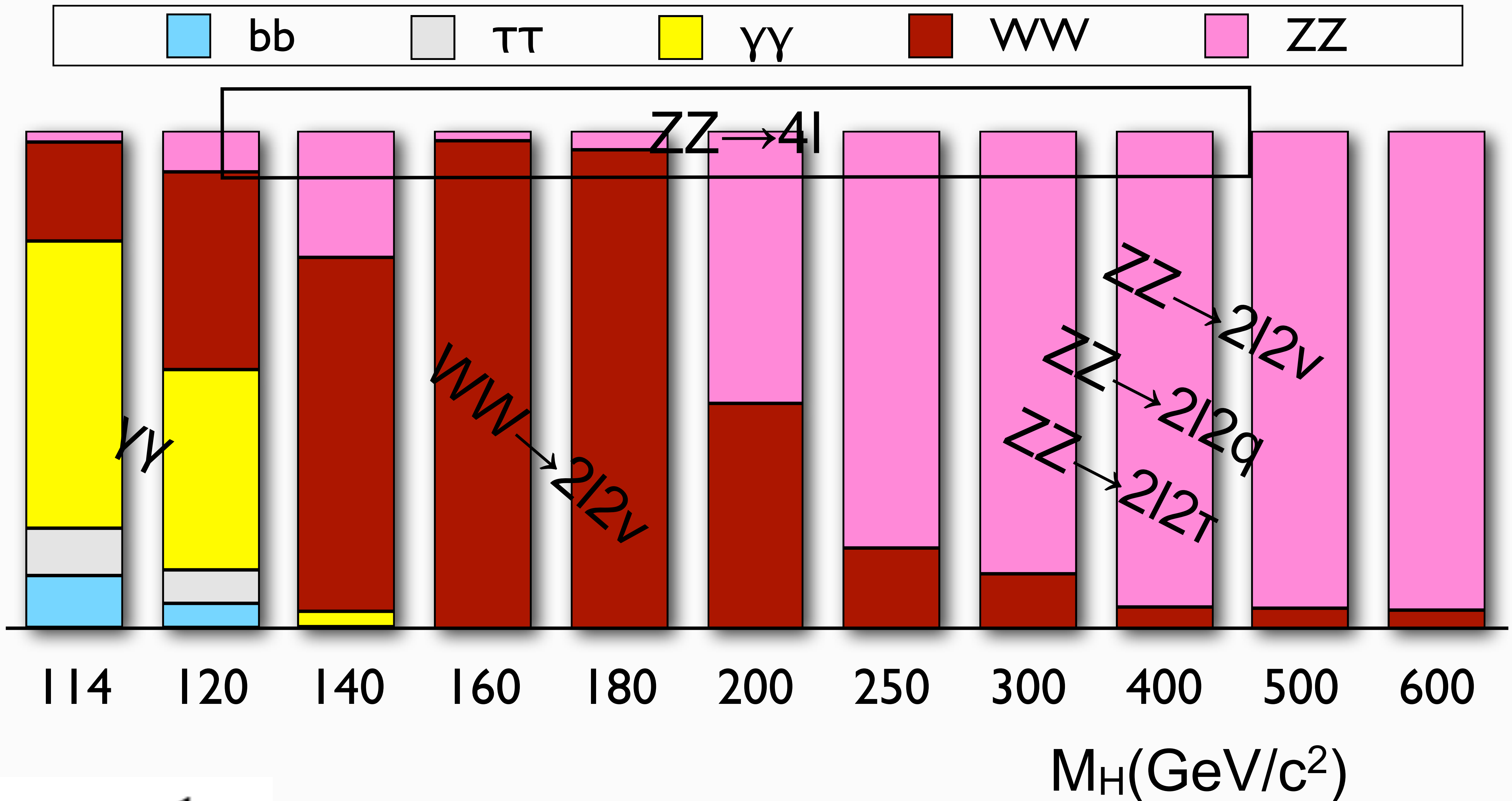
Talks by Iconomidou-Fayard/Codispoti/Duehrssen/Rekovic/Tarrade/Bluj

	Channel	Collab.	m_H range	Lumi.	Type of analysis
low mass	H → bb	CMS	110-135	1.1	MVA cut & count
		ATLAS	110-130	1.0	mass shape
low mass	H → ττ	CMS	110-140	1.6	mass shape (binned)
		ATLAS	110-150	1.1	mass shape (binned)
low mass	H → γγ	CMS	110-150	1.7	mass shape (unbin.)
		ATLAS	110-150	1.1	mass shape (unbin.)
low mass high mass	H → WW → 2l2ν	CMS	110-600	1.5	cut & count
		ATLAS	110-300	1.7	cut & count
low mass high mass	H → ZZ → 4l	CMS	110-600	1.7	mass shape (unbin.)
		ATLAS	110-600	2.3	mass shape (binned)
high mass	H → ZZ → 2l2τ	CMS	180-600	1.1	mass shape (binned)
high mass	H → ZZ → 2l2q	CMS	225-600	1.6	mass shape (unbin.)
		ATLAS	200-600	1.0	mass shape (binned)
high mass	H → ZZ → 2l2ν	CMS	250-600	1.6	cut & count
		ATLAS	200-600	2.0	m_T shape (binned)

Search in the range 110 to 600 GeV

Weight of the individual channels

In the combination presented today



$$w_i = \frac{\frac{1}{\mu_{up,i}^2}}{\sum_j \frac{1}{\mu_{up,j}^2}}$$

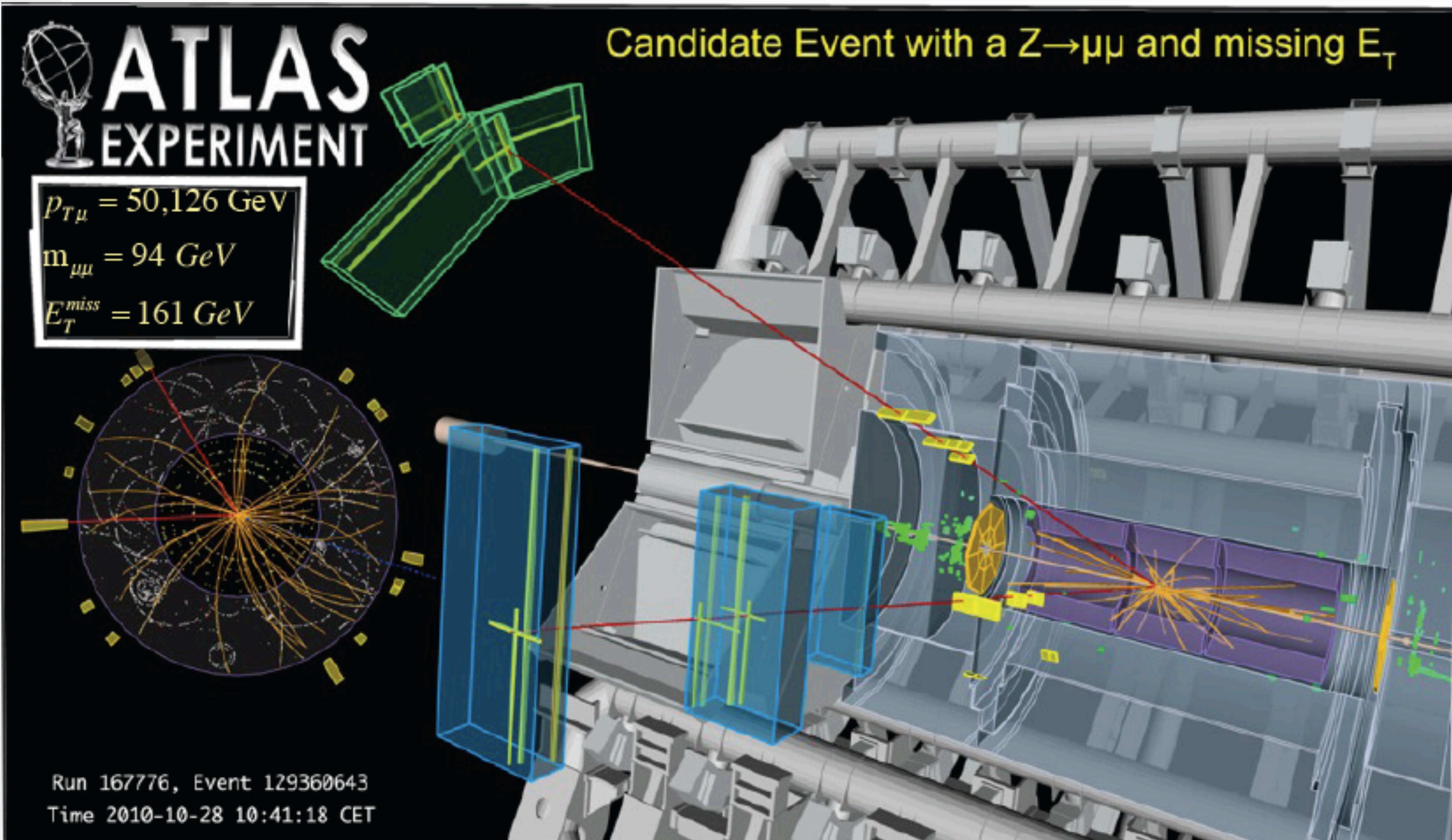
μ_{up} expected upper limit on the signal strength modifier, $\mu = \sigma/\sigma_{SM}$,

The w_i depend on the amount of integrated luminosity of each channel. They are computed in the asymptotic approximation.

Cowan, Cranmer, Gross, Vittels EPJC 71:1554

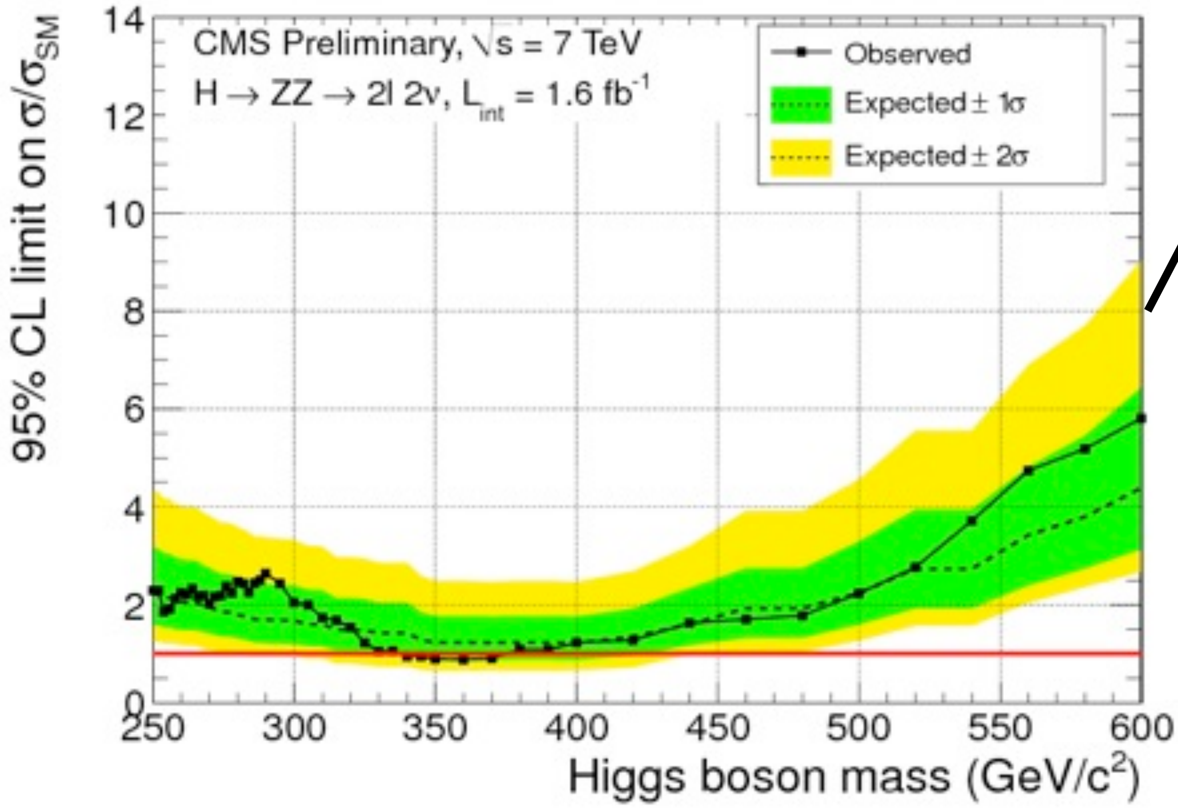
High Mass Region

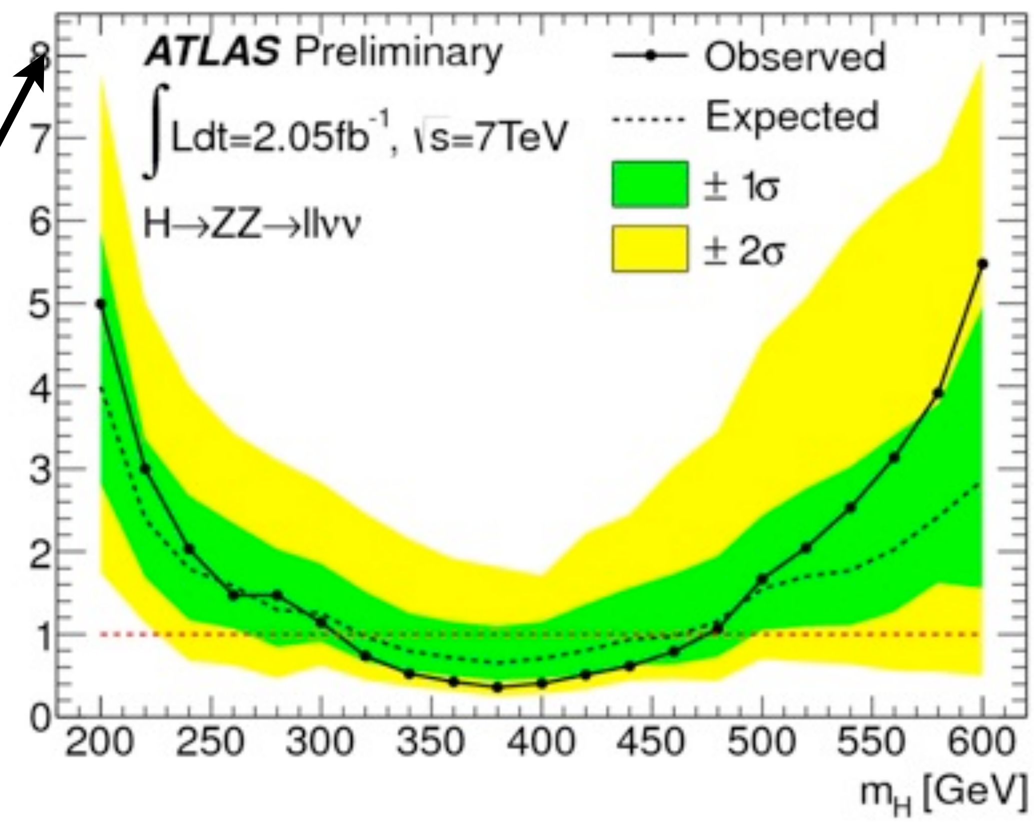
H→ZZ→llνν: Signature two isolated high pt leptons of opposite charge and missing transverse energy



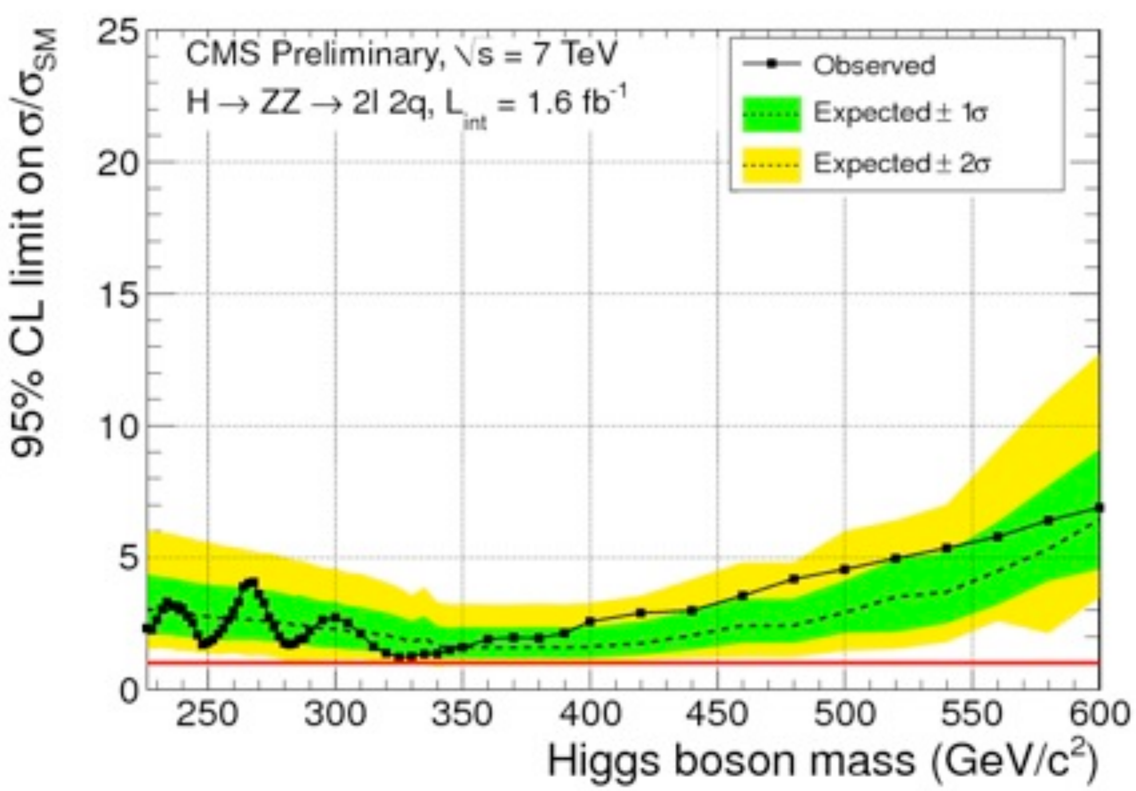
High Mass region

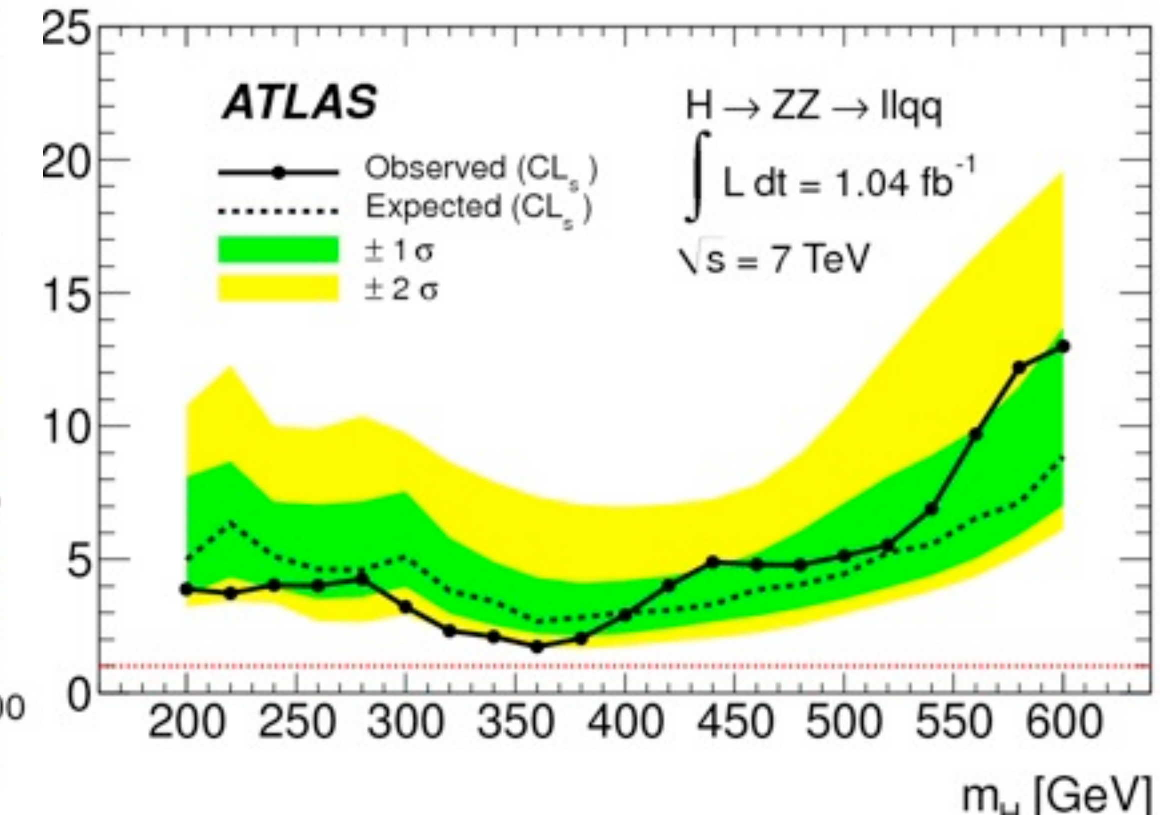
$H \to ZZ \to ll\,\nu\nu$





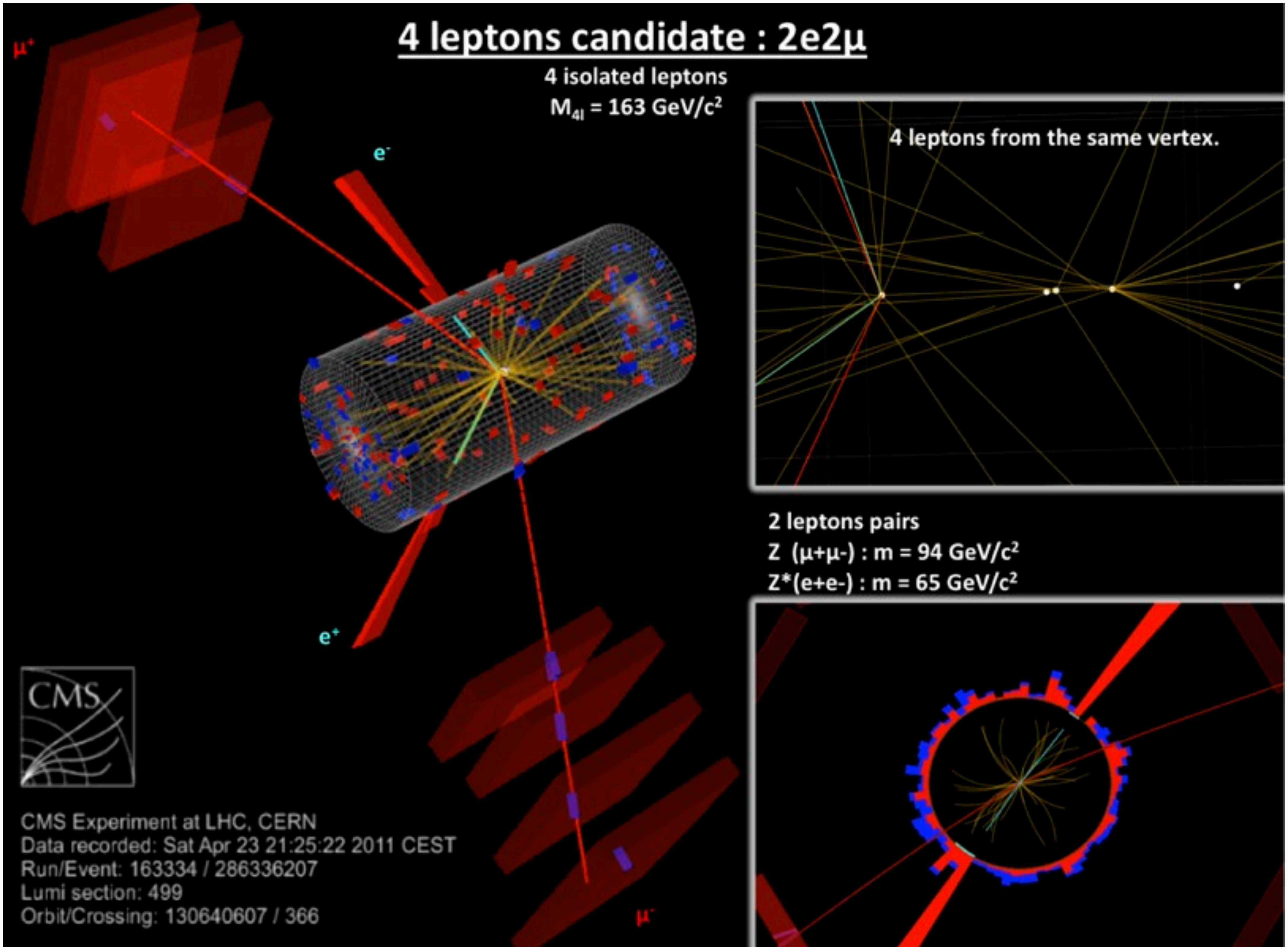
$H \to ZZ \to ll\,qq$





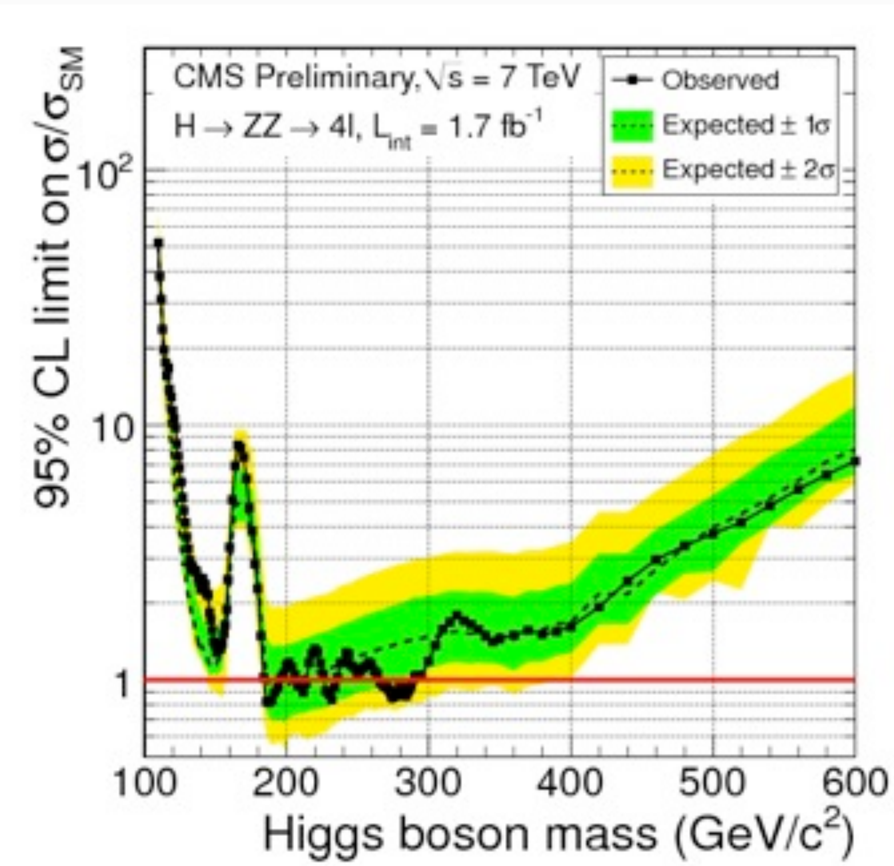
H→ZZ→4 leptons (golden channel)

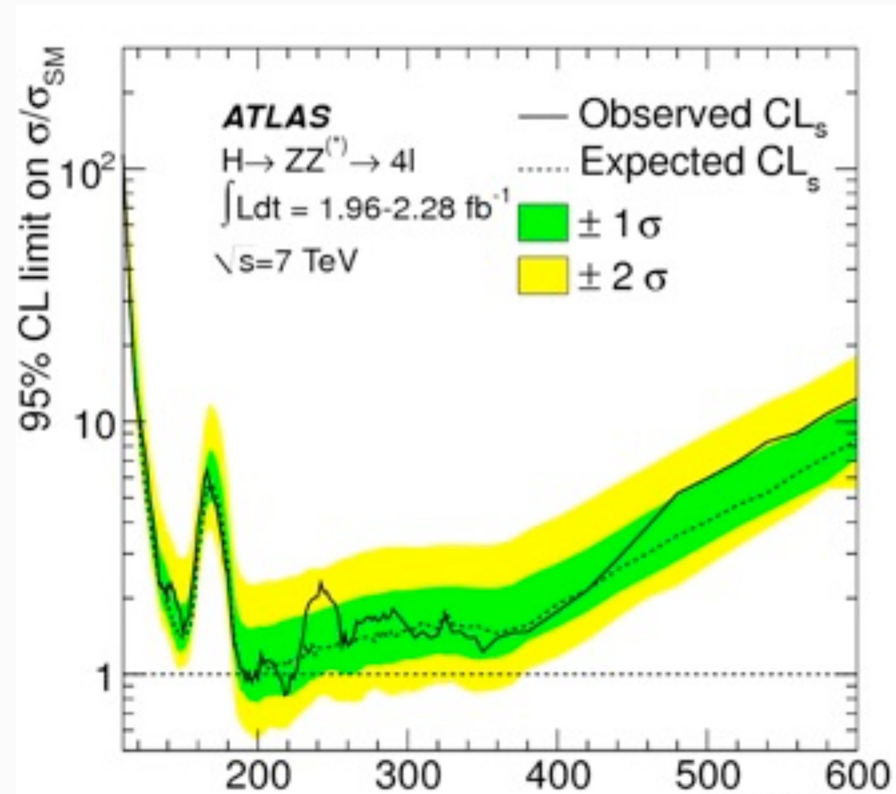
Very clean, full reconstruction of the event



H→ZZ→4 leptons (golden channel)

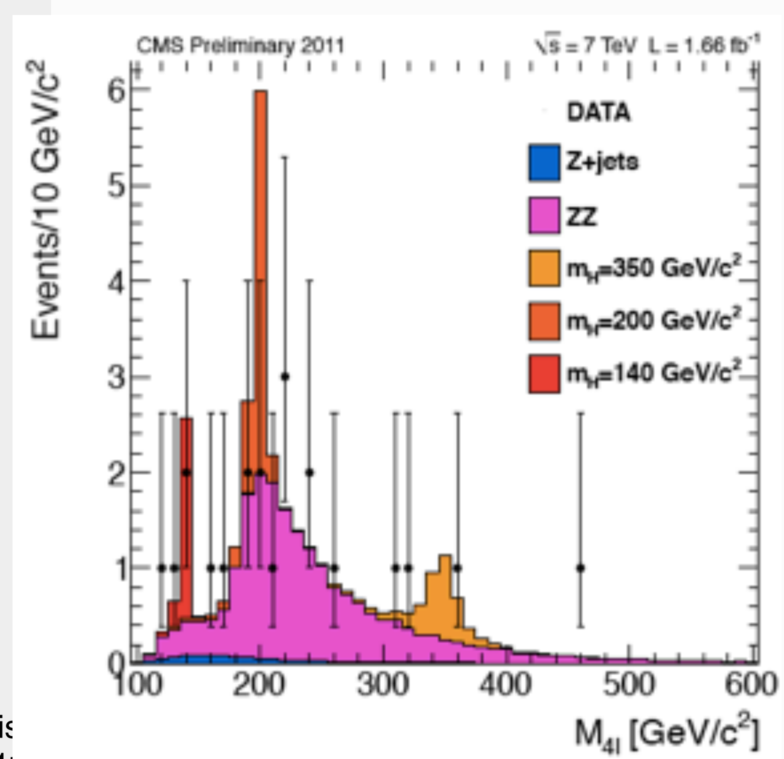
Very clean with full reconstruction of the event





Resolution :FWHM

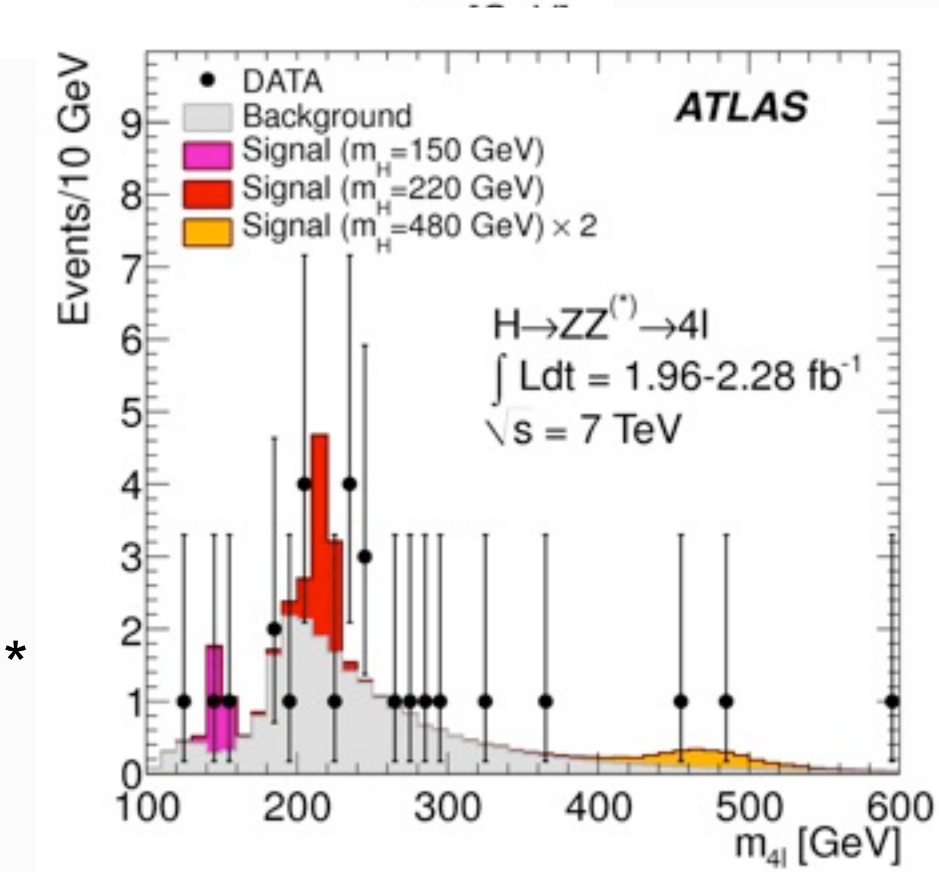
3.5 ÷ 6.5 GeV



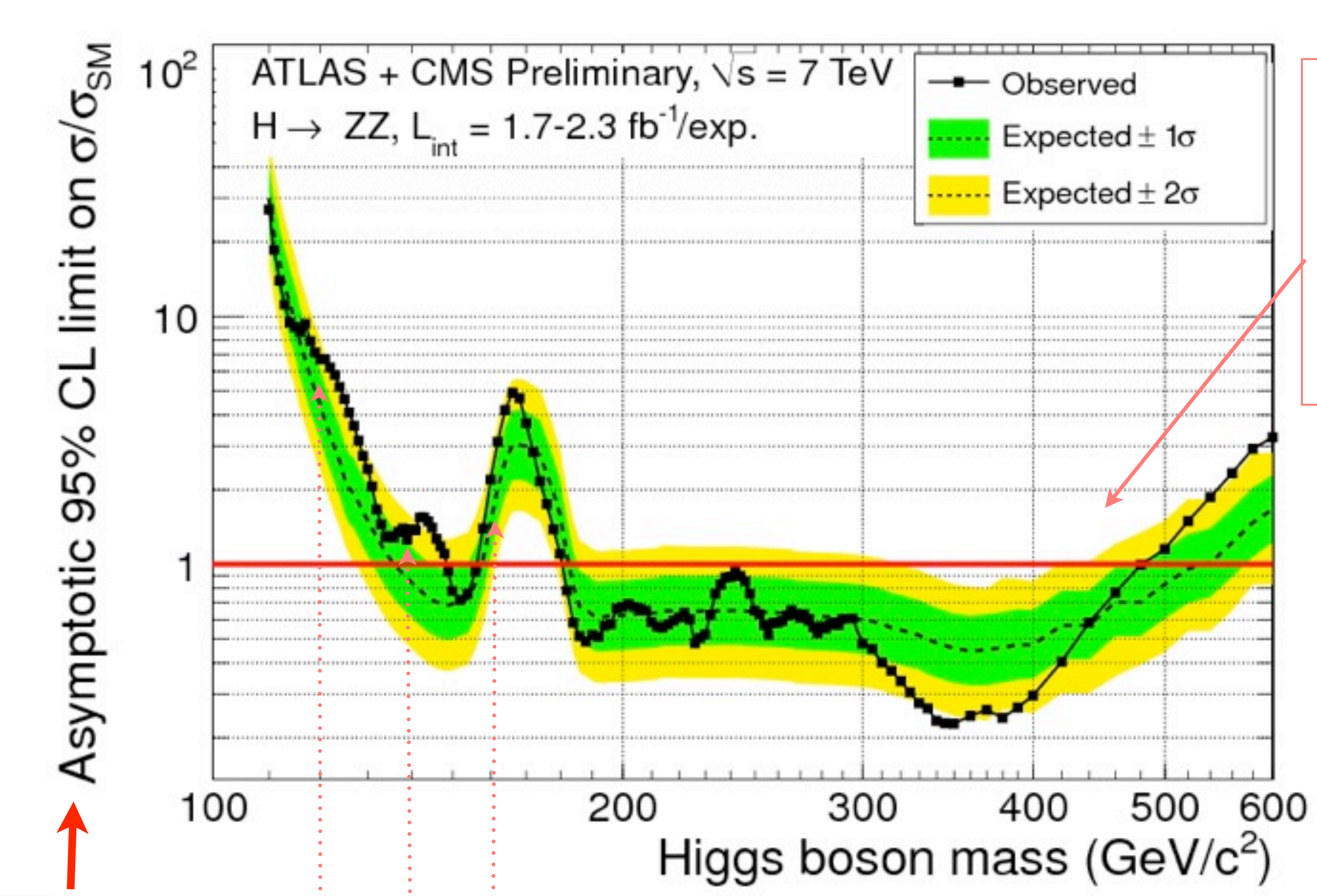
Small excess for m<180 GeV
CMS 6 events ~3 expected*
ATLAS 3 events ~ 3 expected*

CMS M_H=140 ~ 3 expected*
ATLAS M_H=150 ~ 2.3 expected*

* at ~ 10% level

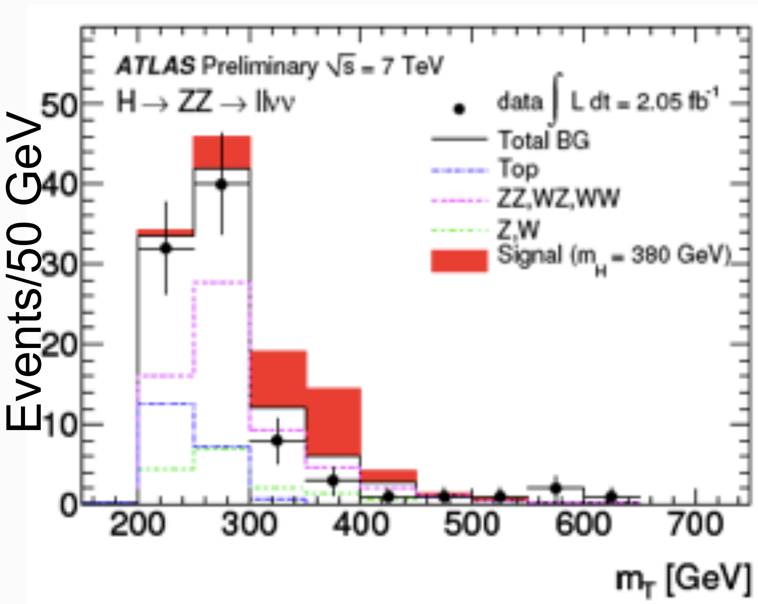


H→ ZZ combined



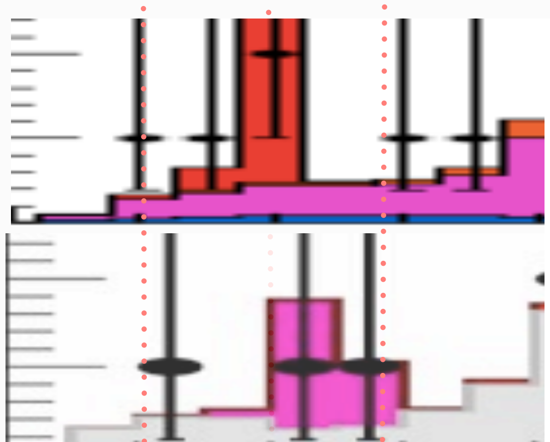
ZZ channels alone exclude 180<MH<480 GeV

High mass search has little background



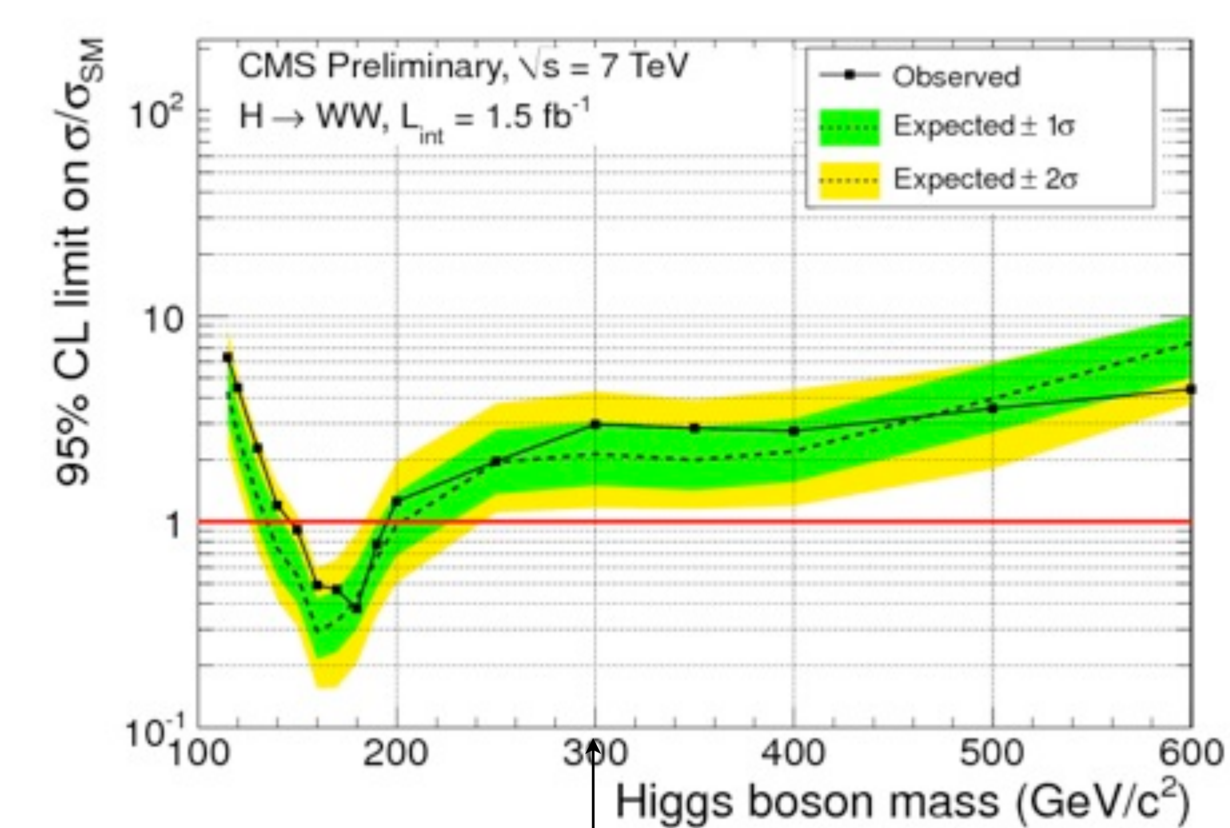
CMS

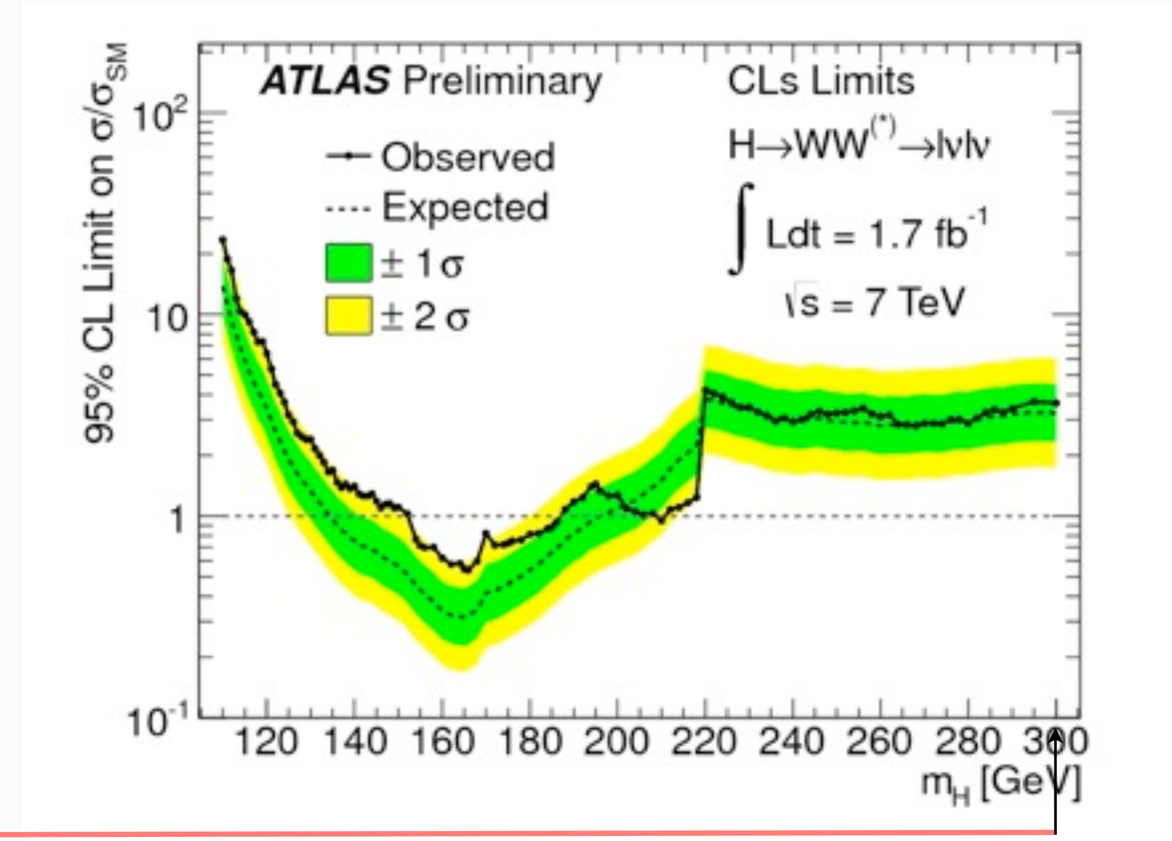
ATLAS

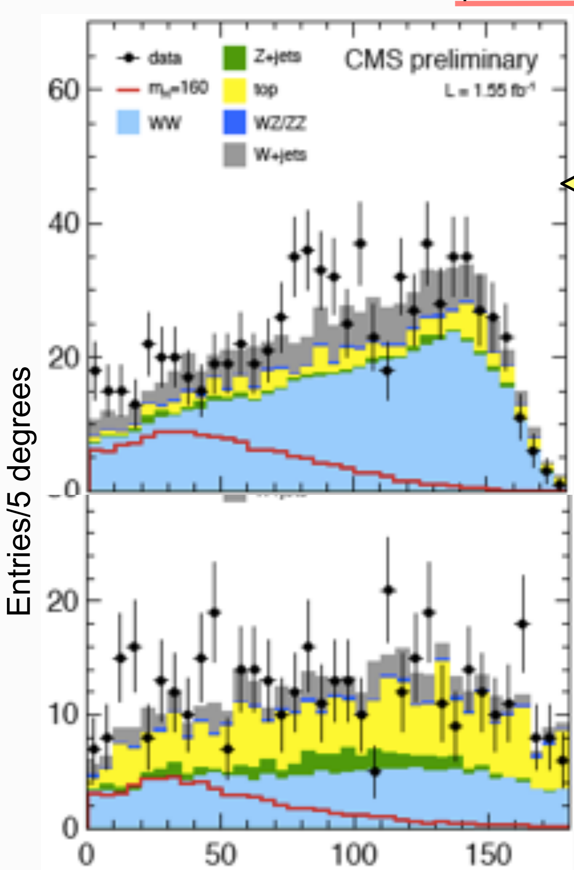


For m<180 GeV the number of expected events in 4 leptons per bin of mass resolution is less than 0.5. This reflects the good mass resolution, however the observation of a candidate in a given bin appears (statistically) unusual.

H→WW→2l2ν

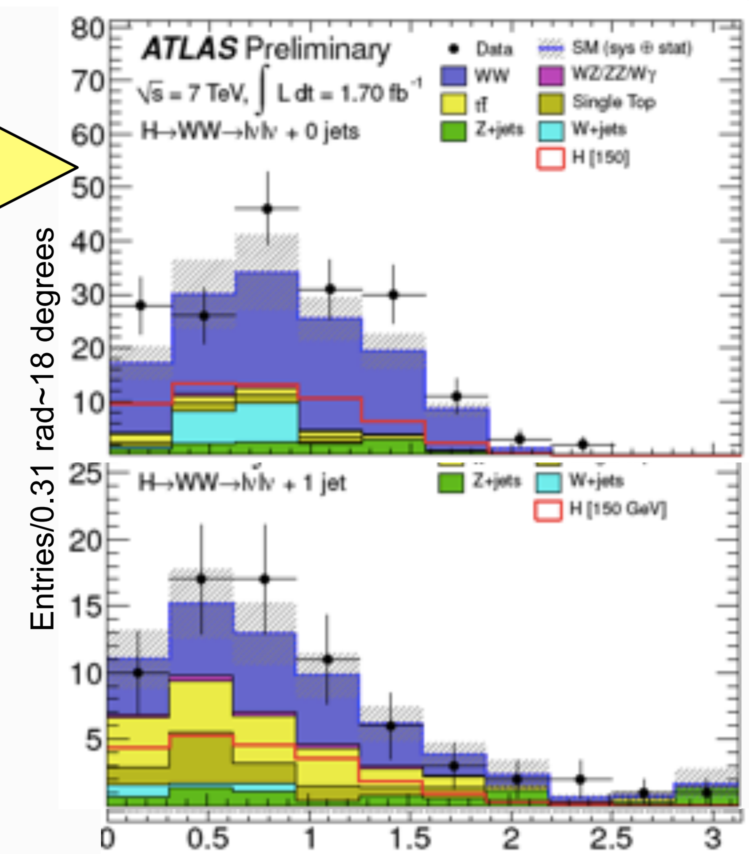






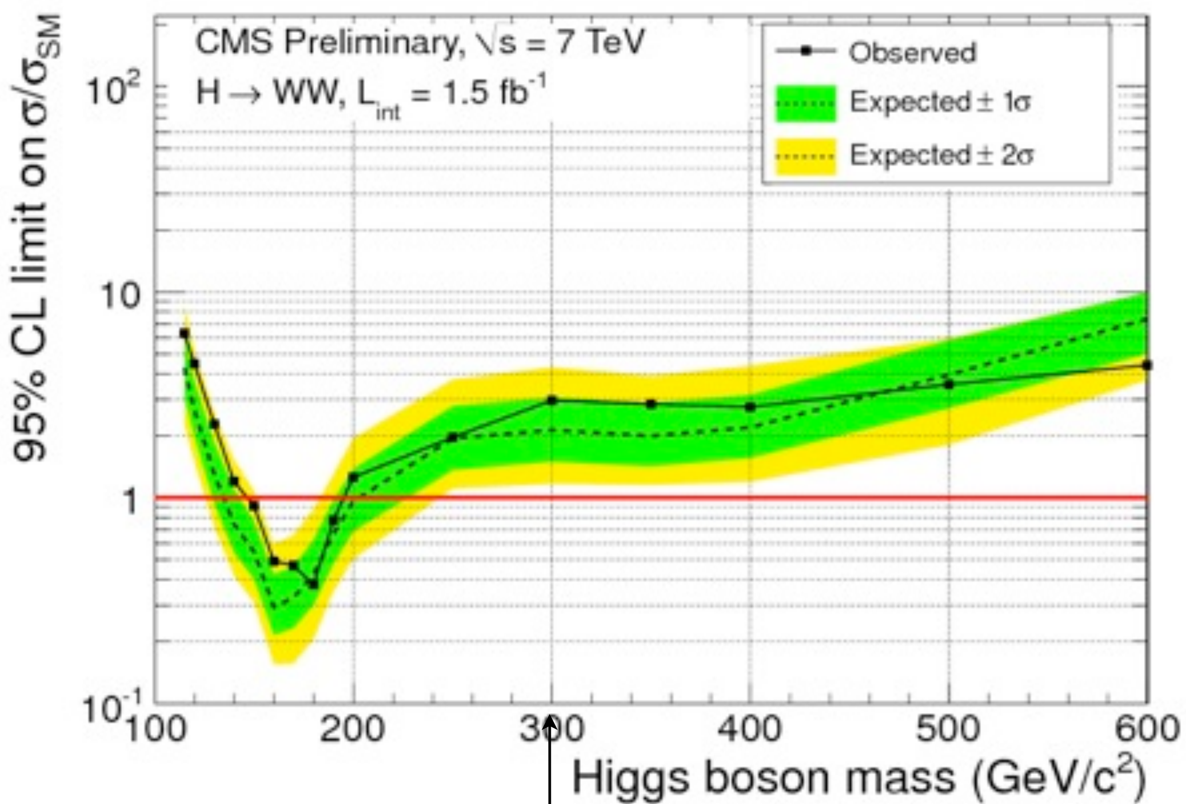
Δφ between the leptons

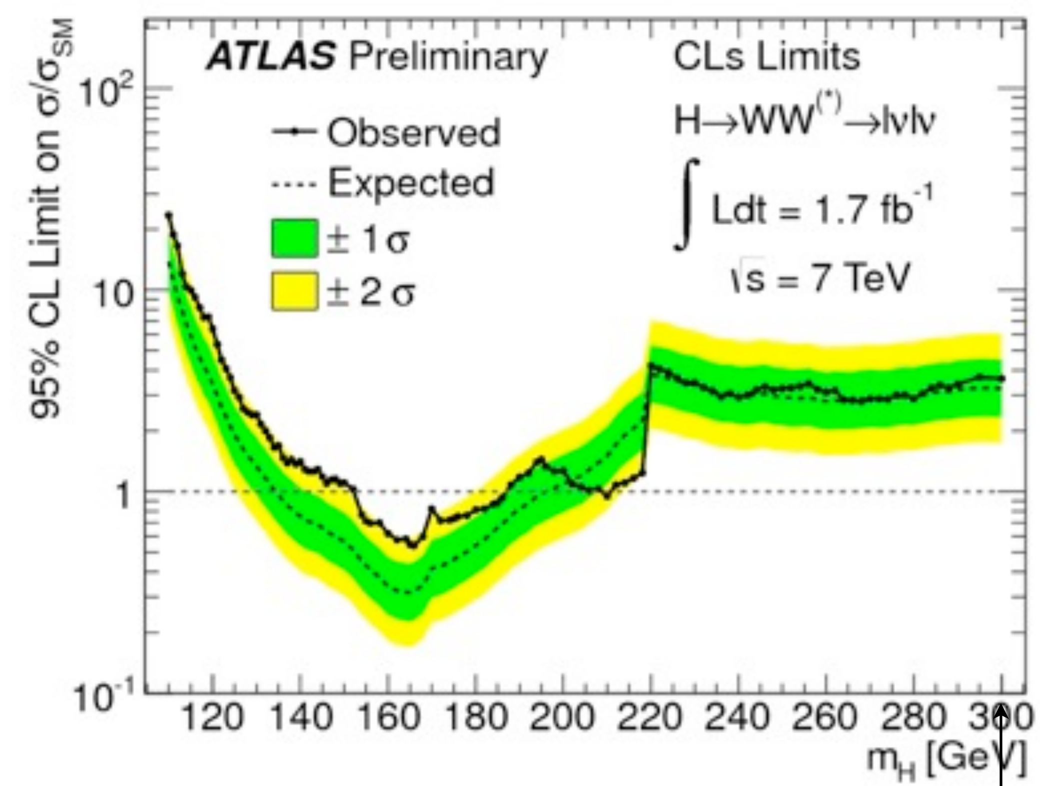
The shape is different because of the cut flow (invariant mass applied in ATLAS)

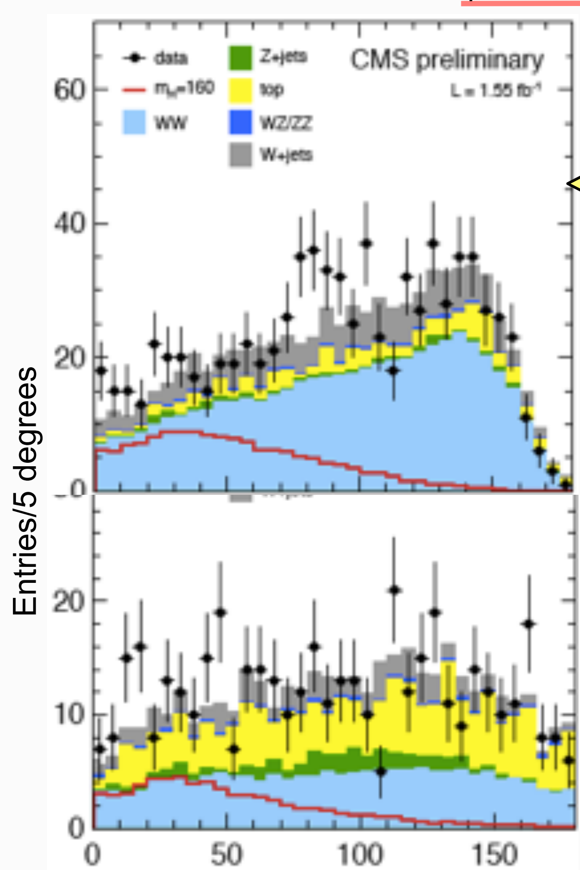


Δφ between the leptons

H→WW→2l2ν





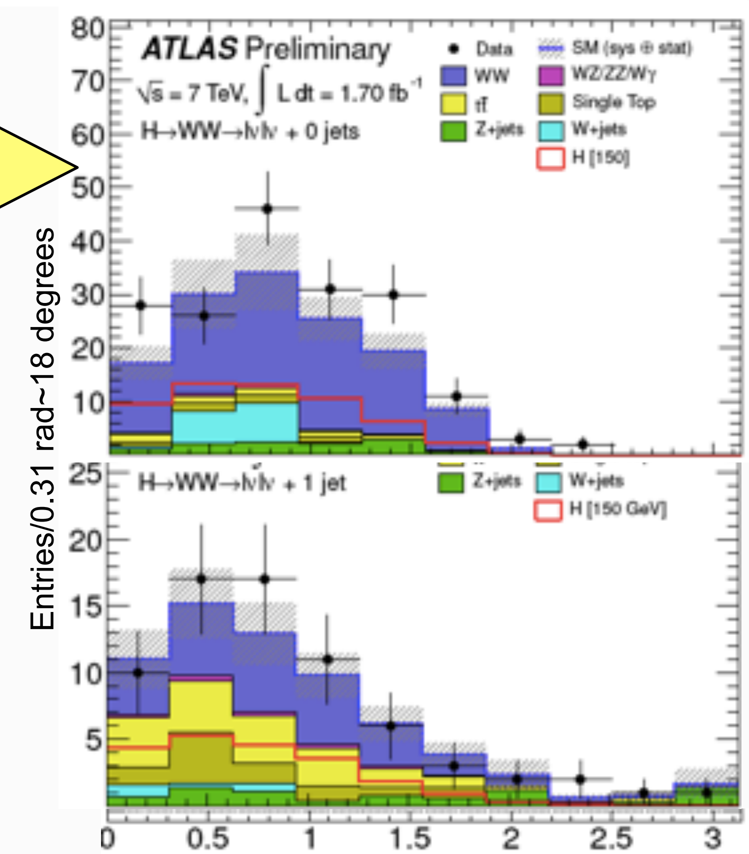


Δφ between the leptons

The shape is different because of the cut flow (invariant mass applied in ATLAS)

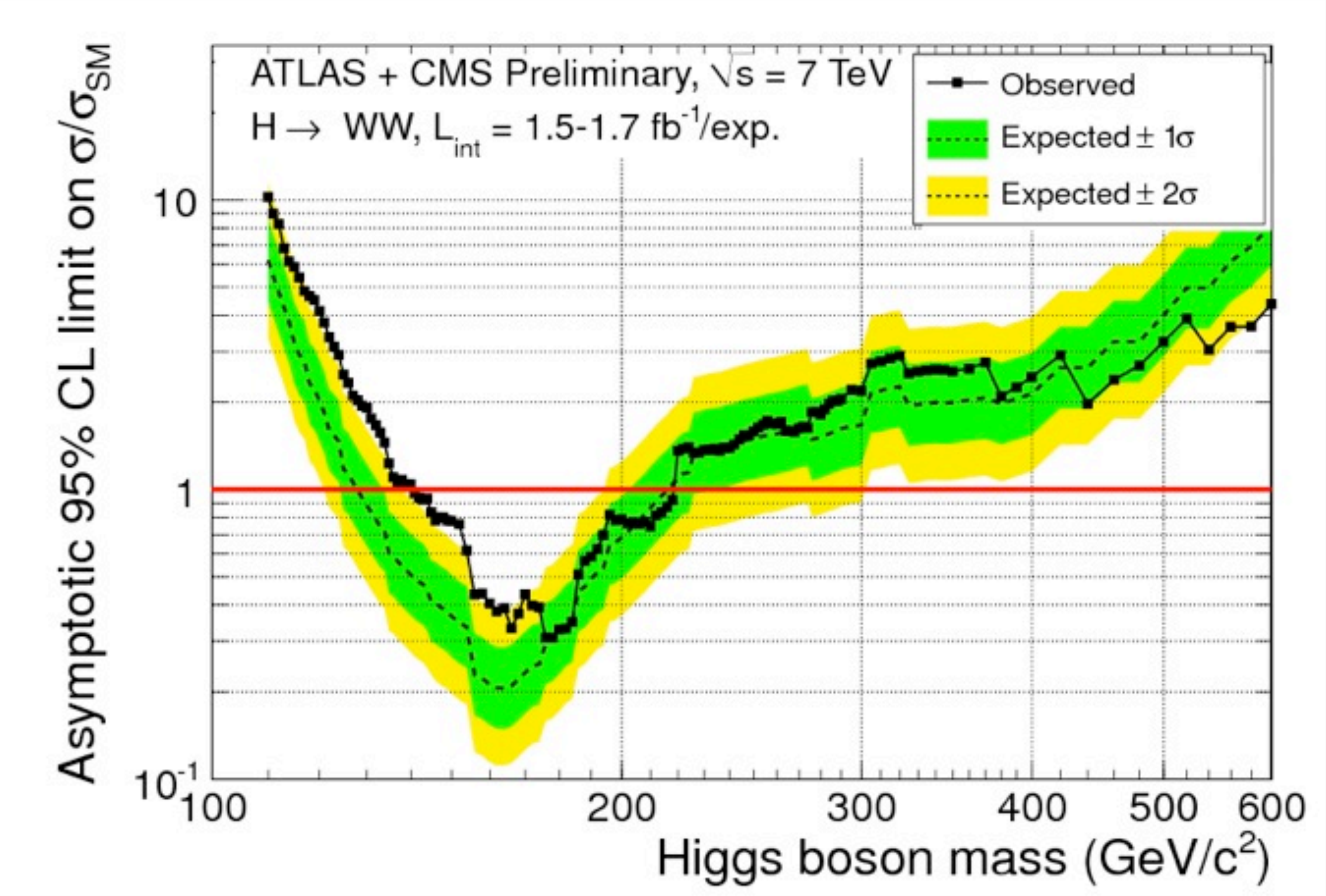
CMS, M_H 140 GeV
141 events, expected 120±11
(expected signal 46)

ATLAS, M_H 150 GeV
93 events, expected 76±10
(expected signal 46)



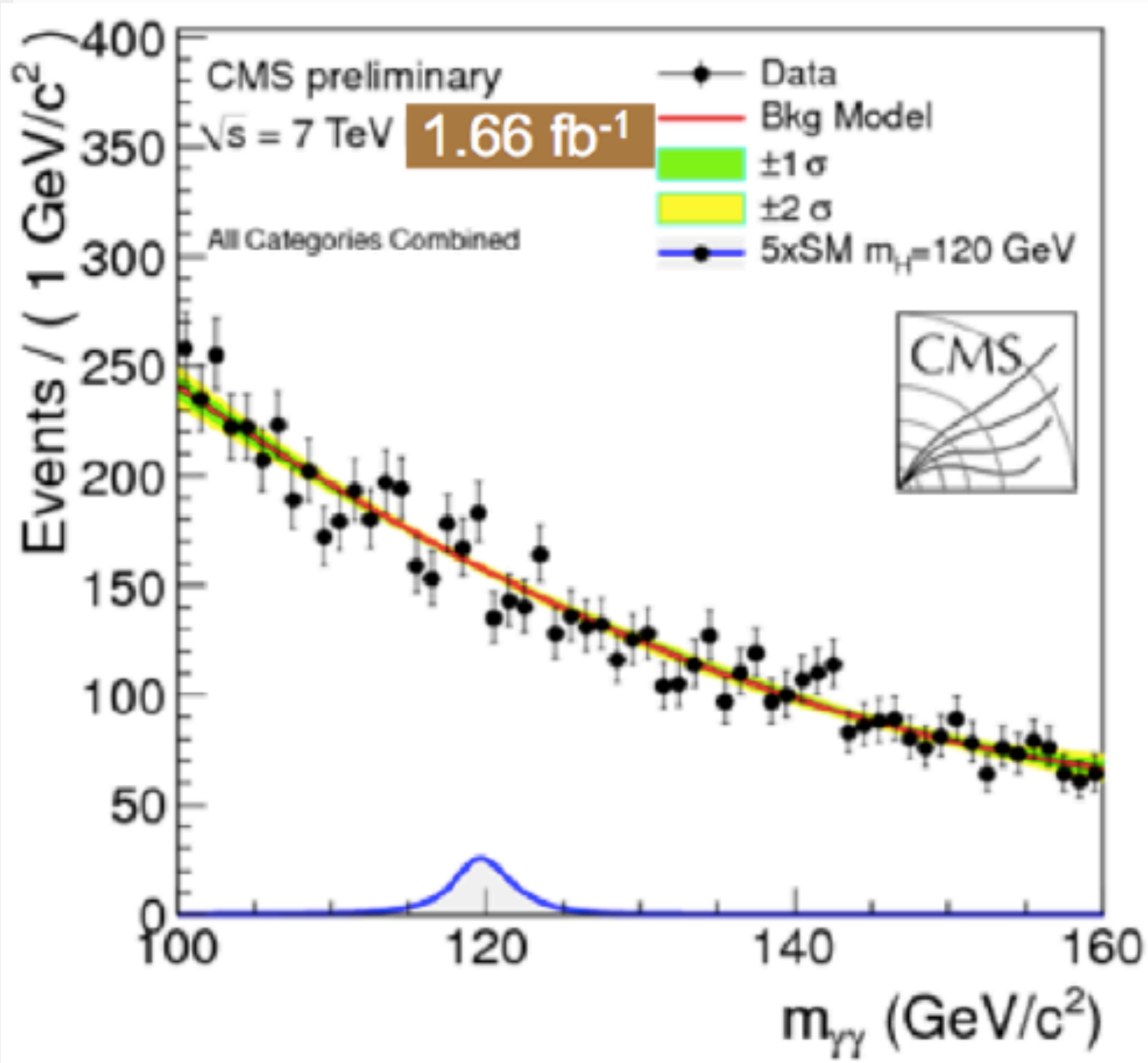
Δφ between the leptons

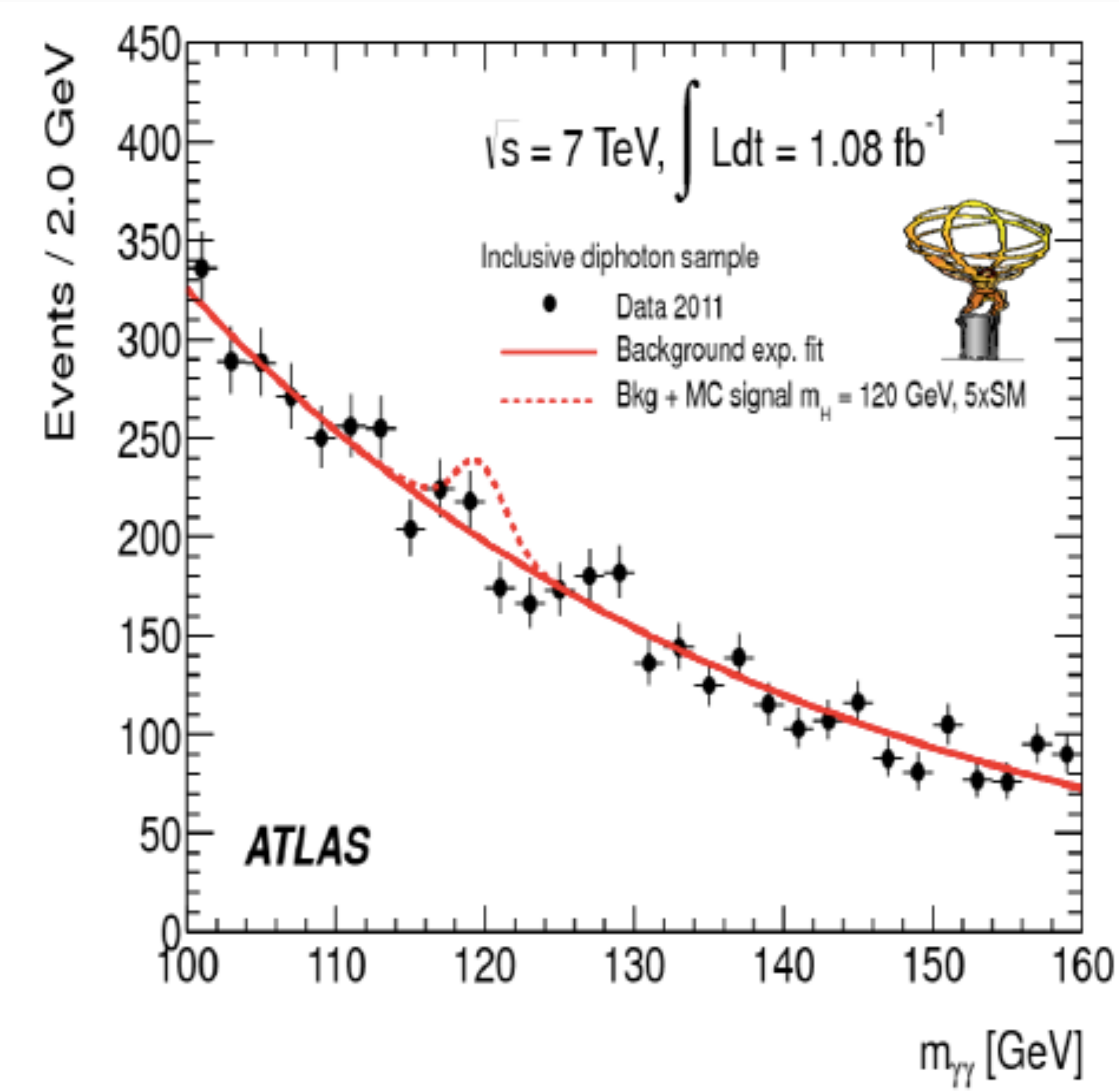
H→WW→2l2ν



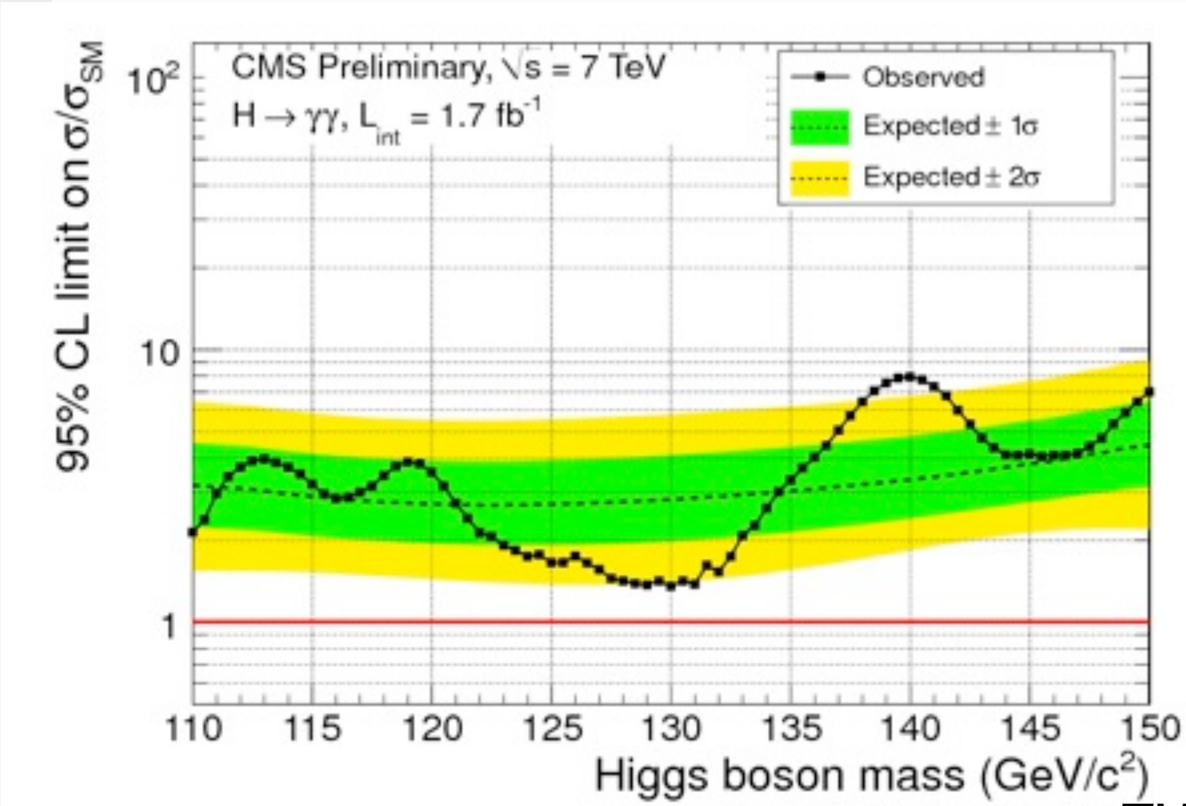
ATLAS and CMS see both a less than 2σ positive fluctuation (mainly 0 jet in ATLAS, mainly 1 jet in CMS) that appear then in the combination. Since this channel has very limited mass resolution, the excess spans in a correlated way over a large mass range.

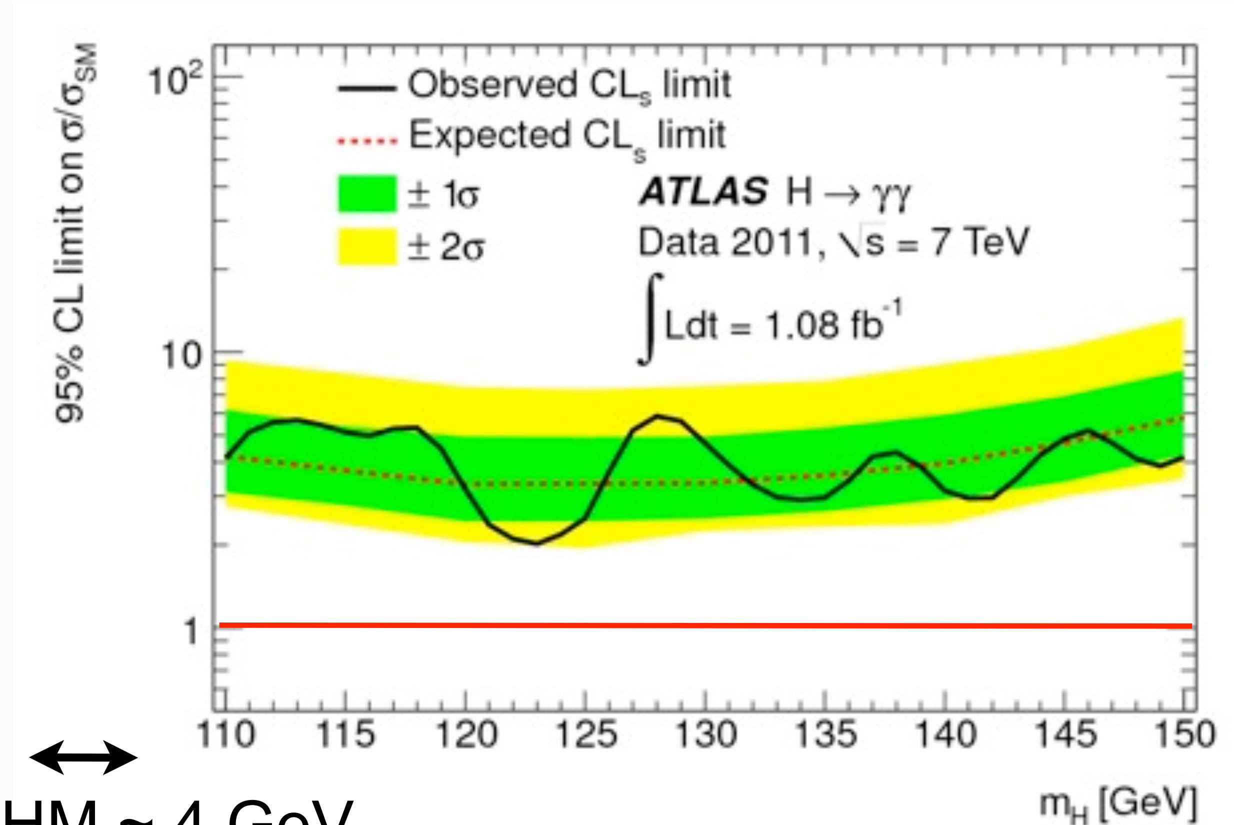
Low mass: $H \rightarrow \gamma\gamma$



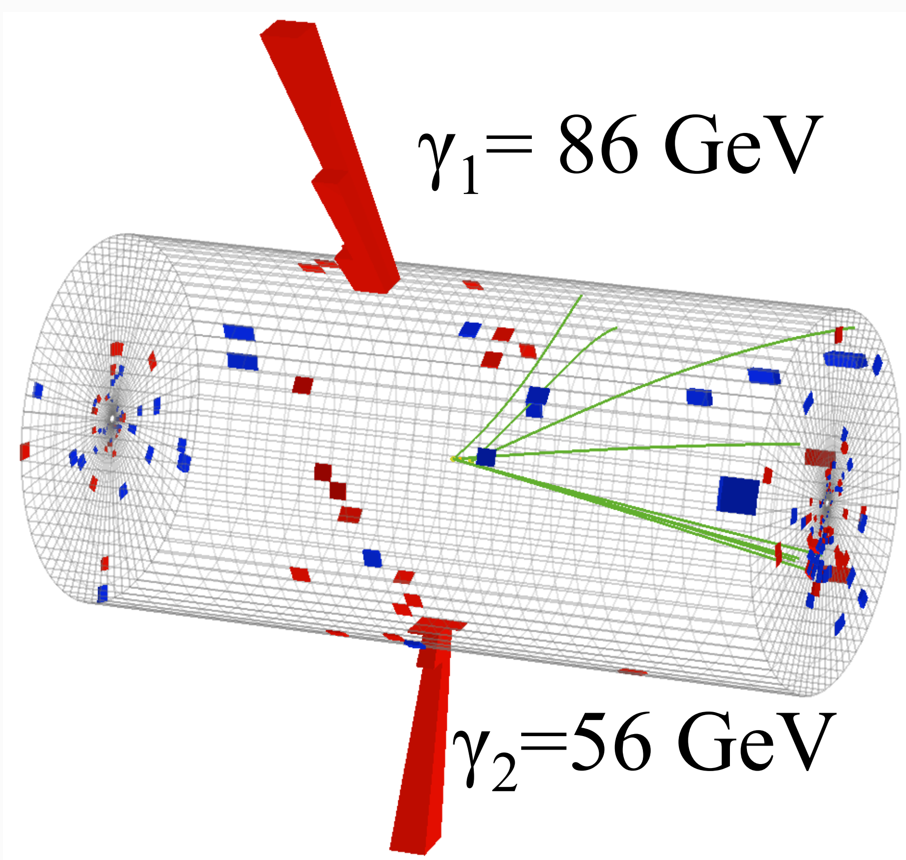


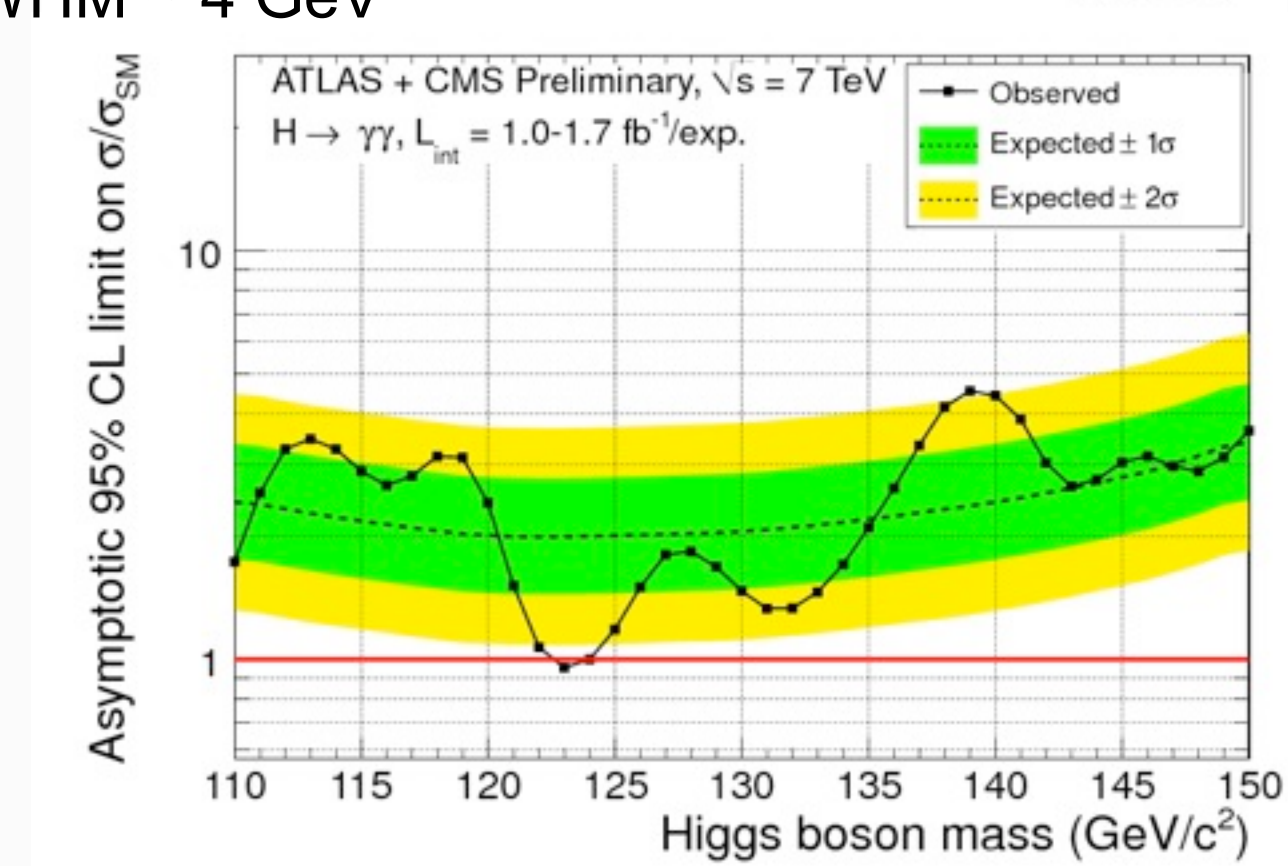
Low mass: H→γγ



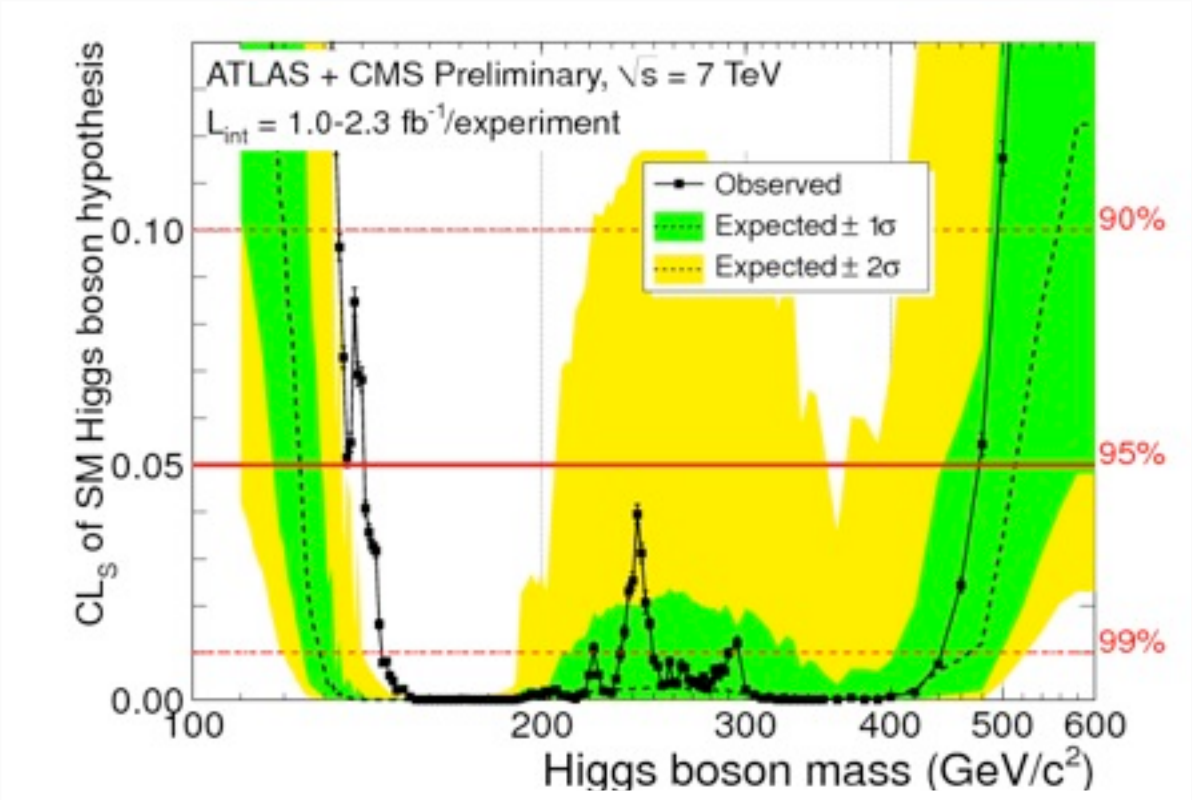


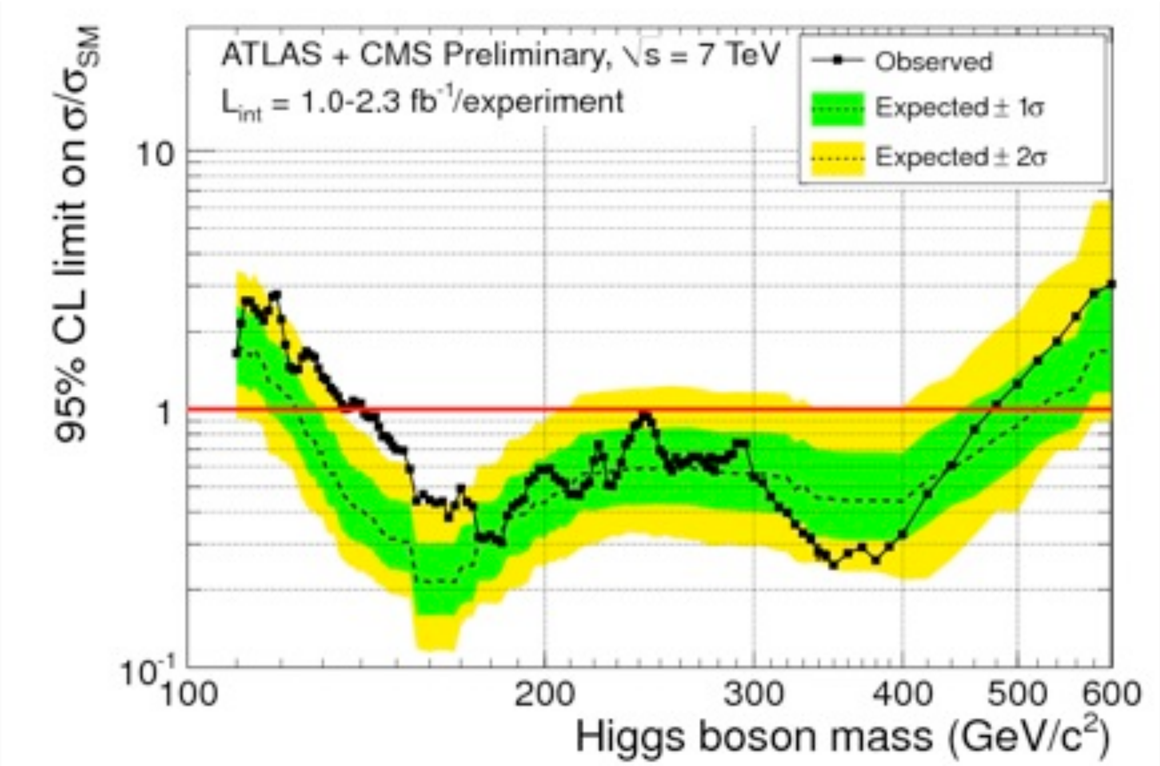
FWHM ~ 4 GeV





All Channels combined

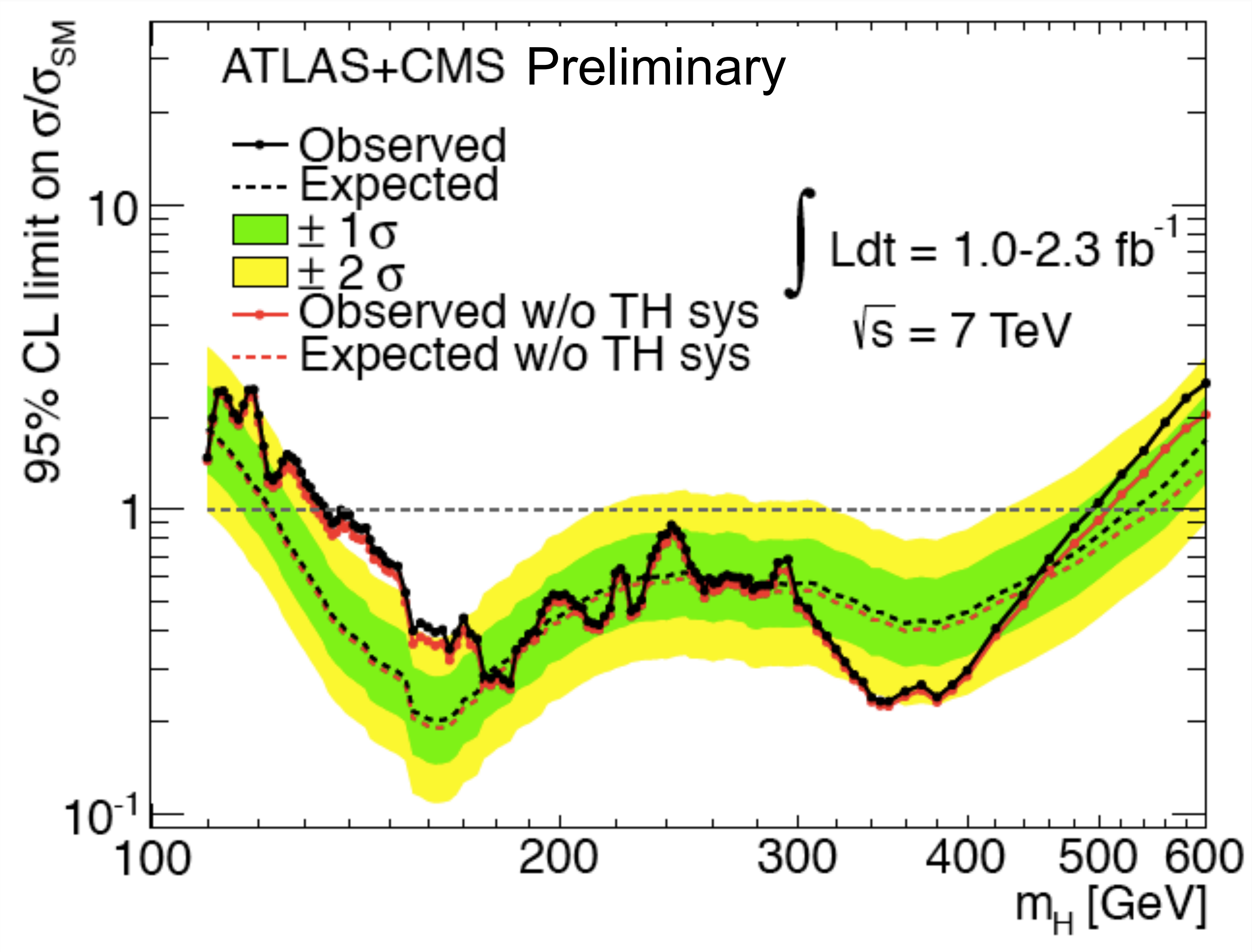




Observed exclusion 95% CL
141-476 GeV

Expected exclusion 95% CL
124-520 GeV

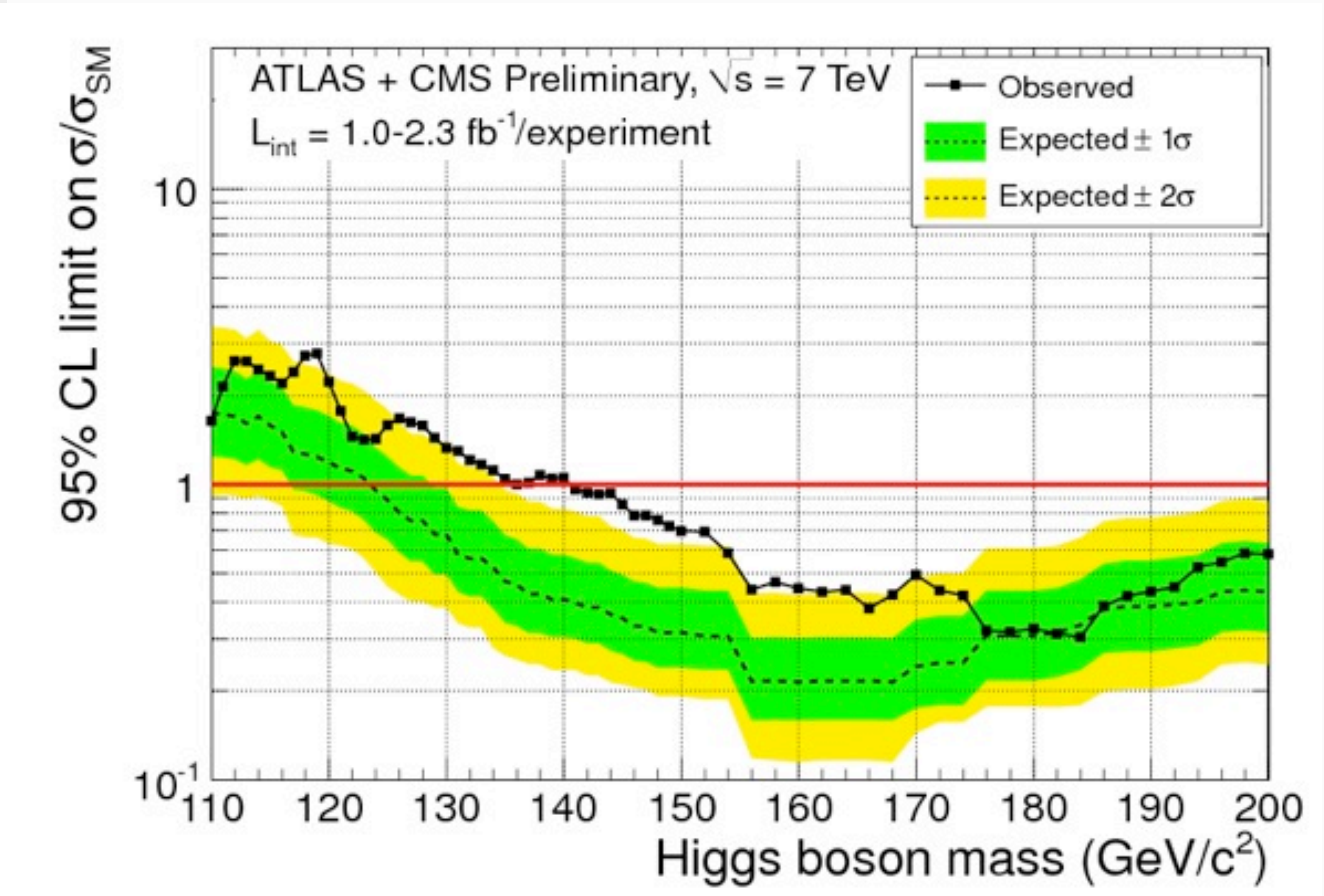
Theoretical systematic uncertainties



Expected exclusion changes by 1 GeV at low mass and 20 GeV at High mass

Thanks to the advances in theory and to LHC Higgs cross section group !

Zoom on low mass



Excess largely due to the WW channel with modulations induced by ZZ and γγ

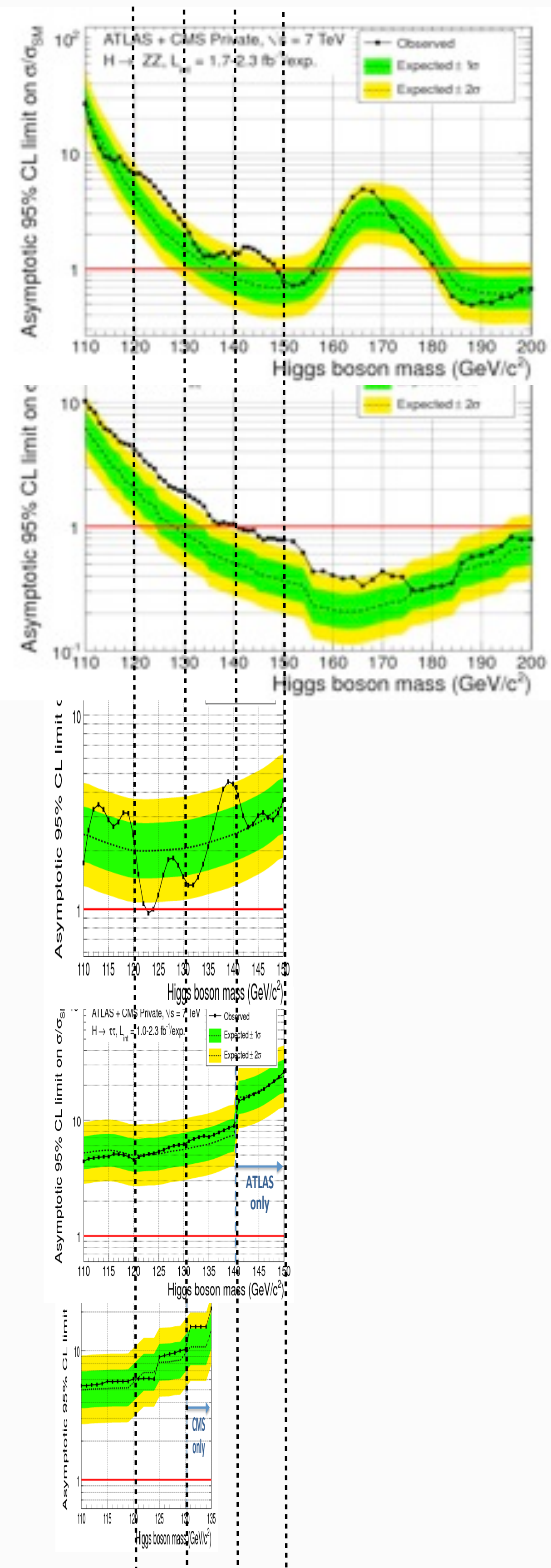
ZZ

WW

γγ

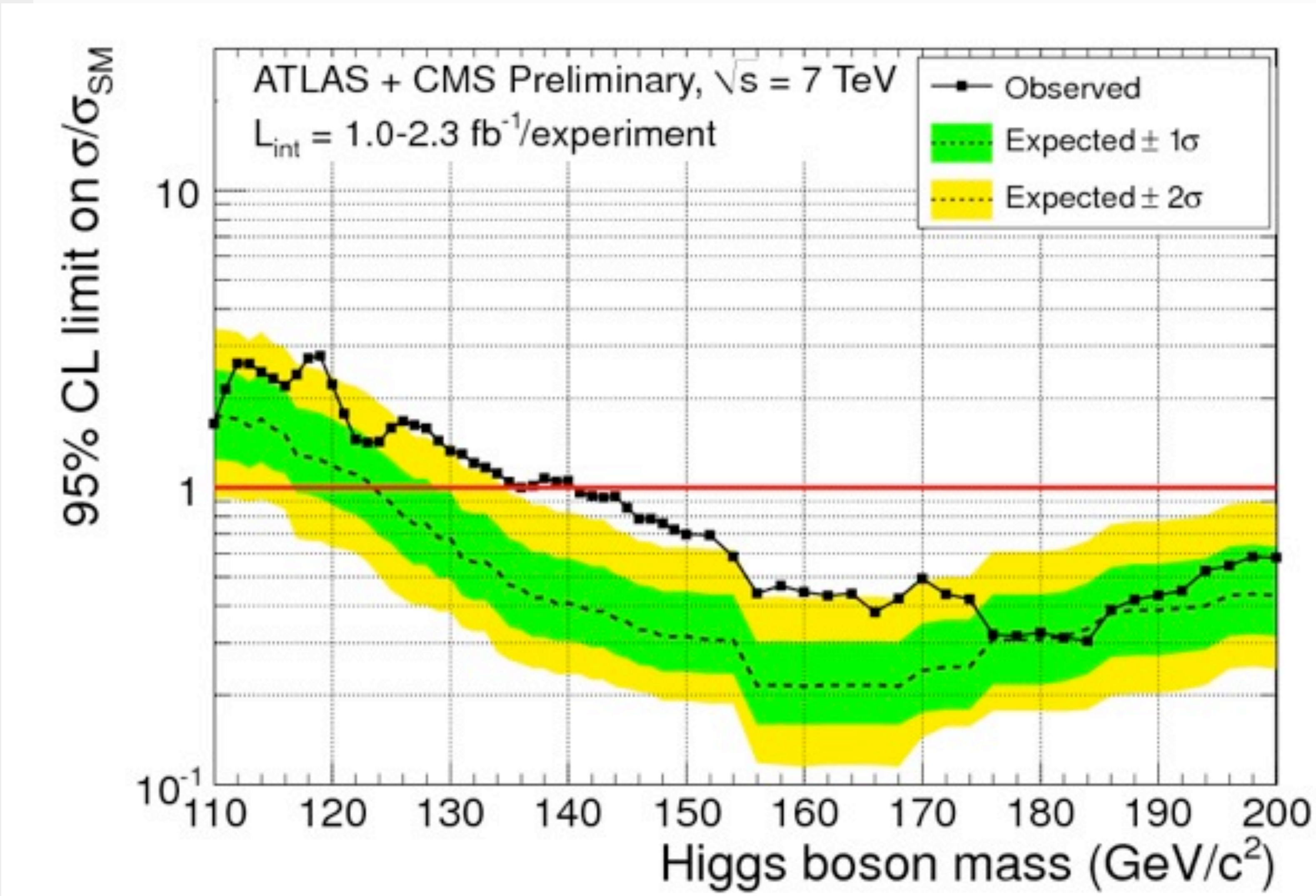
ττ

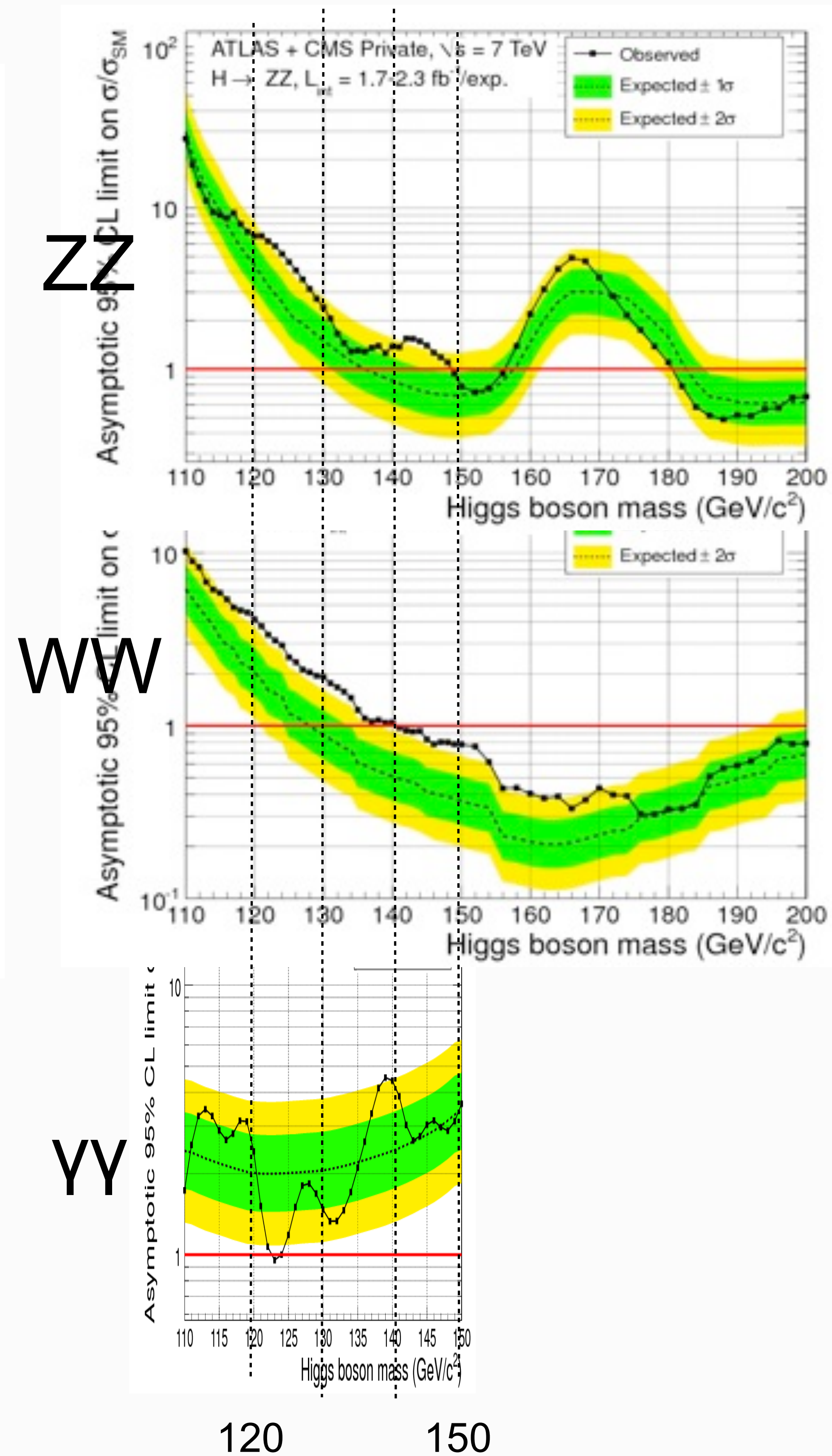
bb



120 150

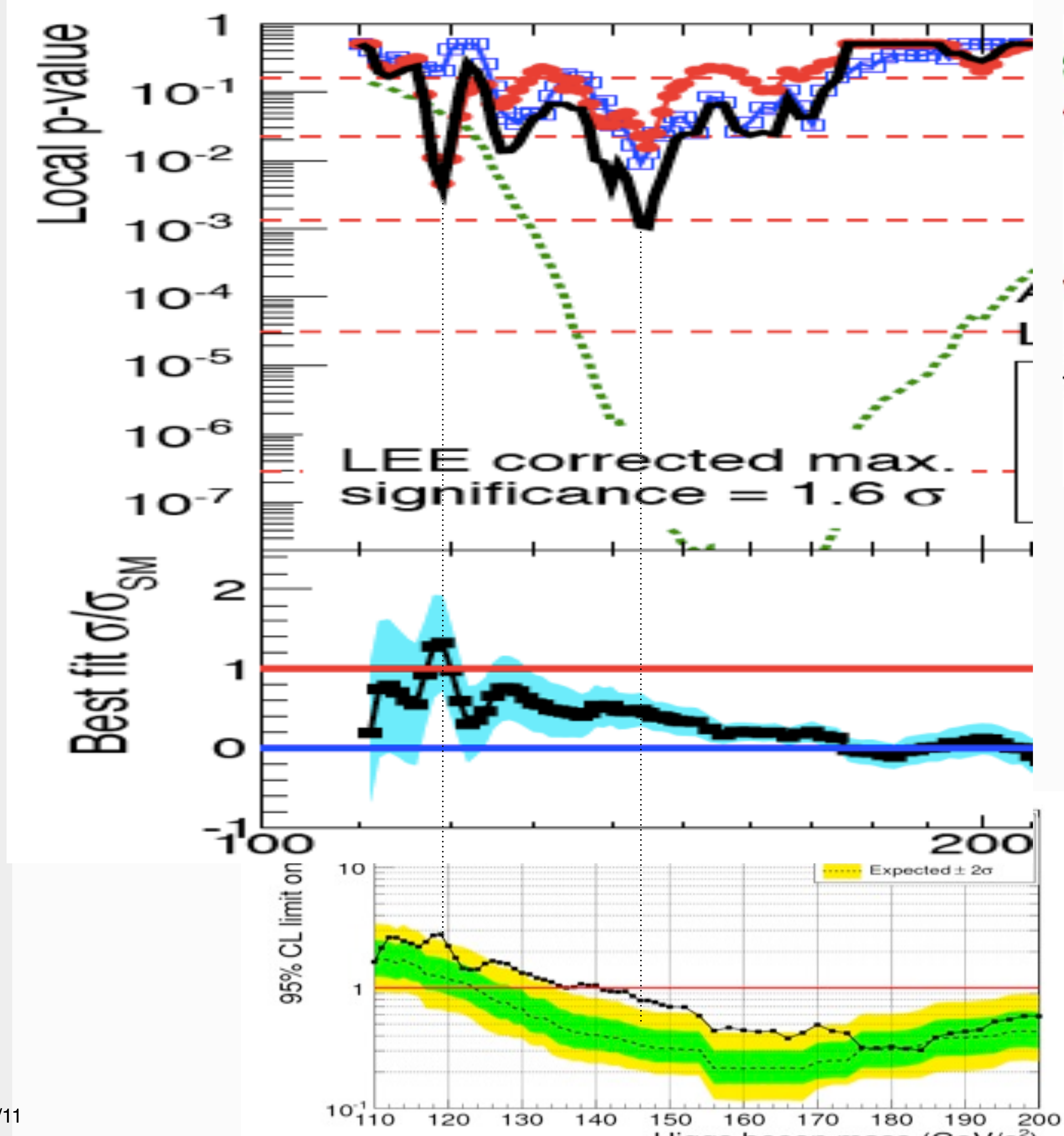
Zoom on low mass

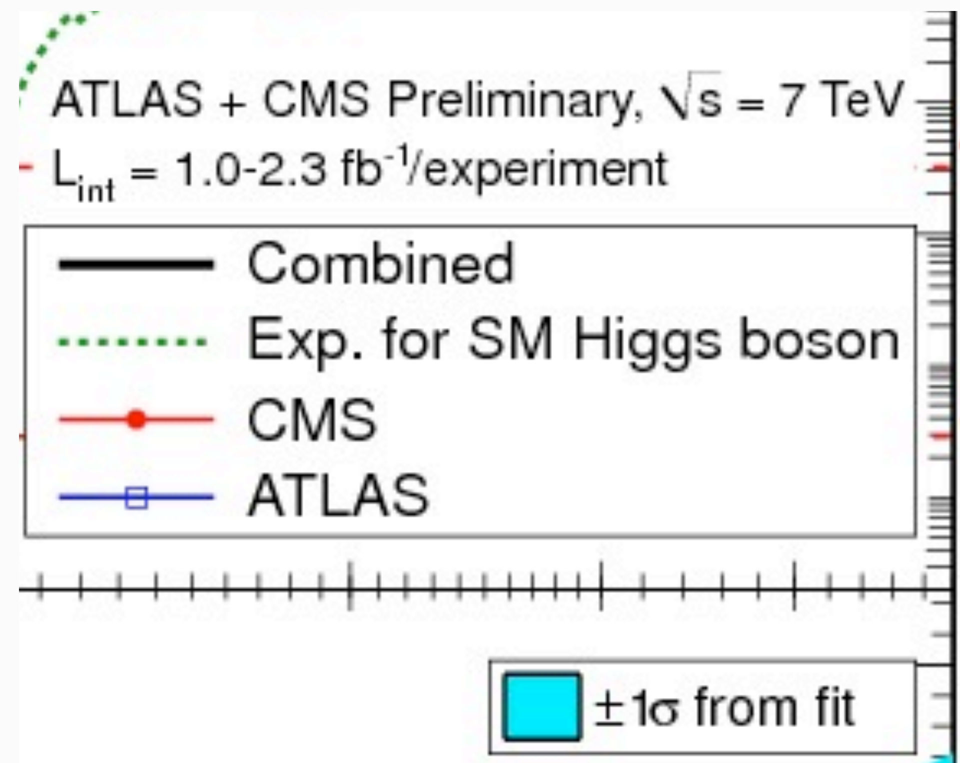




Excess largely due to the WW channel with modulations induced by ZZ and γγ

Combination: p-values and σ/σ_{SM}

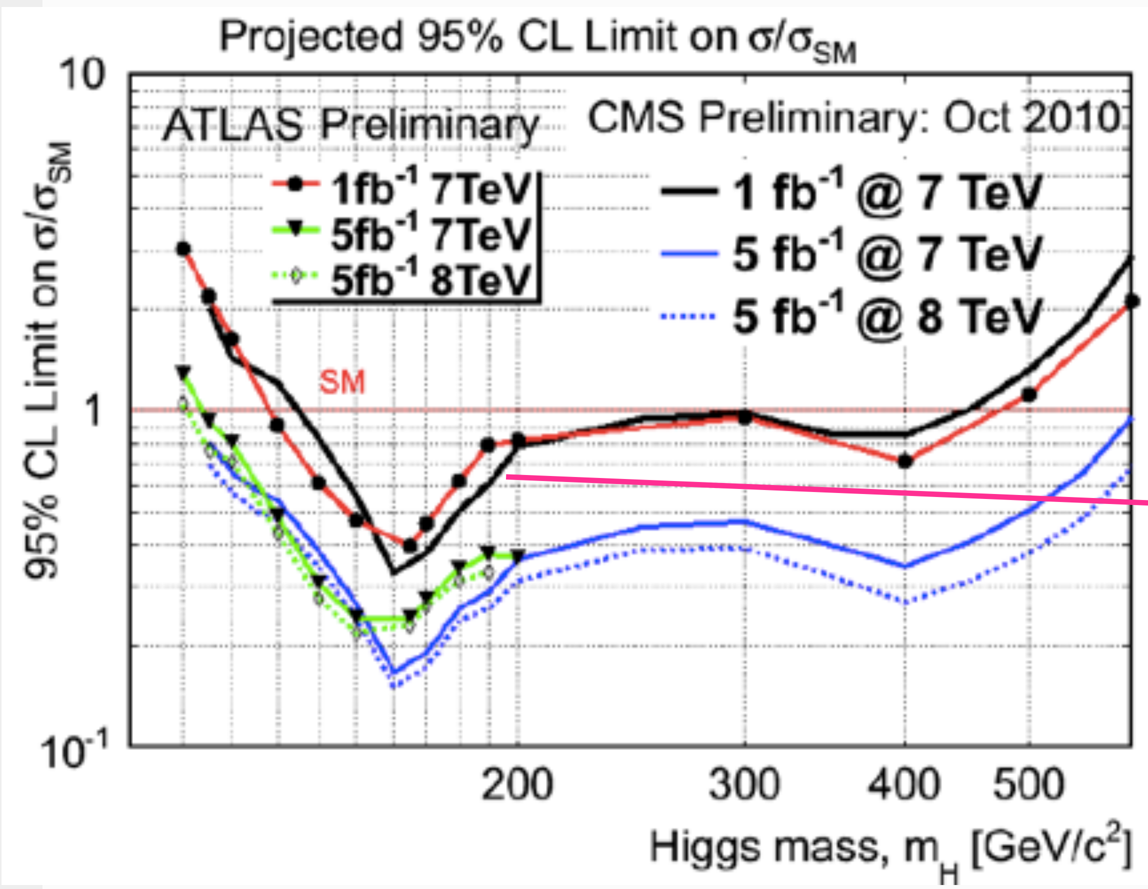




LEE CORRECTED MAX SIGNIFICANCE 1.6σ

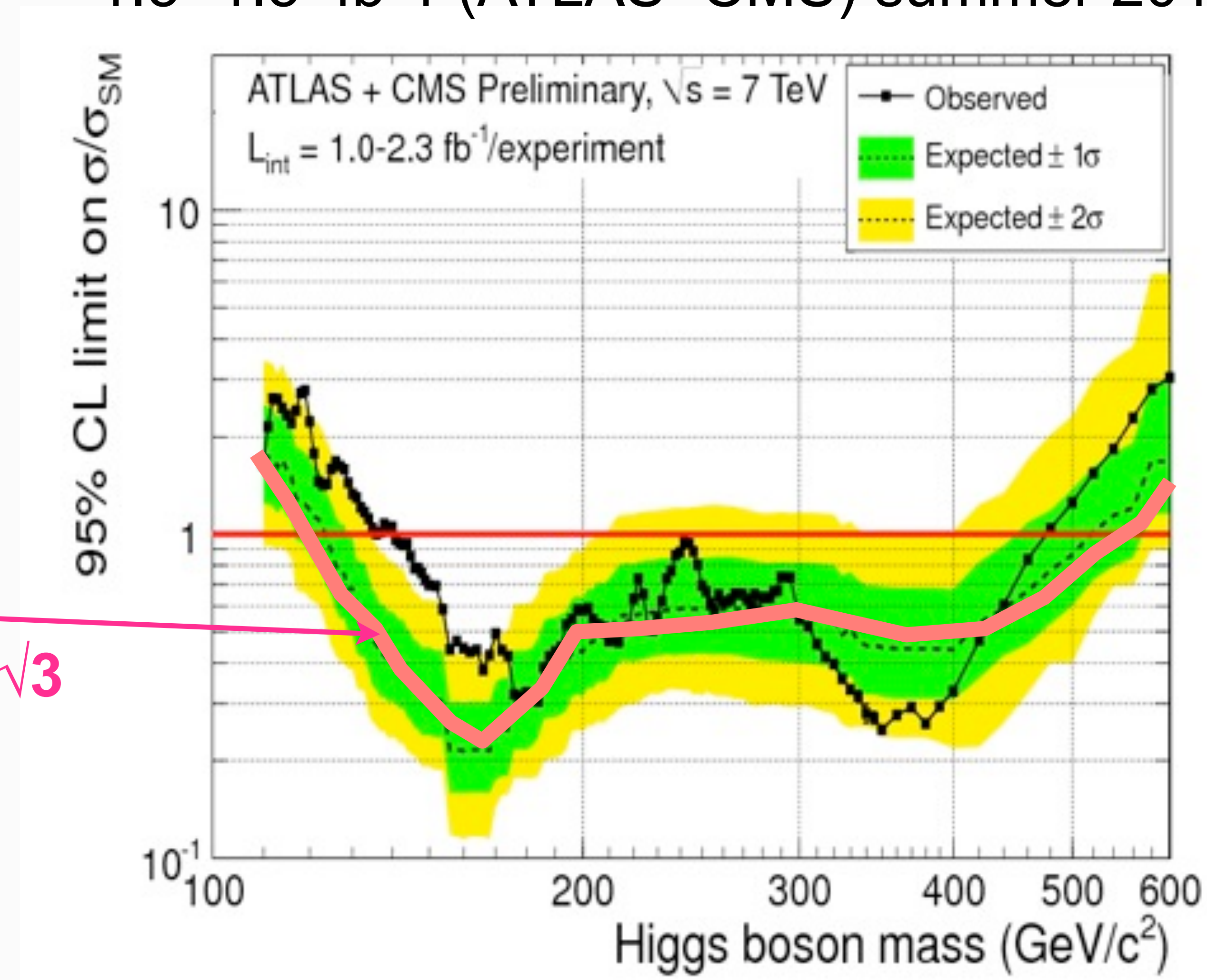
The full 2011 LHC dataset

1 fb-1 projected 95 % exclusion winter 2011



x 1/√3

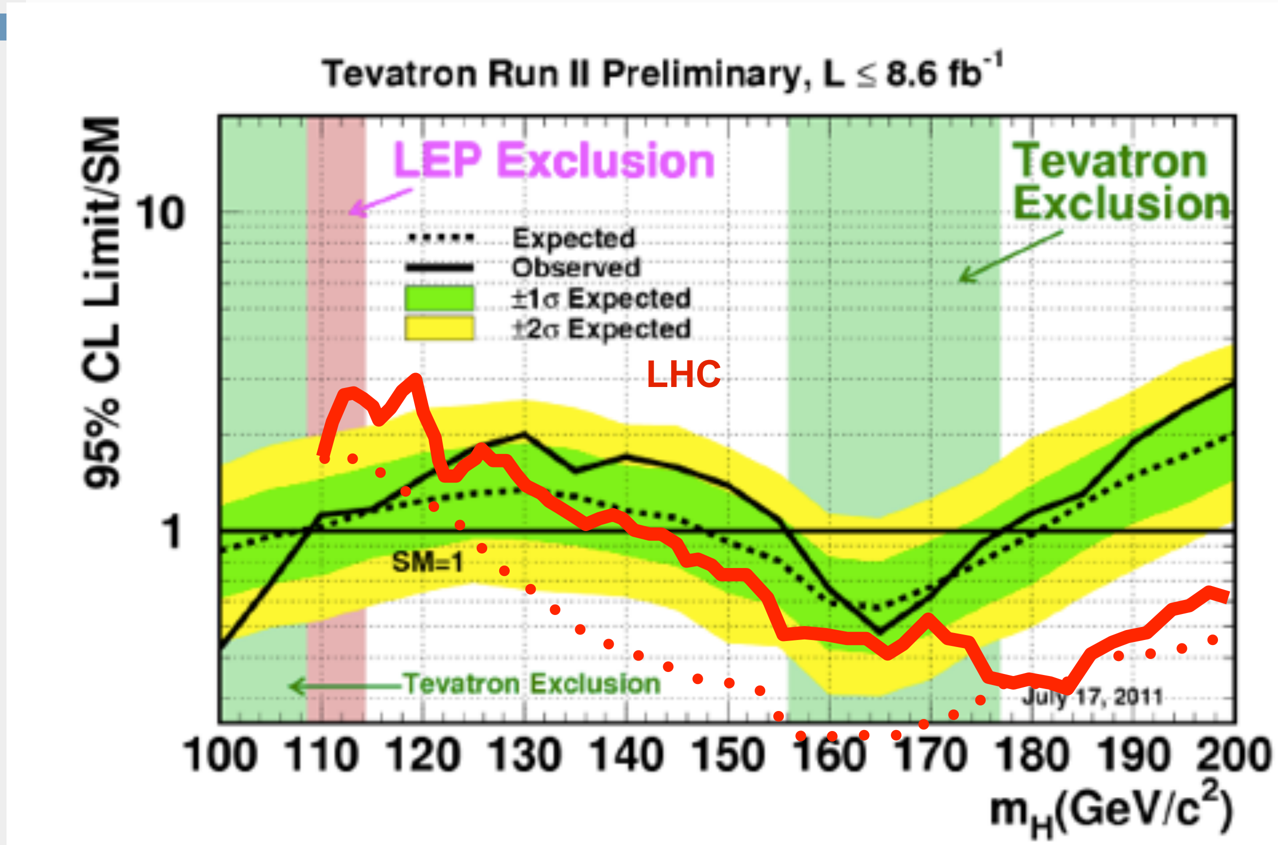
~ 1.5+1.5 fb-1 (ATLAS+CMS) summer 2011

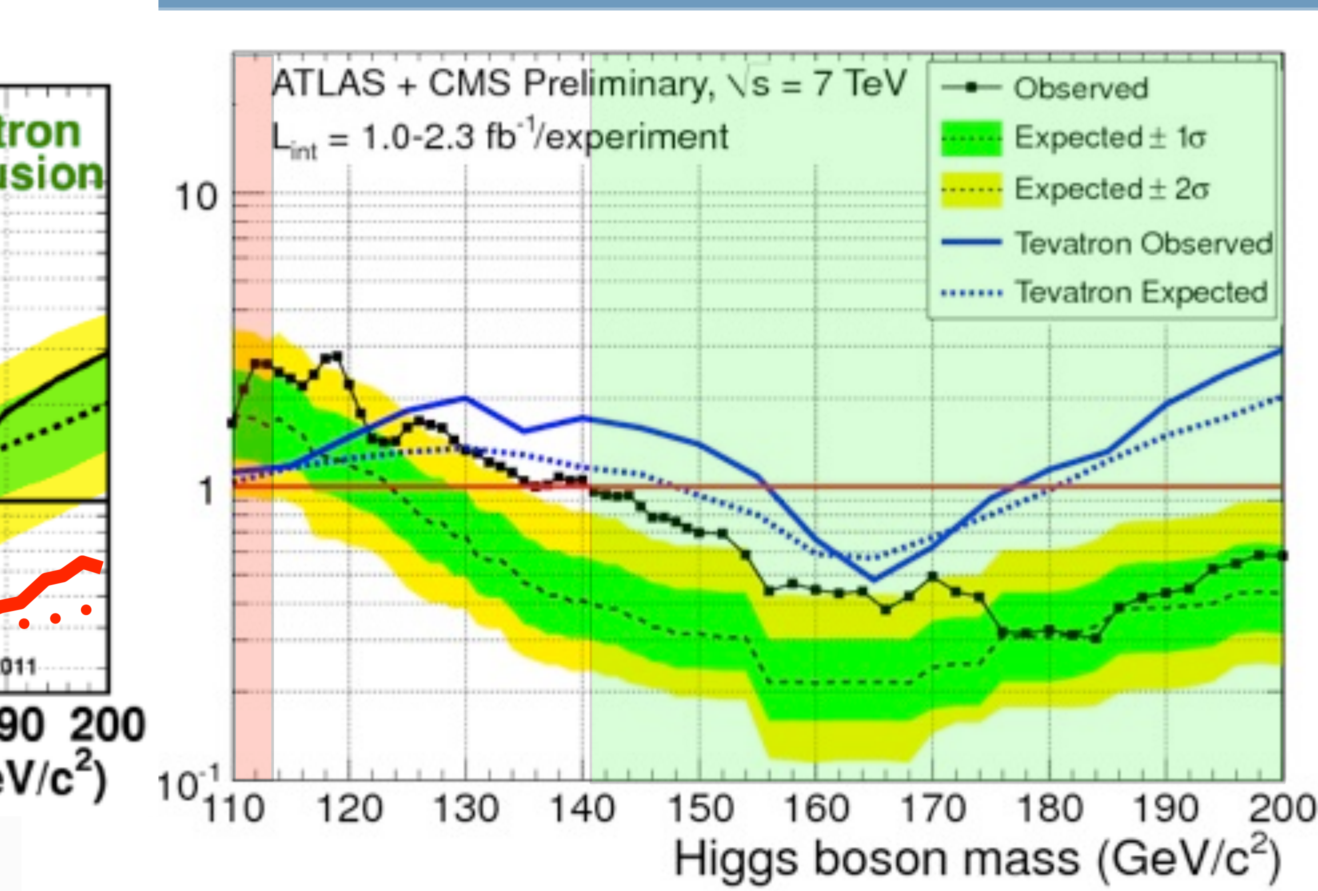


Statistical sensitivity will improve by 1.5÷2 depending on the channel, WW may be the exception because one starts seeing the systematics.

Sensitivity will also improve, especially at low mass : basic physics object identification, reconstruction and calibration (eg γγ) , use of MVA, more analyses (VBF and boosted bb in ATLAS). Higher pileup will somewhat degrade.

Comparison LHC/Tevatron





In the non excluded region both colliders show an excess compared to the expectation. Tevatron observed 95% limit is in the 1σ band. LHC excess has a max significance of 1.6σ .

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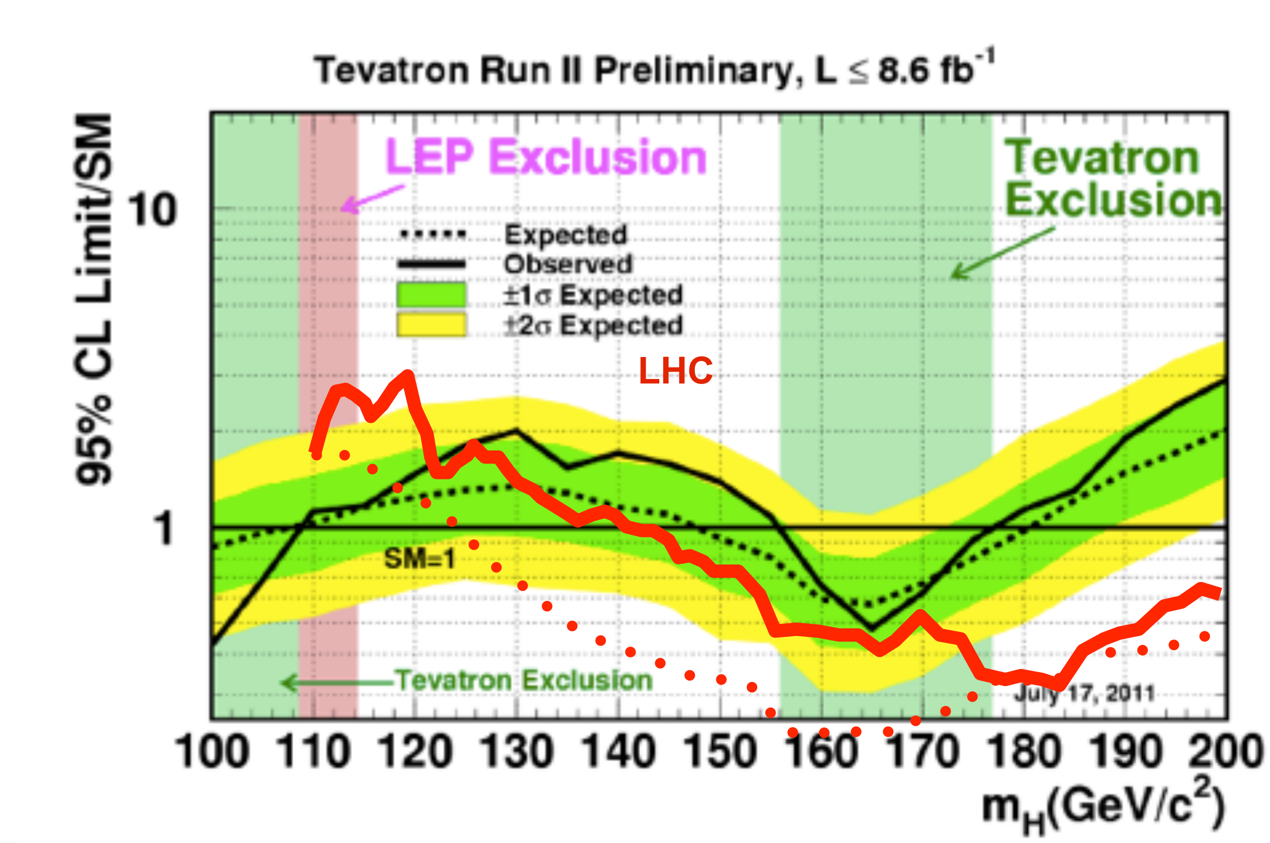

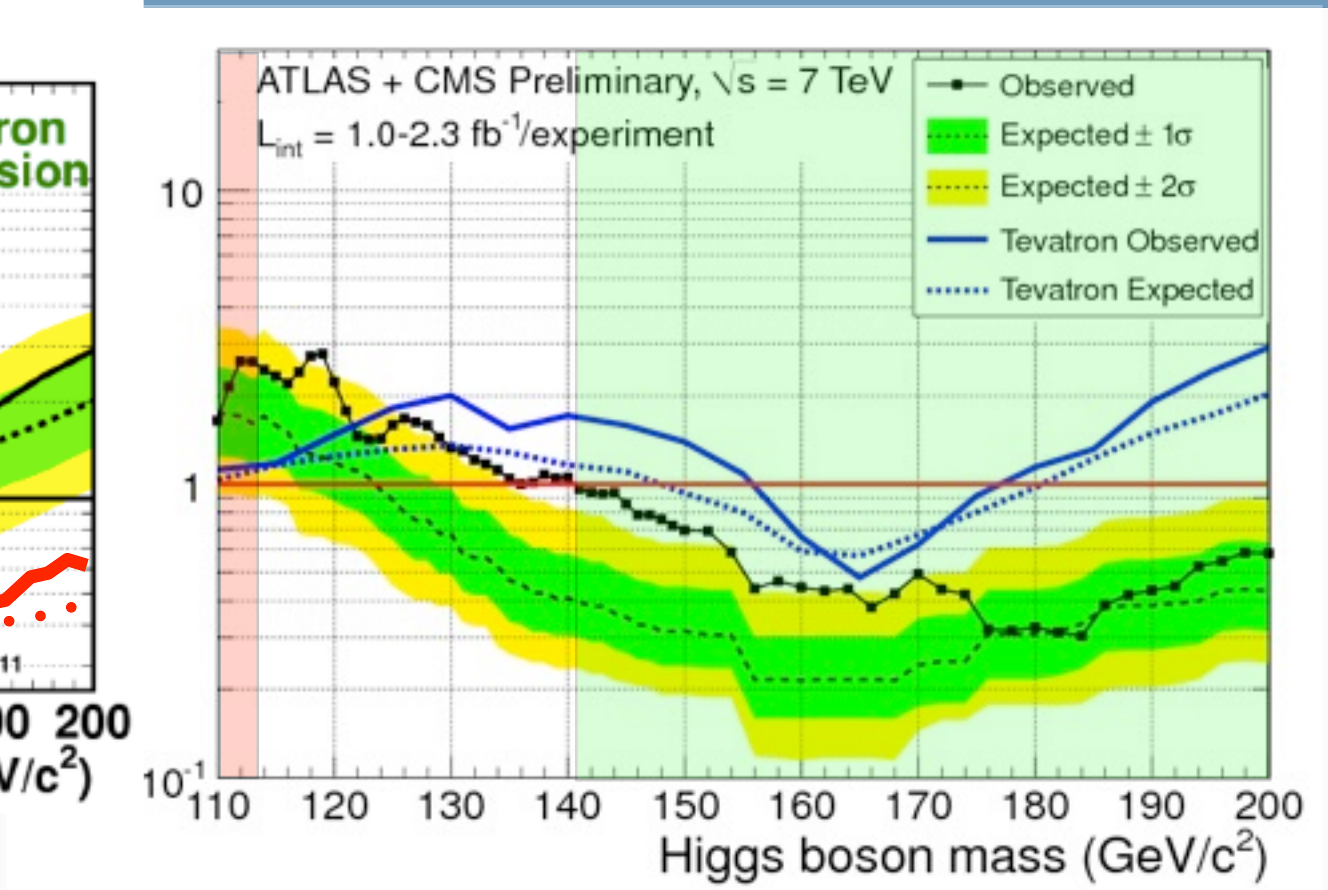

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Every discovery starts with the inability to exclude, it is good to see that we have excess compared to expectation !

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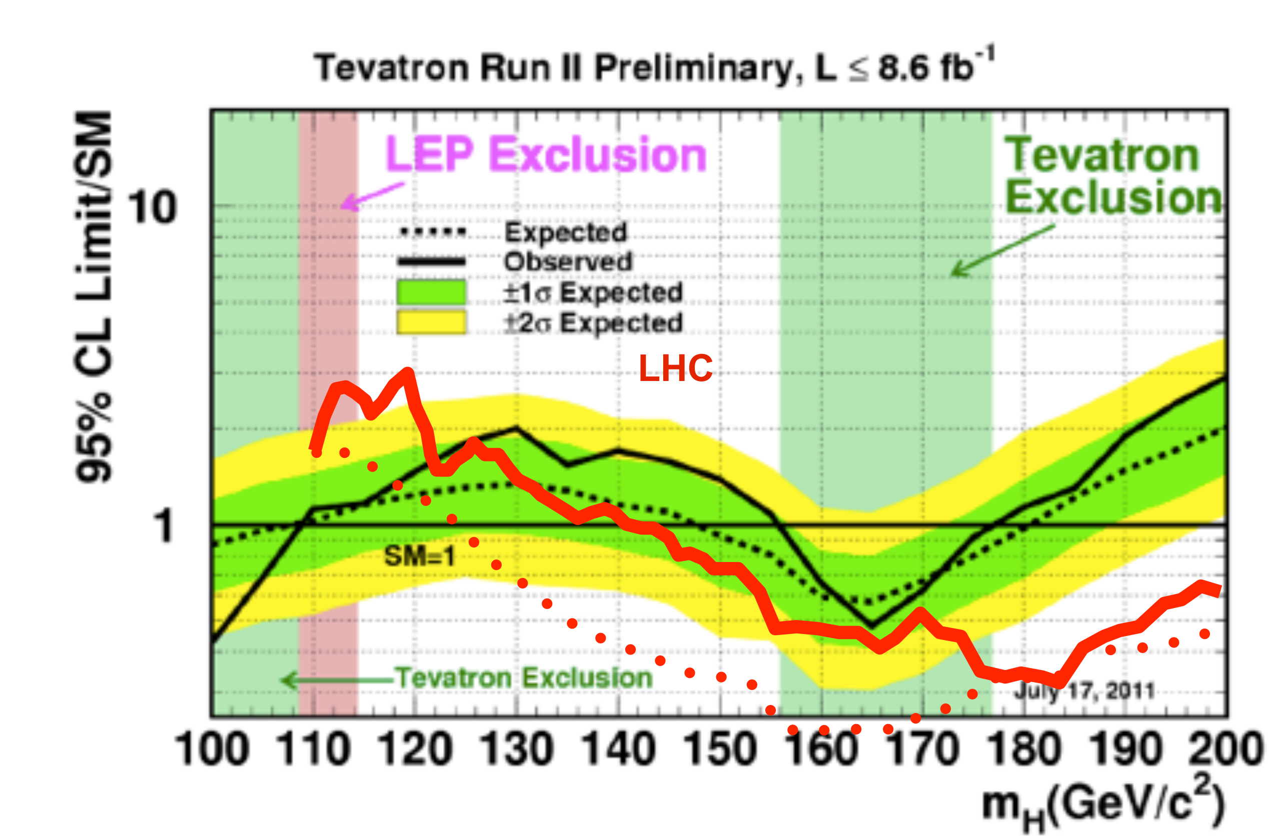

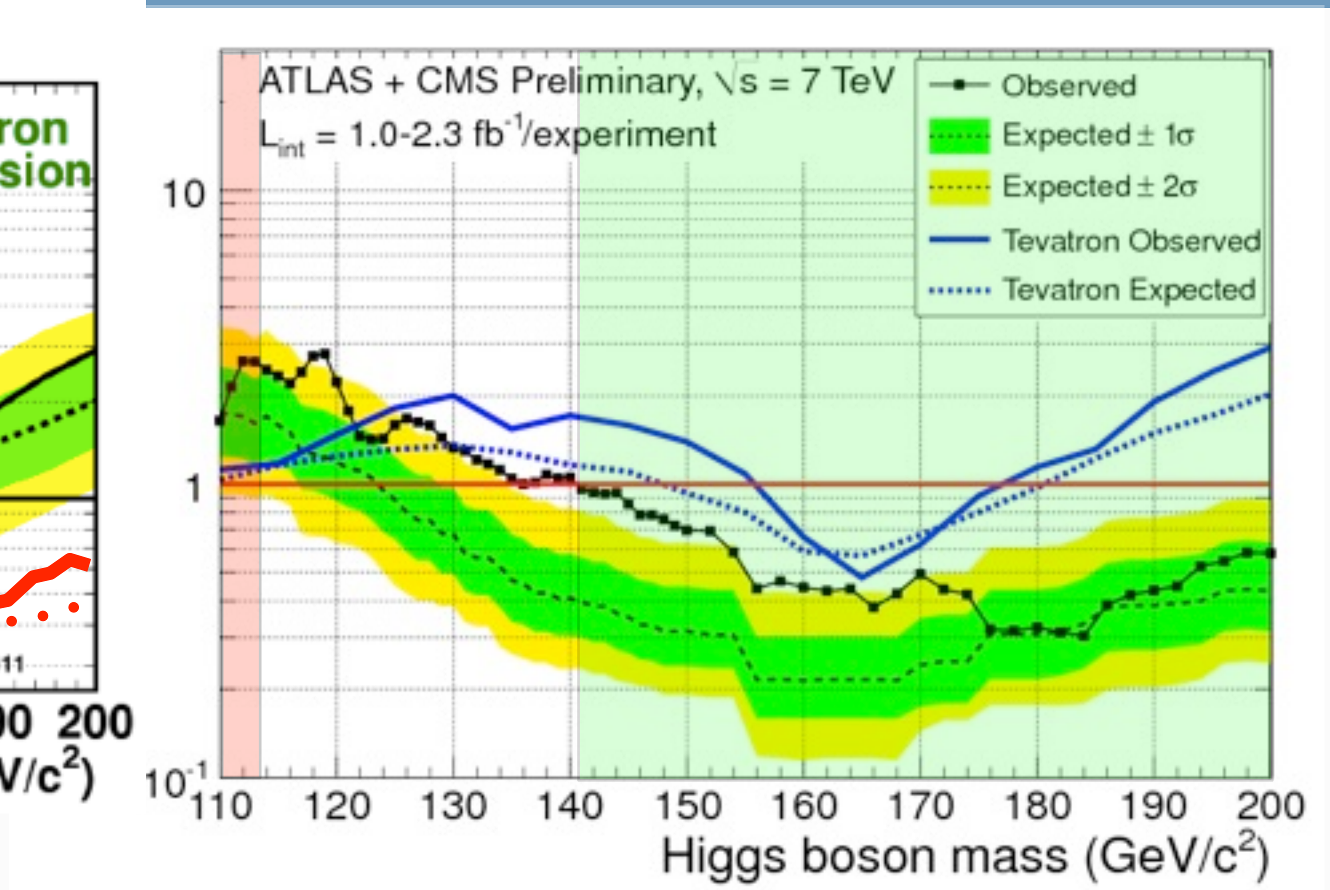

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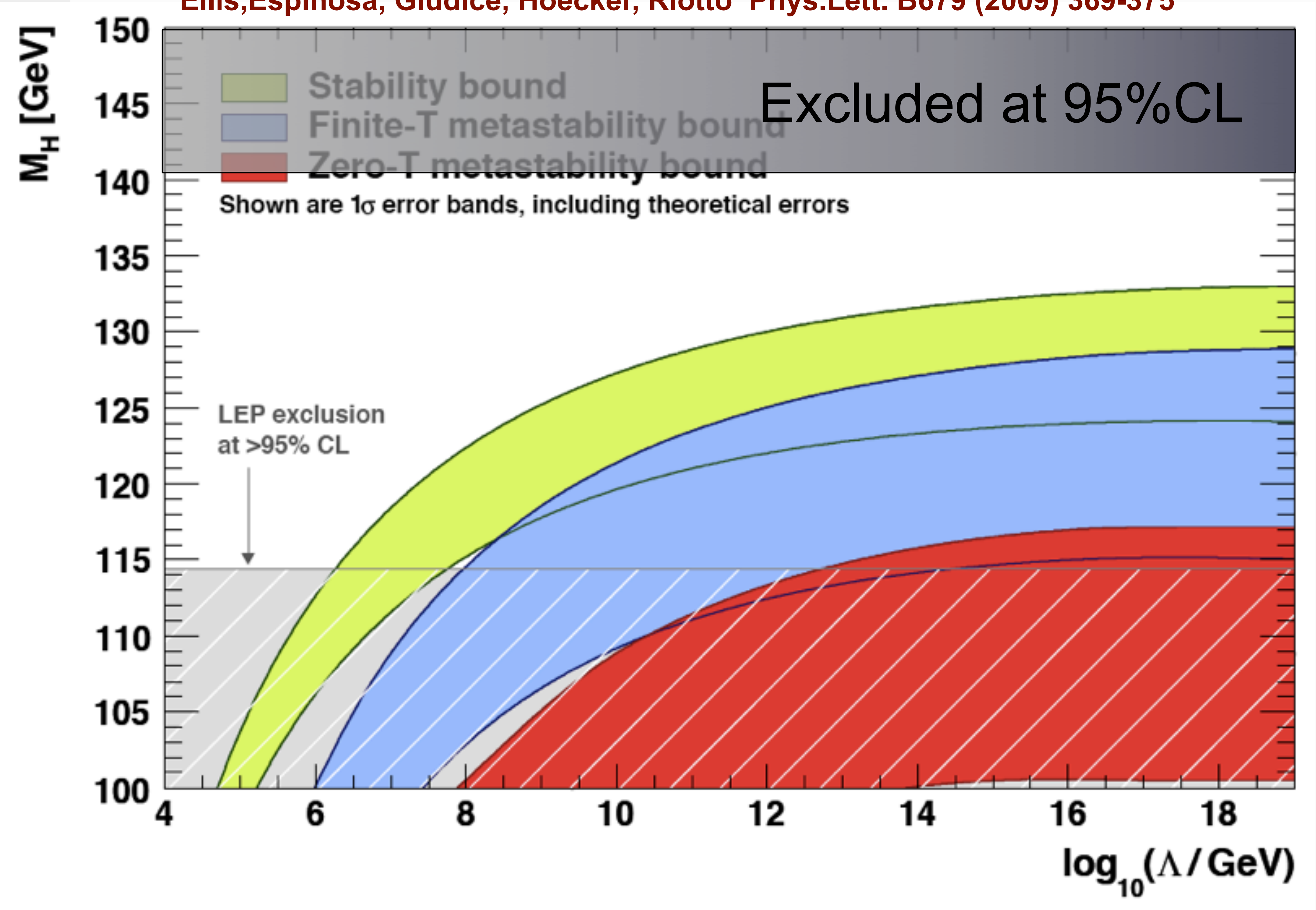
Every discovery starts with the inability to exclude, it is good to see that we have excess compared to expectation !

However here we do not have the clear picture of why do we have this excess. More data (that we have already) will tell us more about the WW excess. And the other channels will become more and more sensitive. **Stay tuned !**

The good news.......

Ellis,Espinosa, Giudice, Hoecker, Riotto Phys.Lett. B679 (2009) 369-375



Only a small stable region left at 95% CL

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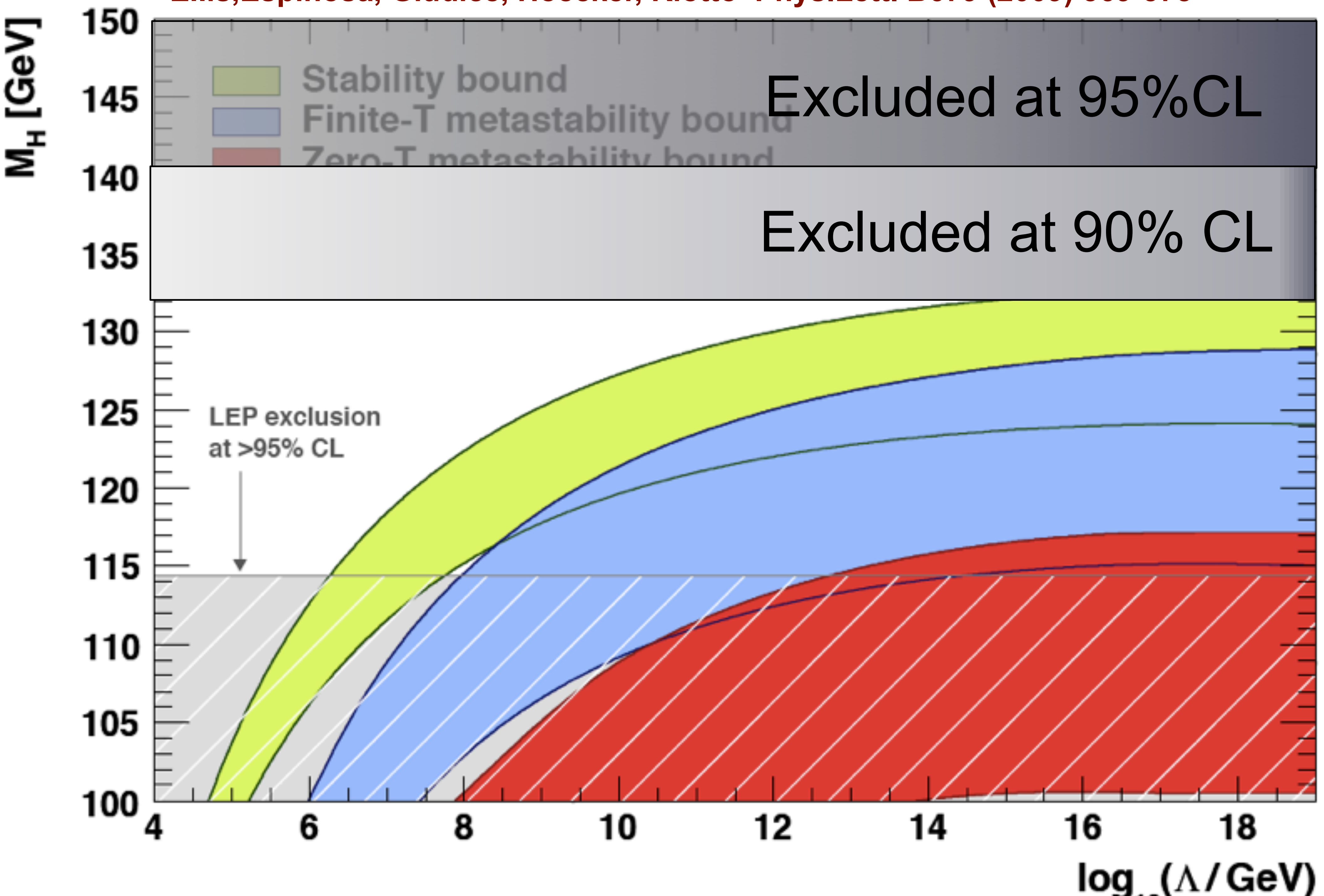
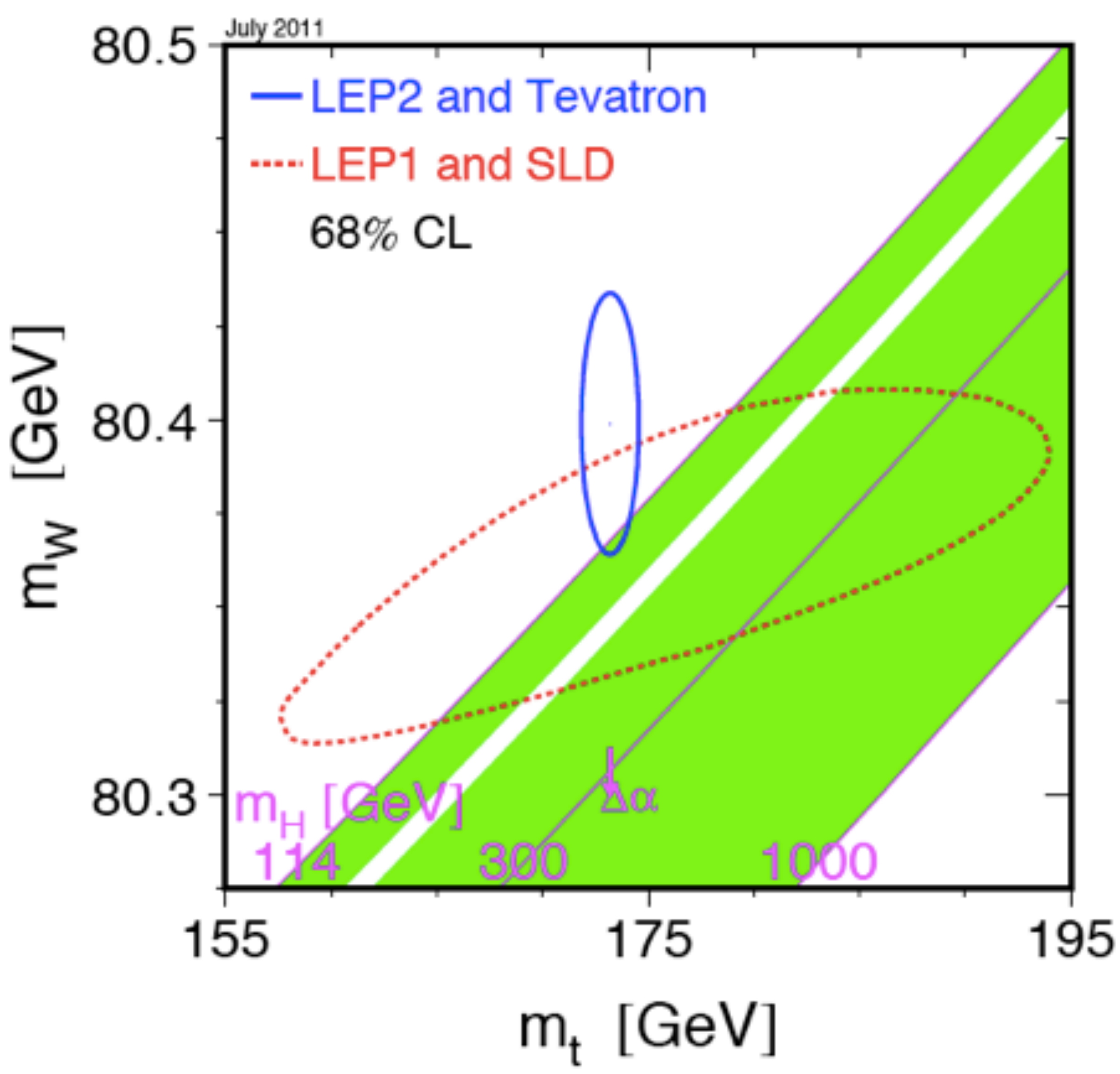
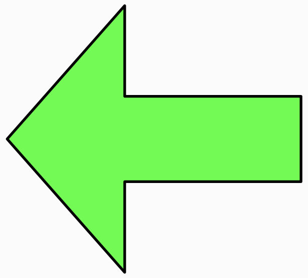


Only a small stable region left at 95% CL

And furthermore the region between ~ 132 and 141 GeV is also excluded at 90% CL by the LHC combination.

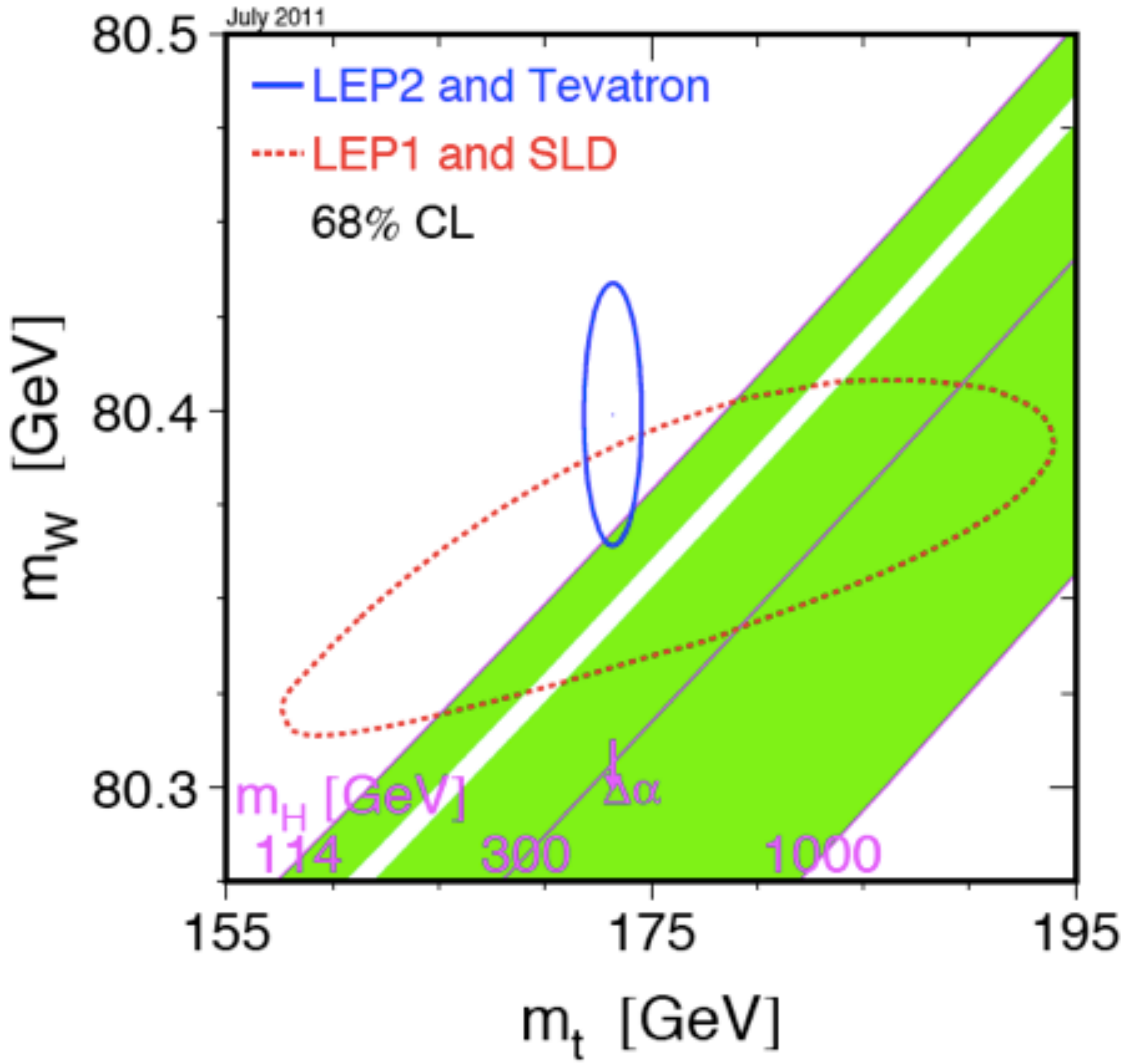
Impact of the new limits on the green band



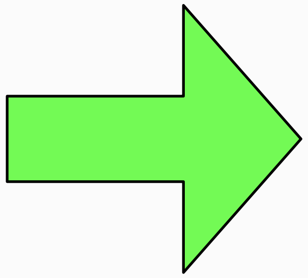


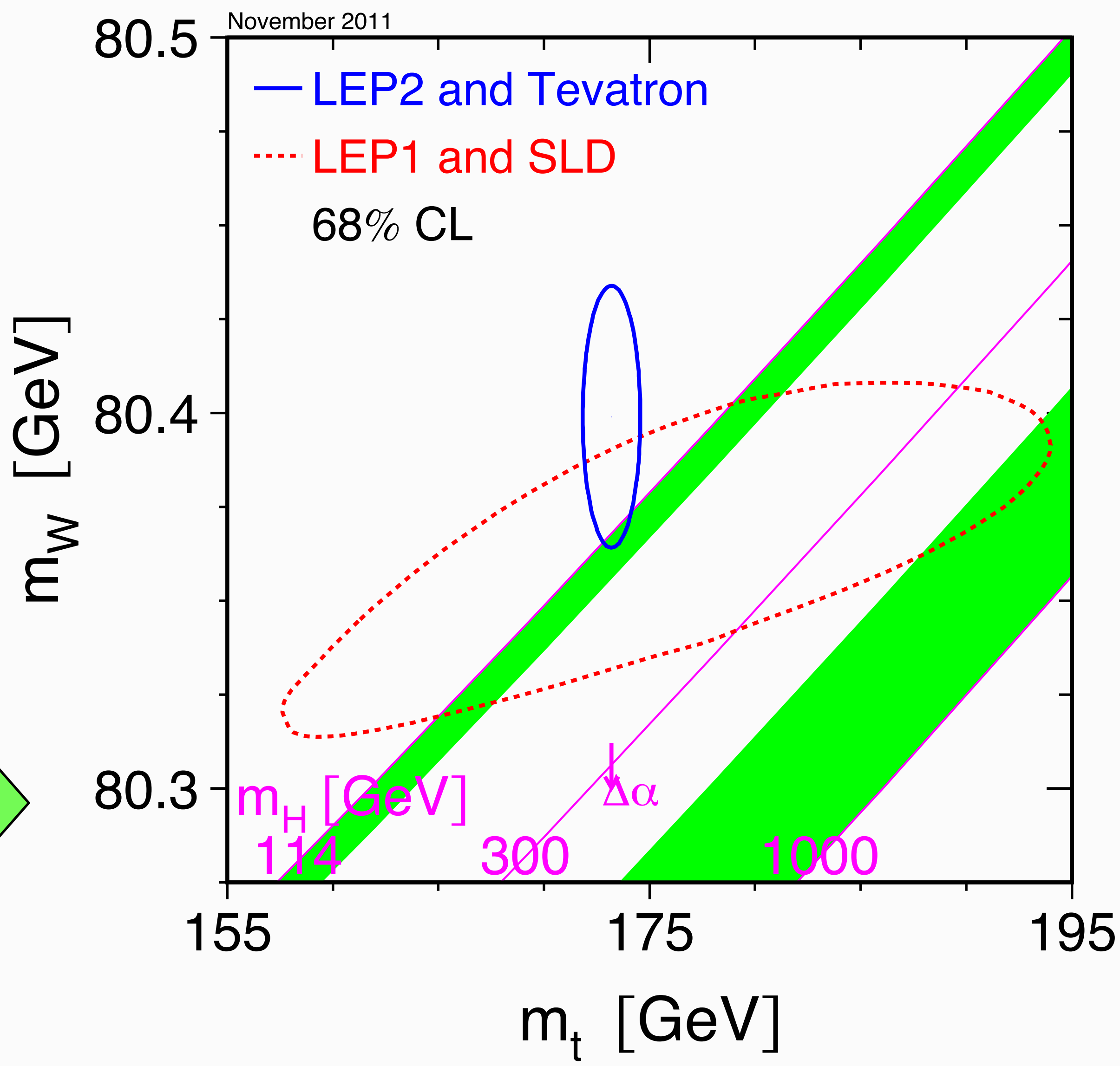
Before LHC 2011 Run

Impact of the new limits on the green band



With < 2.3 fb^{-1} from LHC





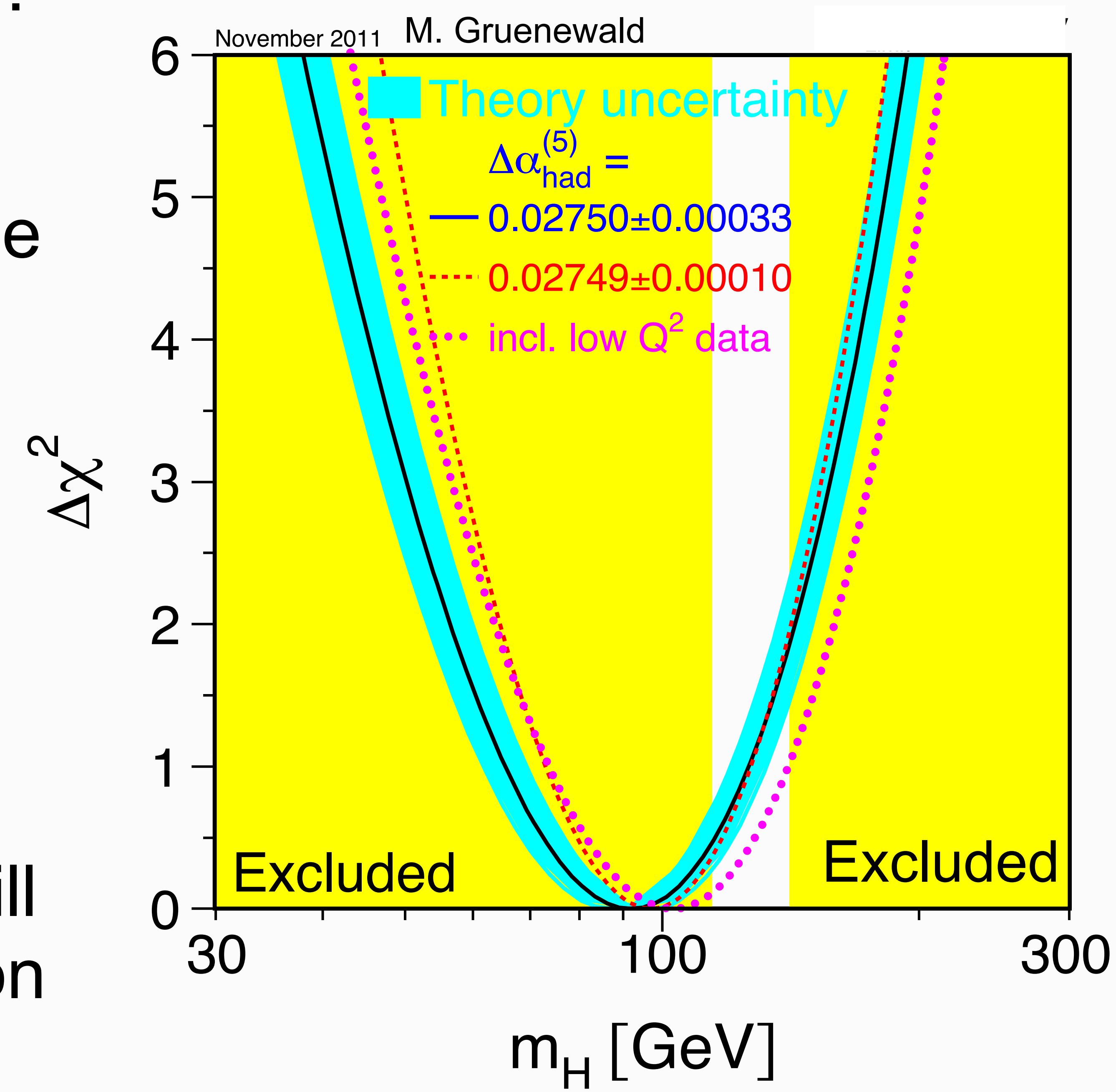
Conclusions

Little room left for the SM Higgs !
$114<m_H<141$ GeV @ 95% CL

LHC experiments will analyze the x3 data already collected before 2012 Winter Conferences

Tevatron will provide the final results on 10 fb^{-1} by the 2012 Summer Conferences

On the same time scale there will be a combination LHC + Tevatron

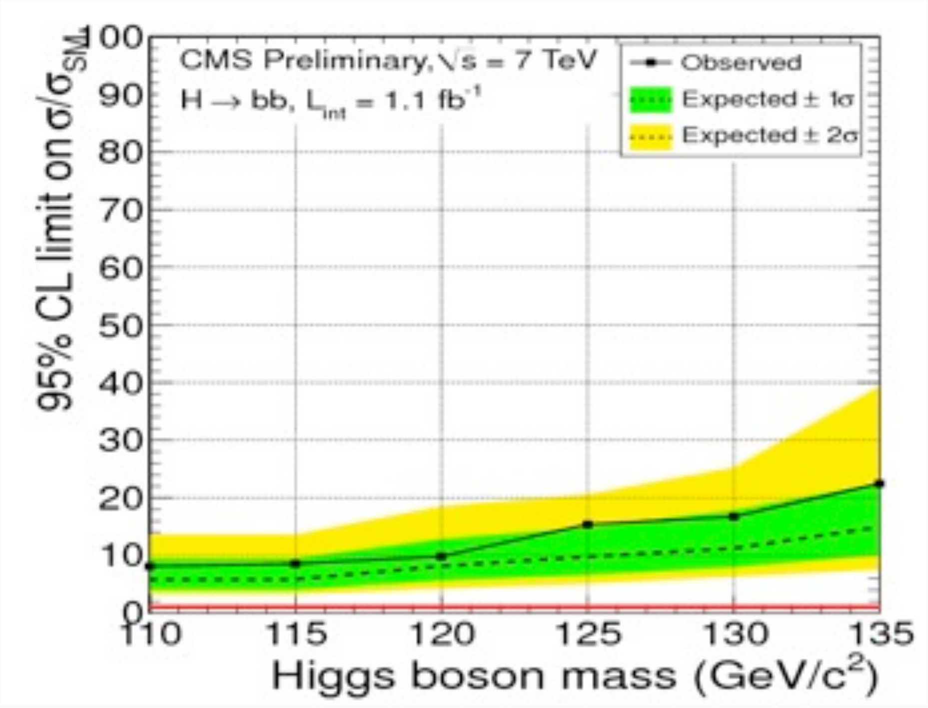


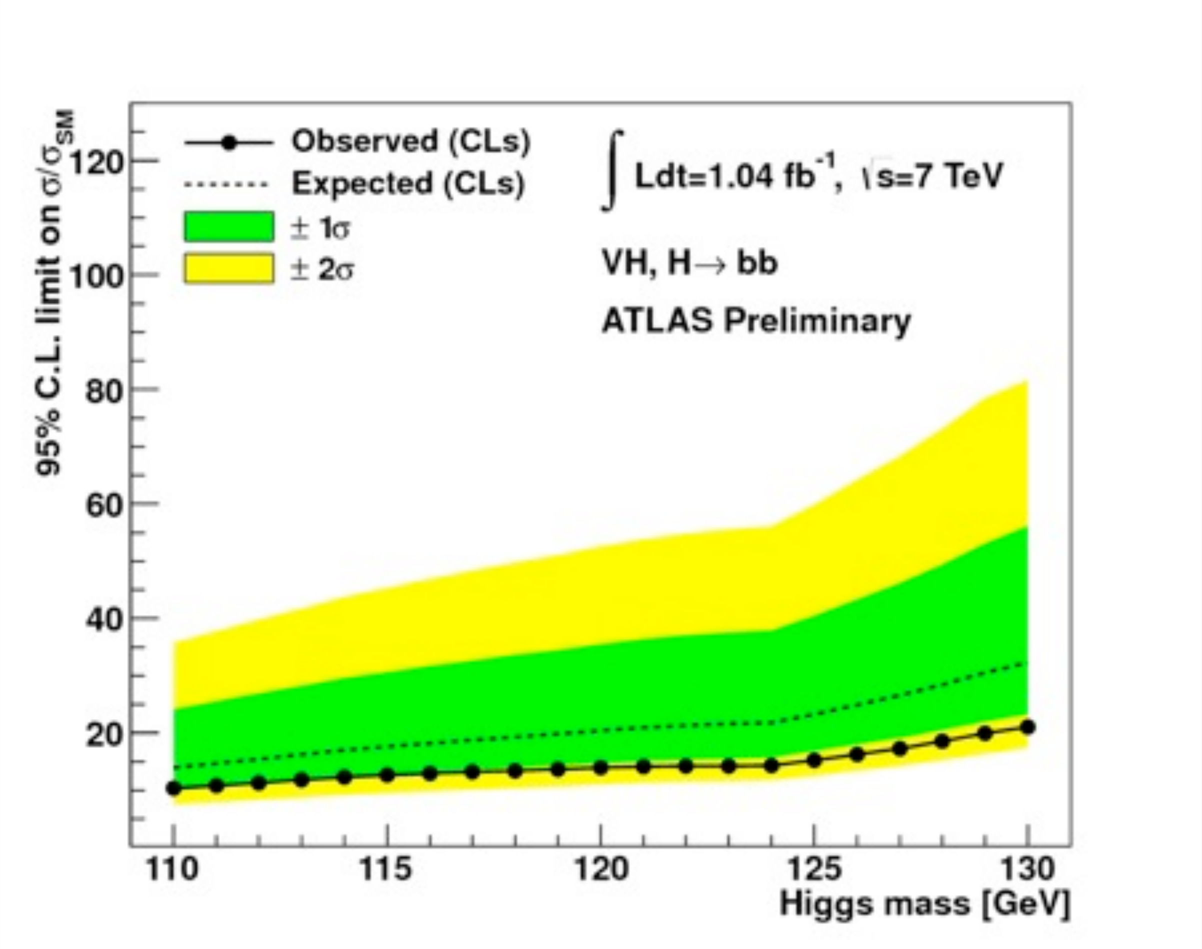
Backup

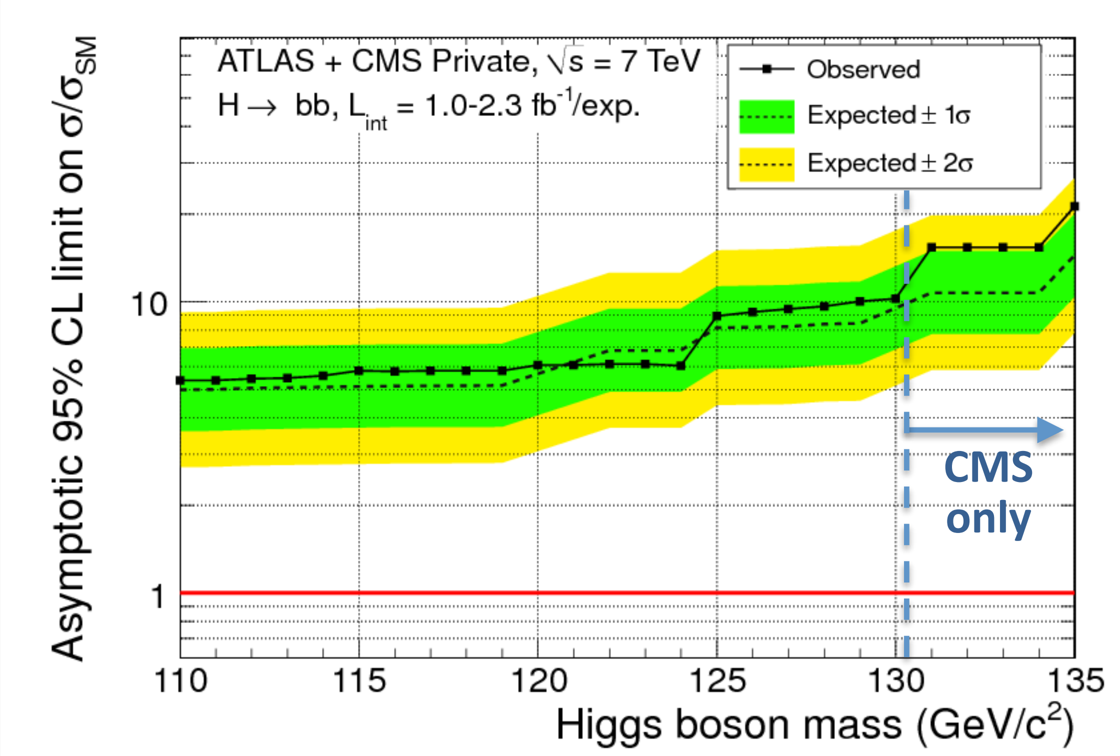
Correlated uncertainties

Source	Affected Processes	Typical uncertainty
PDFs+α_s (cross sections)	$gg \to H$, $t\bar{t}H$, $gg \to VV$	$\pm 8\,\%$
	VBF H, VH, VV@NLO	$\pm 4\,\%$
Higher-order uncertainties on cross sections	total inclusive $gg \to H$	$^{+12\,\%}_{-7\,\%}$
	inclusive "gg" $\to H + \geq 1$ jets	$\pm 20\,\%$
	inclusive "gg" $\to H + \geq 2$ jets	$\pm 20\%$ (NLO), $\pm 70\%$ (LO)
	VBF H	$\pm 1\,\%$
	associated VH	$\pm 1\,\%$
	$t\bar{t}H$	$^{+4\,\%}_{-10\,\%}$
	uncertainties specific to high mass Higgs boson, see Section 2.1	$\pm 30\%$
	V	$\pm 1\,\%$
	VV up to NLO	$\pm 5\,\%$
	$gg \to VV$	$\pm 30\,\%$
	$t\bar{t}$, incl. single top productions for simplicity	$\pm 6\,\%$
acceptance	acceptance for $H \to WW \to \ell\nu\ell\nu$ events	$\pm 2\%$
phenomenology	modelling of underlying event and parton showering	$\pm 10\,\%$
	fake lepton probability ($W + jets \to \ell\ell^{fake}$)	$\pm 40\%$
luminosities	ATLAS and CMS uncertainties on their luminosity measurements	$\pm 3.7\,\%$, $\pm 4.5\,\%$

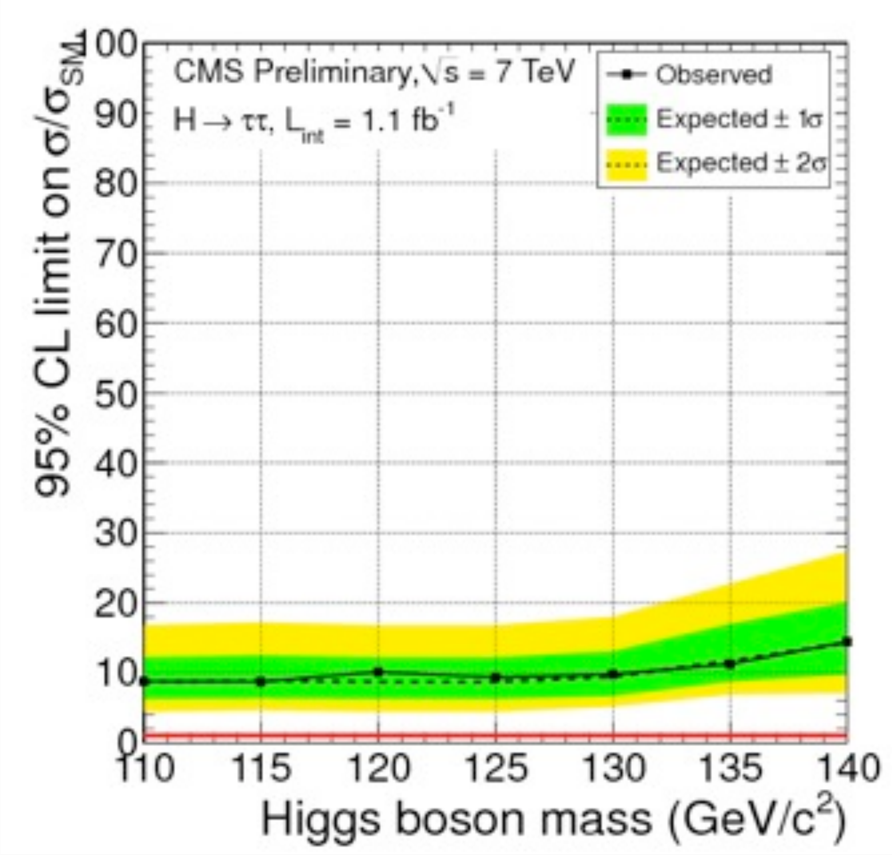
Individual Channels H-->bb

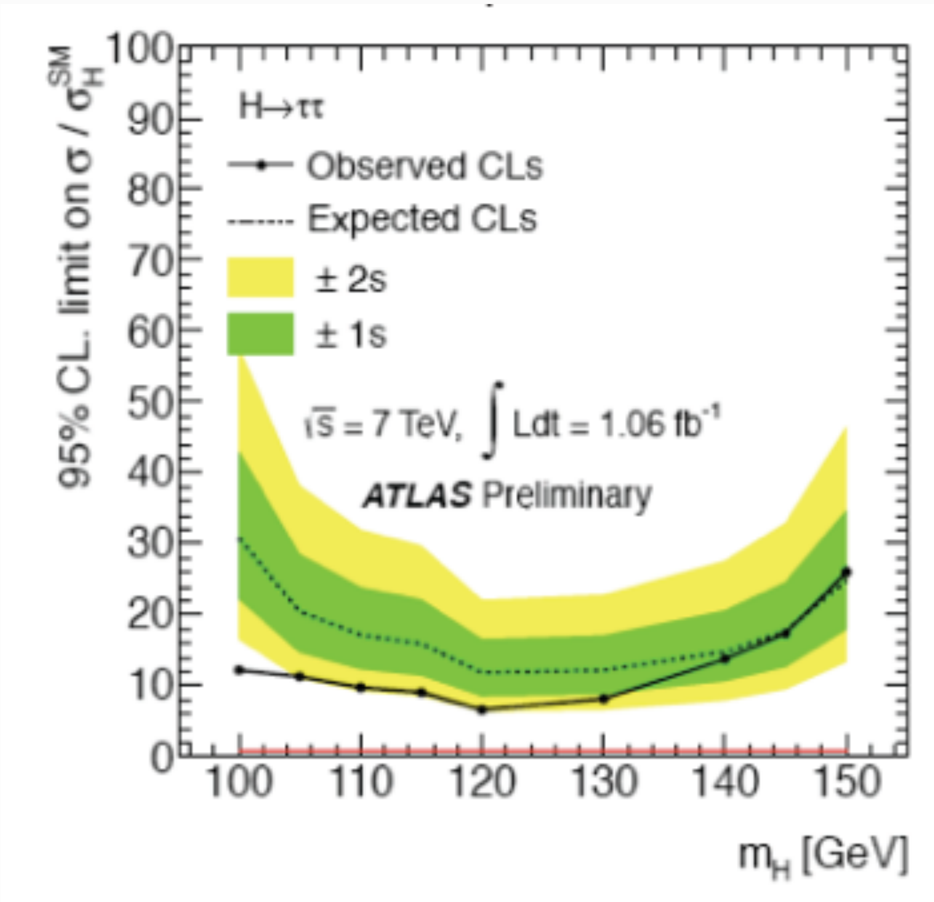


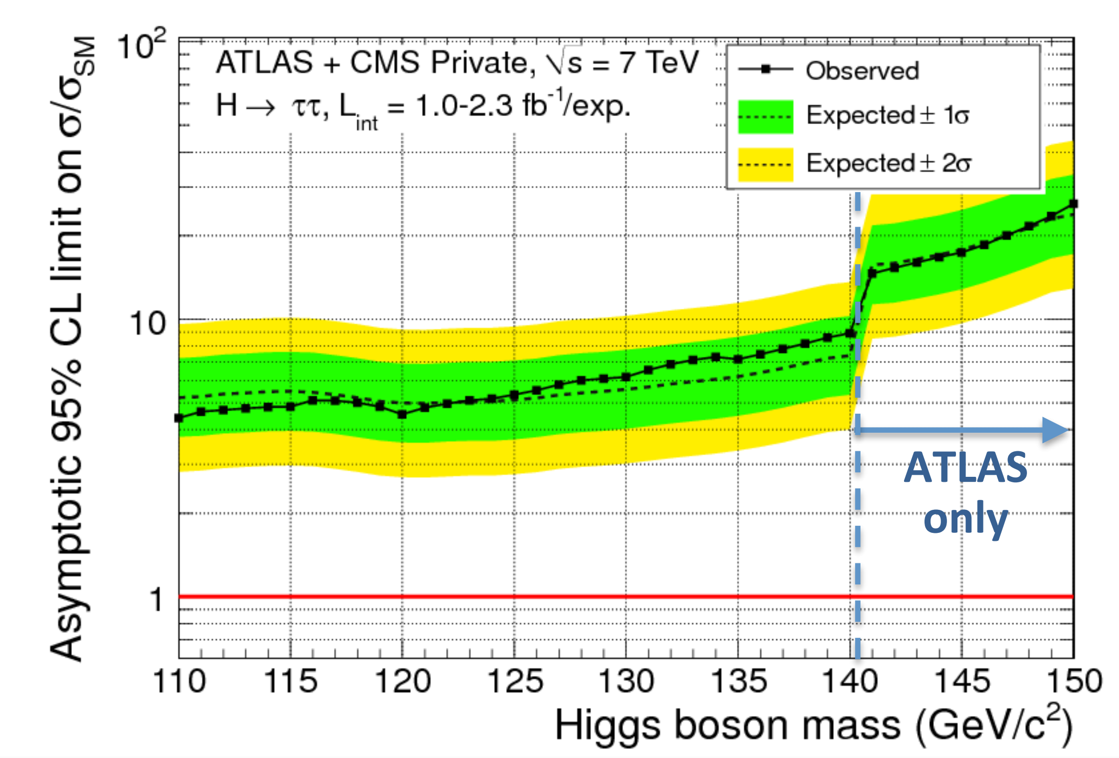




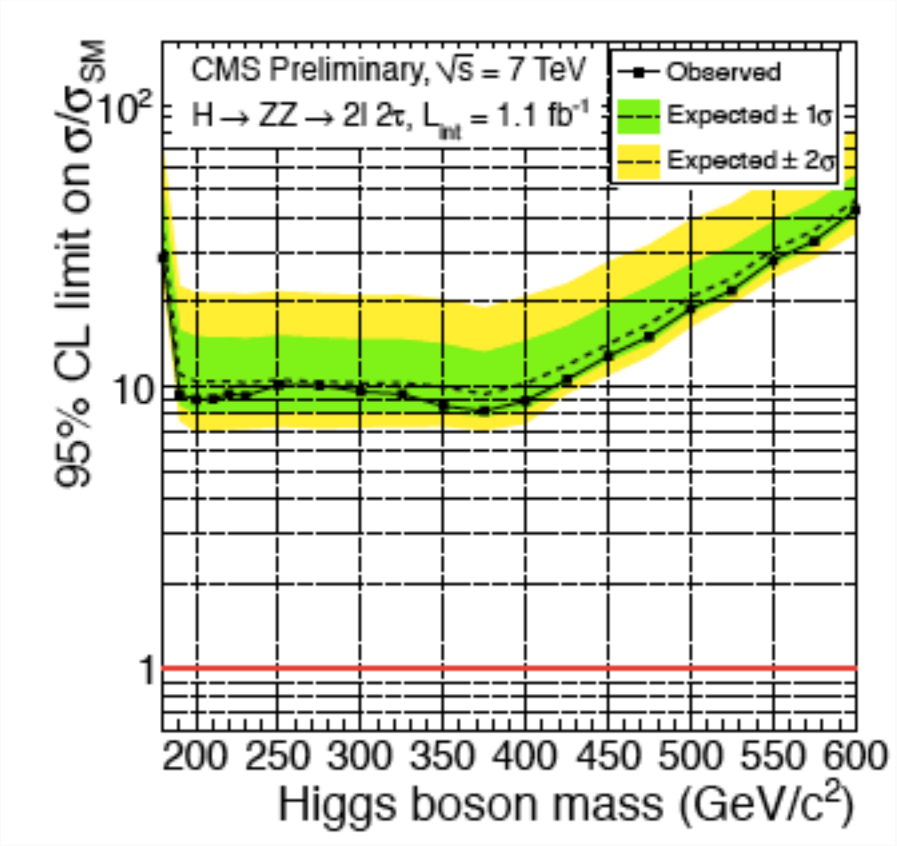
Individual Channels H--> tau tau



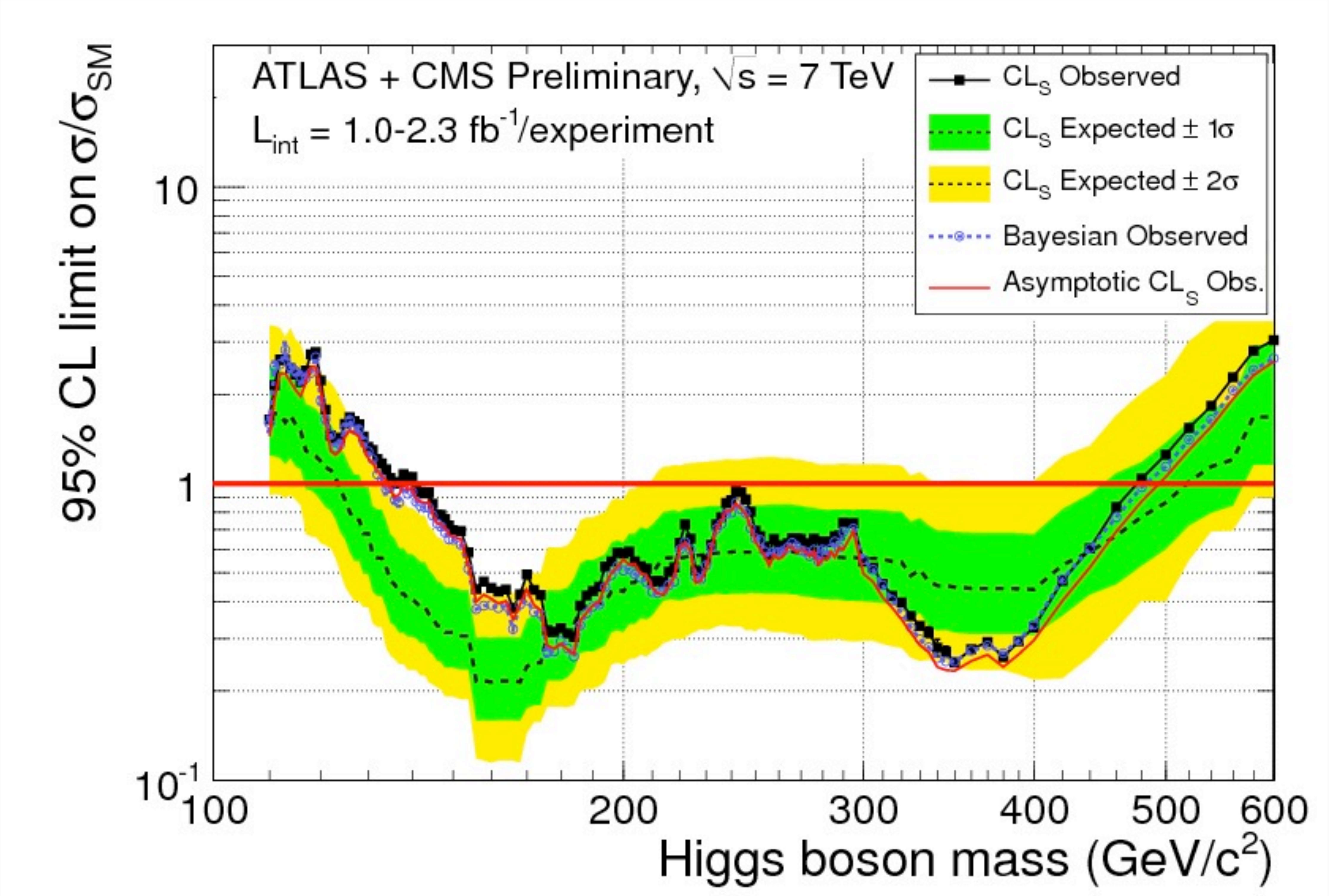




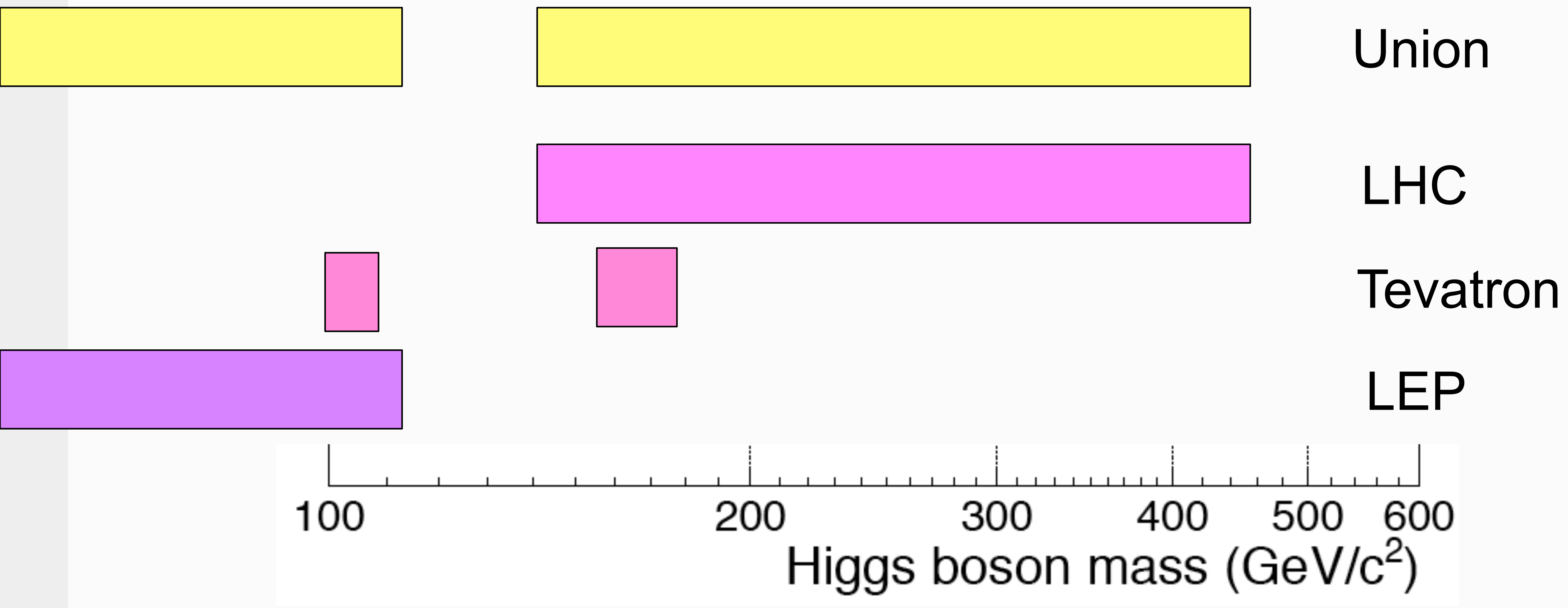
Individual channels H-->2l2tau



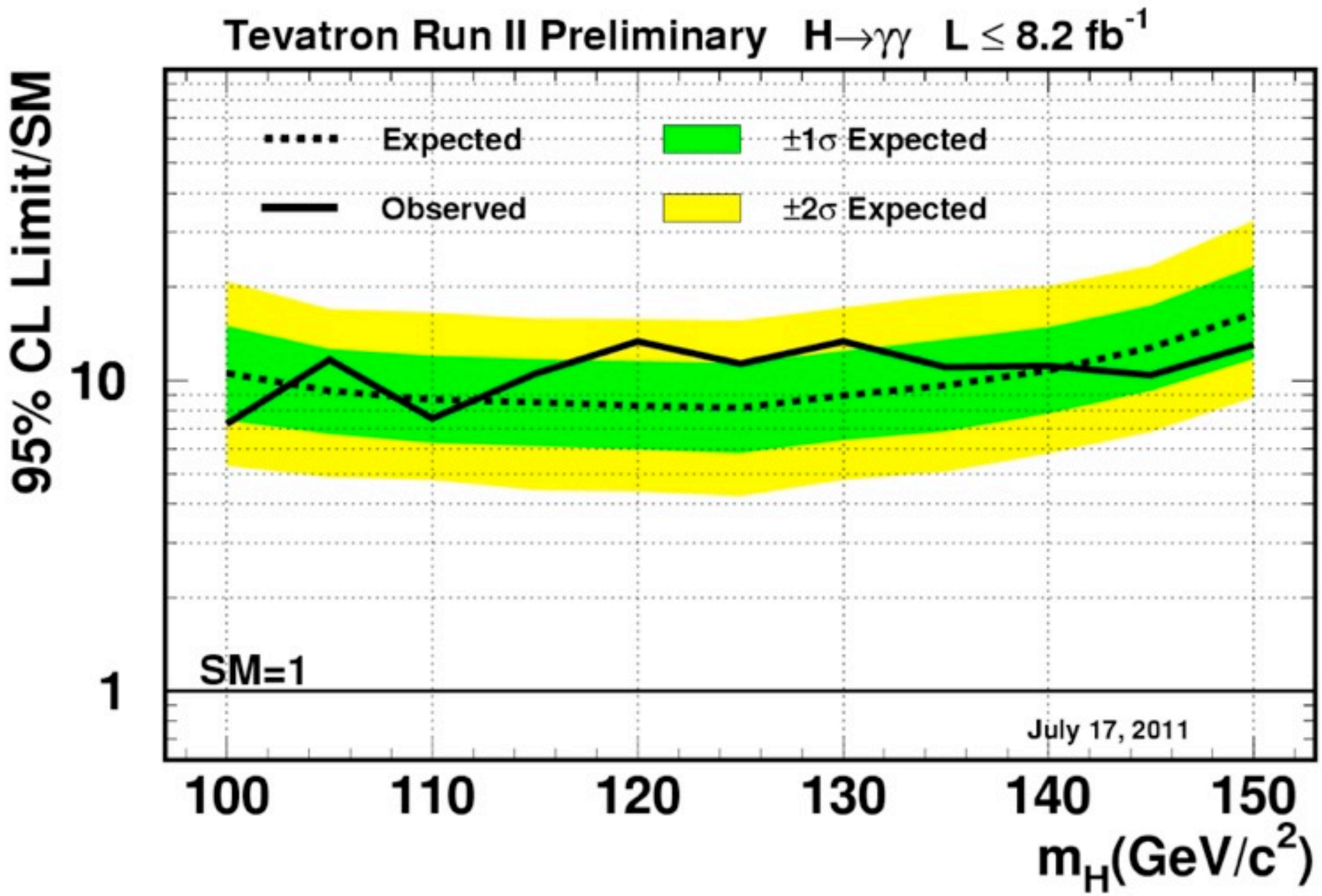
Comparison of different combination methods



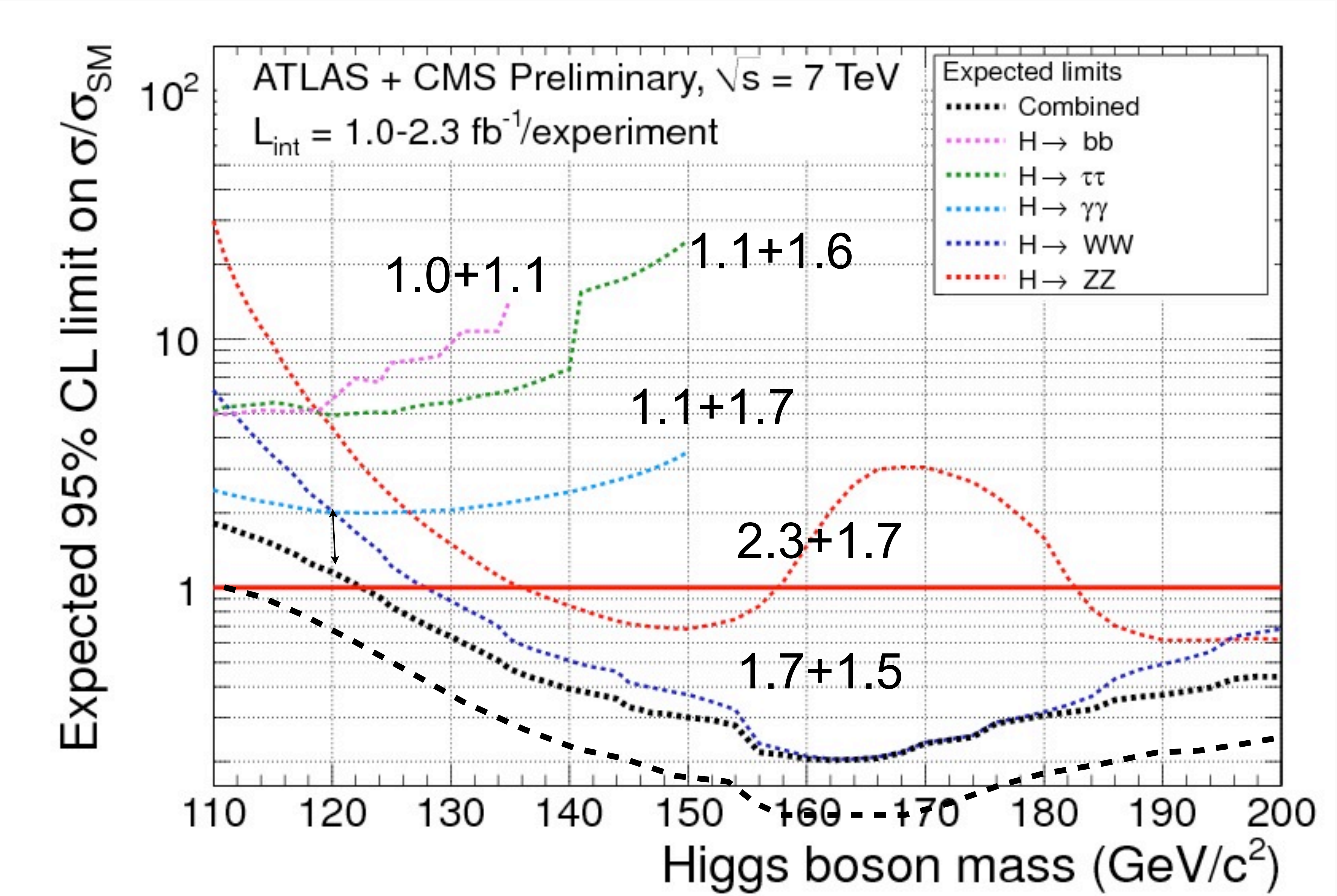
Exclusion Regions SM Higgs

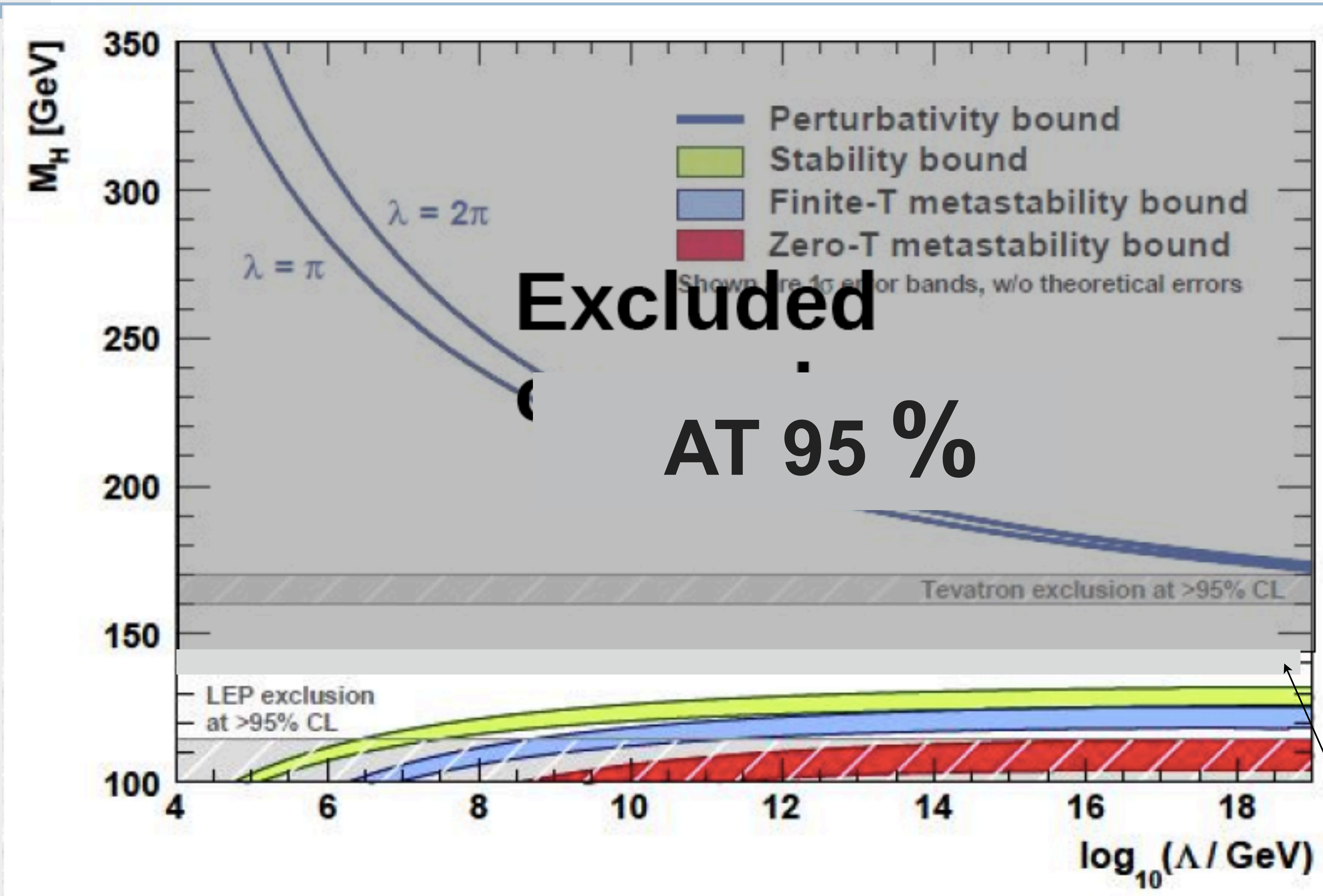


Tevatron H→γγ



Expected limit - low mass zoom





Excluded region at 90% CL

Statistical analysis: modelling

- For each measurement directly entering the combination, expected outcome depends on:
  - The lack or presence of a higgs boson signal. represented by the signal strength $\mu = \sigma/\sigma_{SM}$
  - Quantities affected by systematical uncertainties: represented by nuisance parameters θ
    These parameters usually have an associated measurement that provides a preferred value θ_0 (e.g. from control sample, theory calculation, ...), and a probability distribution around that value.

Statistical analysis: modelling

The likelihood function is built as a product

$$L(\text{data}|\mu, \theta) = L_{obs}(\text{data}|\mu, \theta) \cdot L(\theta_0|\theta)$$

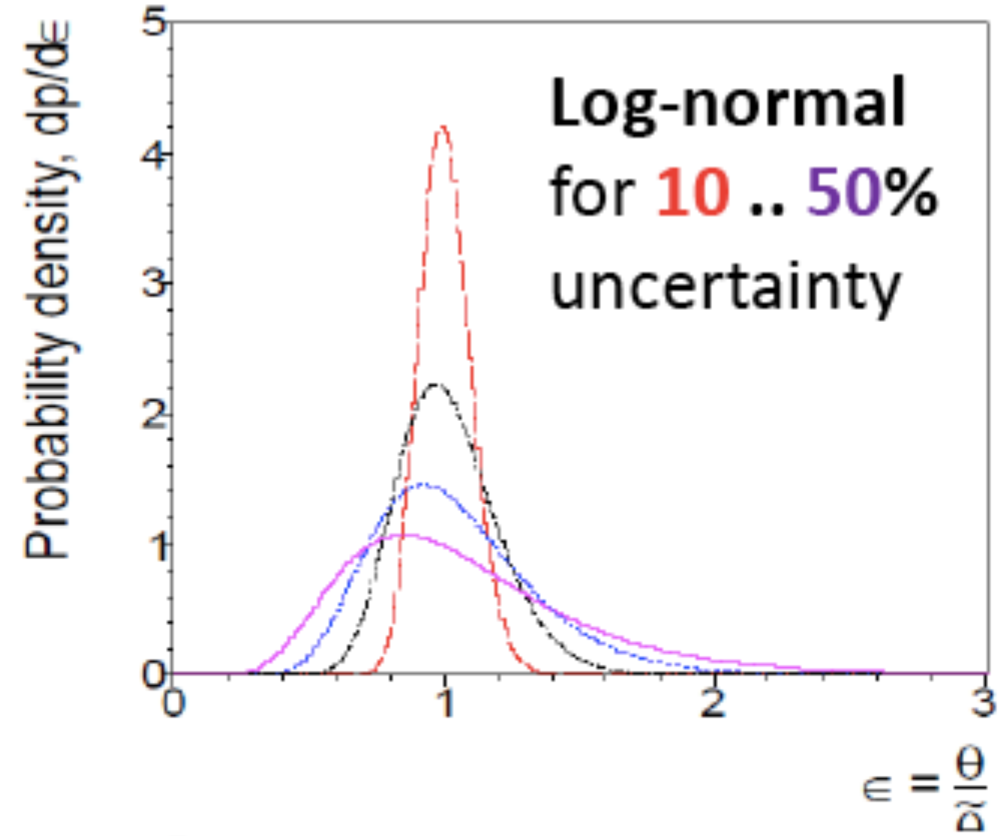
Prob. of observing the data given μ, θ.
In the case of counting experiment with
$b(\theta)$ background and $s(\theta)$ signal
it's just a Poisson($N \mid \mu \cdot s(\theta) + b(\theta)$)

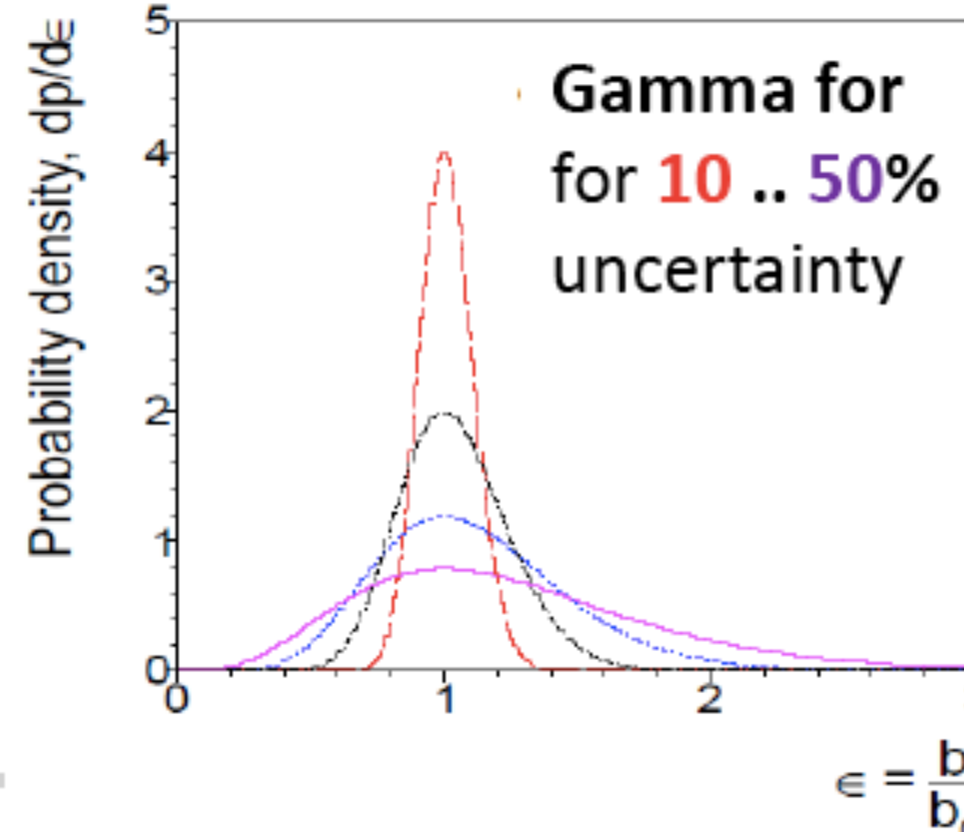
Likelihood of θ_0 given θ (Frequentist).
Posterior prob. of θ after measuring θ_0
and assuming flat prior on θ (Bayesian)

Statistical analysis: modelling

P.d.fs for nuisance parameters:

- For yields measured from a control sample with stat. uncertainties: Gamma
- Other uncertainties on yields: log-normal distribution (remains "regular" for large uncertainties)
- Parameters with no prior knowledge, e.g. the γγ background: uniform distrib.
- Other parameters, usually affecting shapes: Gaussians





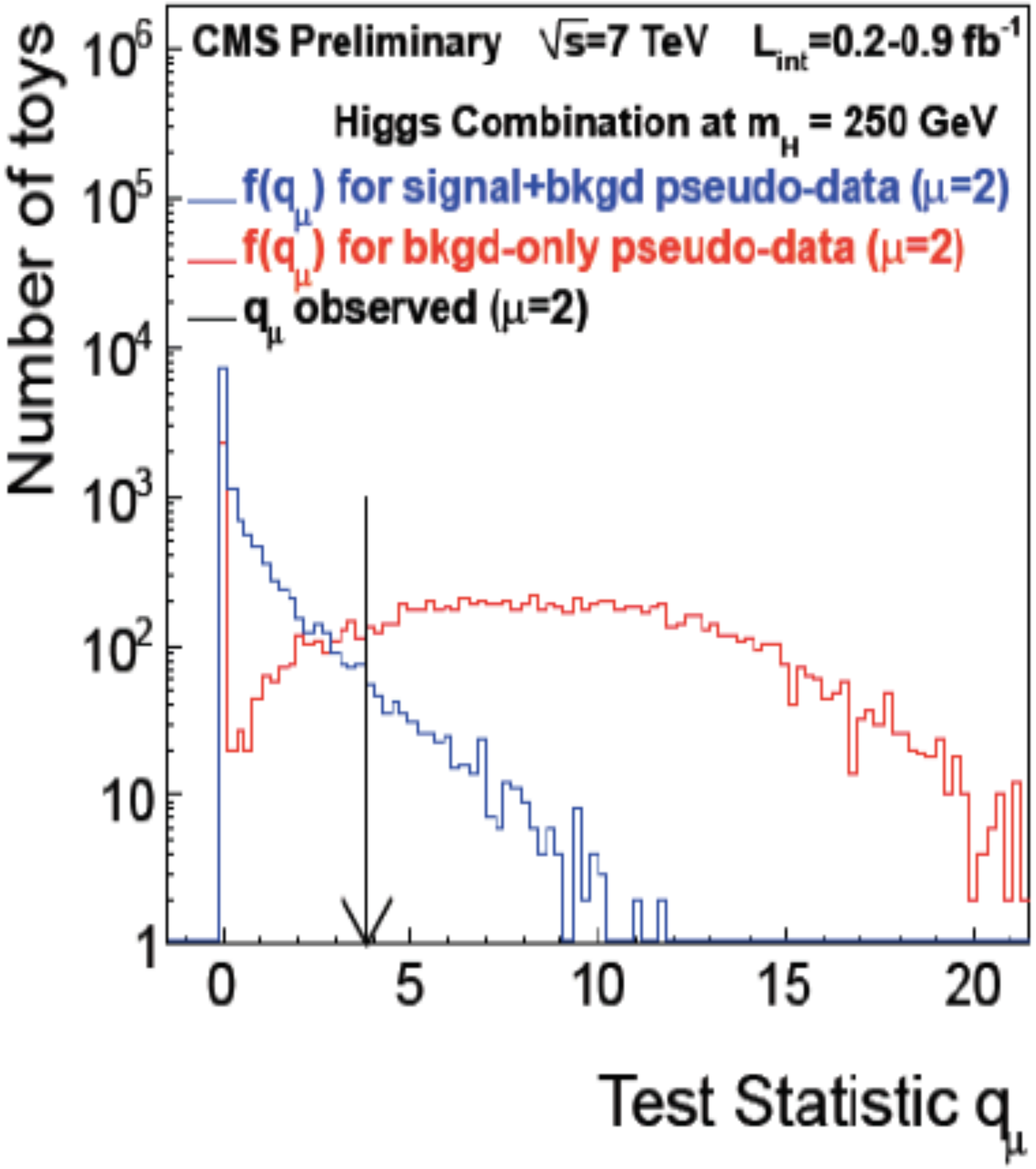
Statistical analysis: limits(1)

Two paradigms for limits:

- Frequentist: test values of $\mu = \sigma/\sigma_{SM}$ by tossing pseudo-experiments and evaluating how often they are more signal-like than the real data observation.

  Use "CLs" construction to be conservative in the presence o background fluctuations

  Small differences w.r.t. LEP anc Tevatron (see backup)



Statistical analysis: limits (2)

- Bayesian: interpret the likelihood function as a p.d.f. for $\mu = \sigma/\sigma_{SM}$ assuming a flat prior, compute the interval $[0, \mu]$ that contains 95% of prob.

  Exactly as PDG & Tevatron
- CLs and Bayesian are different definitions, results are within 10%