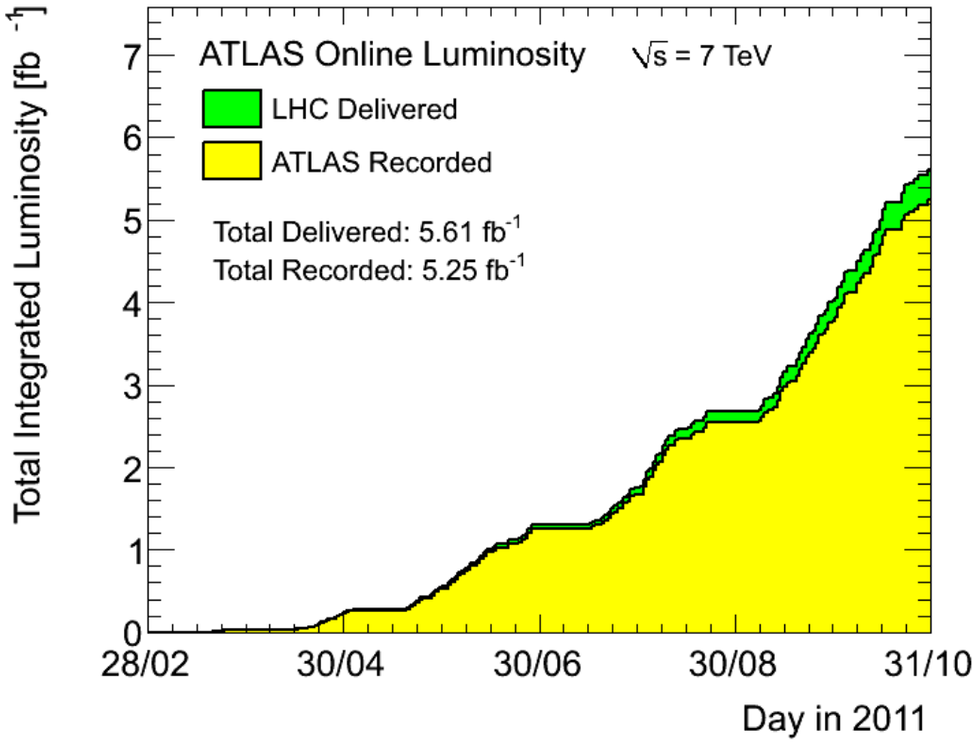
Search for the (SM)Higgs boson at LHC

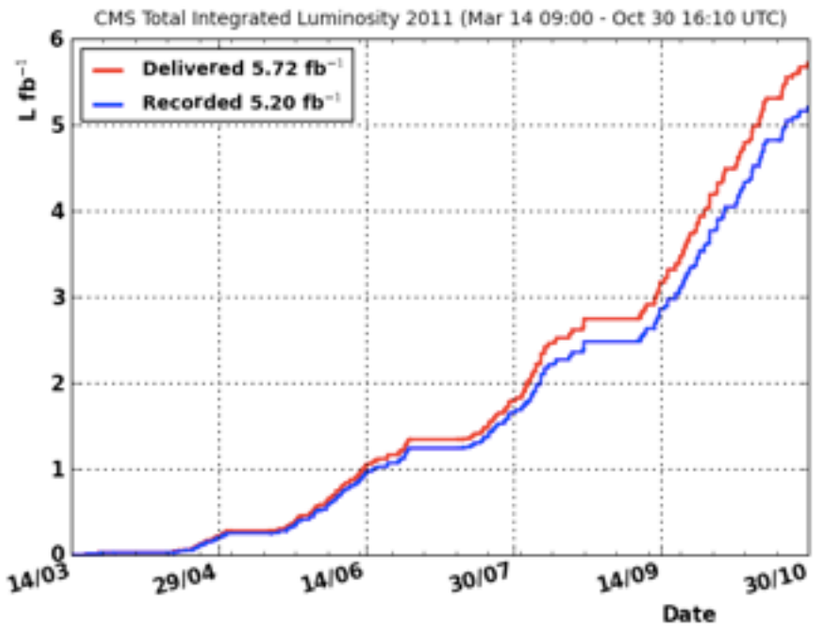
SUPERFIELDS - Eighth Joint Seminar - Torino March 2012

Gigi Rolandi,
CERN and Scuola Normale Superiore , Pisa

LHC 2011 Run

- About 5 fb-1 collected by each experiment in 2011



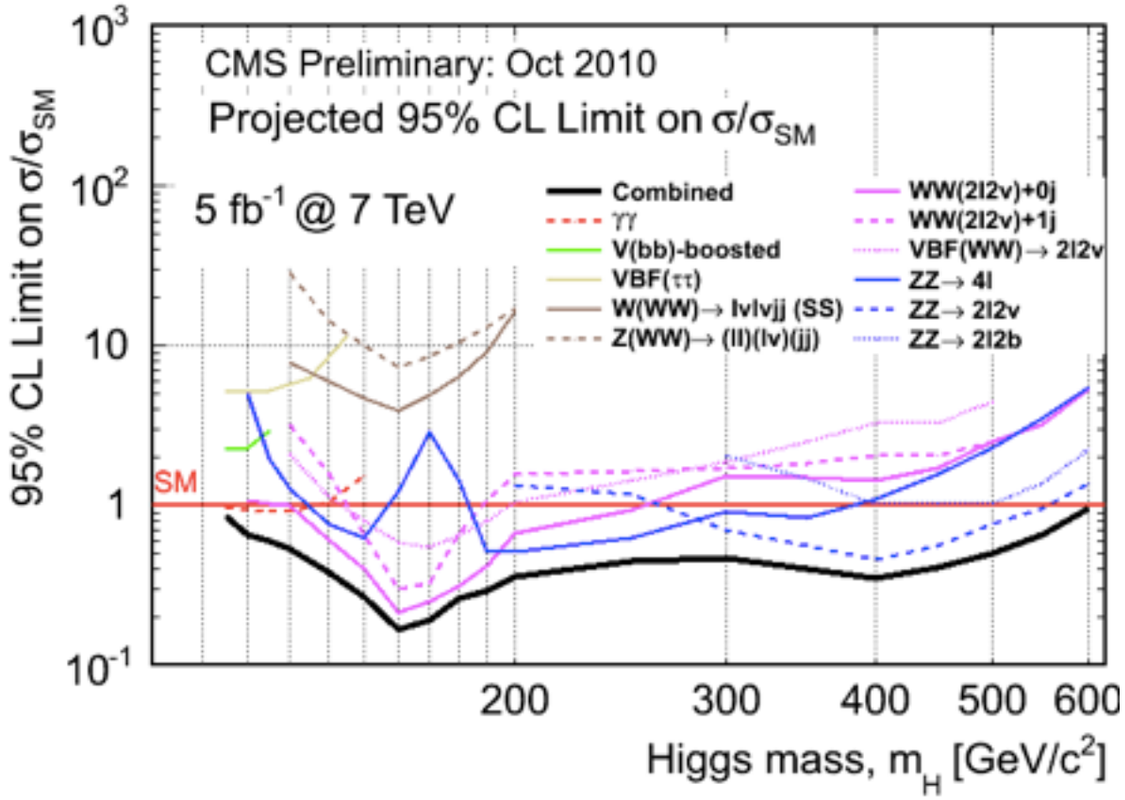


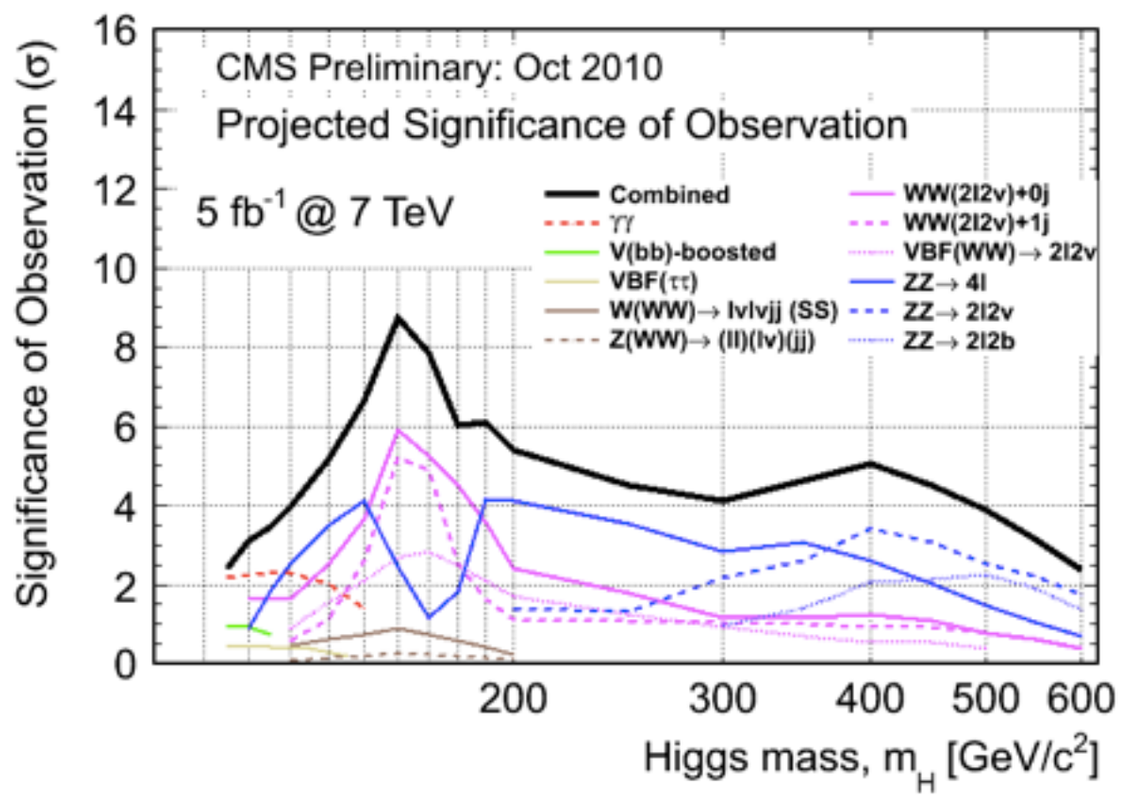
- many improvements on LHC allowed to reach instantaneous luminosity in excess of 310^{33} cm^{-2} s^{-1}

Projected (2010) sensitivity with 5/fb

- With this statistics the Higgs boson can be excluded in the whole range, if it does not exists.

ATLAS has very similar projections

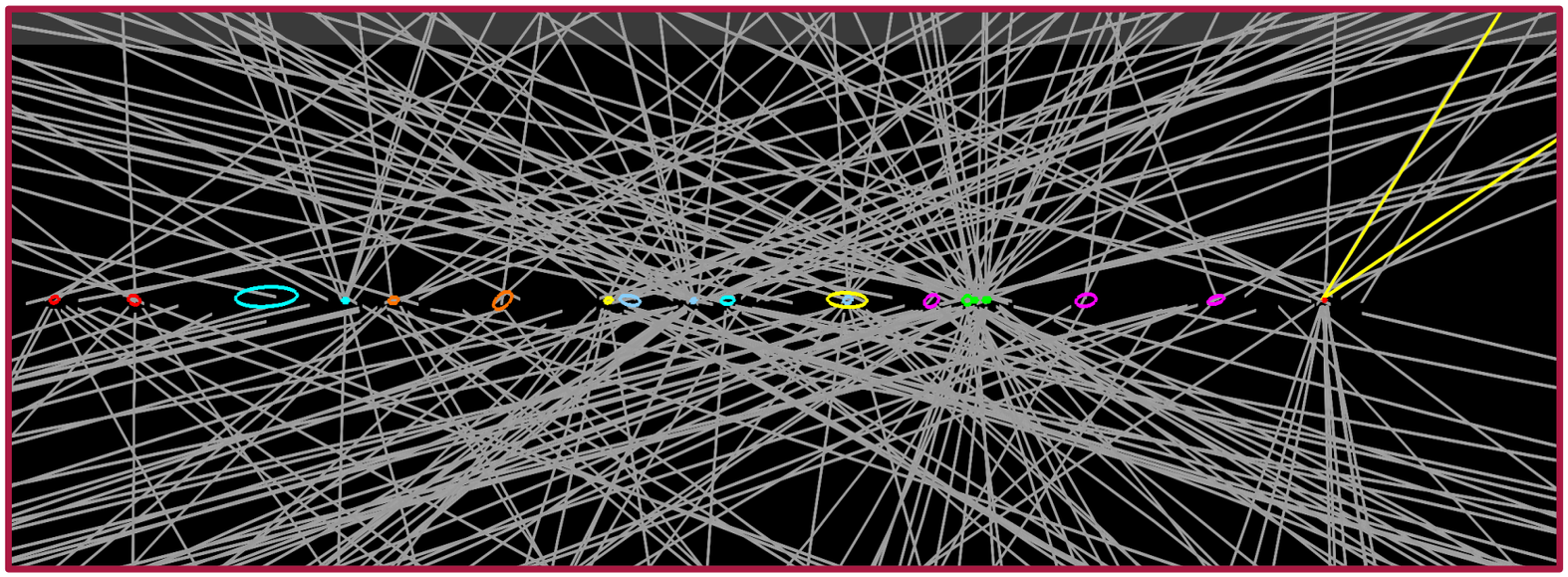


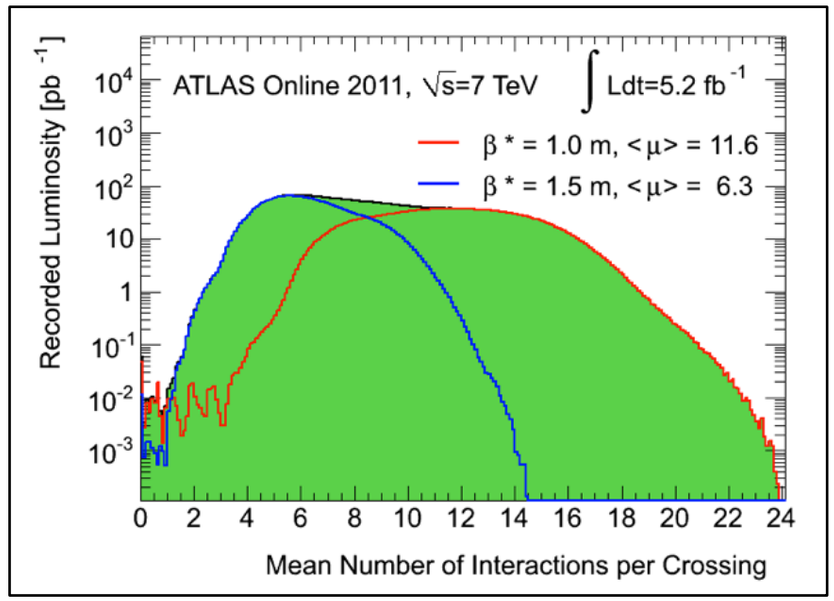


- Or >3 σ evidence above 120 GeV...

High-Luminosity --> High pileup

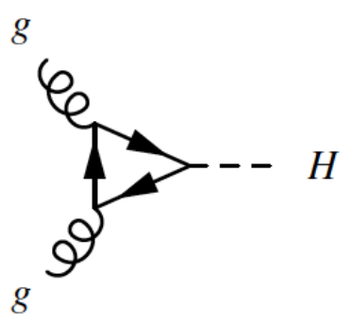
- Price to pay for the high luminosity: larger-than-expected pile-up



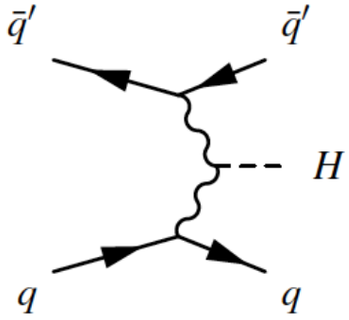


- Challenging for trigger, computing resources, reconstruction of physics objects (in particular ETmiss, soft jets, ..)

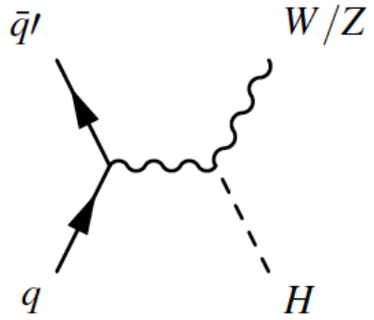
Higgs production pp@7Tev



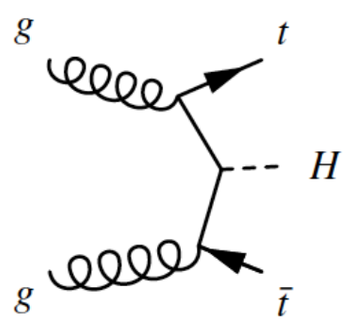
(a) $gg \to H$



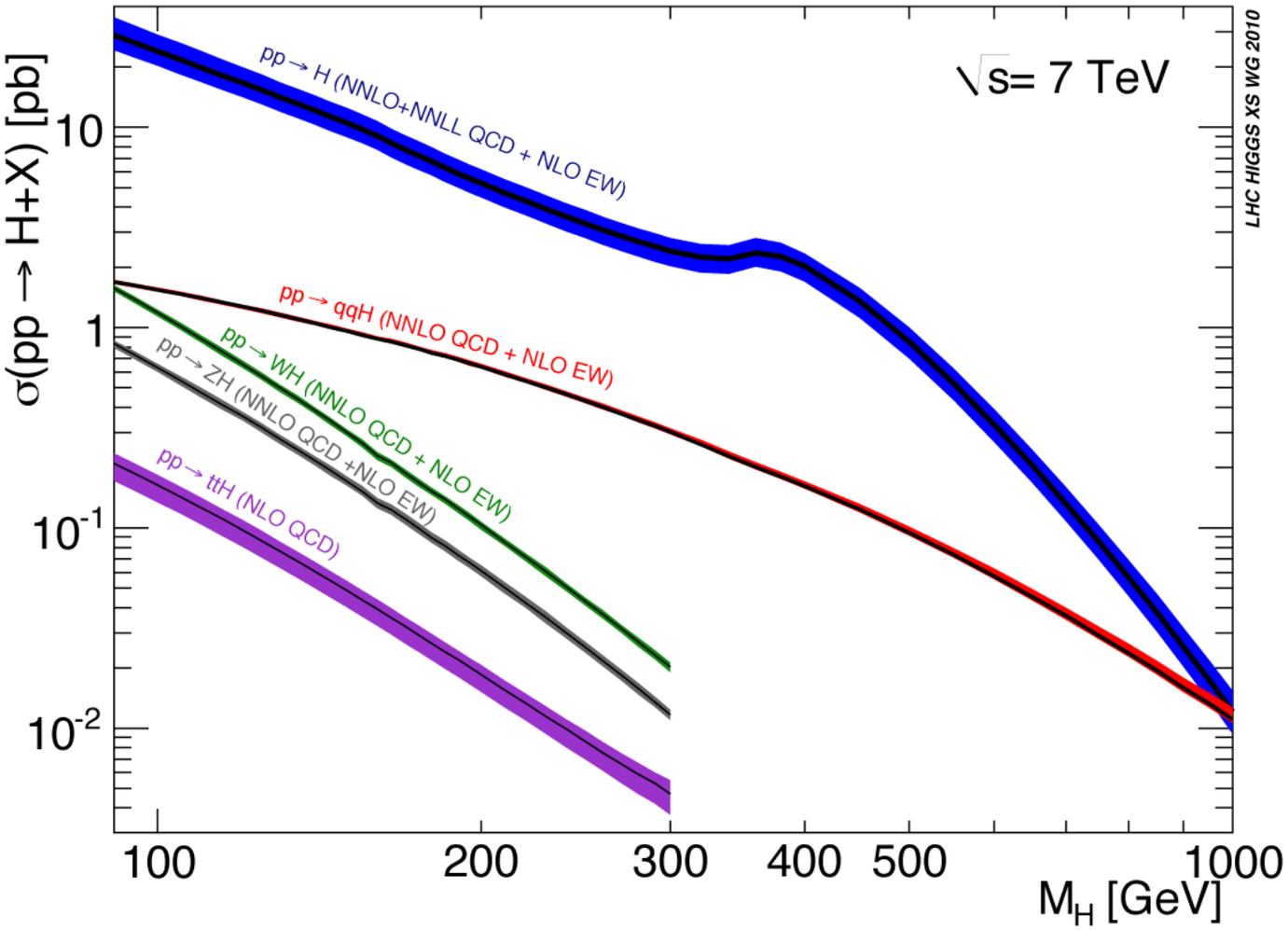
(b) VBF



(c) VH

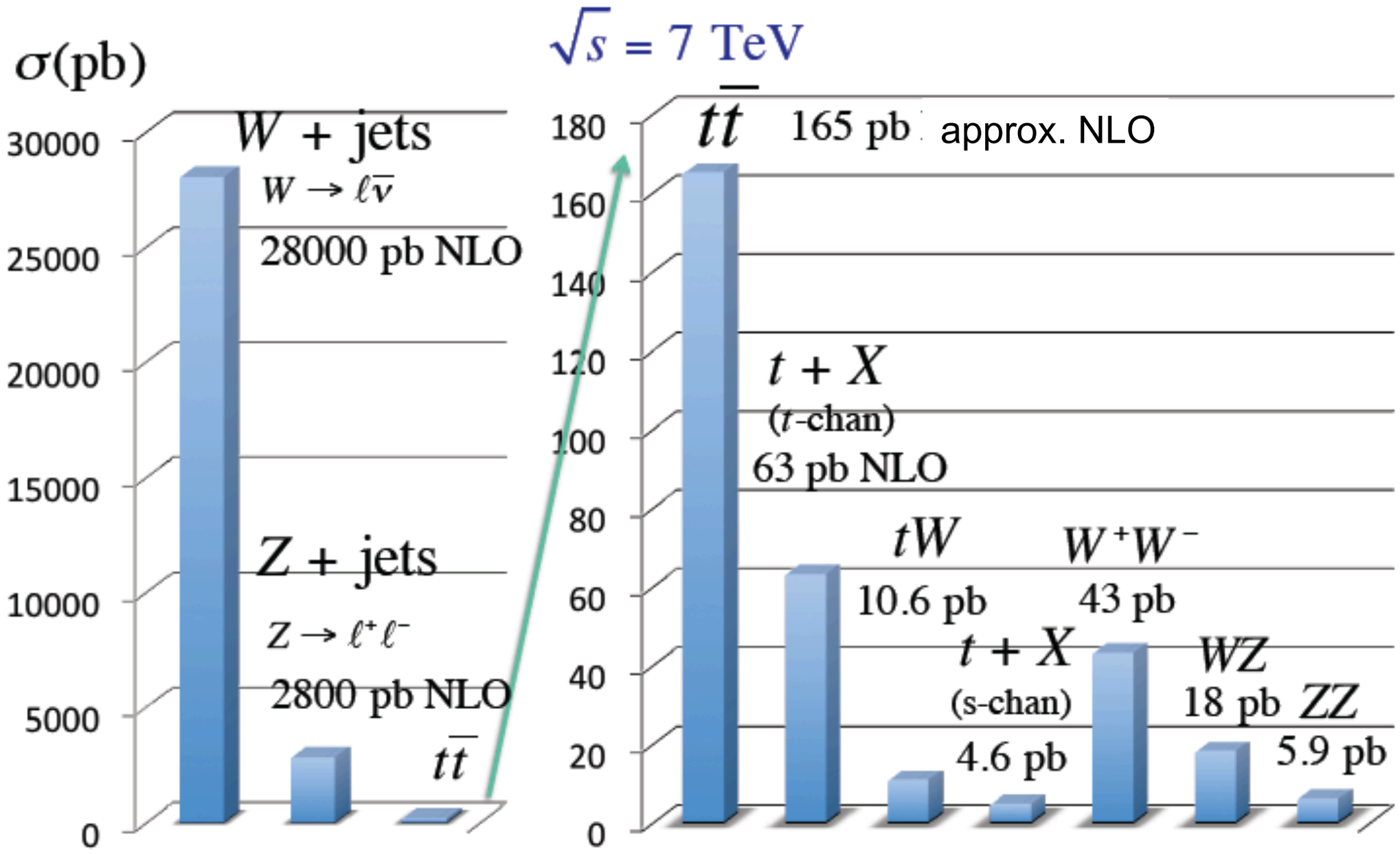


(d) $t\bar{t}H$



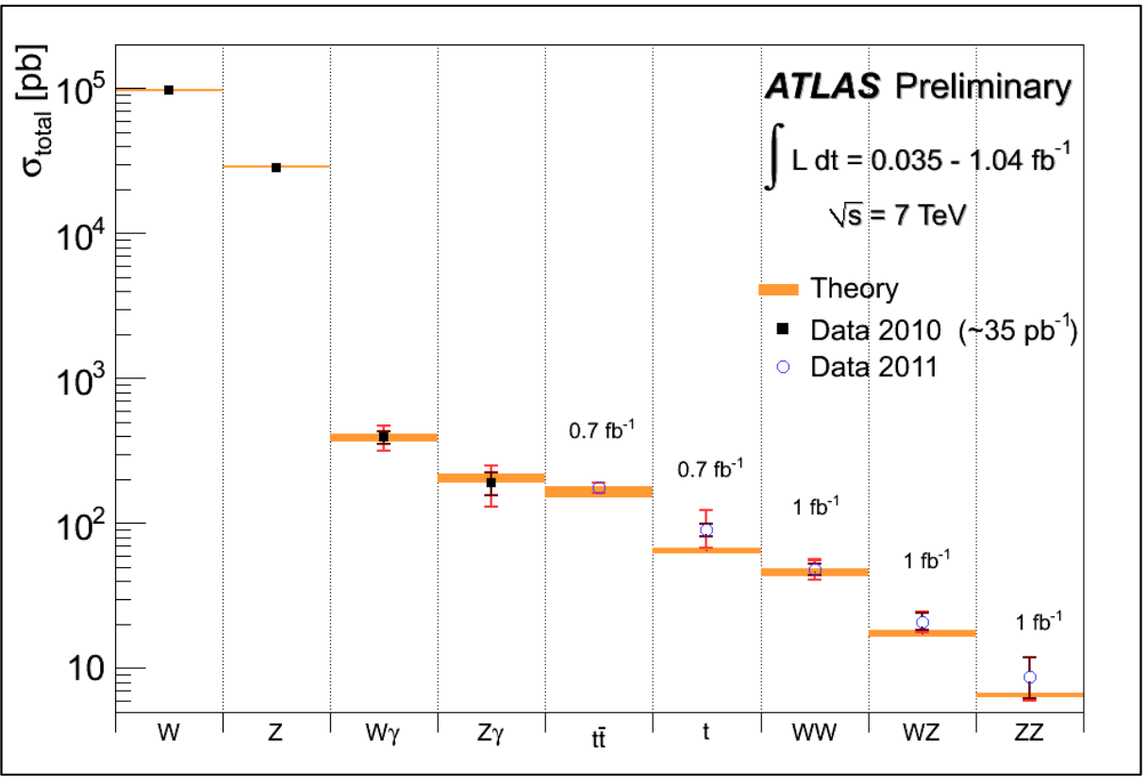
Key SM Background processes

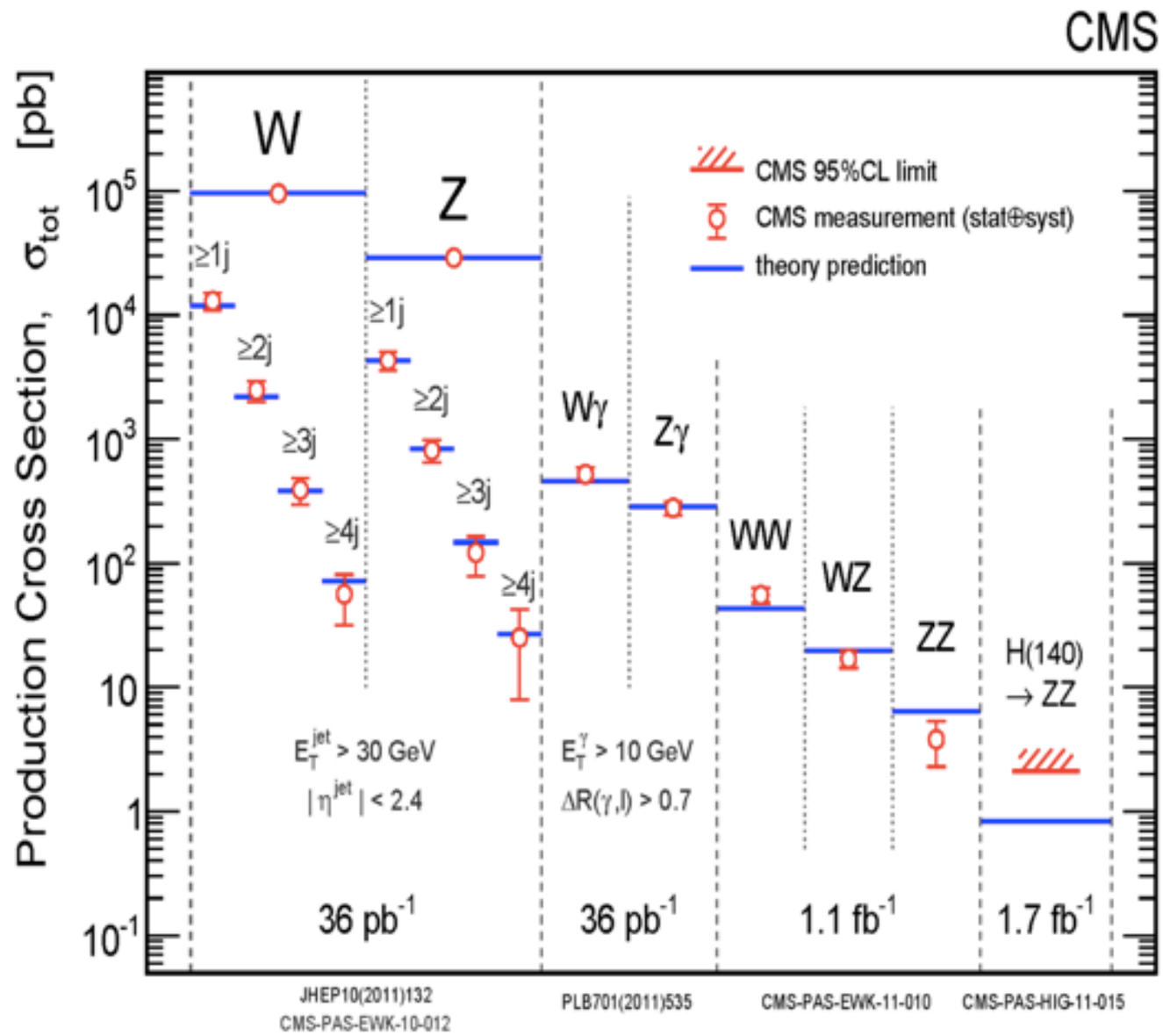
AT LHC



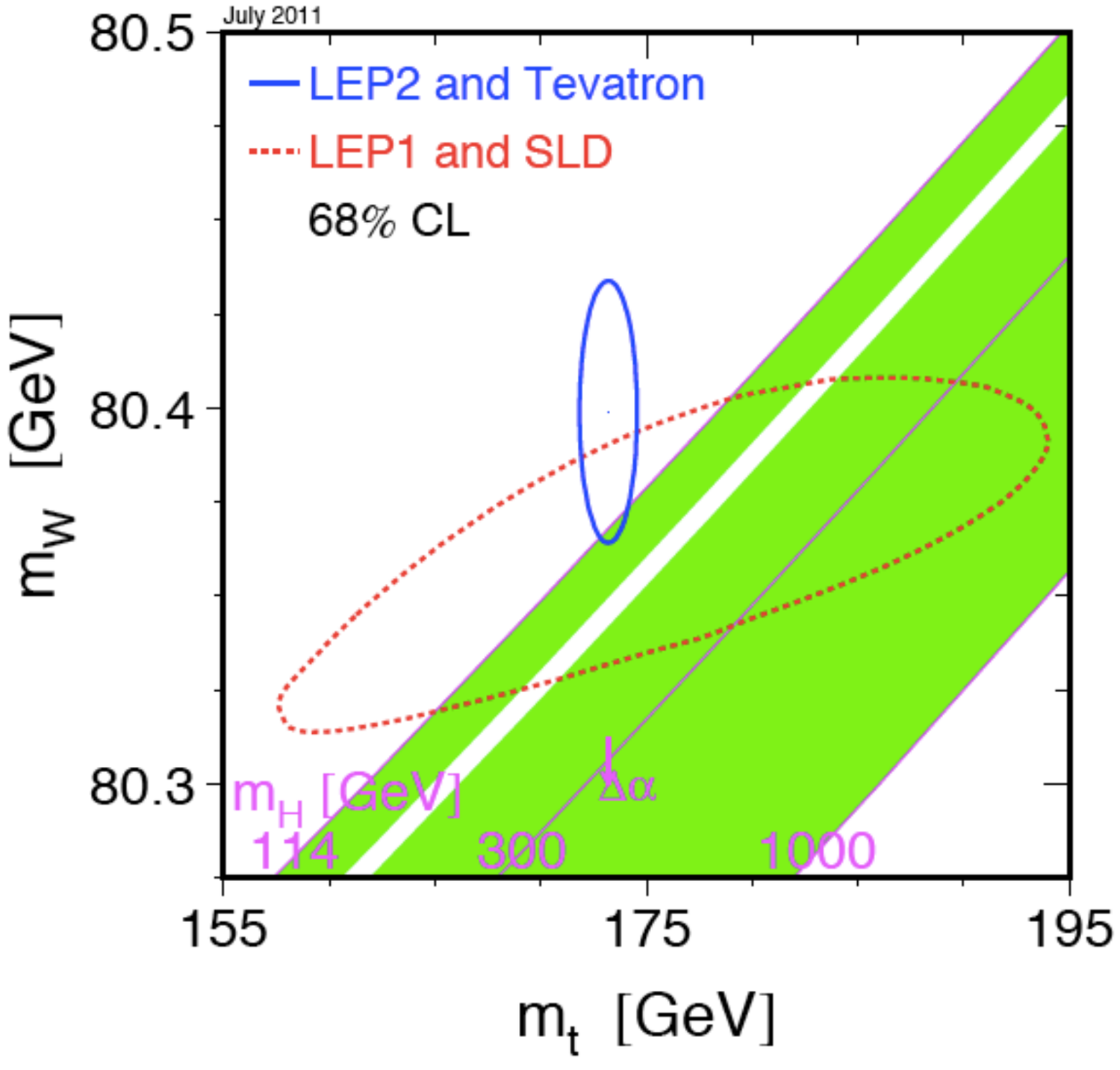
V. Sharma

SM processes are all “well measured”





SM Higgs search range



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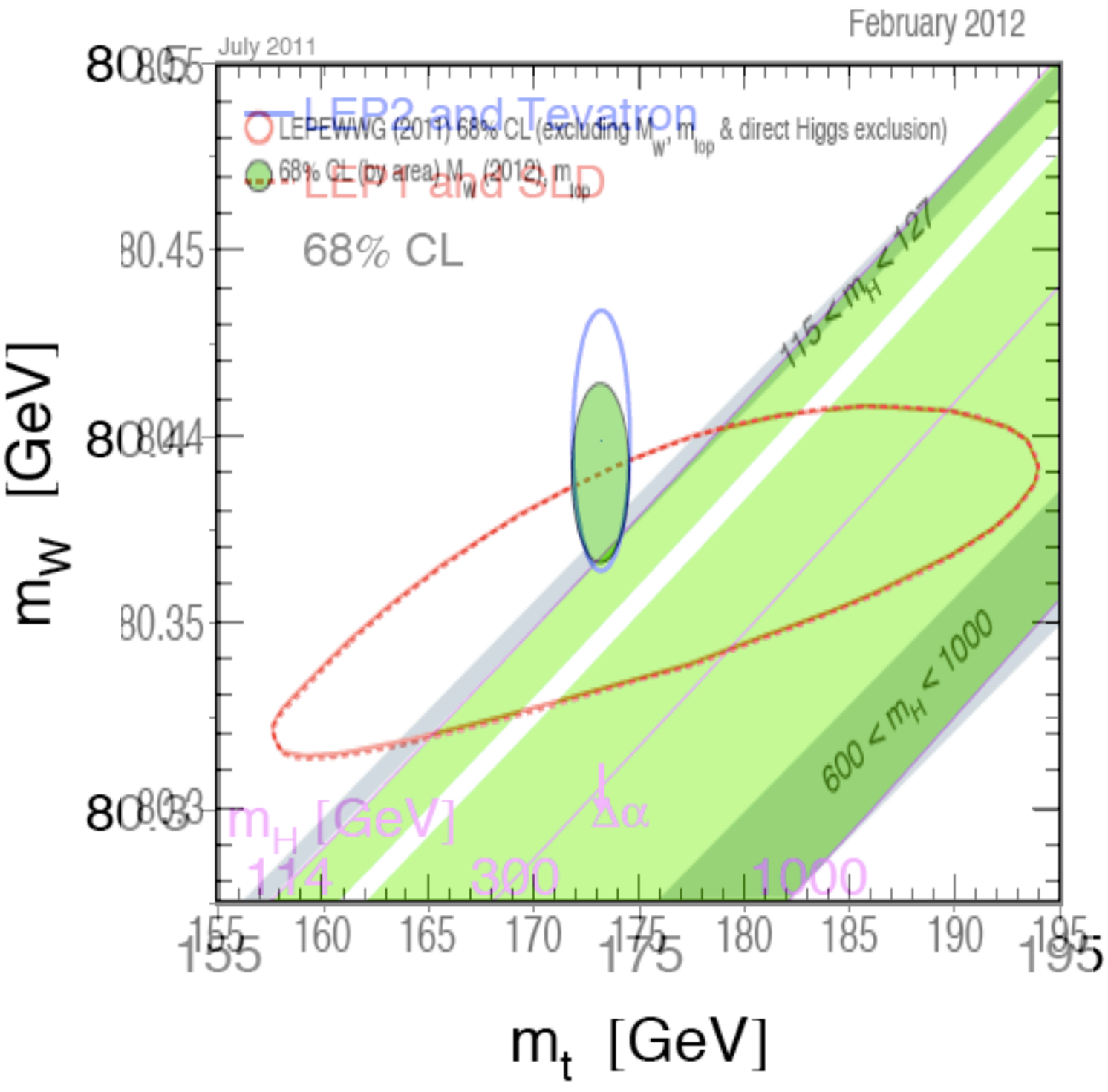


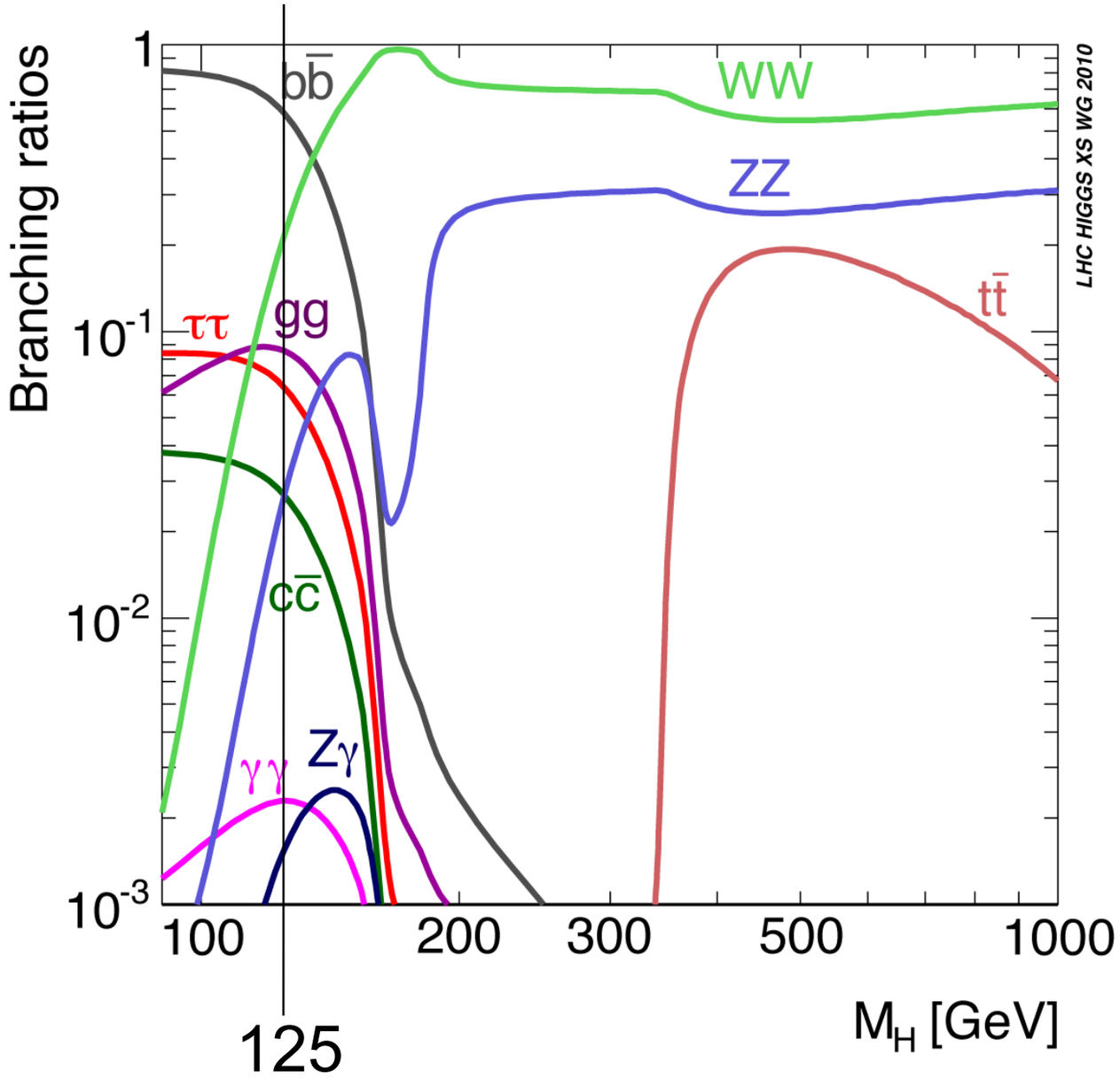
New W mass measurement from Tevatron (CDF)

Mw=80390 ± 16 MeV

In this talk I will concentrate on the low mass Higgs search.

Also including new LHC and Tevatron results presented at “Moriond EW” two days ago.

Higgs Searches



High mass : ZZ and WW

Low Mass: many channels

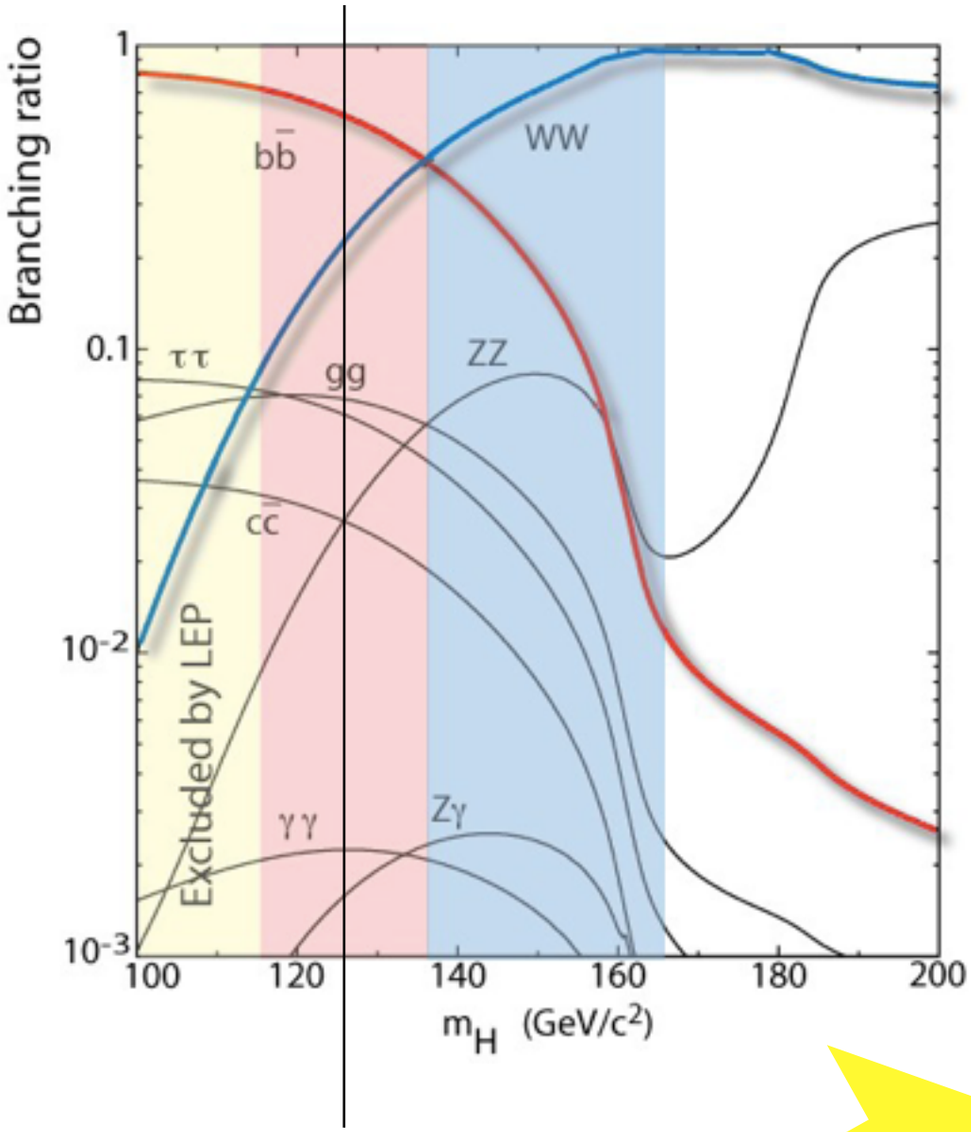
@ 125 GeV

σ ~ 15+1 pb

BR

4l	$1.2\ 10^{-4}$	(ZZ->4l)
γγ	$2.3\ 10^{-3}$	
2l2v	$1.0\ 10^{-2}$	(WW->2l2v)
ττ	$6.0\ 10^{-2}$	
bb	$5.8\ 10^{-1}$	

Higgs Searches



@ 125 GeV σ ~ 15+1 pb.
σ*BR*5 fb^{-1}

4l ~10 **Excellent mass resolution, small bkg. After selection 3 events and bkg of 0.6 event per ~ 1.5 GeV resolution**

γγ ~200 **Excellent mass resolution, large bkg. After selection 50 events and bkg of 150 event per ~ 1 GeV resolution**

2l2v ~800 **Poor mass resolution, large bkg. After selection 30 events and bkg of 150 event**

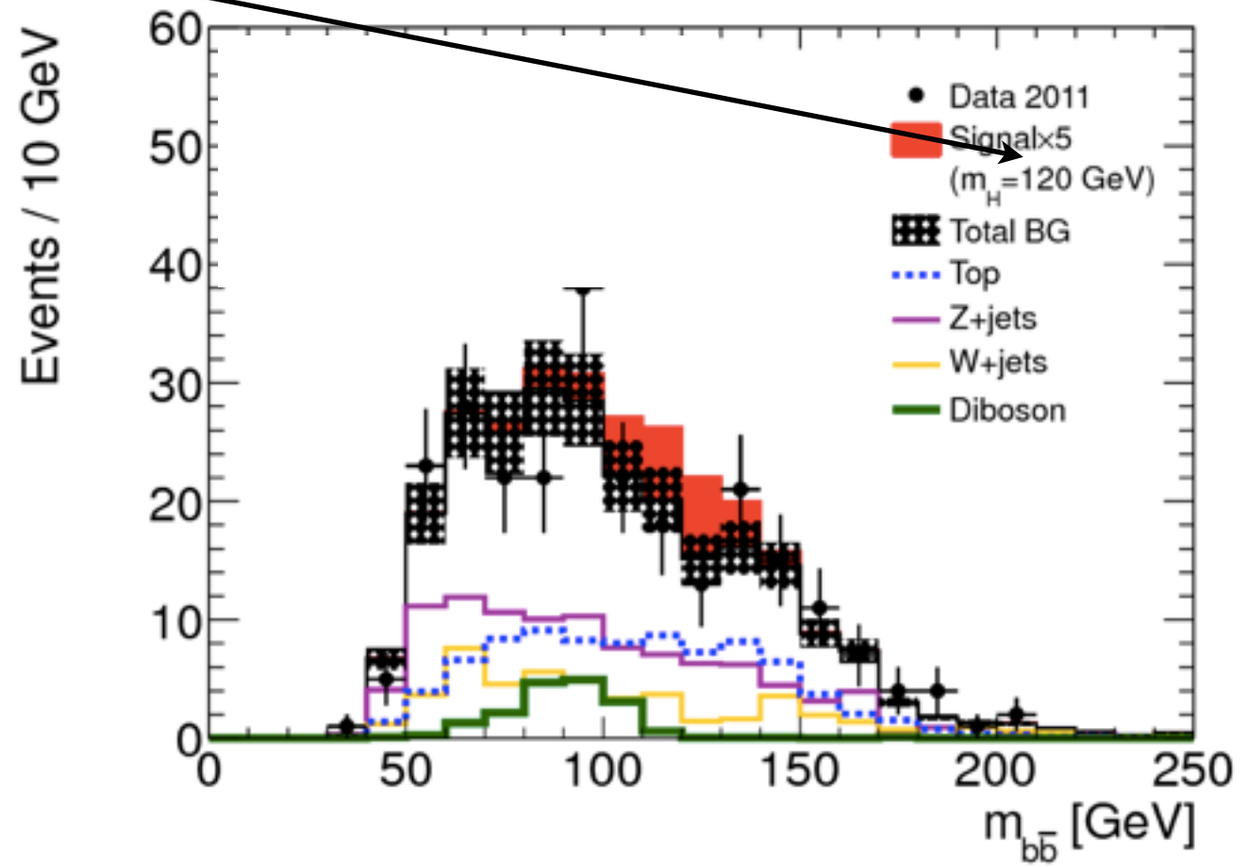
ττ ~5000 **15% mass resolution, large bkg. After selection 7 events and bkg of 70 event**

bb ~50000 **10% mass resolution, overwhelming bkg. After selection 4 events and bkg of 40 event**

Very rough figures, to guide the eye..... Analyses much more sophisticated

Typical analysis

Design a selection at a given mass maximizing an estimator (eg s/√bkg)



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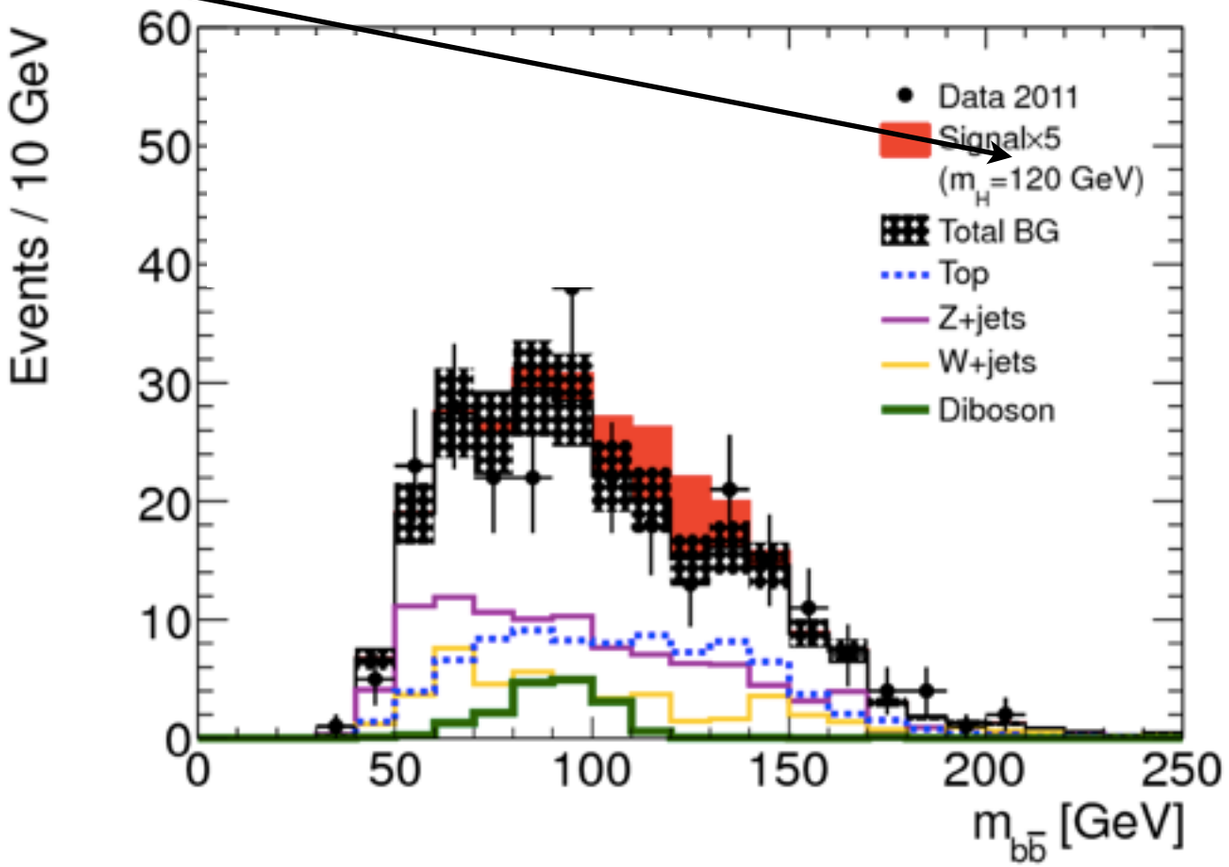
Often cutting the phase-space in many regions

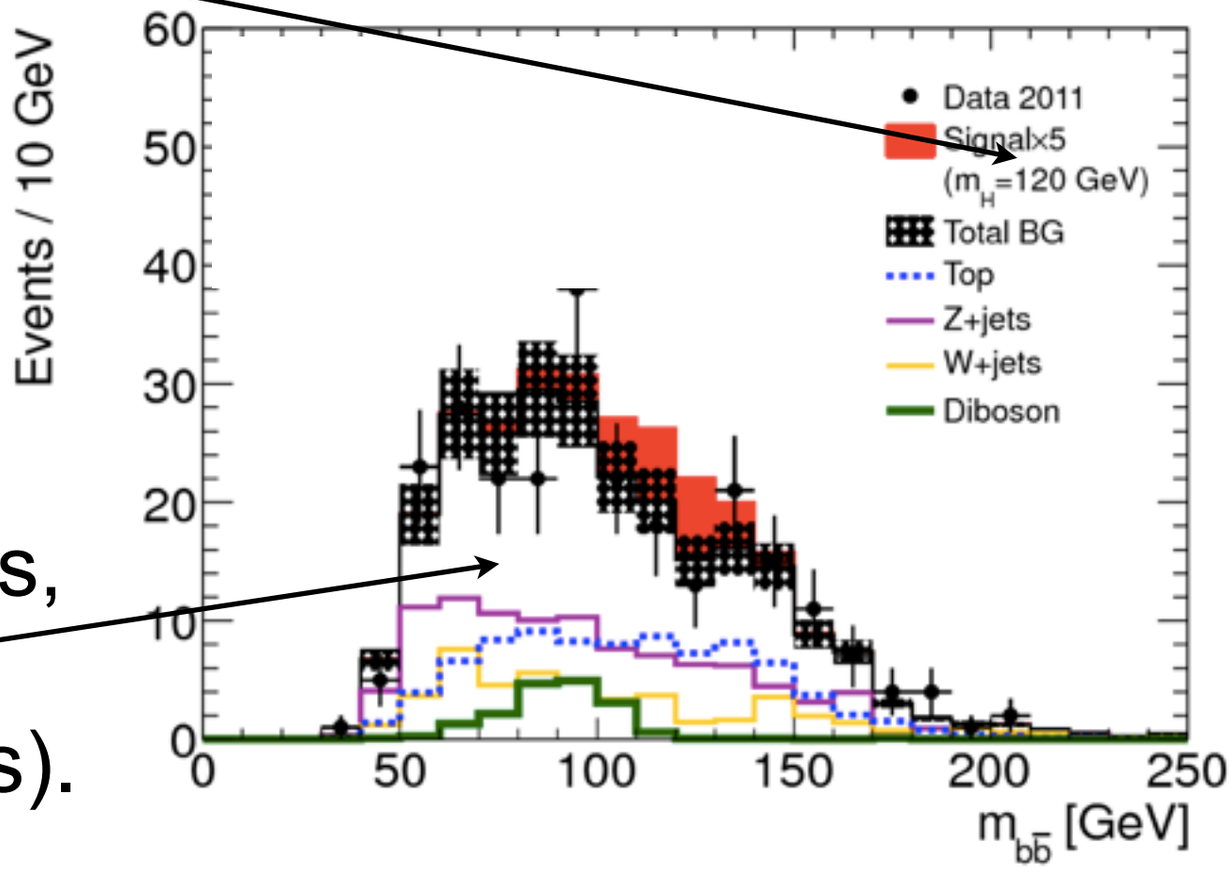


Typical analysis

Design a selection at a given mass maximizing an estimator (eg s/√bkg)

Often cutting the phase-space in many regions

Compute the expected SM background from control samples, side bands, etc.. often with the help from MC simulation (shapes). Assess the systematic error.



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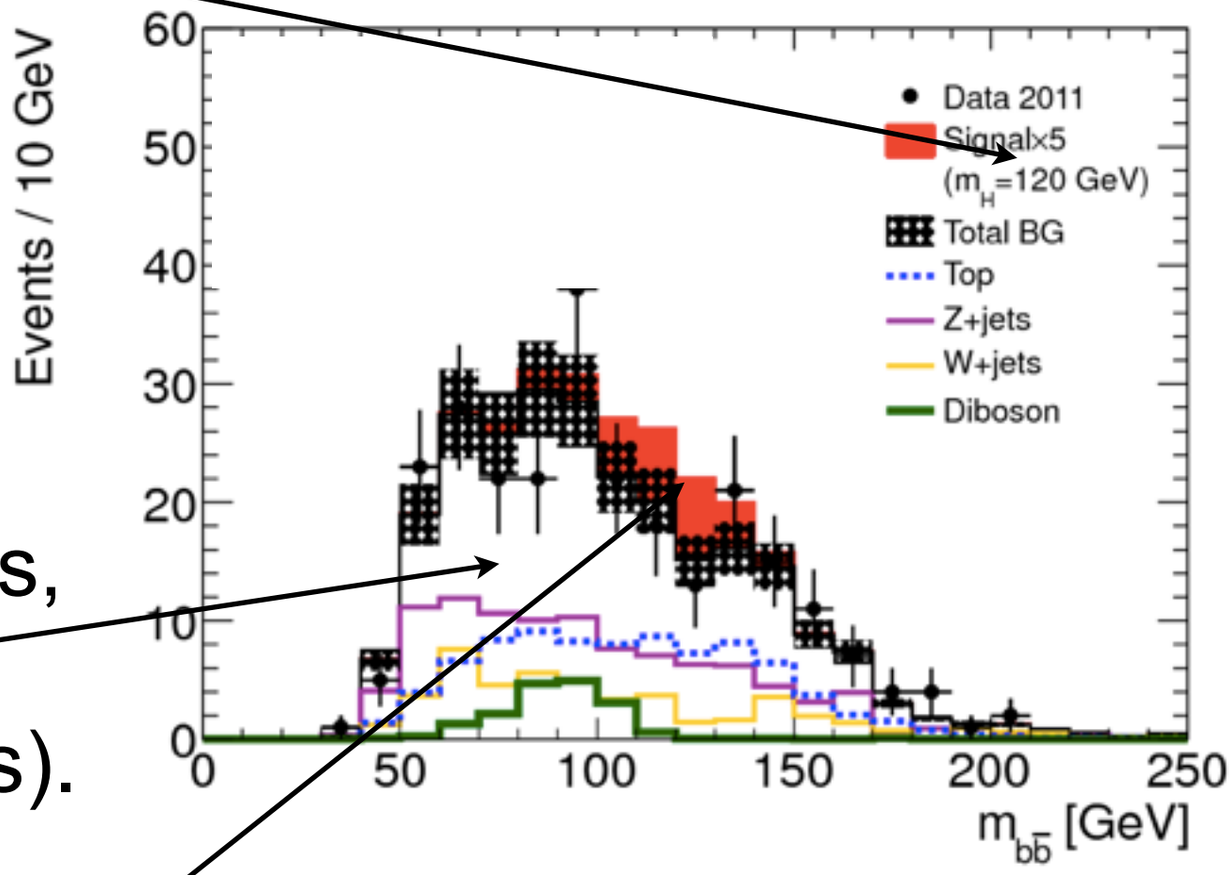
Evaluate the signal efficiency using SM Higgs MC simulation



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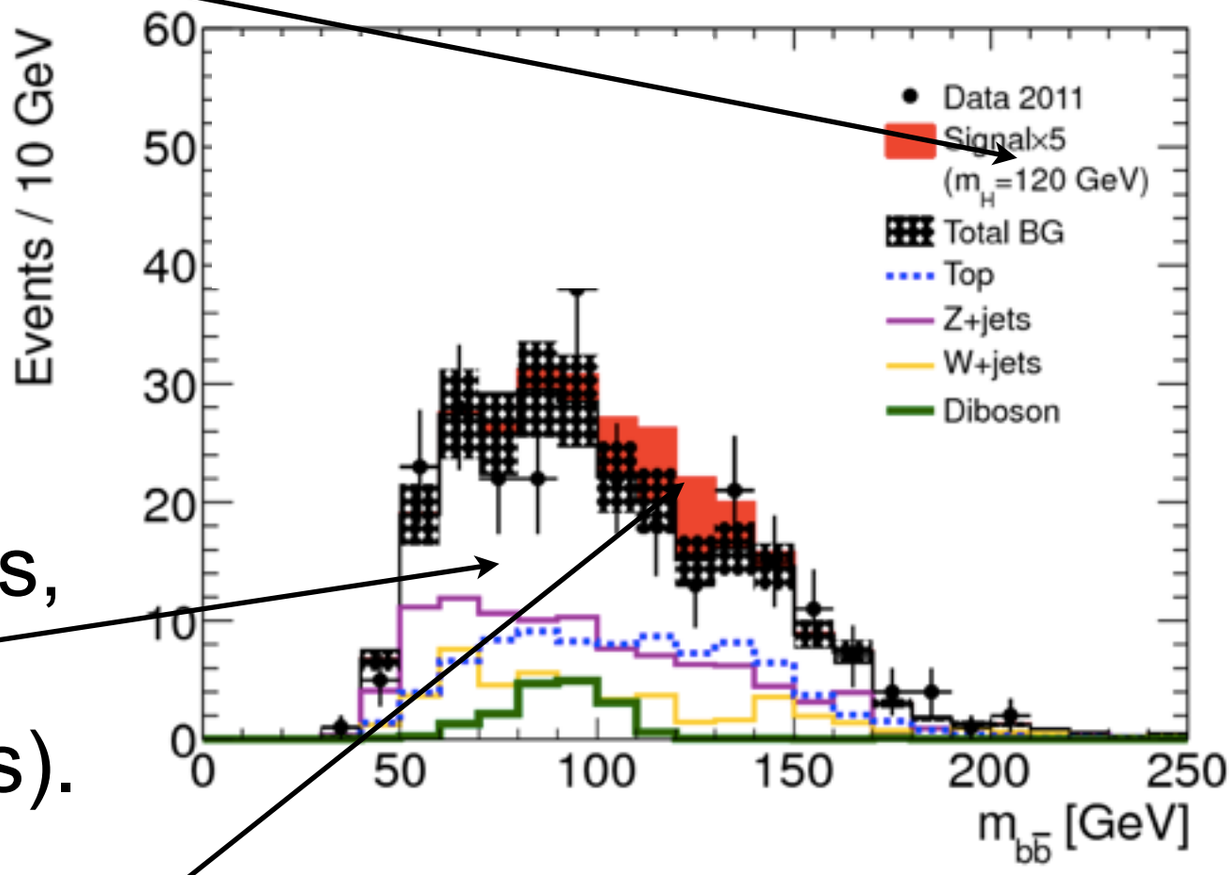
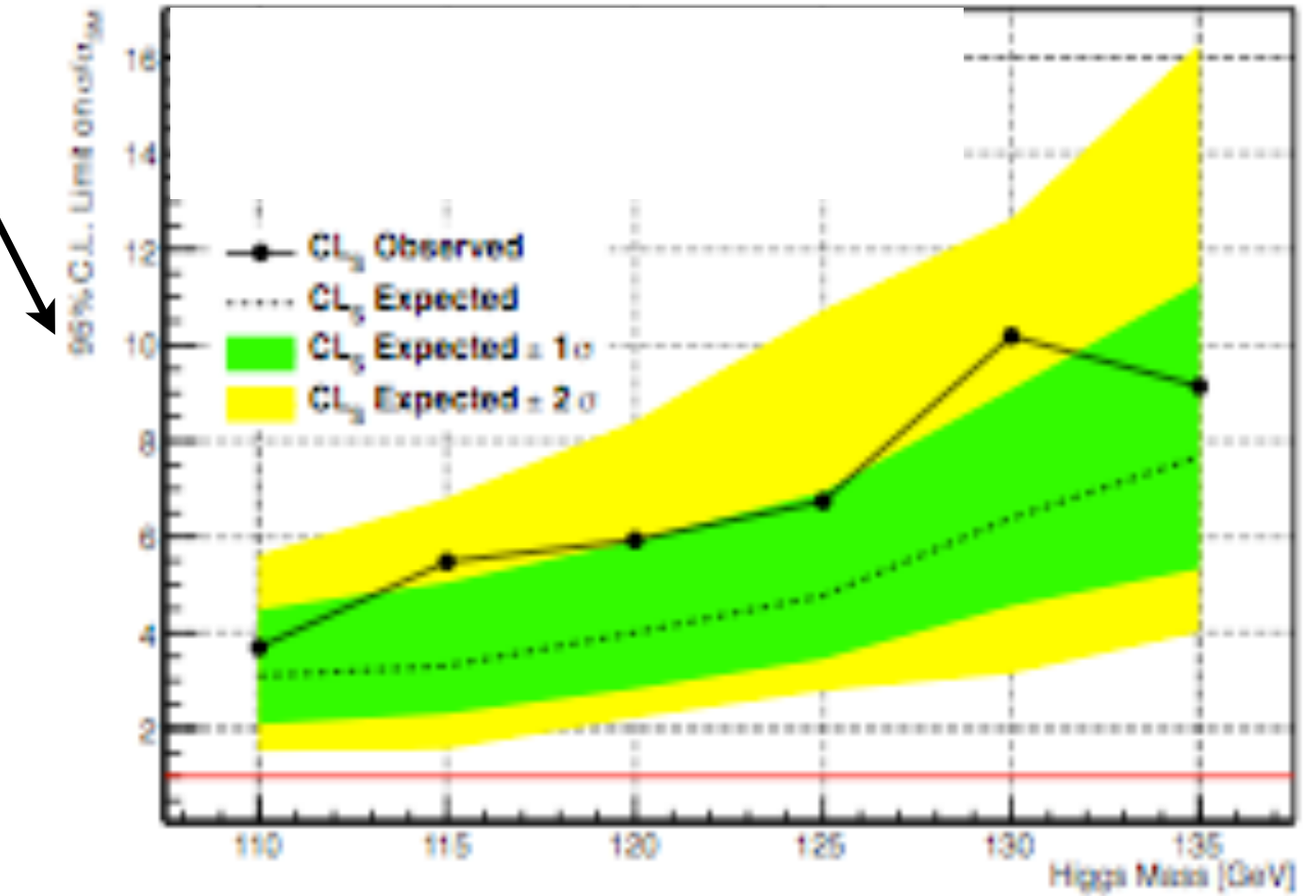


Compute with statistical methods the largest signal cross section one can accommodate in the data.

The “typical plot”

Analyses optimized for exclusion.
The result is expressed at a given mass as exclusion at 95% of a cross section.



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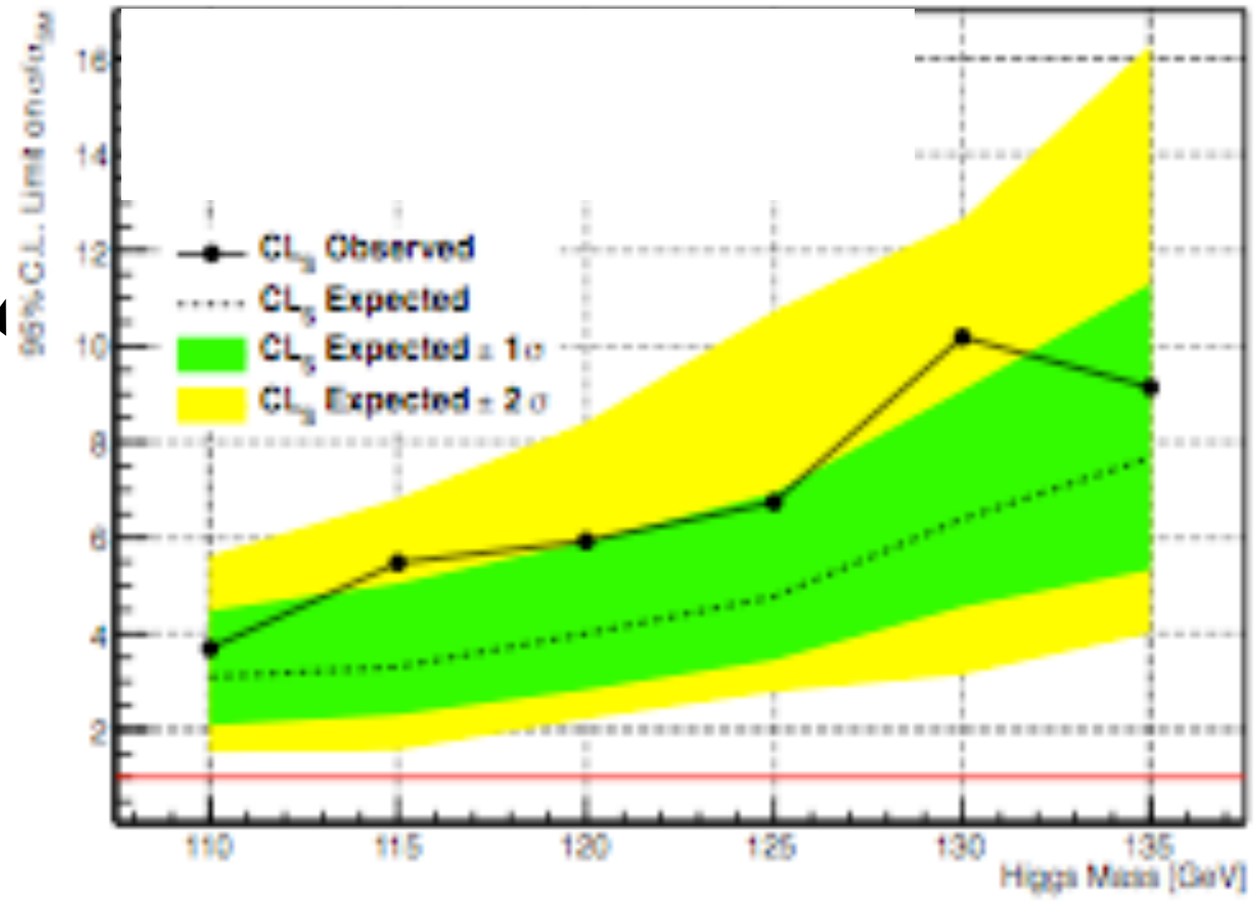

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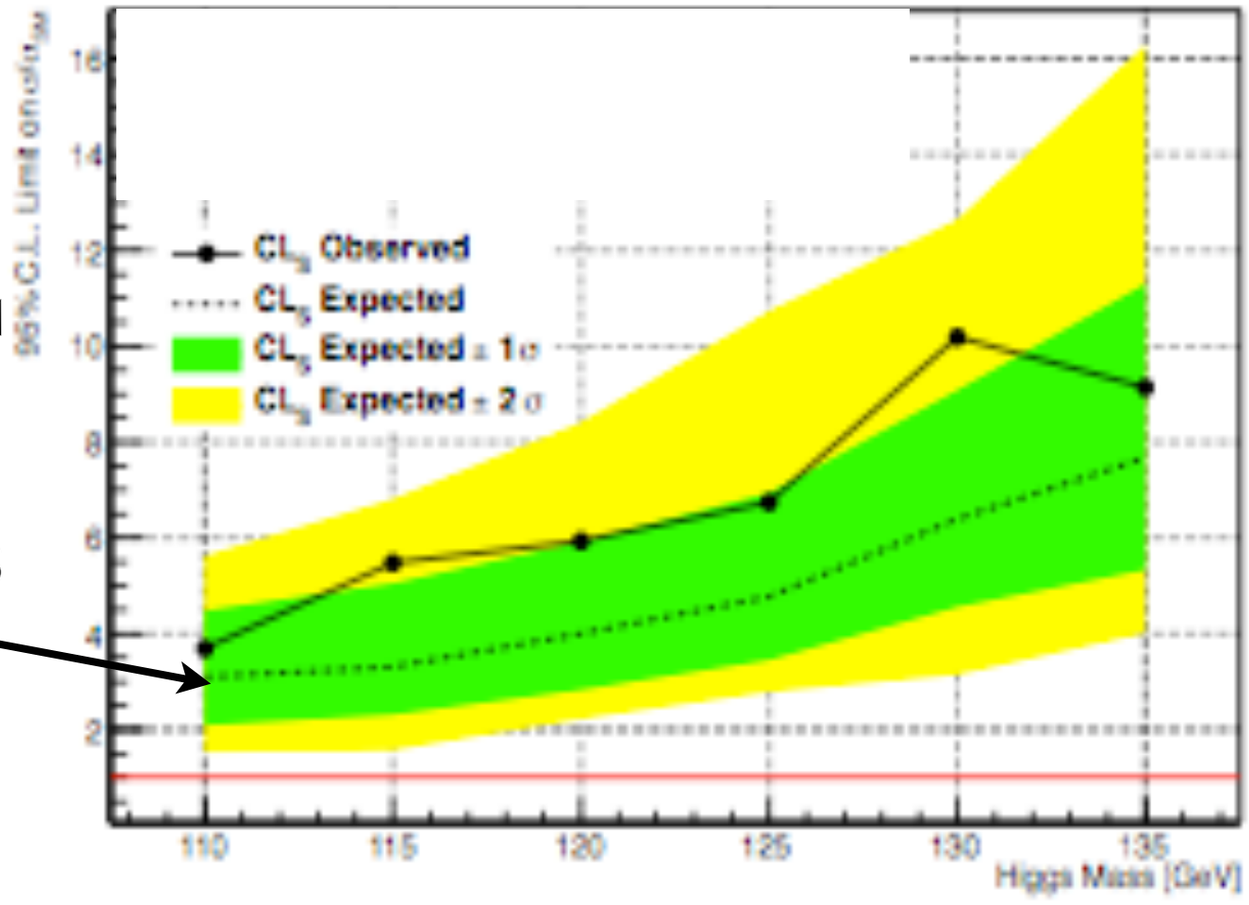
Expected sensitivity: measures how performing is the analysis



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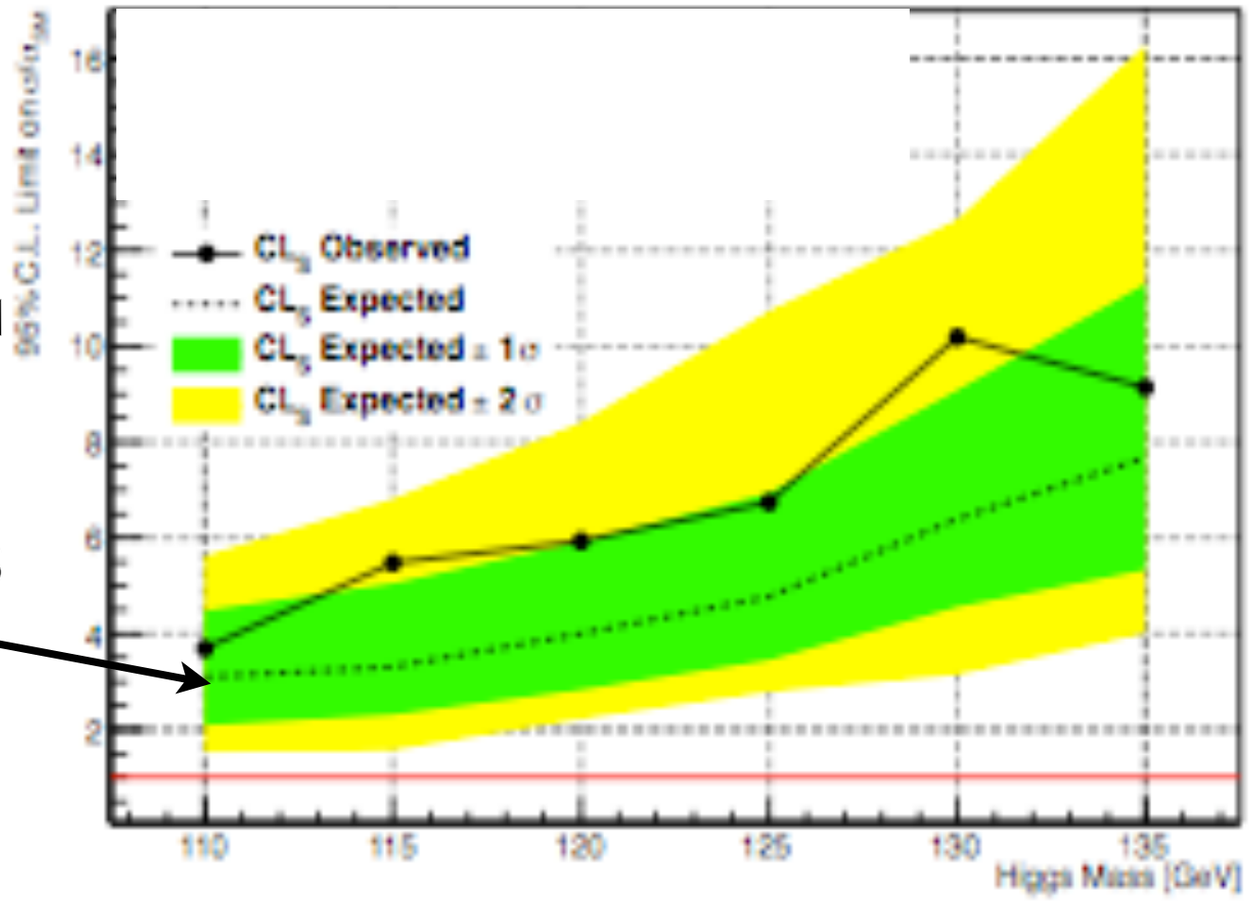
The colored bands give the expected statistical⊕systematic variation of the result wrt to the “expected”



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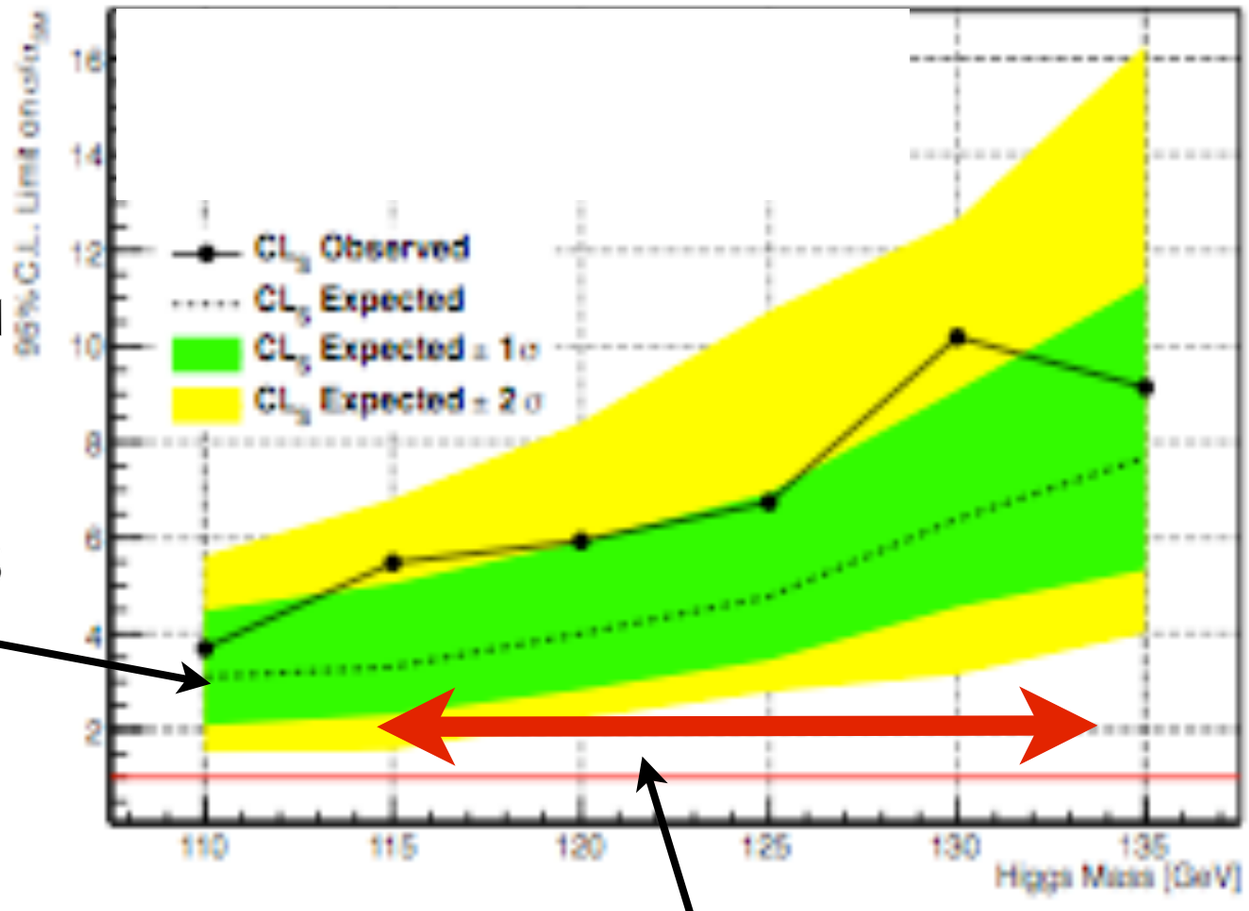
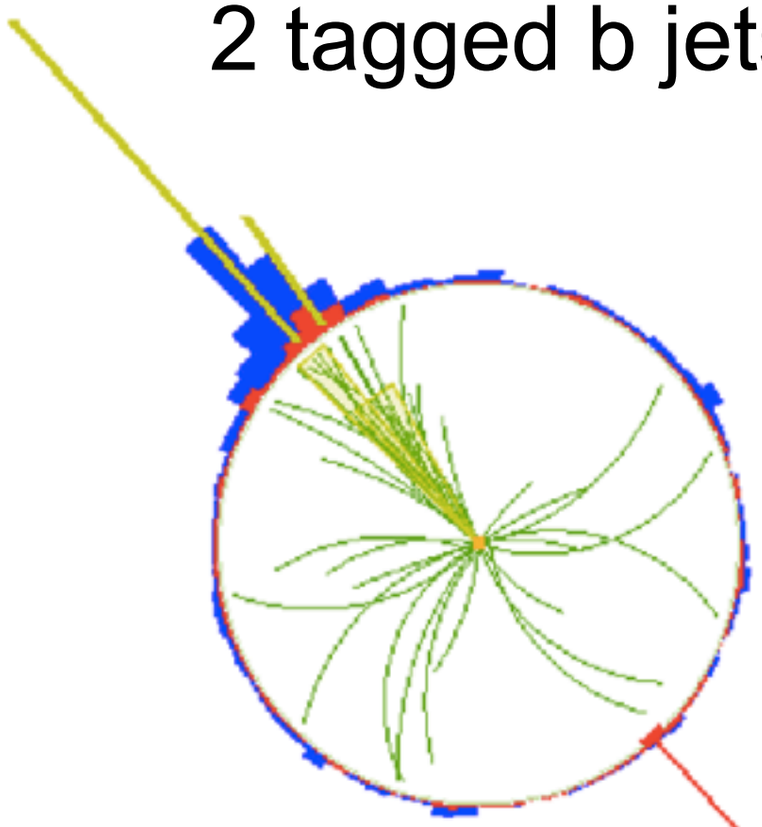


Nearby points are correlated depending on the mass resolution (FWHM)

VH --> Vbb

Overwhelming bkg from QCD. Reduced requiring associated production with V .and boosted H

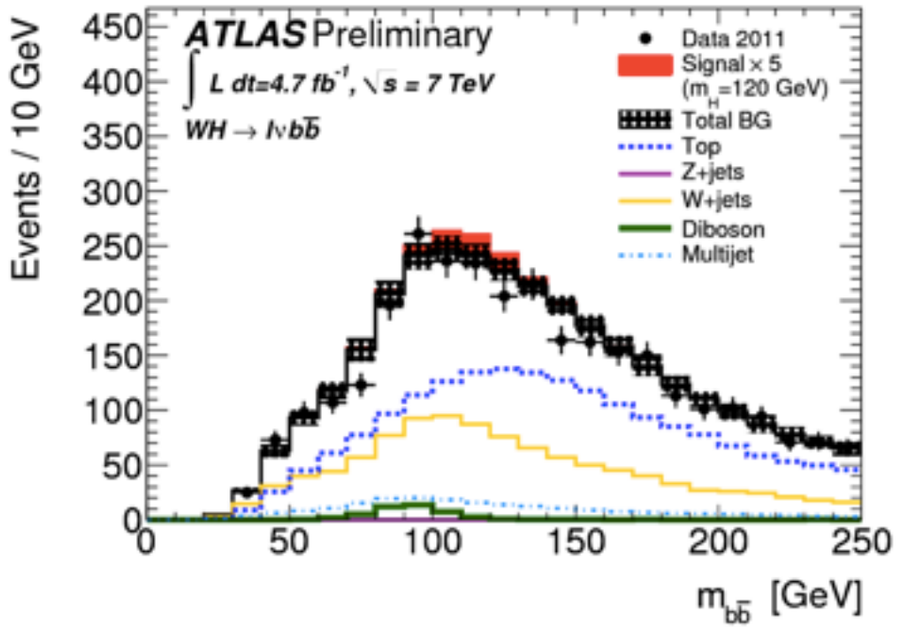
2 tagged b jets, mbb 105 GeV

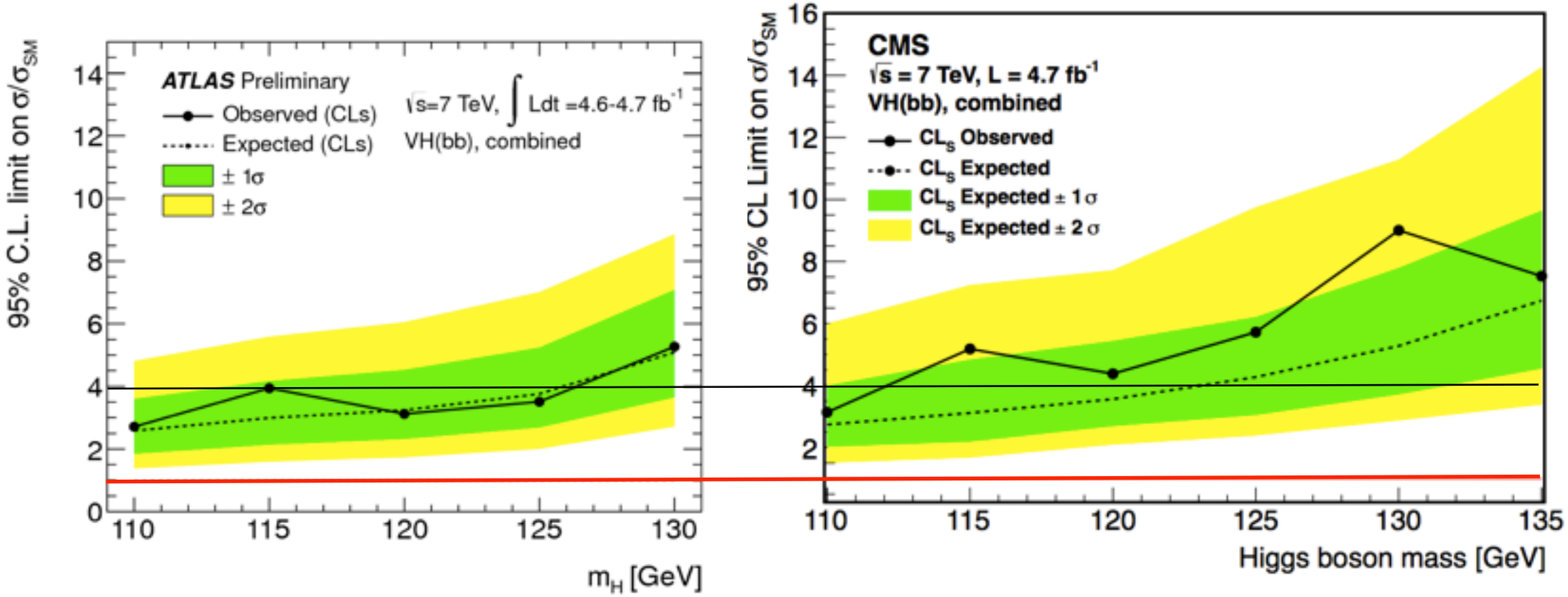


198 GeV Met (Z-->vv)

VH-->Vbb

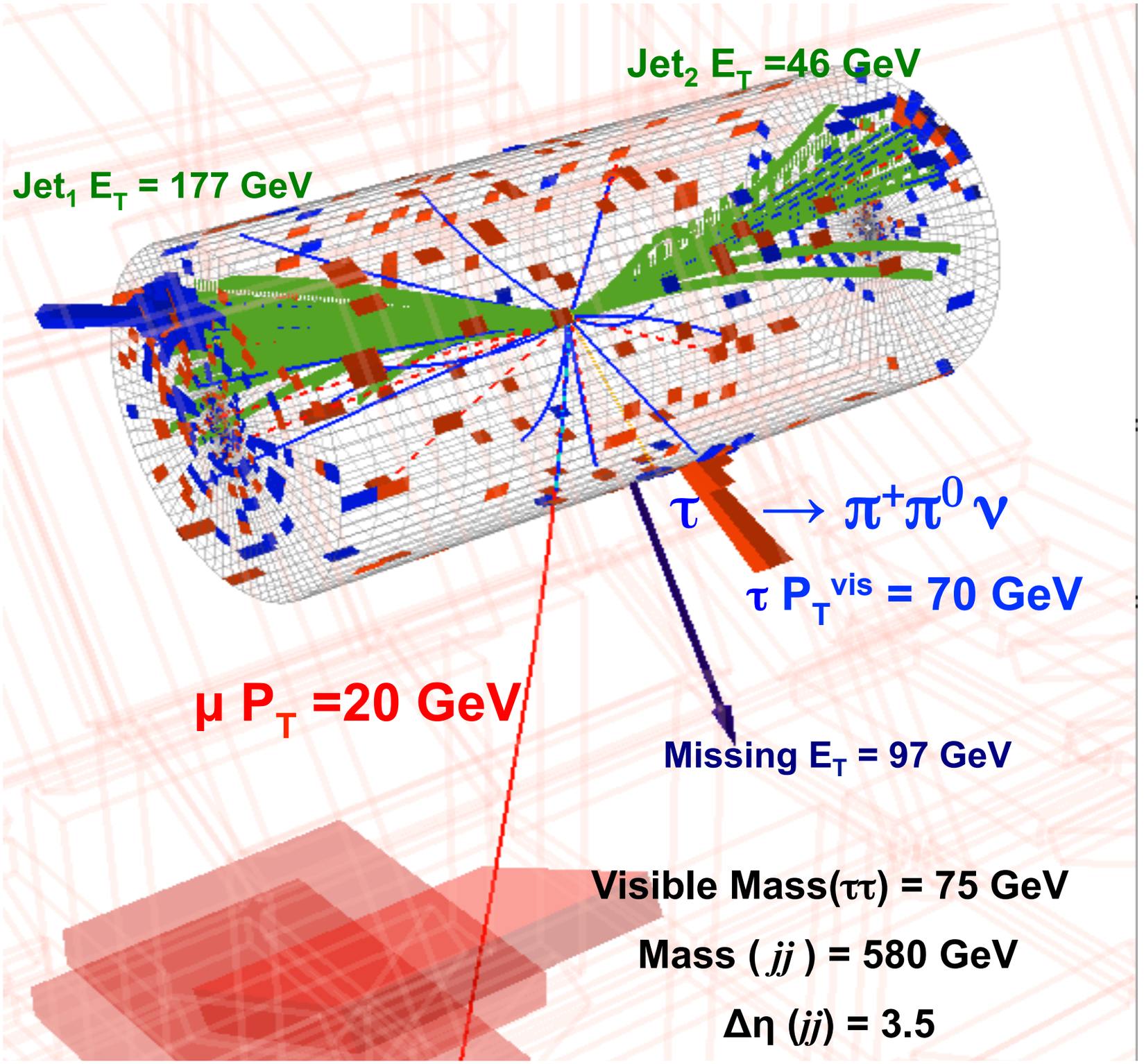
- W+Jets, Top, di-bosons bkg from sidebands and control regions





$\mu_{exp(125)}=4$

H --> ττ



VBF cleanest most sensitive channel

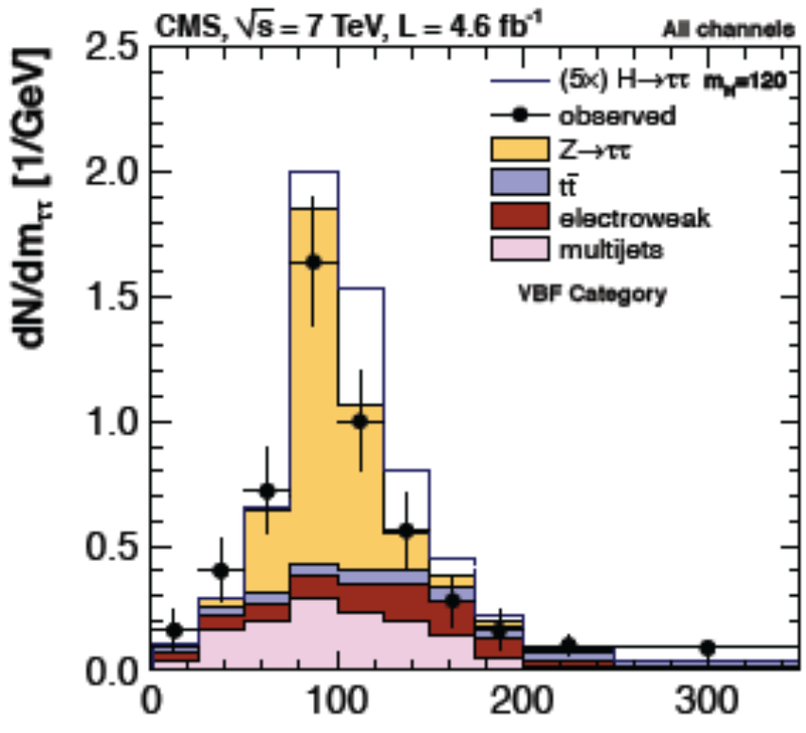
2l 4v

1l τ_{had} 3v

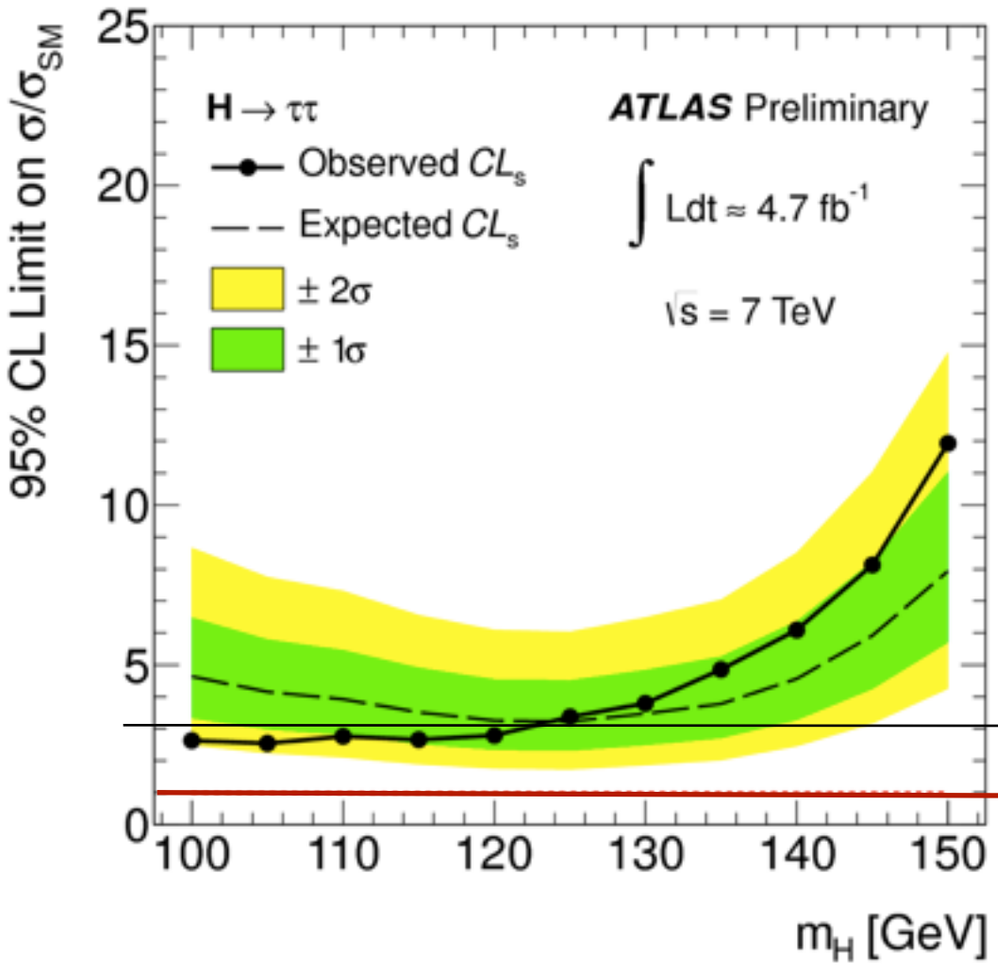
τ_{had} τ_{had} 2v

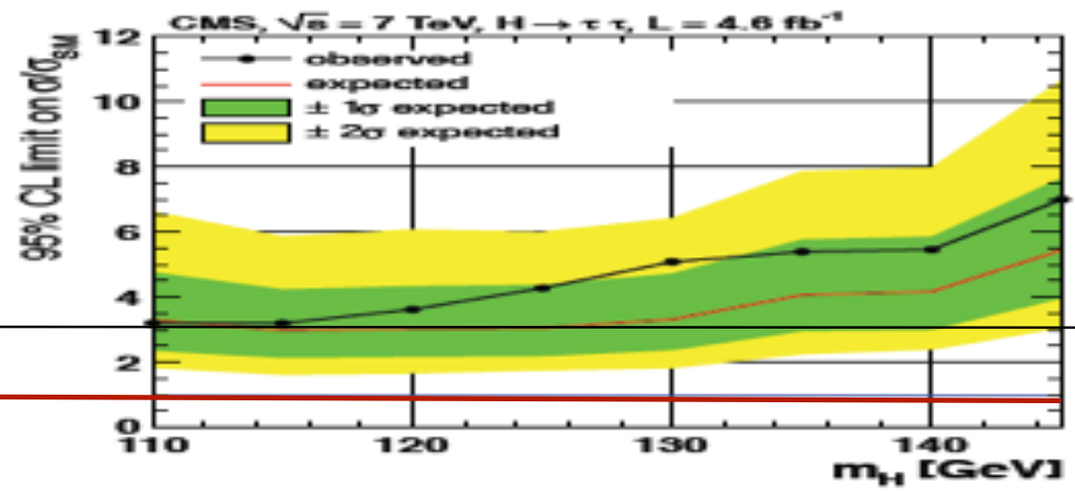
H --> ττ

- Major bkg Z --> ττ, evaluated from Z-->μμ replacing mu with simulated tau.



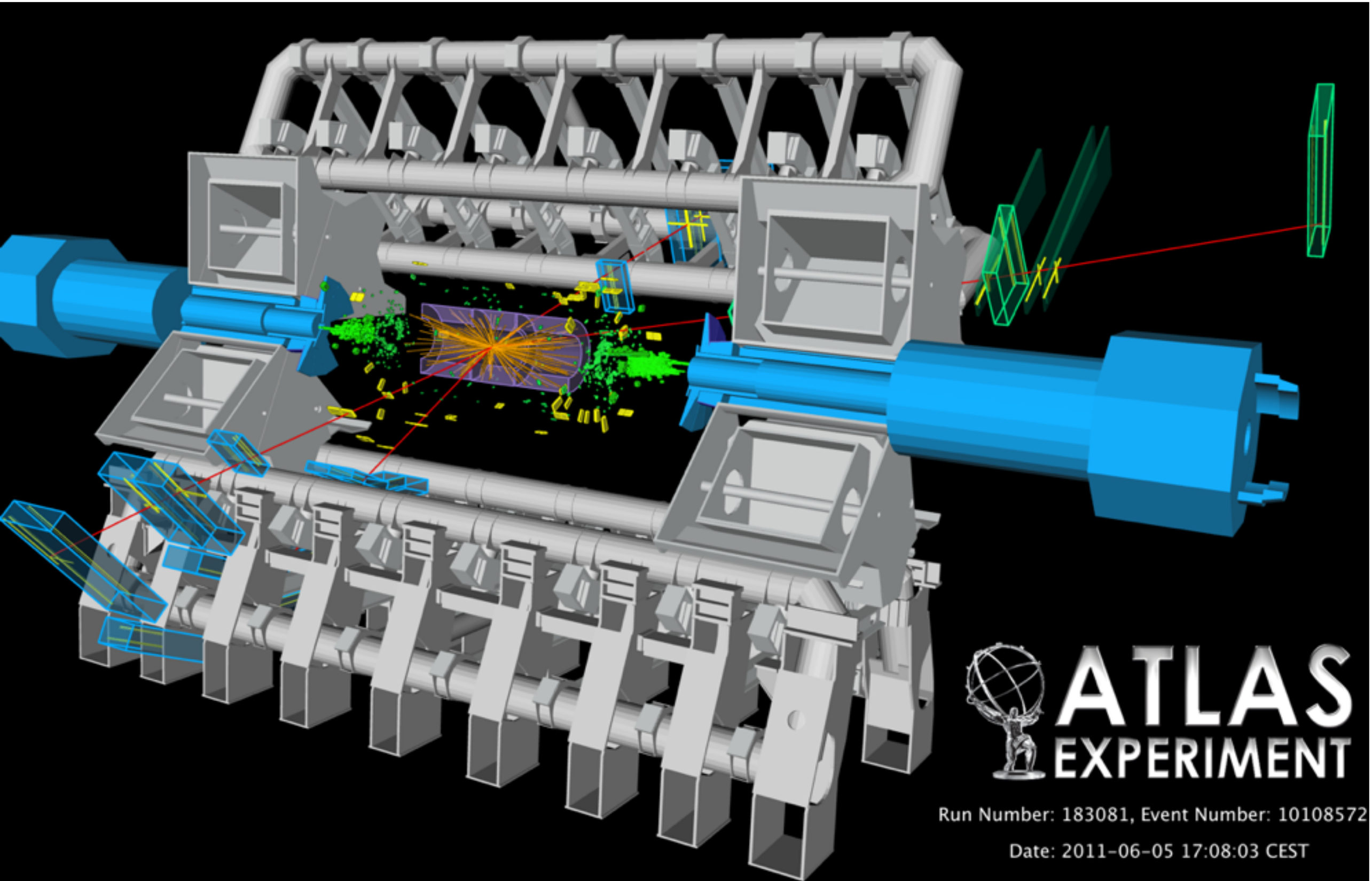
$\mu_{exp(125)}=3$



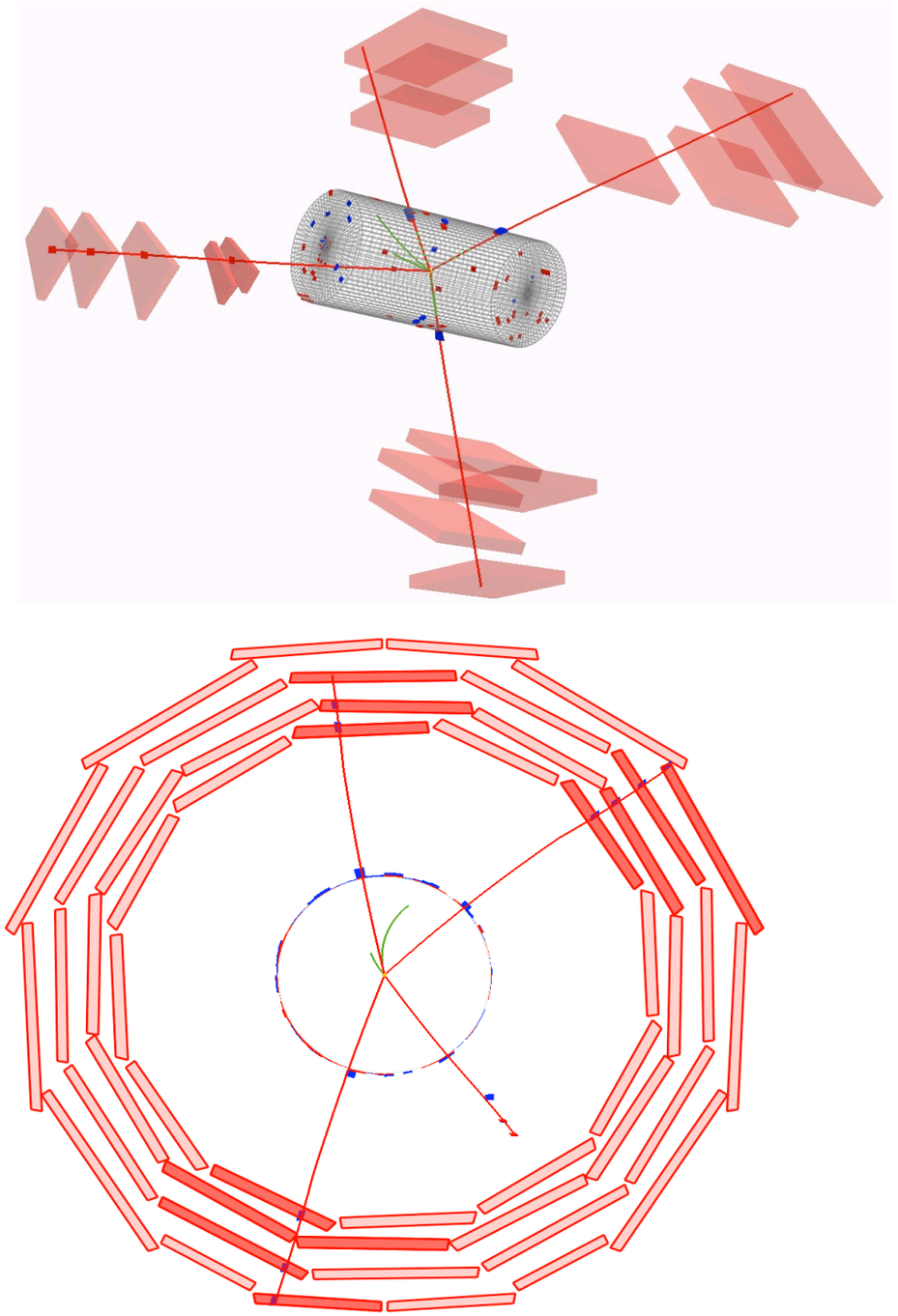


H --> ZZ-->4l

Best s/bkg, however very small statistics (at low mass)

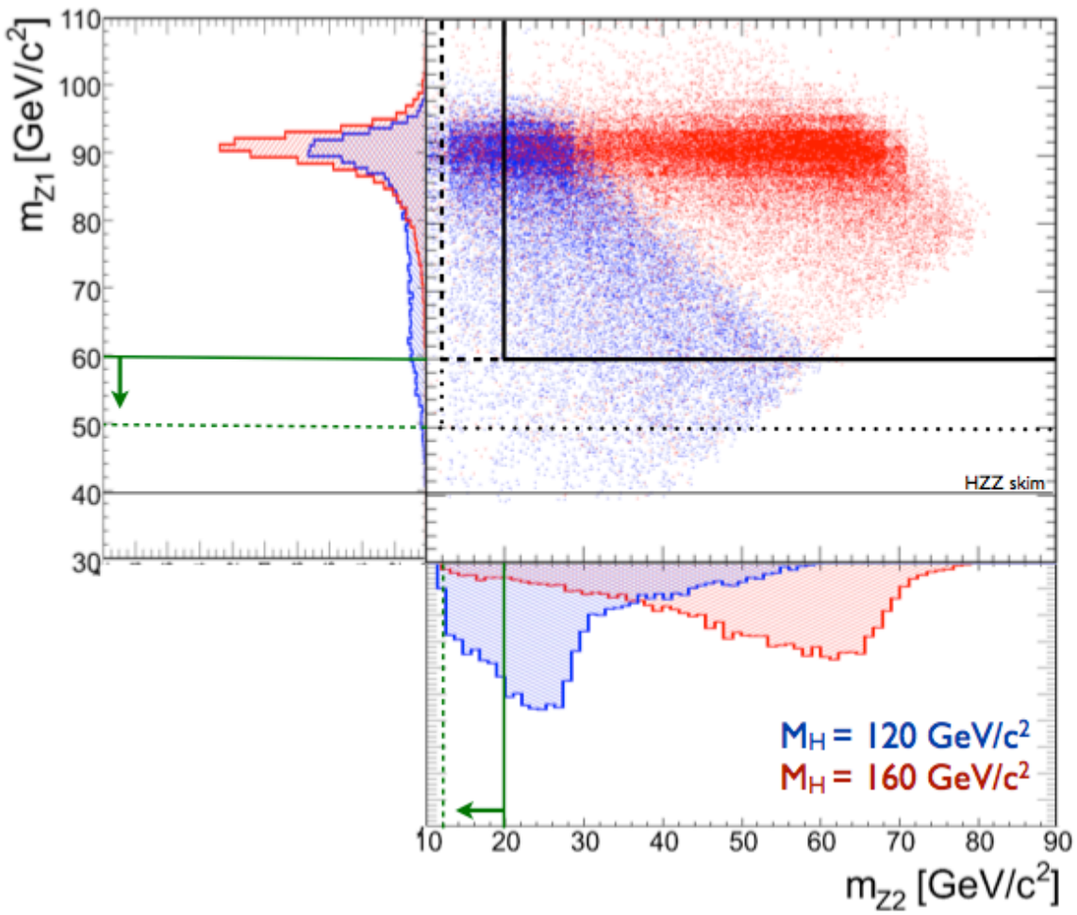


4 leptons channel



Improved sensitivity at low Higgs masses

- Reduce MZ_1 cut from 60 → 50GeV
- Reduce MZ_2 cut from 20 → 12GeV



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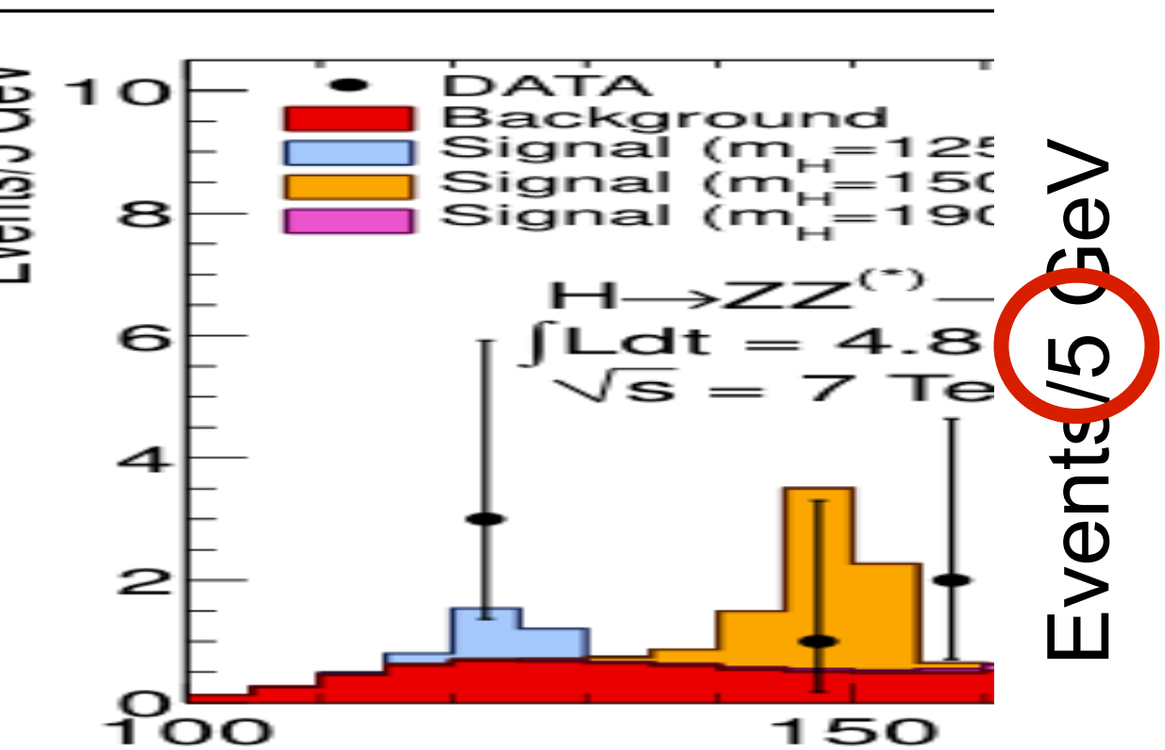
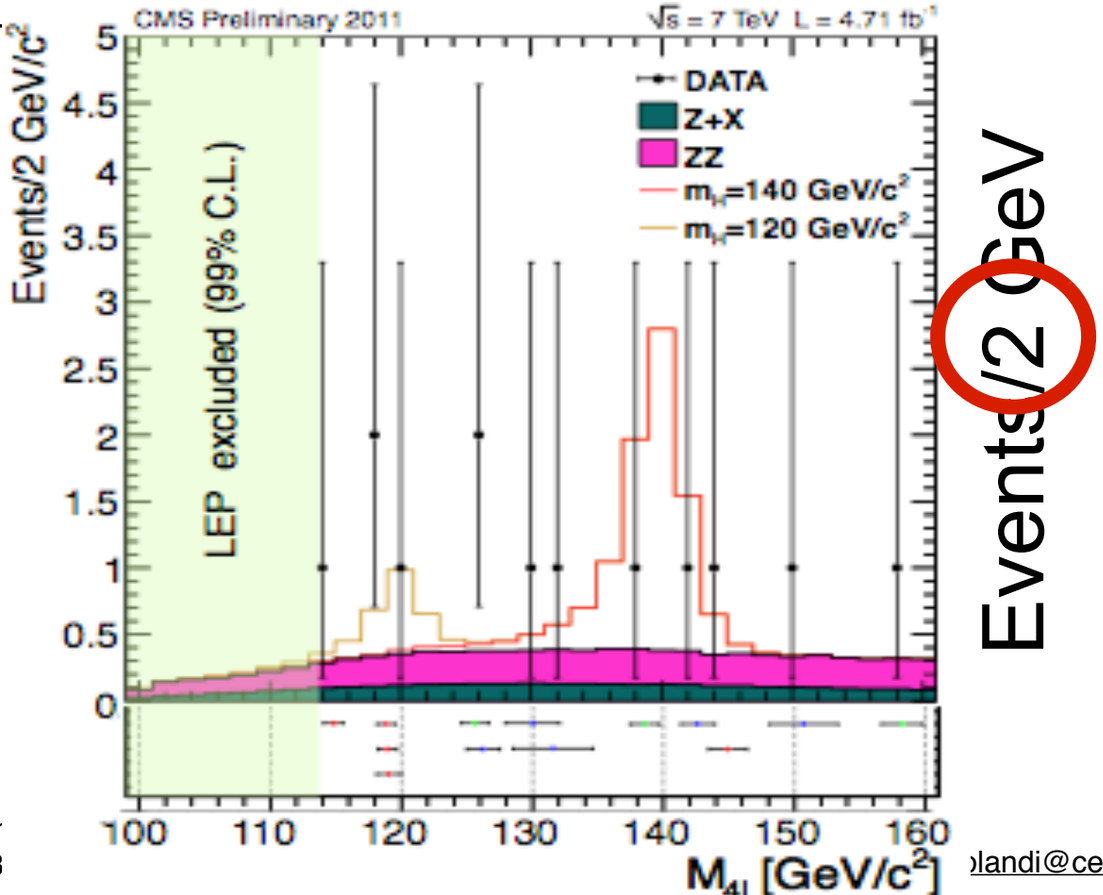


ATLAS
Below 140 GeV
~ 4 expected from SM and 3 seen

3 events 123.6 124.3 124.6

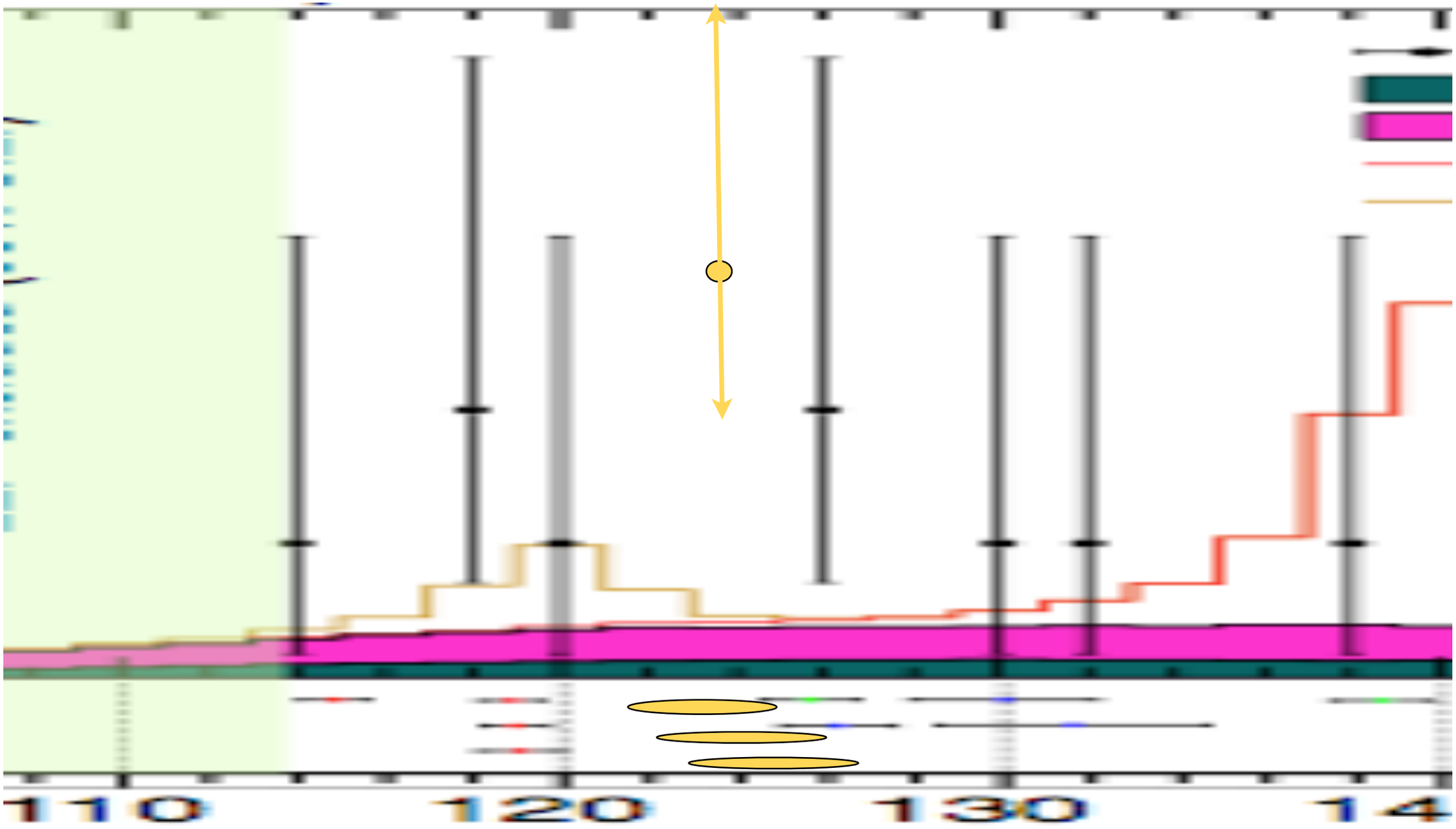
Higgs (125) ~ 2 Events



CMS
Below 140 GeV
~ 6 expected from SM and 9 seen

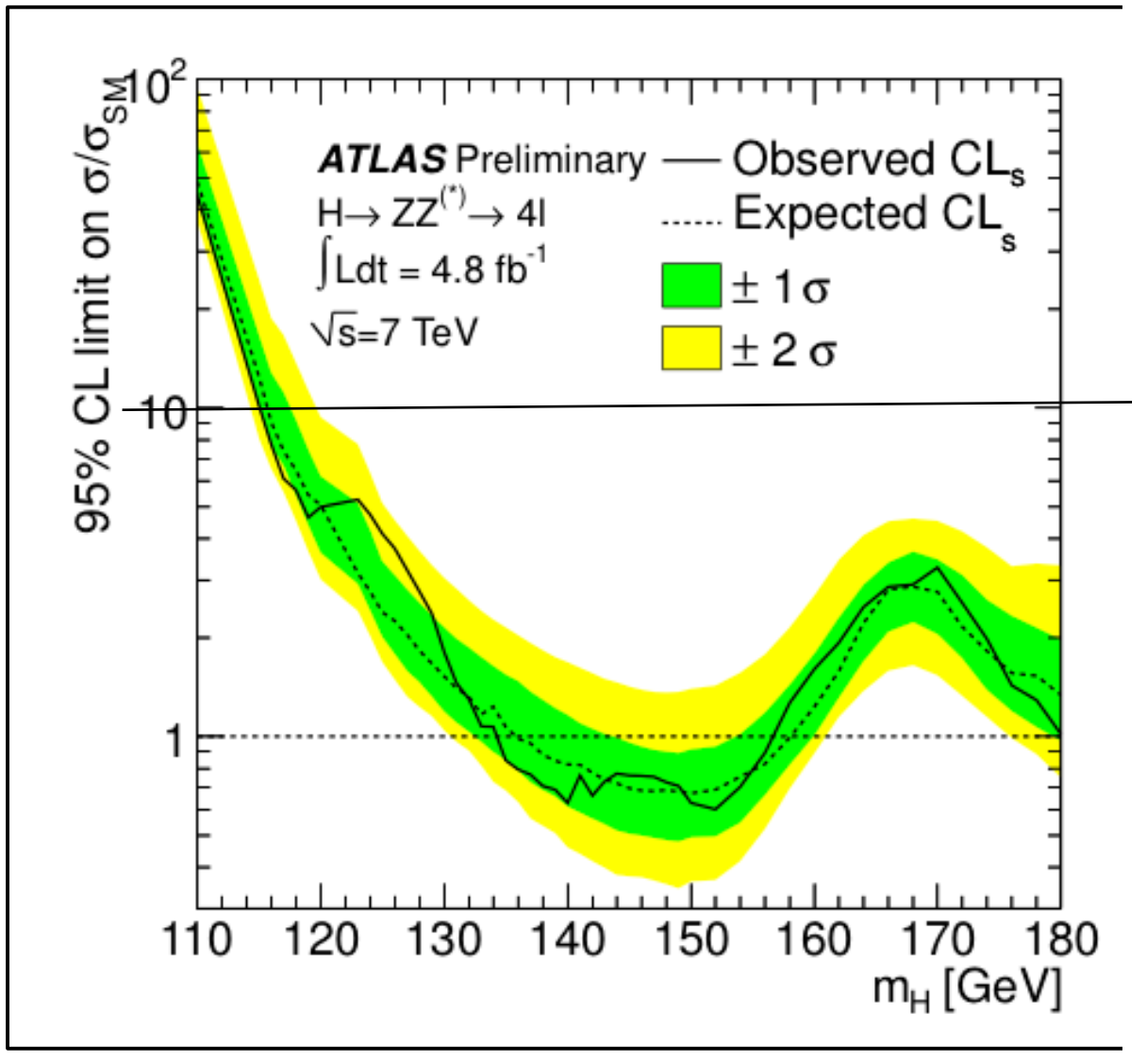
3 events 118.3 118.9 119.0
Higgs (125) ~ 3 Events

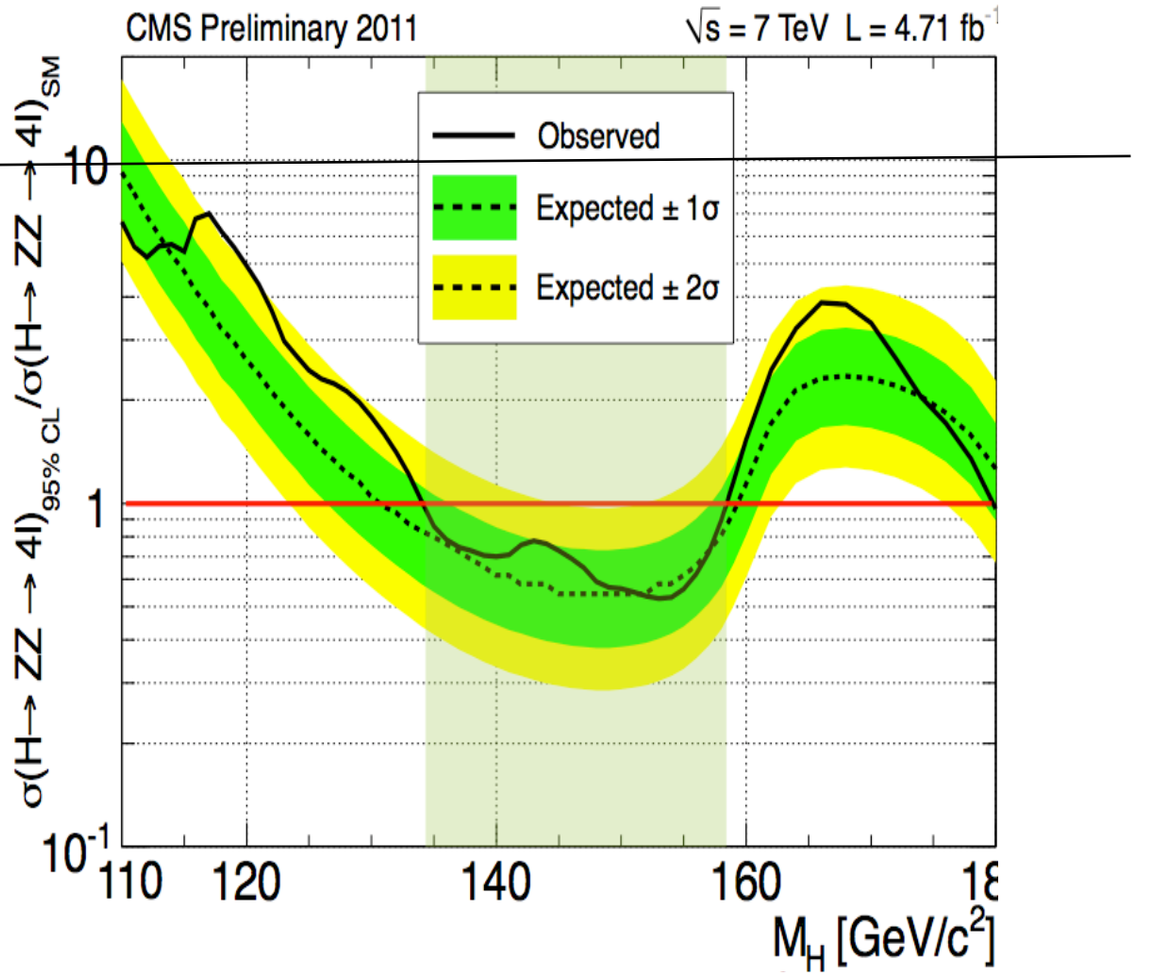
All low mass 4 leptons events



How good ATLAS vs CMS scale ? ~ 1% ?

4 leptons channel limits

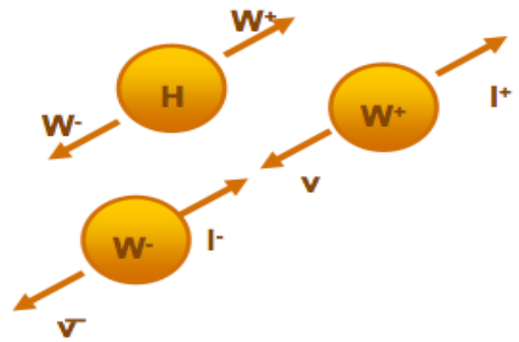




$\mu_{exp(125)}=2.5$

$\mu_{exp(125)}=1.6$

H --> WW-->2l2ν



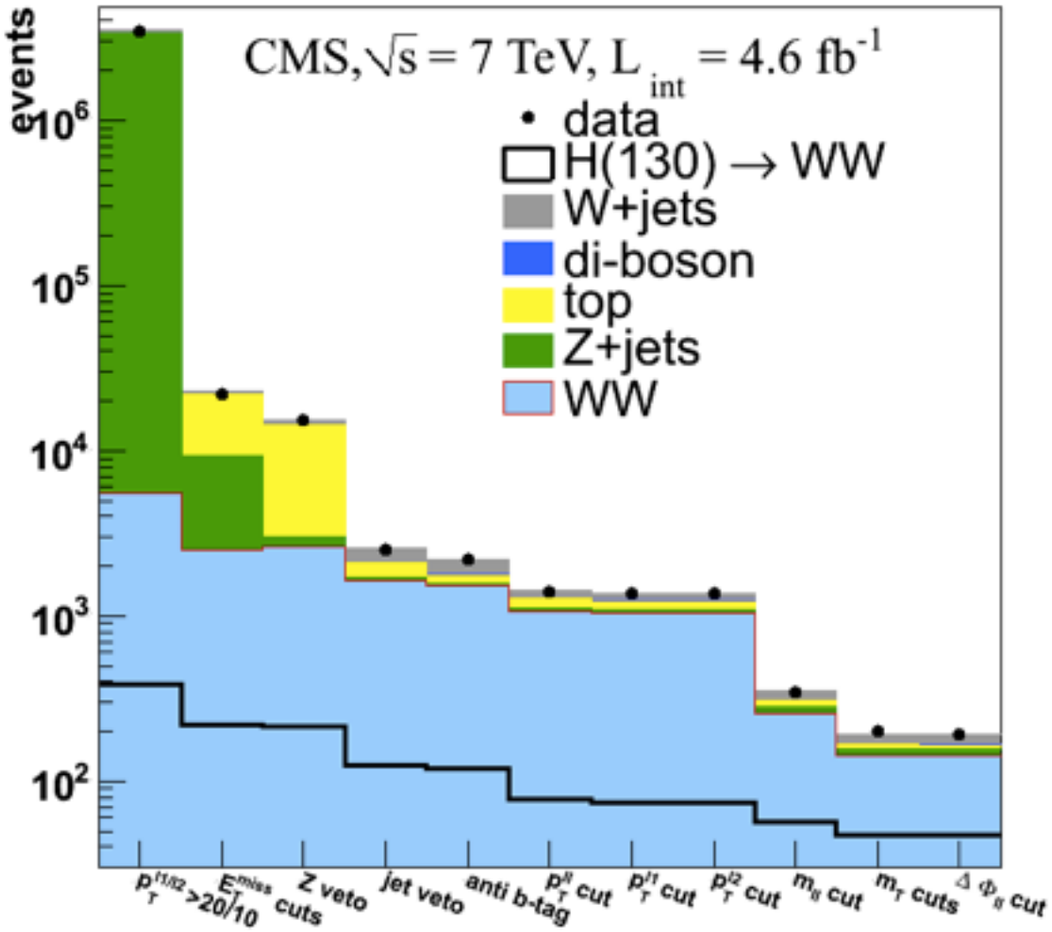
Large sensitivity 125/180 GeV

No mass peak !

Counting experiment

H --> WW-->2l2v

- Two opposite sign leptons + large MET
- BKG estimation crucial
  - WW: control sample (Δφ) - shape from simulation
  - top: control samples (N_jet, b tagging)
  - Z +jets: |m −m_Z | <15 GeV, correcting for mismodeling of MET tails.
  - W + jets: inverted lepton ID passing loose criteria.



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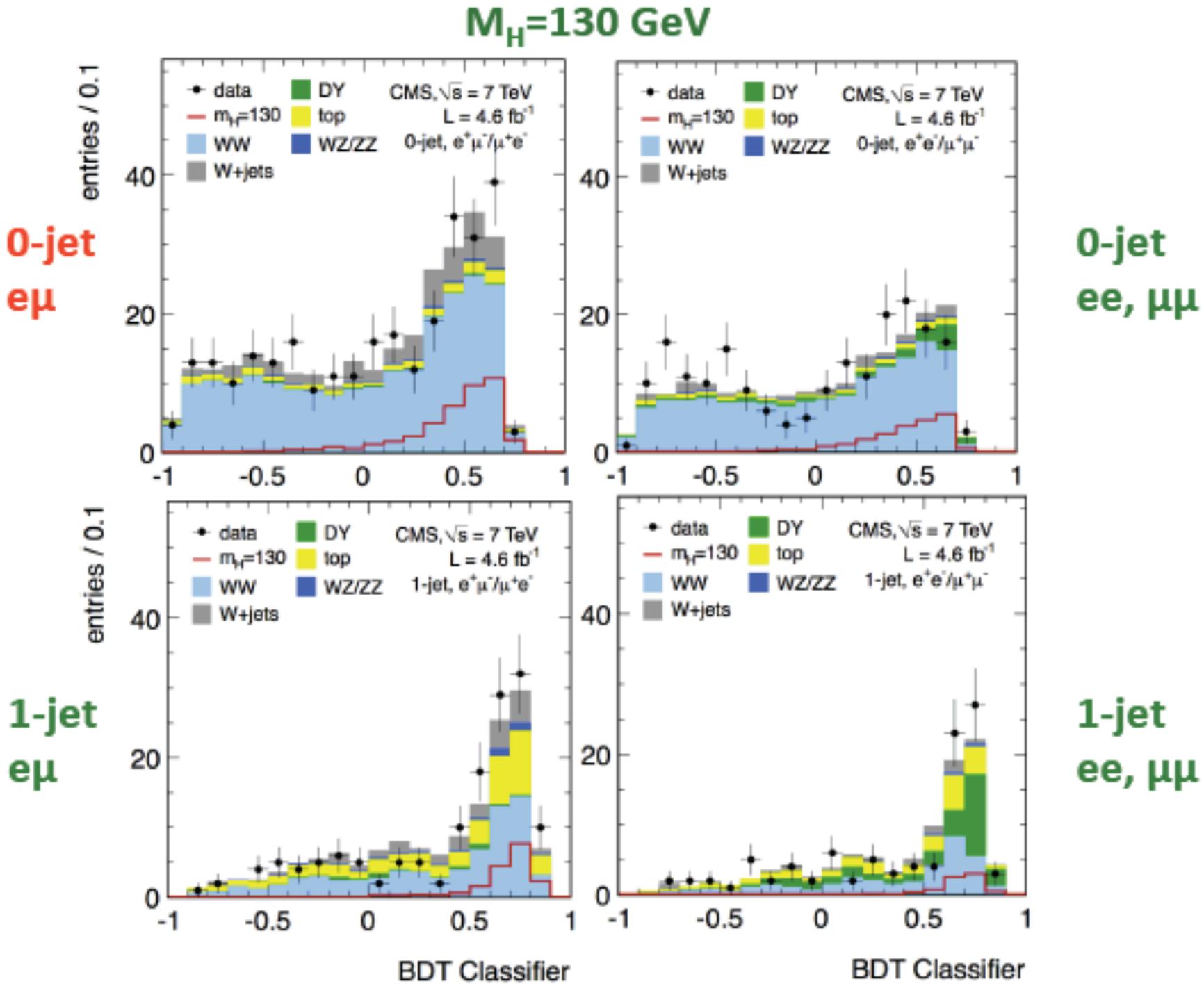
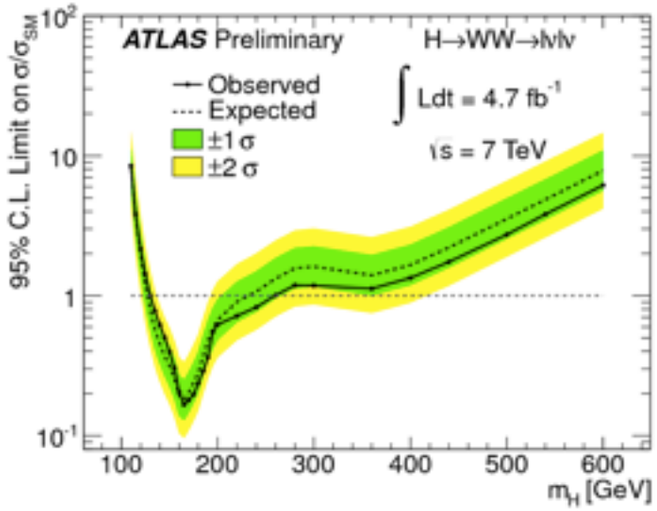
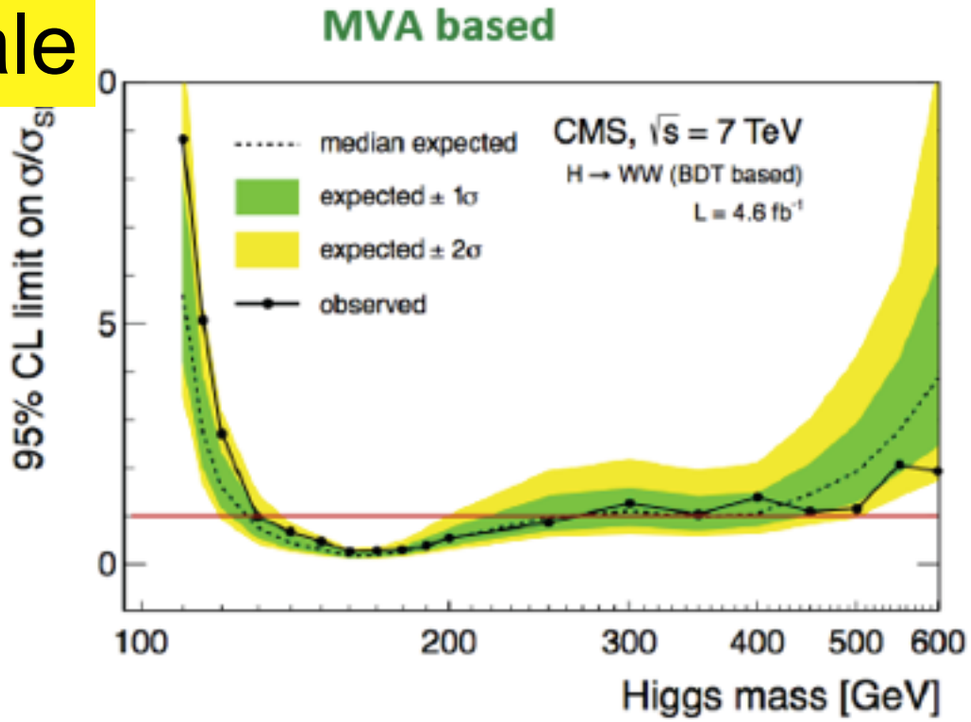


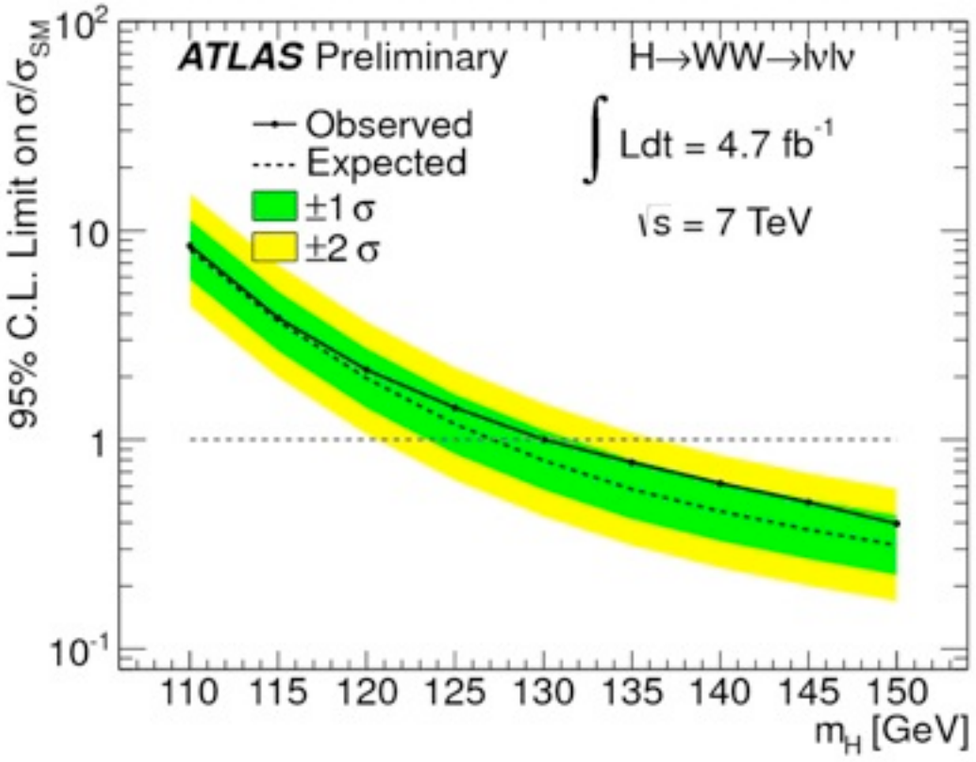
Analysis split in several classes, most sensitive e-μ 0-jet

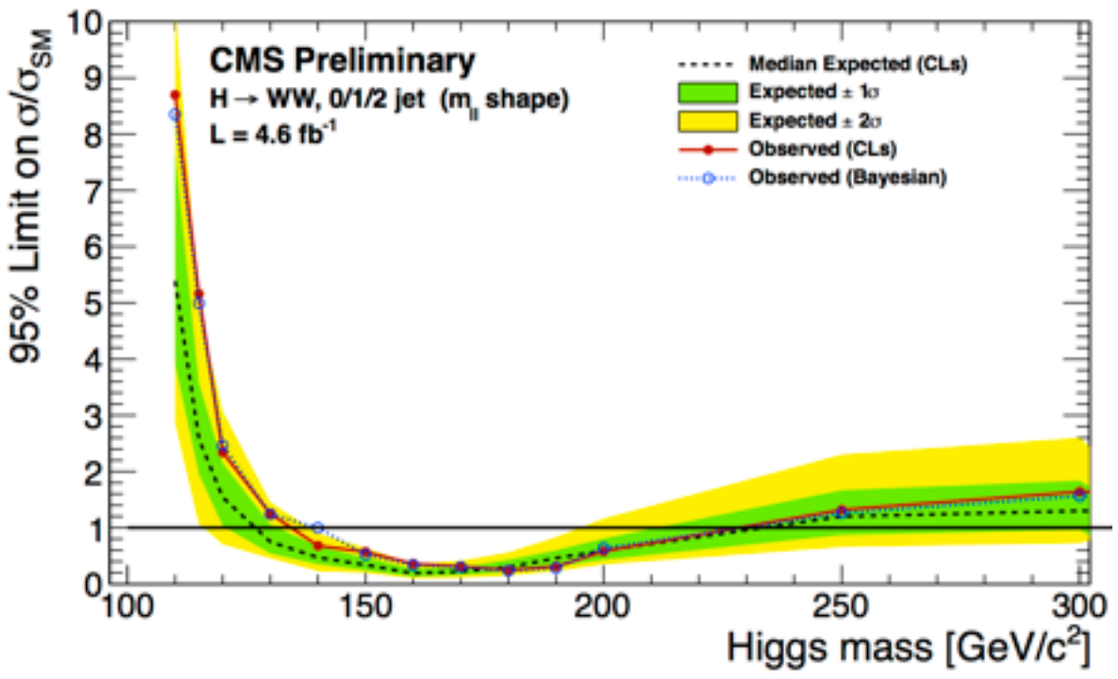
H --> WW-->2l2ν

watch the scale









$\mu_{exp(125)}=1.2$

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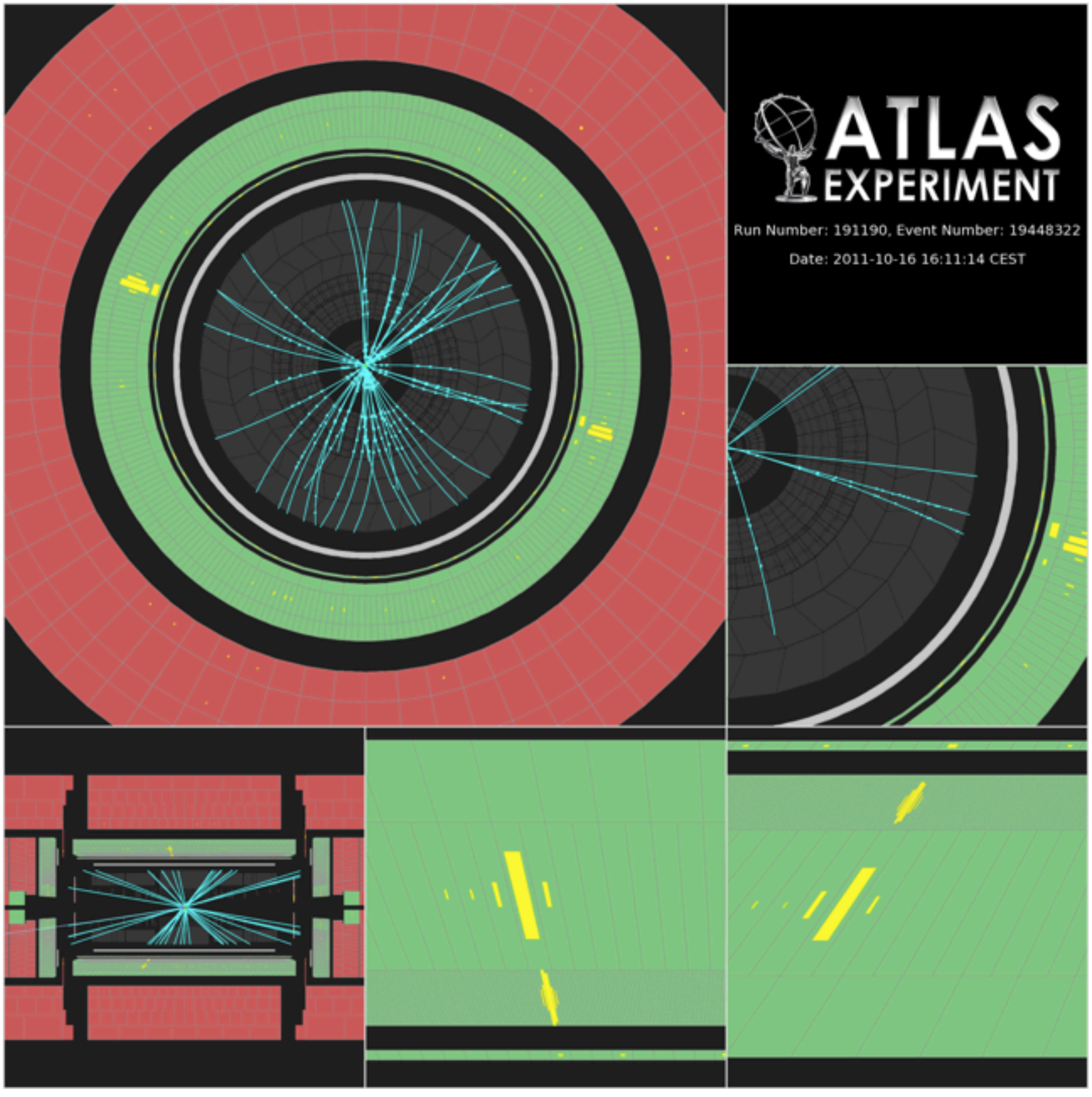
H --> γγ

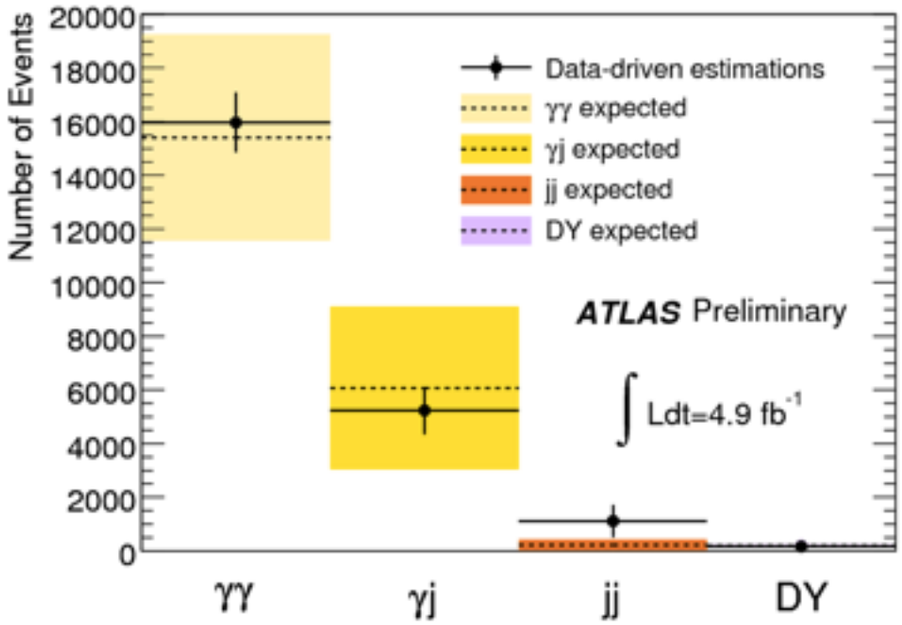


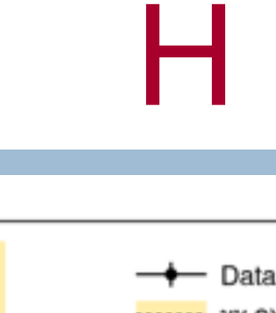
Main backgrounds:
* ırreducible (30 pb);
* reducible j (200 nb);
* reducible jj (500 μb).

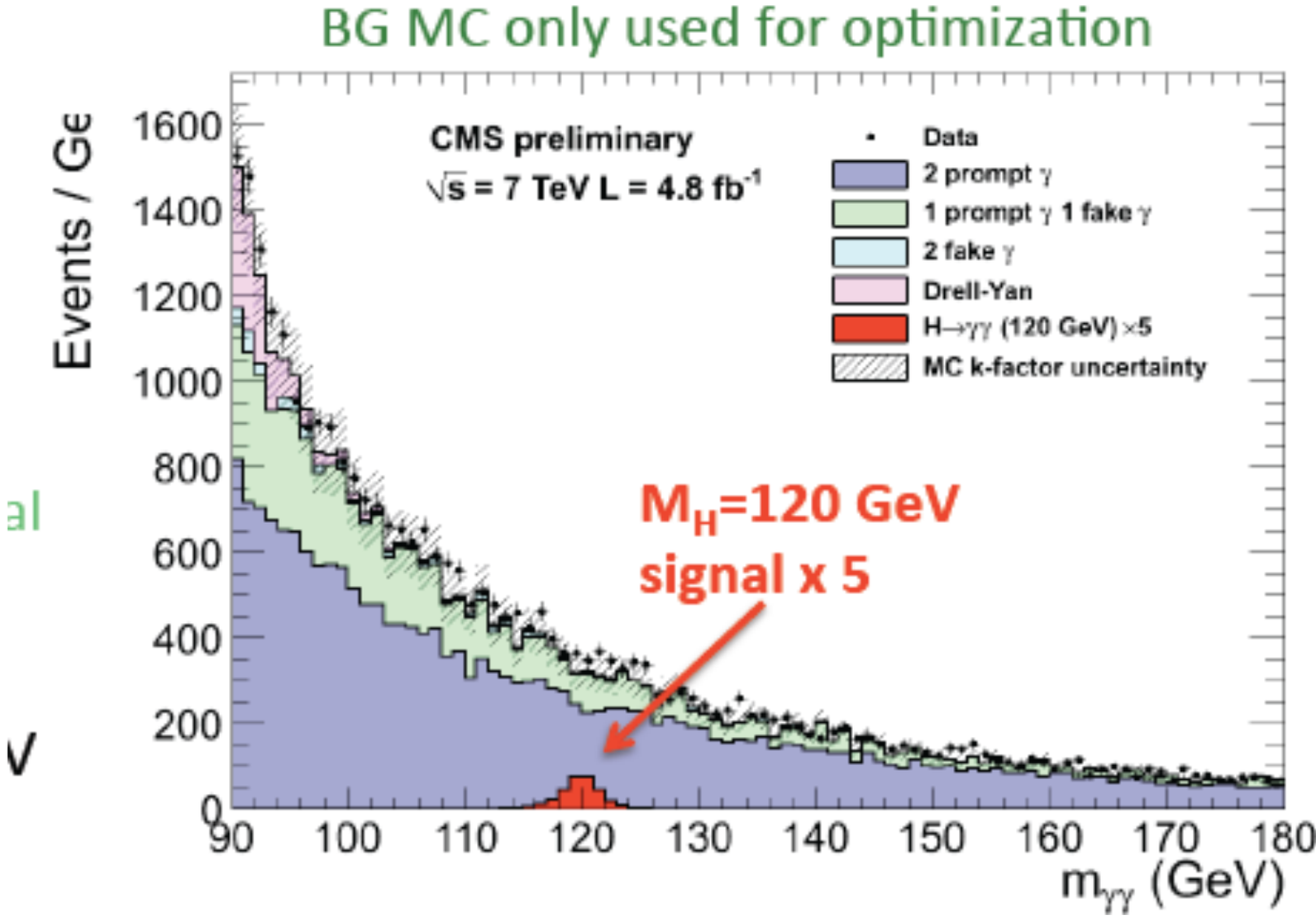
Powerful /jet separation is crucial.

Need an excellent mass resolution.

H --> γγ



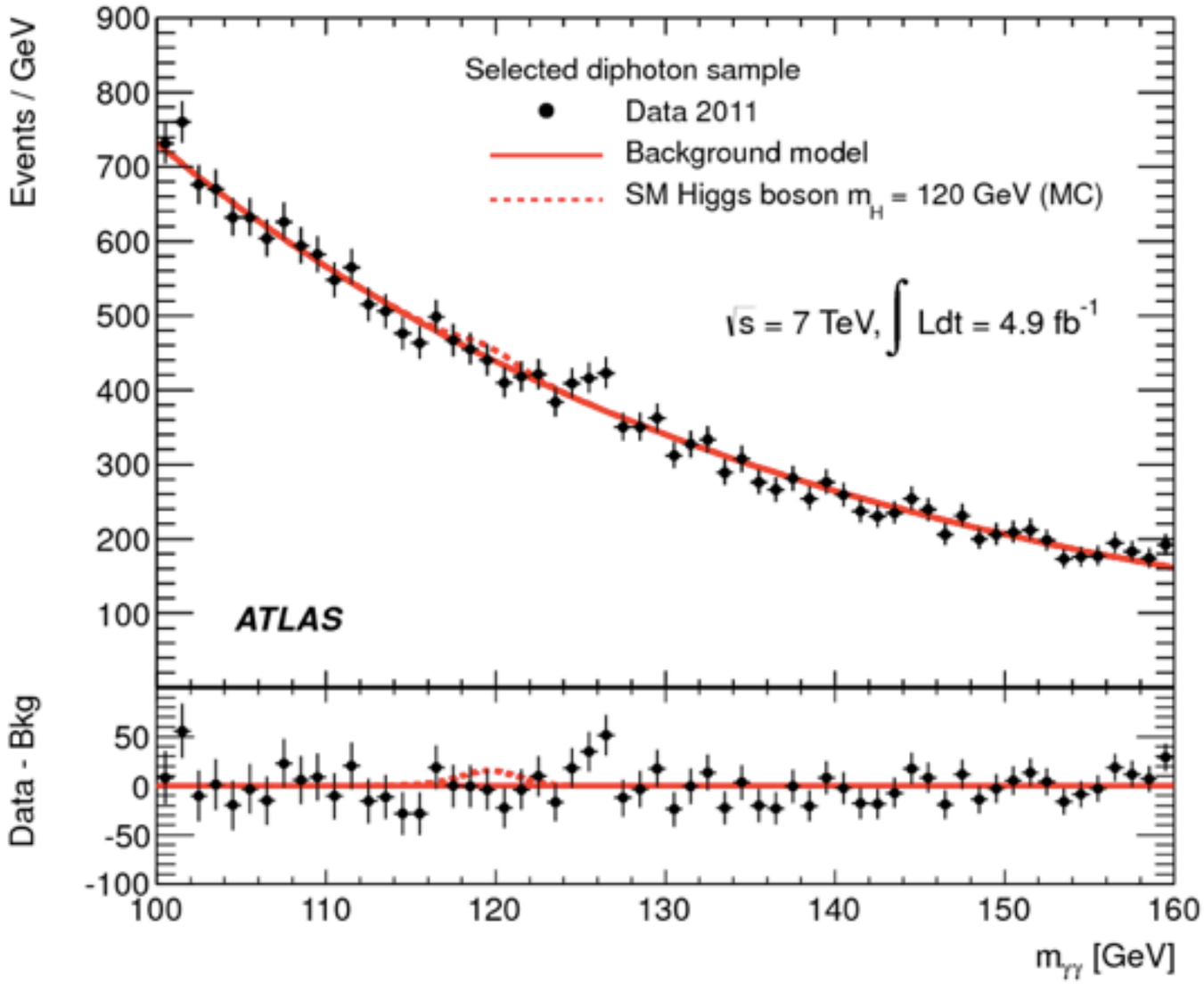


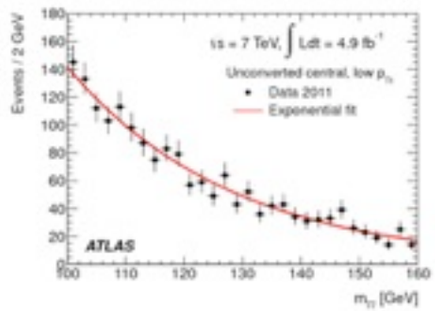


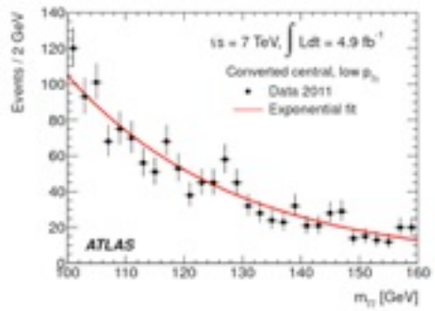
Photon id performance
checked with control samples

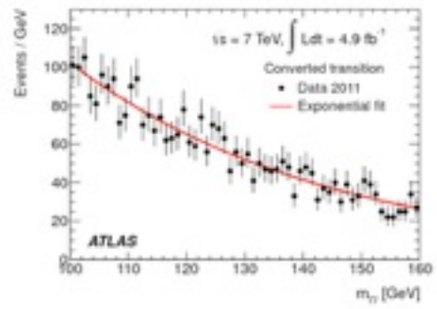
Bkg is data driven fitting the spectrum in the sidebands

H --> γγ



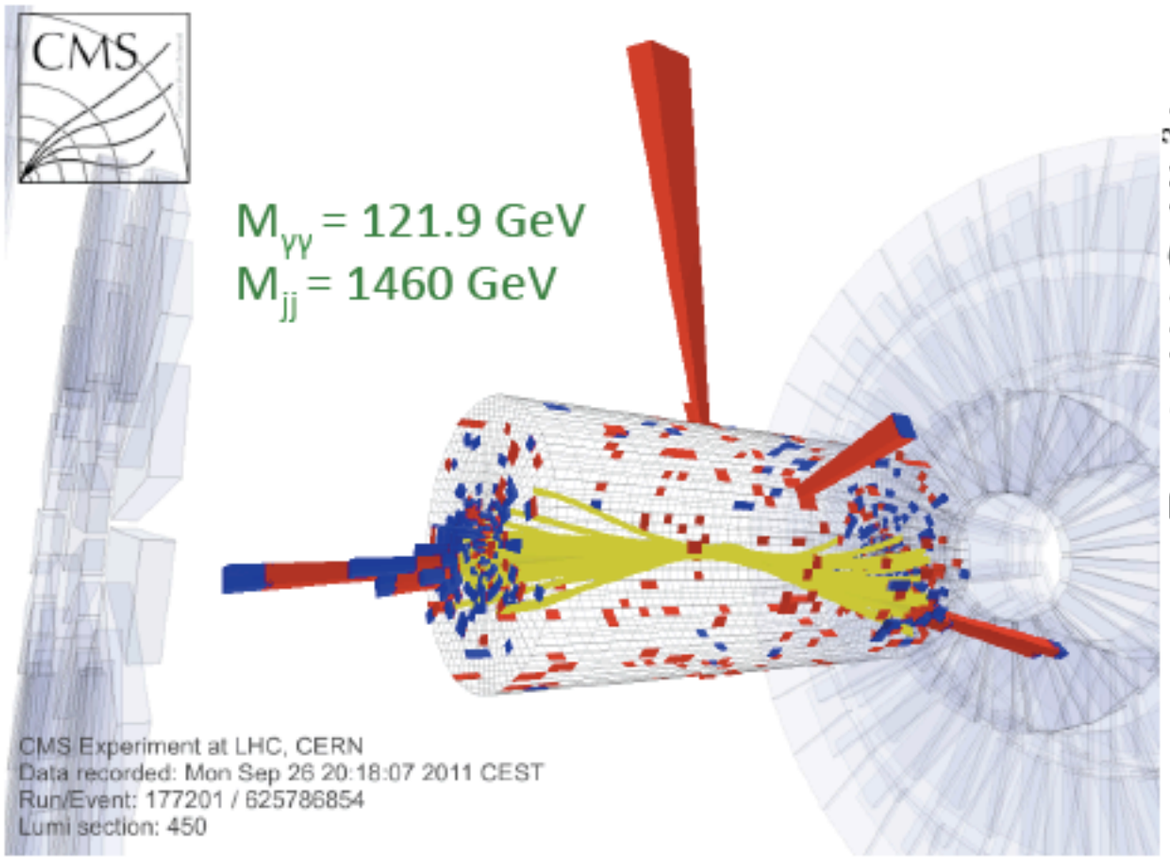




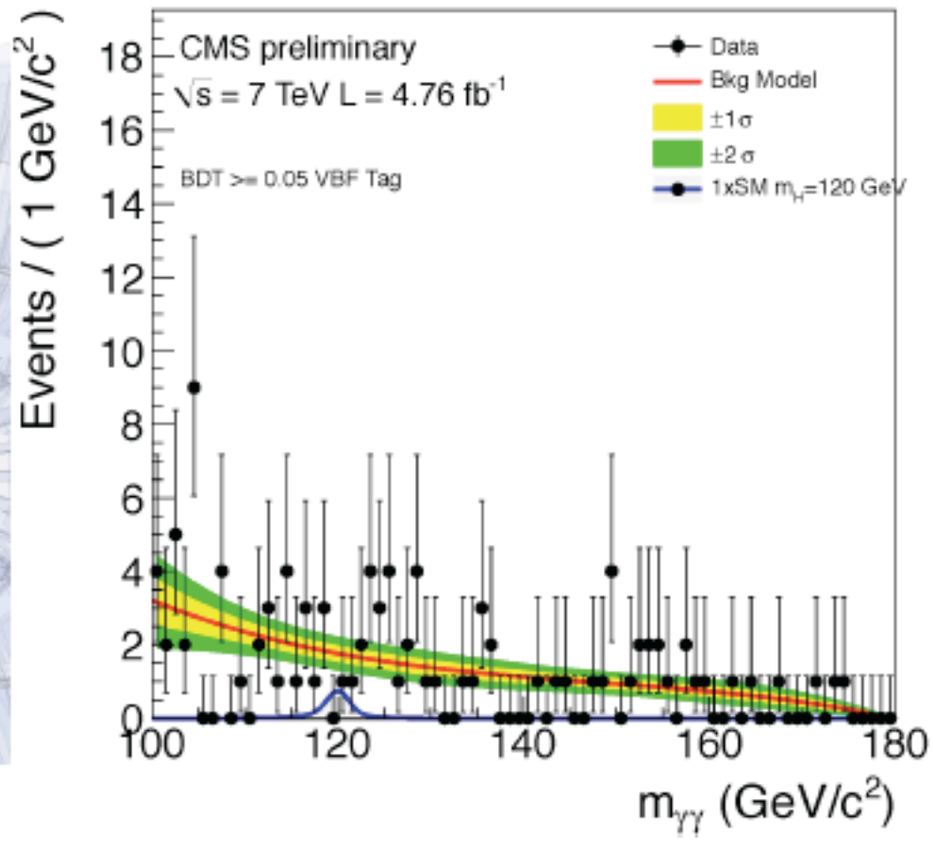


Analysis in ATLAS split in 9 categories depending on eta, conversion status, photon topology

H --> γγ

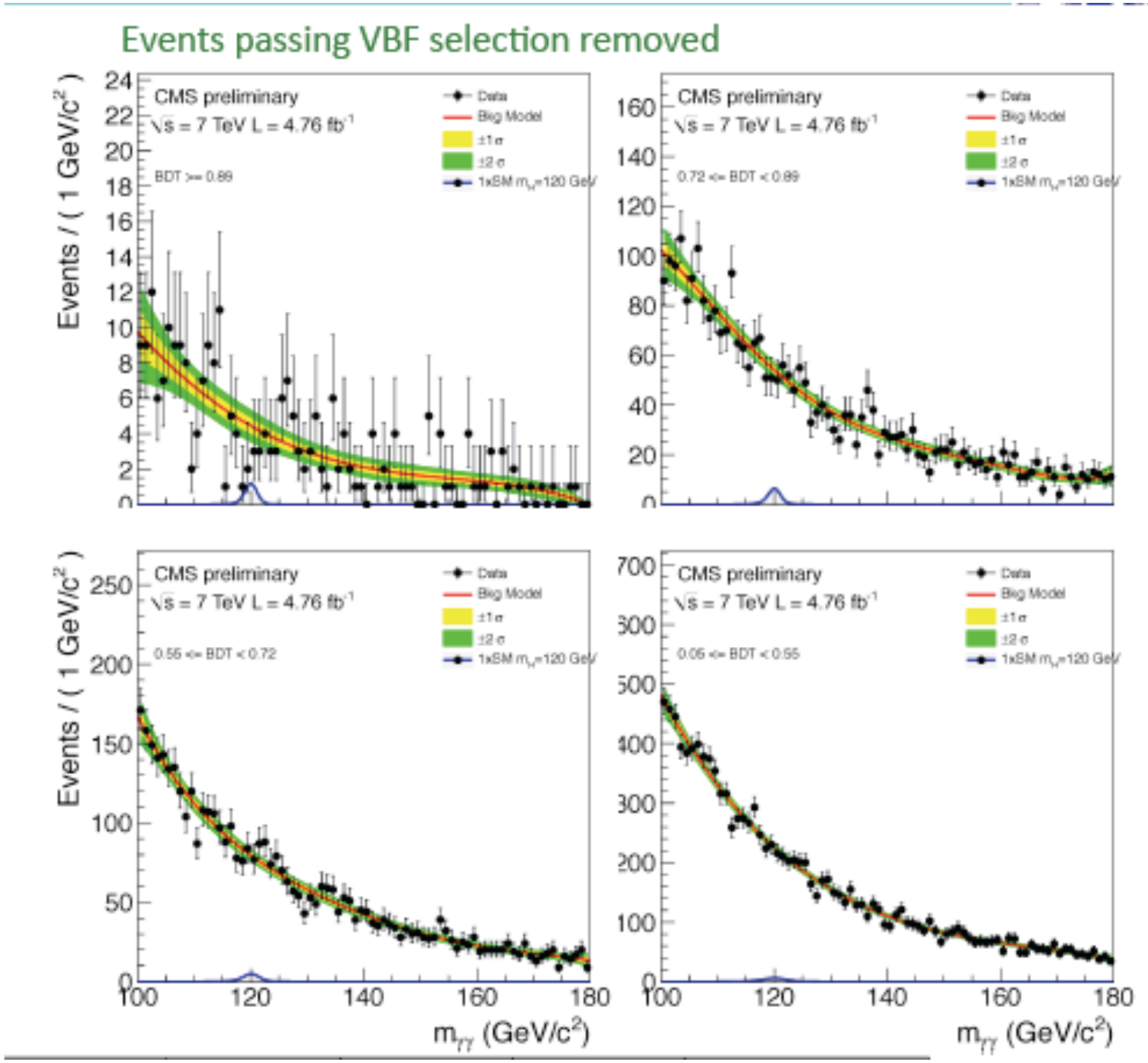


Dijet tag selection has high s/b, ~1/3



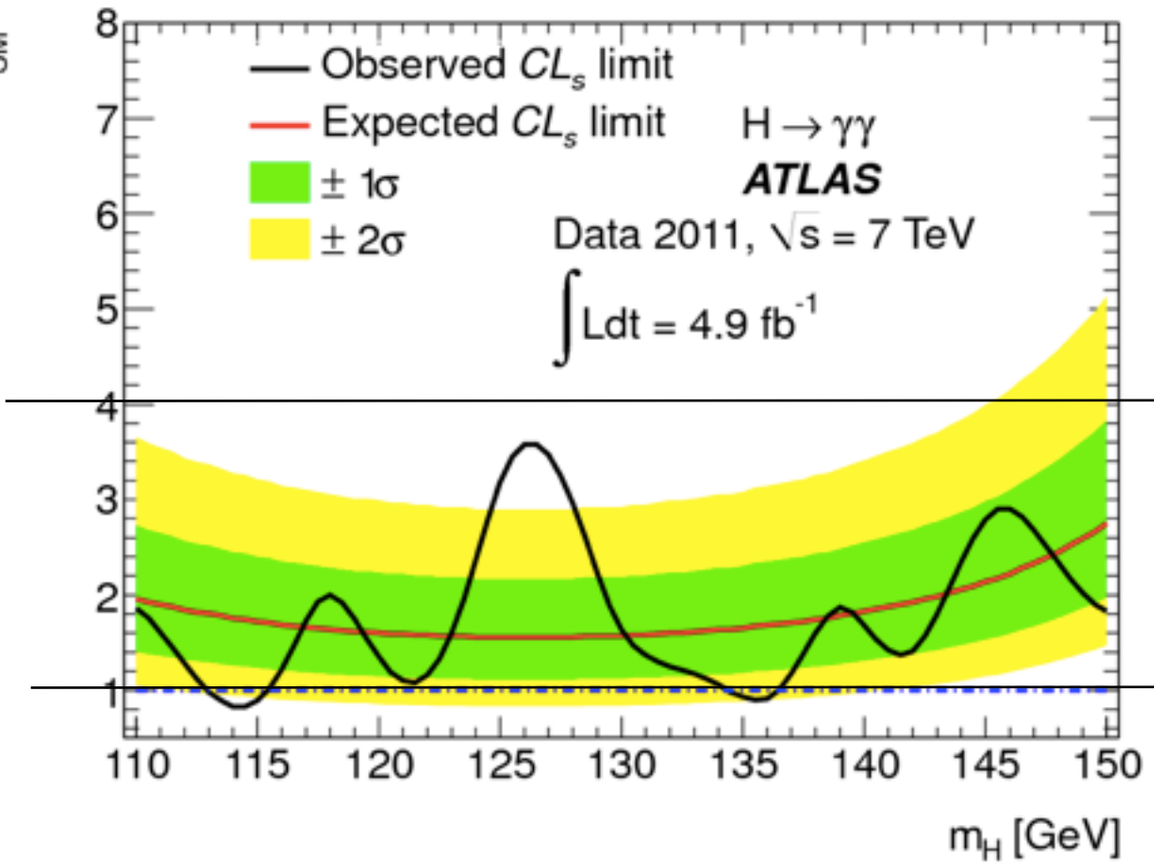
In CMS events with two jets (VBF motivated selection) are separated from the rest [in MC the sample is 70% VBF and 30 % gluon gluon]

H --> γγ

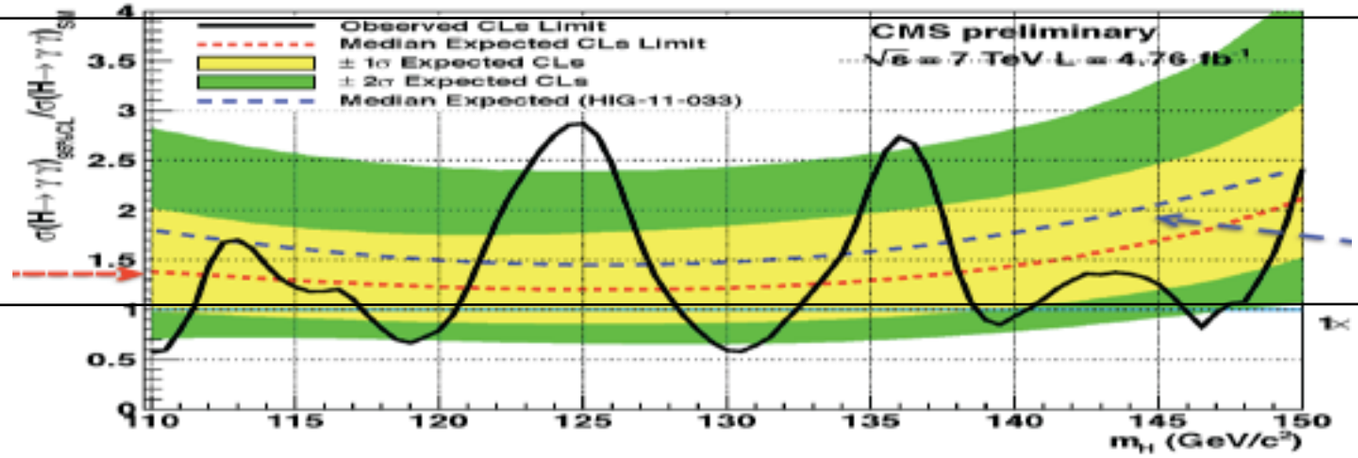


Remaining events are split in 4 categories depending on photon id / resolution / mass resolution with an MVA method

H --> γγ

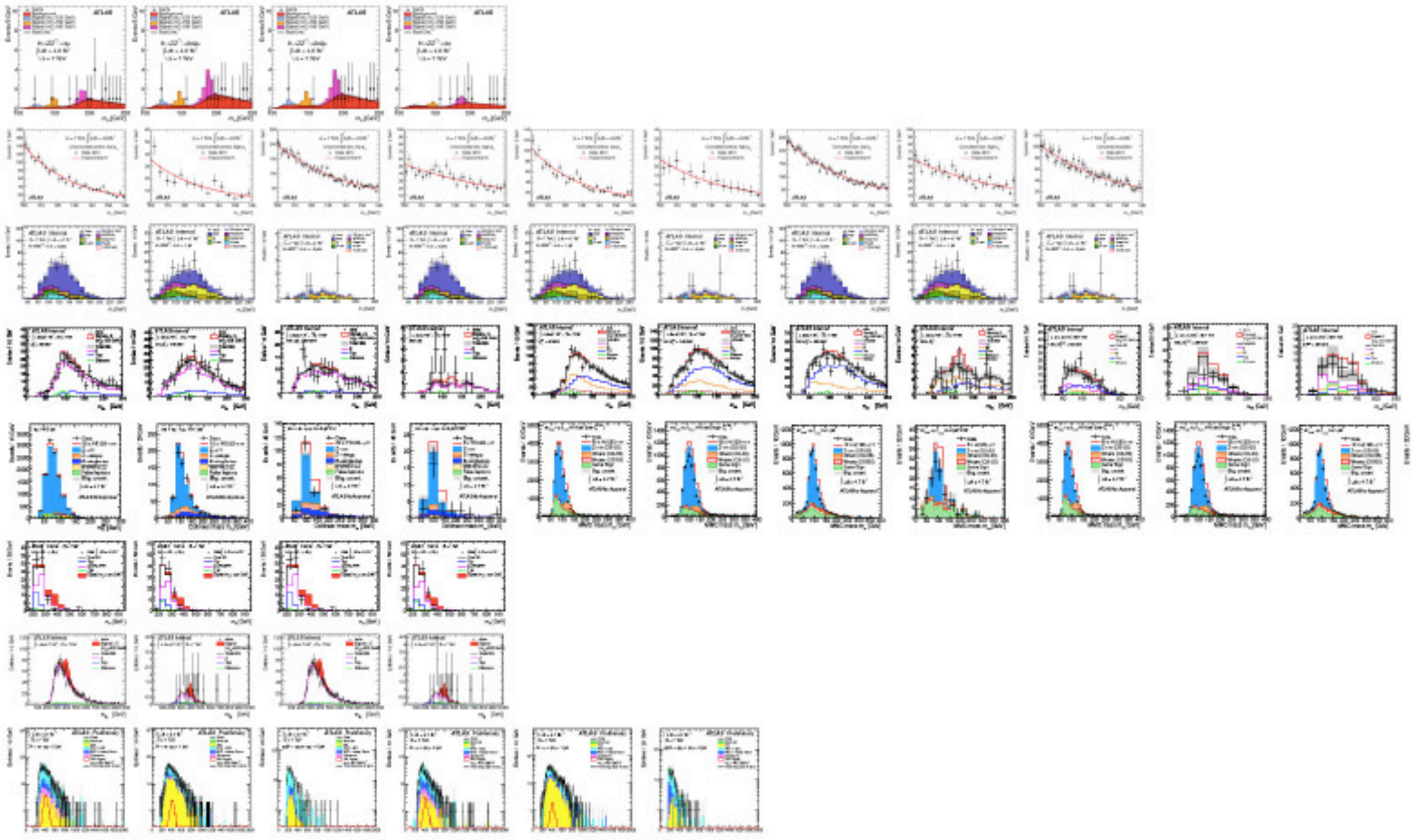


$\mu_{exp(125)}$=1.5



$\mu_{exp(125)}$=1.2

COMBINATION



Combination

- Exclusions in each channel are combined assuming SM branching ratios.

- In the following slides there are two kinds of "brasilian flag" plots
  - CLS : at which level can we exclude the SM cross section at a given Higgs mass ?
  - μ : which fraction μ of the SM cross section can be exclude at 95% CL at a given Higgs mass (same plot as before)

Approximate weight of the channels

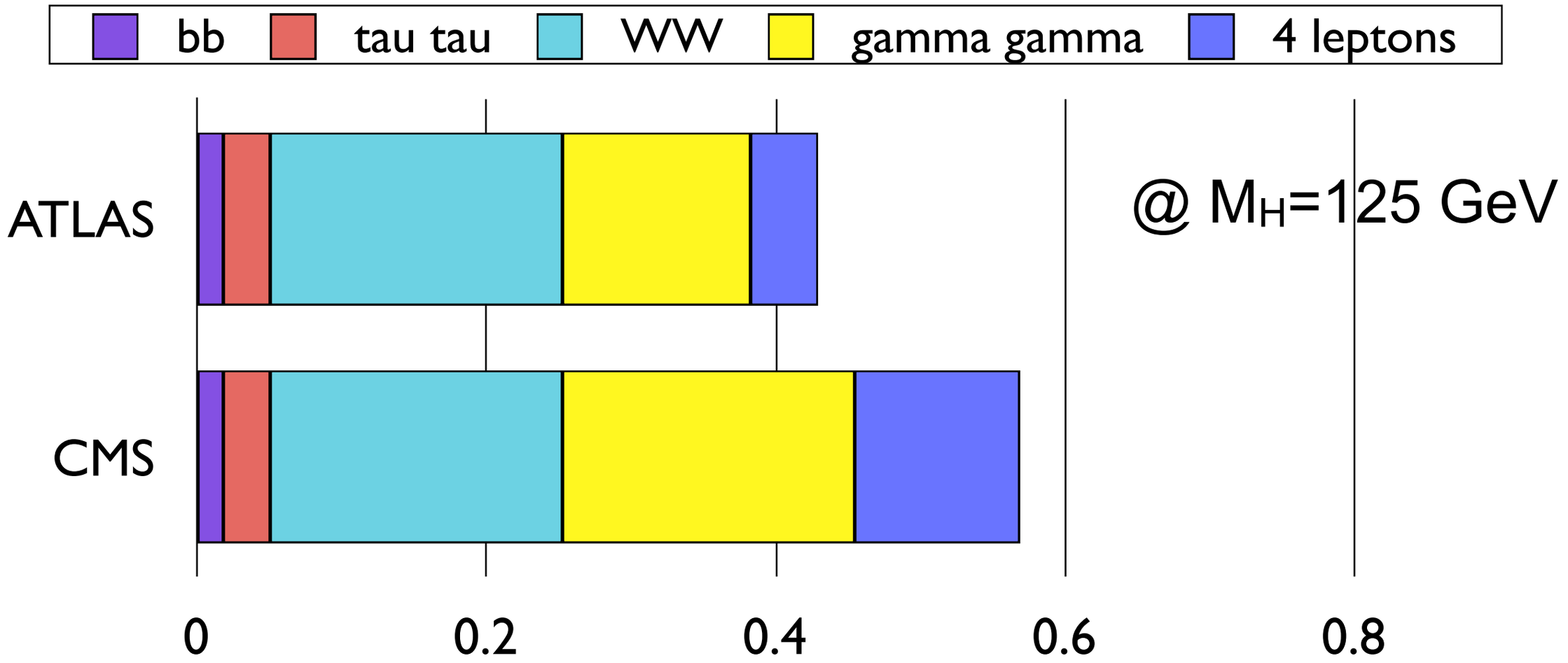
(in a very simple minded combination)

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

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.

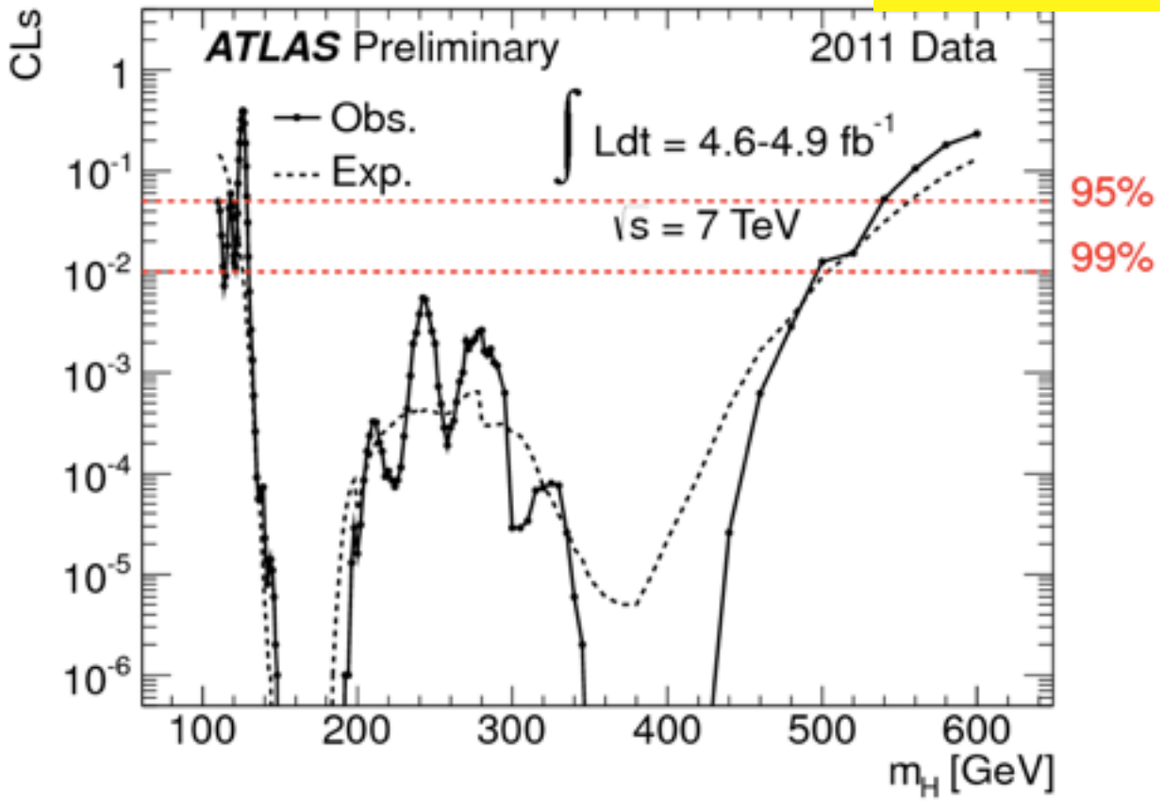
Cowan, Cranmer, Gross, Vittels EPJC 71:1554

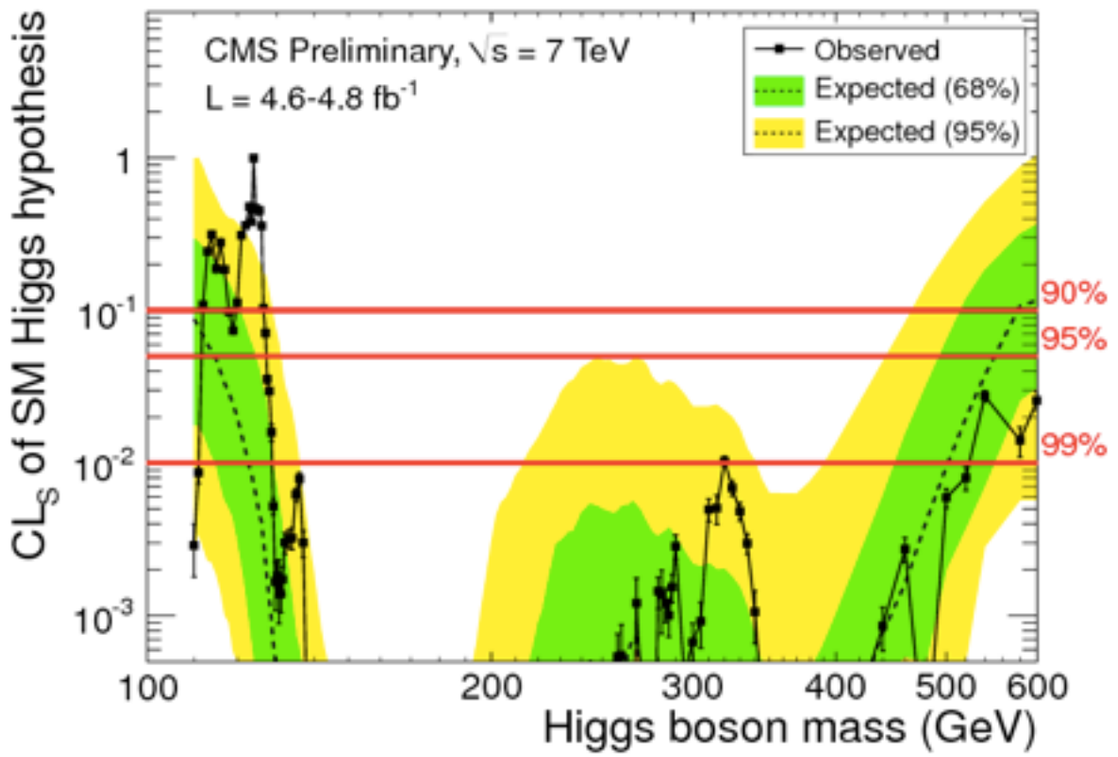


Warning: I am not going to combine ATLAS and CMS

Full mass range exclusion CL

watch the scale





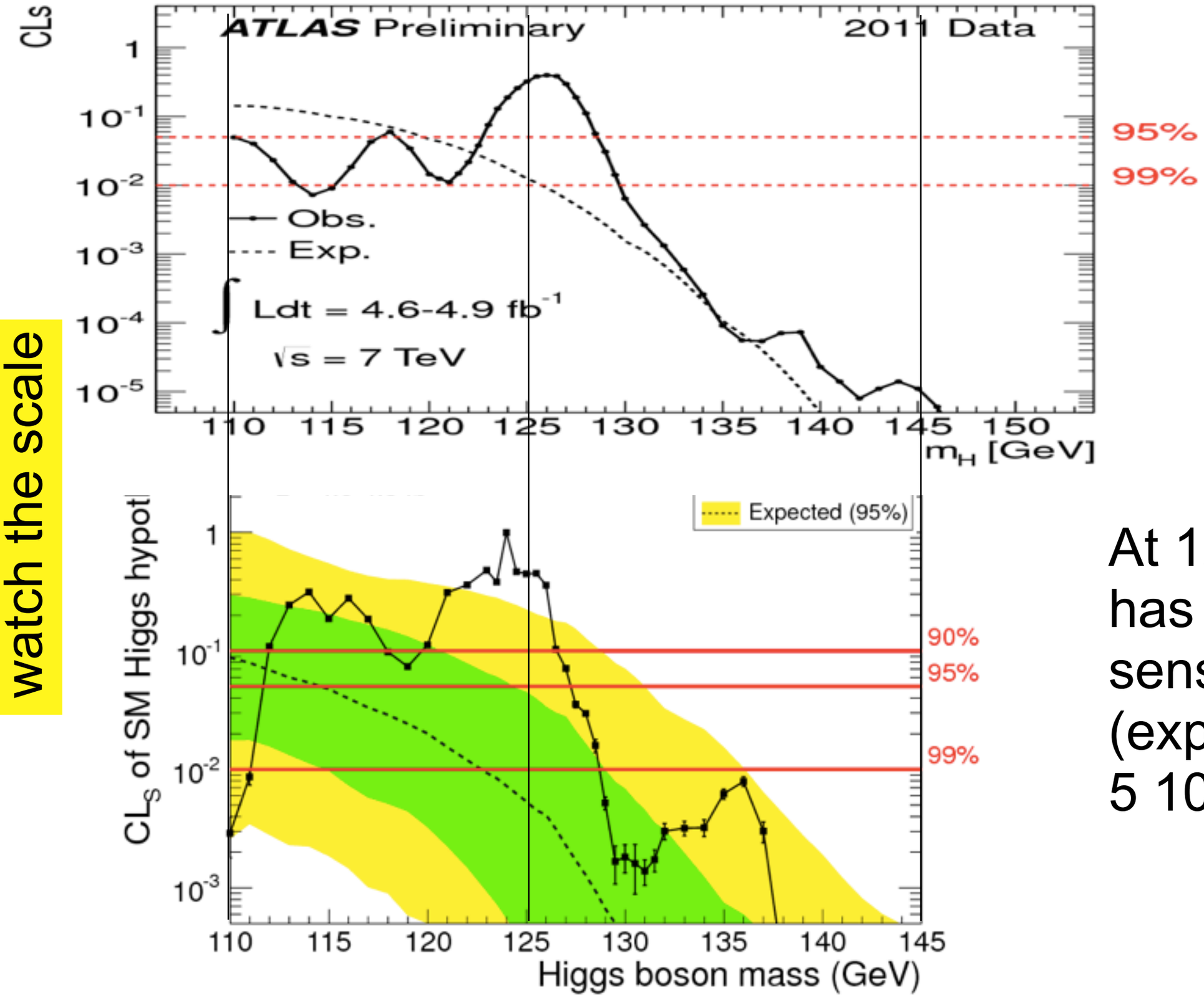
95% exclusion 110 - 117.5 GeV
118.5 - 122.5 GeV
129 - 539 GeV

95% exclusion 127.5 - 600 GeV

Safe statement: the region 129-600 GeV is excluded for a SM Higgs Boson

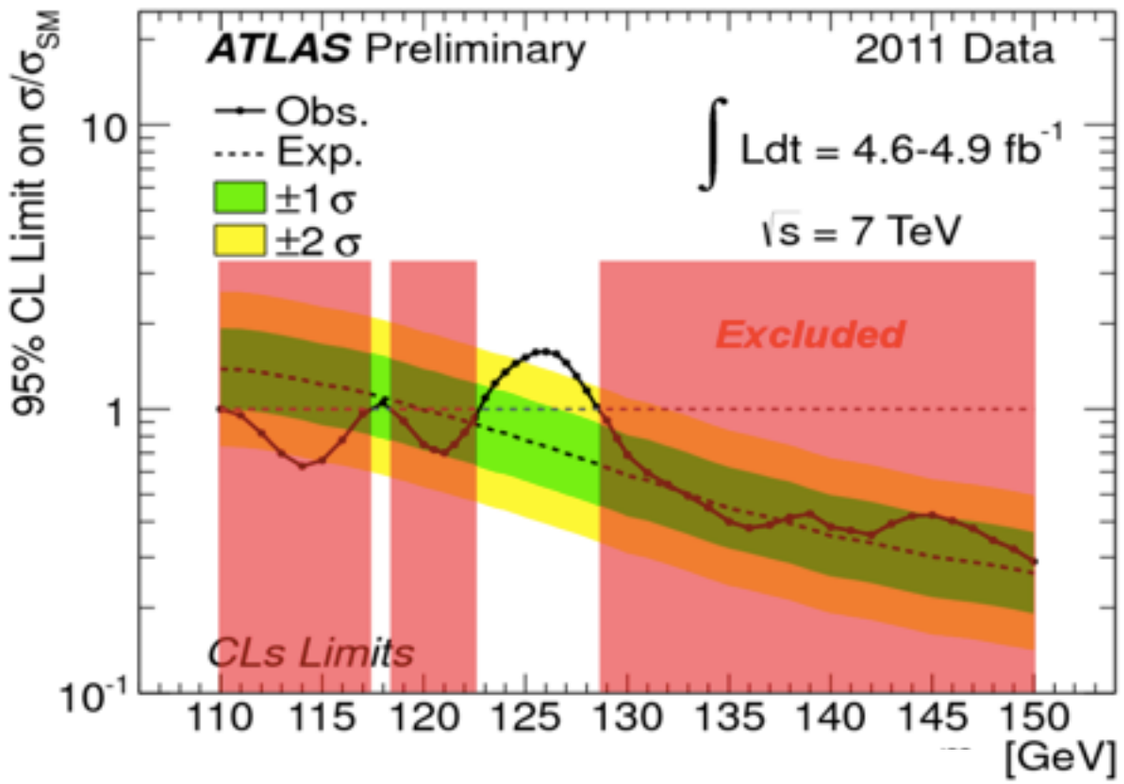
Low mass region CLS

watch the scale



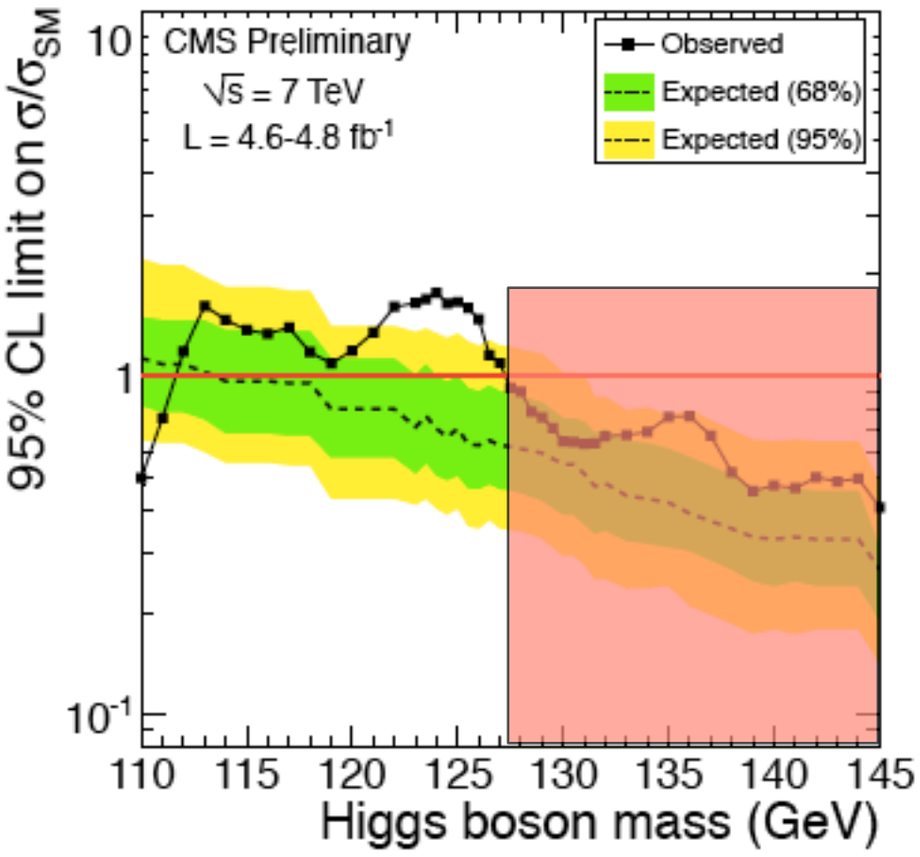
At 125 GeV CMS has a larger sensitivity (expected curve) 5 10^{-3} vs 10^{-2}

Combination at low mass: μ



One cannot take , in general, the OR of the exclusions !

$\mu_{exp(125)}=0.8$



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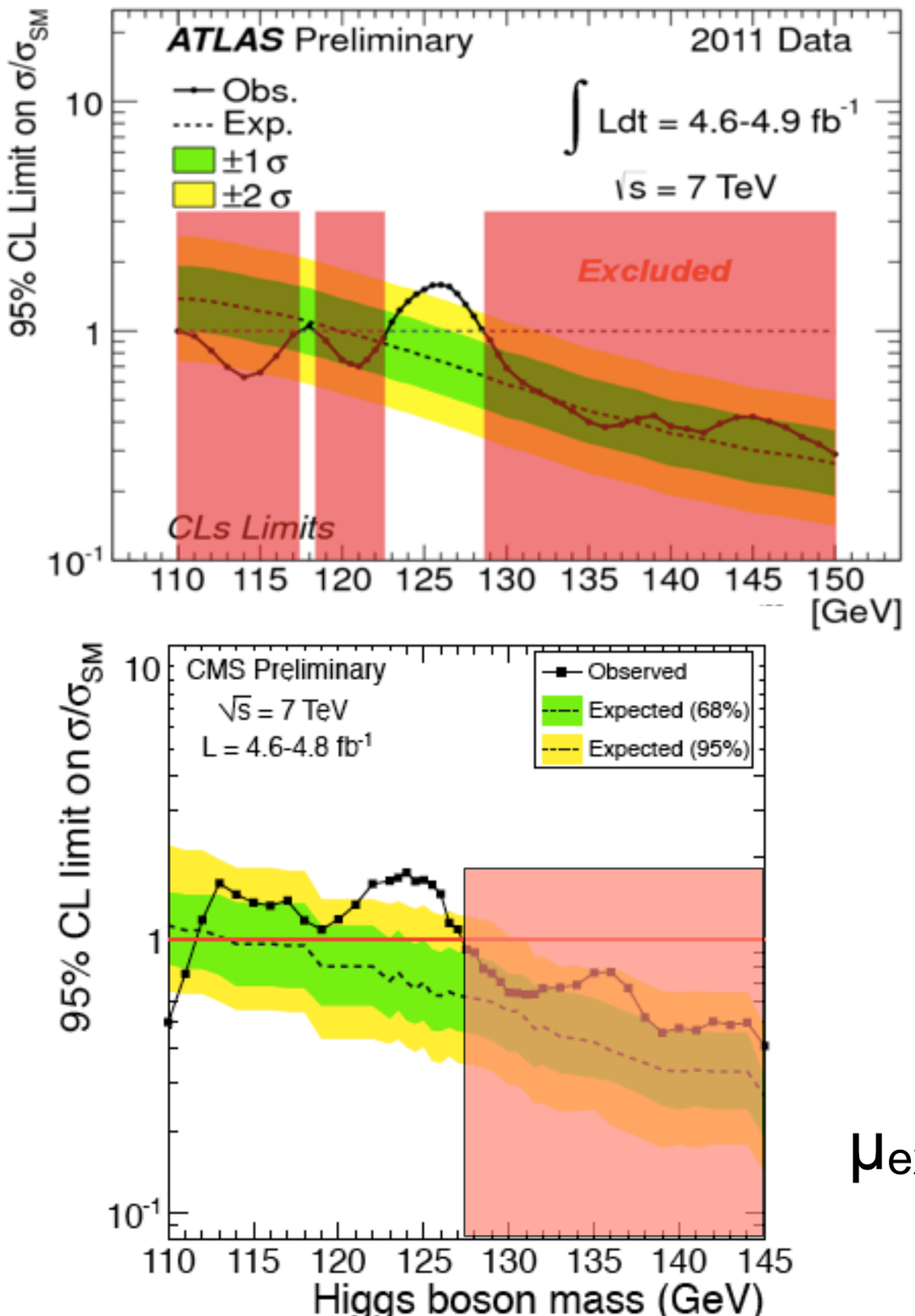

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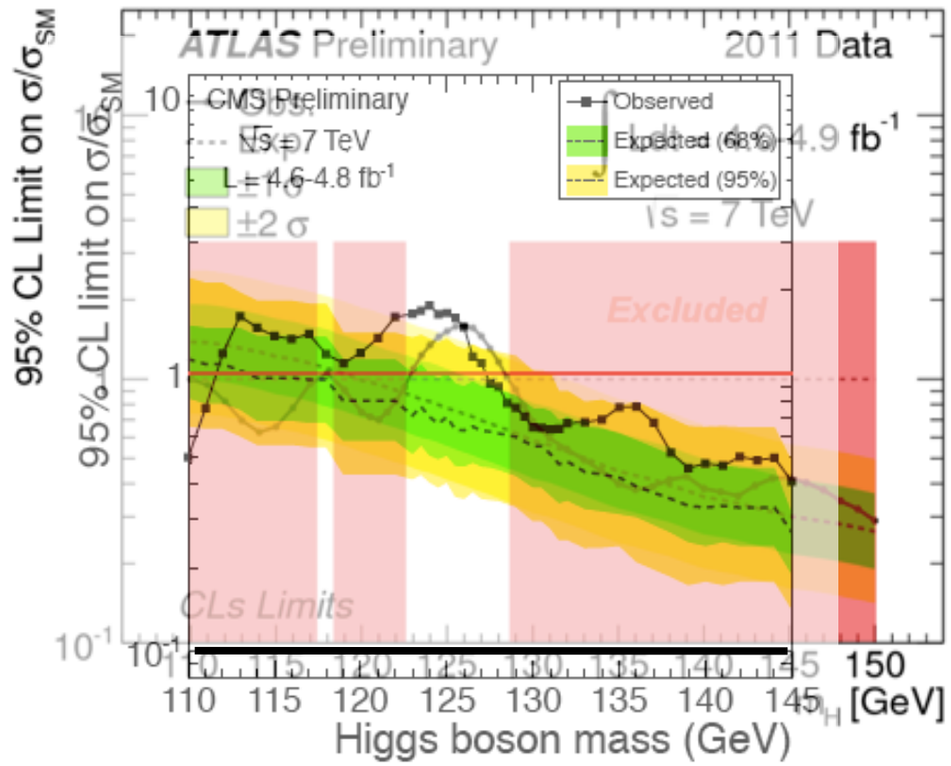
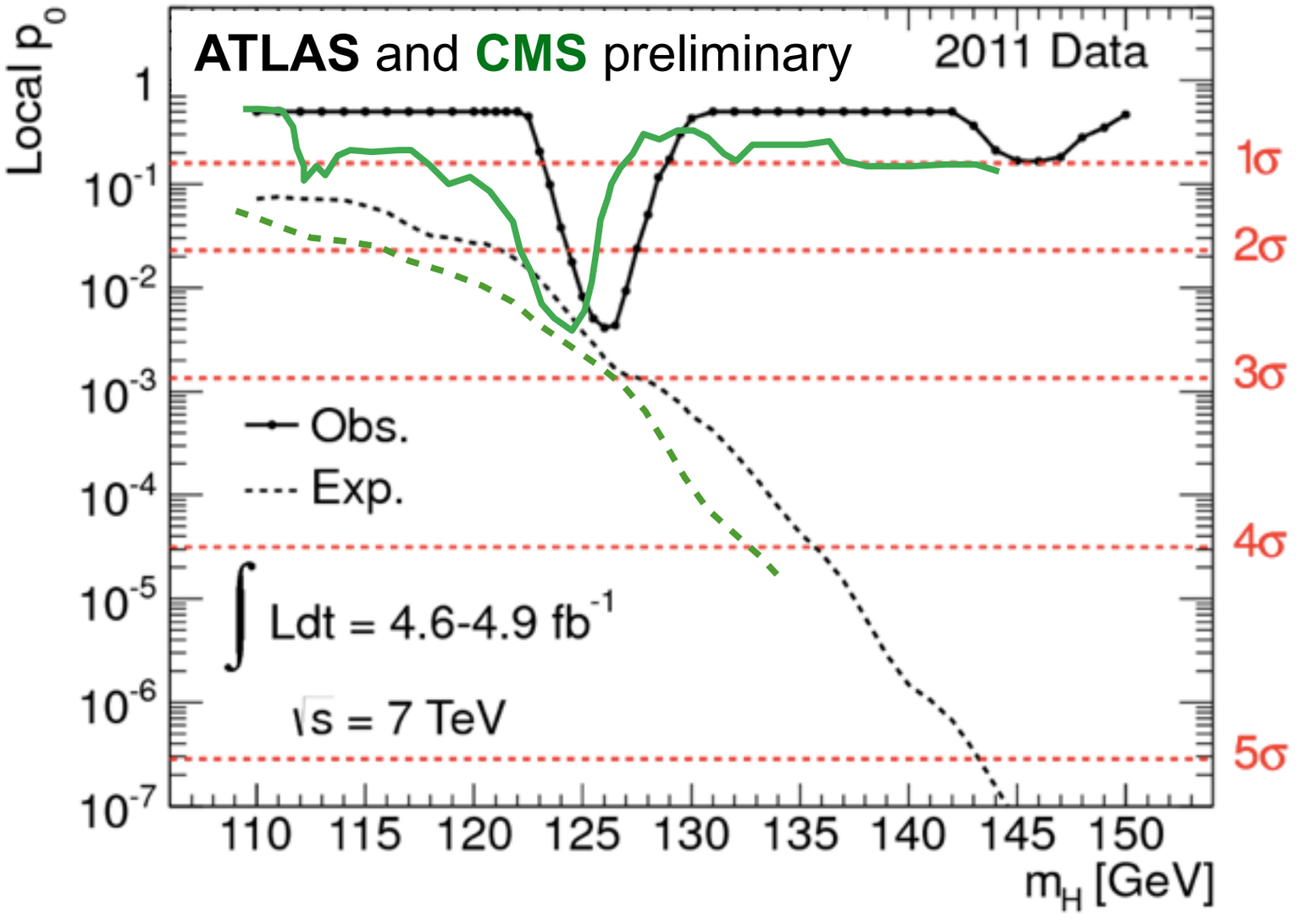


$\mu_{exp(125)}=0.65$

Is the excess seen in the region of 125 GeV due to a fluctuation of the background ?

local p- value

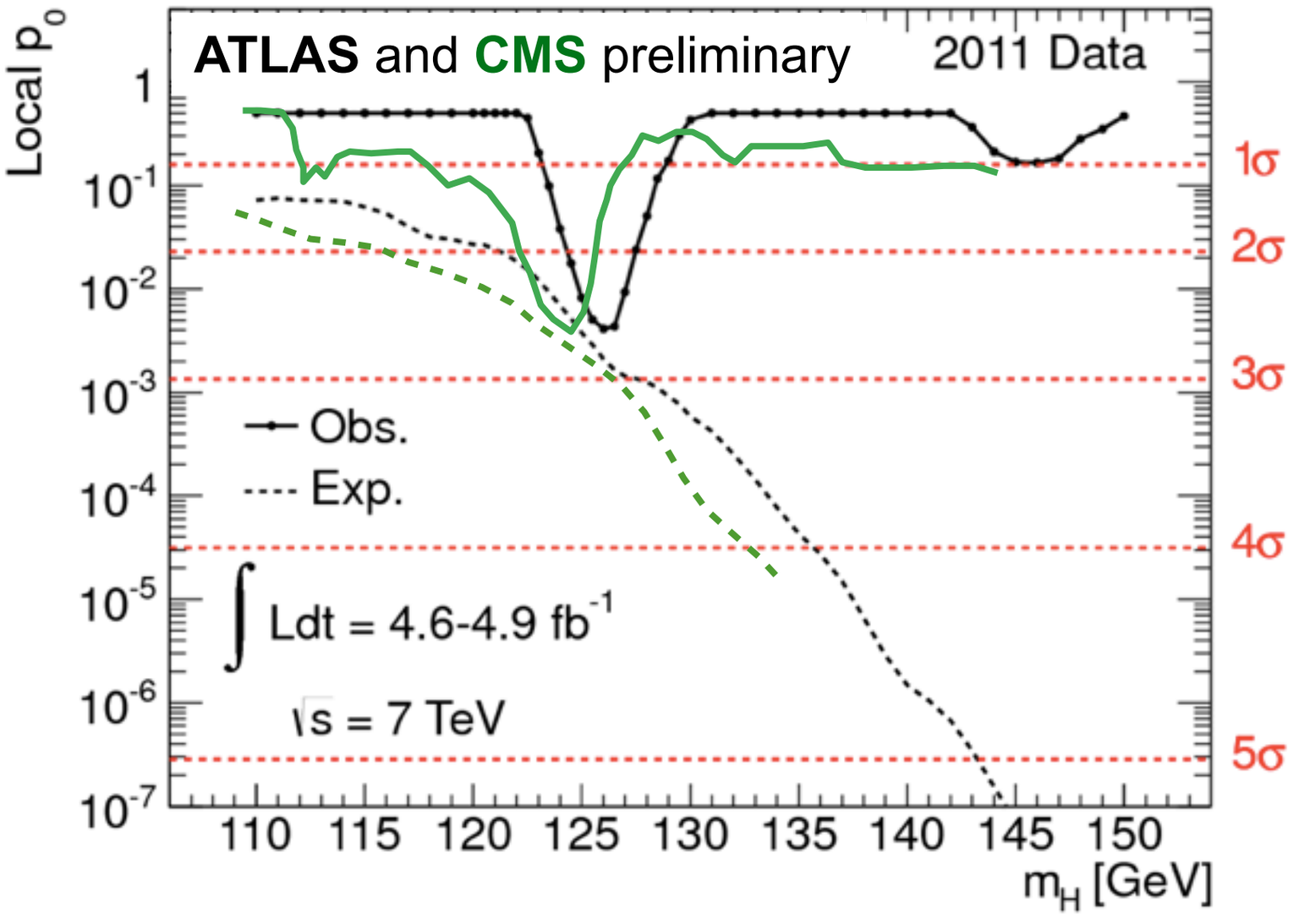
- The p value is computed at each mass. It is the probability that the expected background - at that mass point - has fluctuated more than what seen in the data.



Near 125 the significance is ~2.5σ in either experiment.

global p- value

- This significance must be decreased taking into account the probability that a fluctuation may happen anywhere in the search region and the correlation among nearby masses

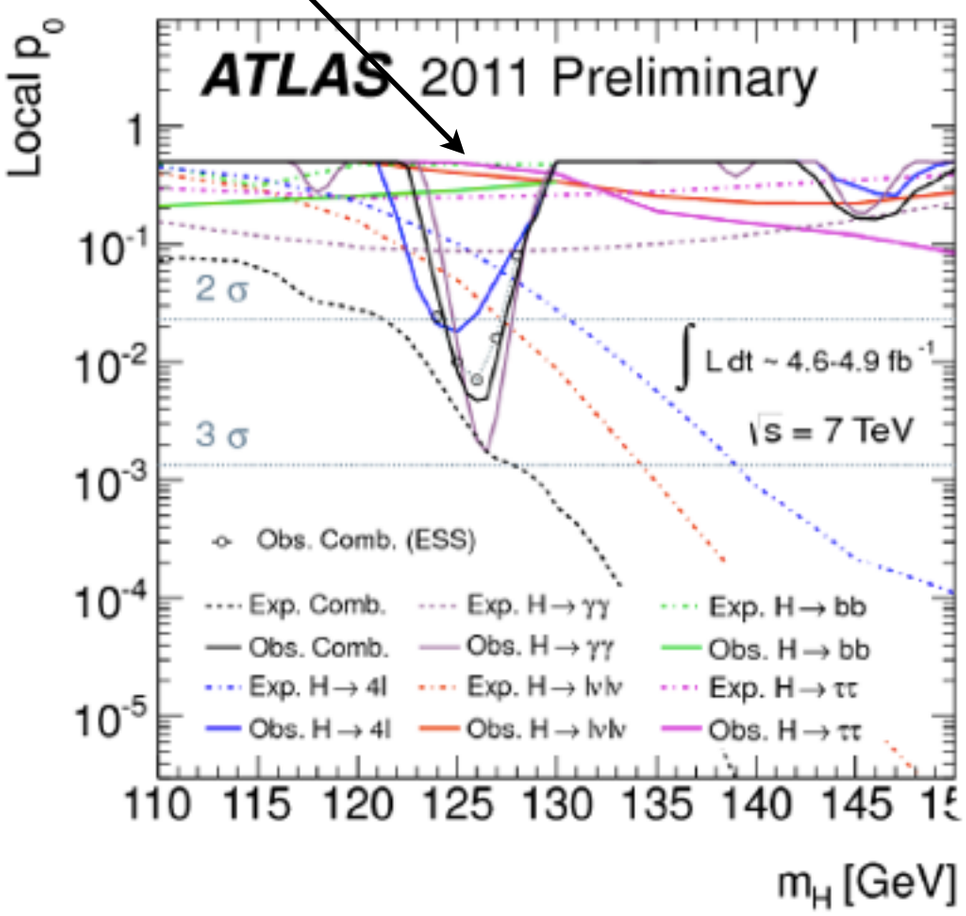


Quite obvious in a single channel, somewhat arbitrary in the combination

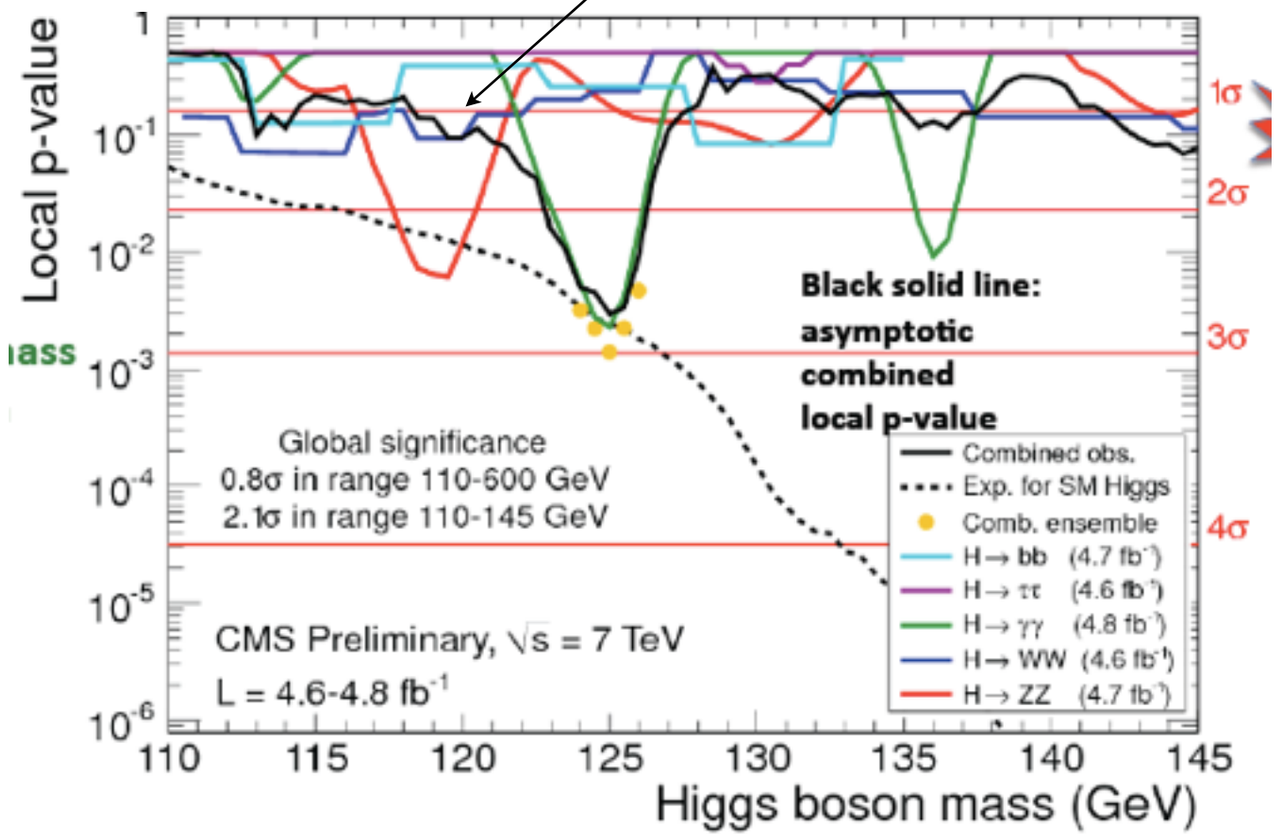
Both Collaboration quote a ~ 10% probability to have a larger excess in 110-150 GeV

P-value channel by channel

Lack of signal in WW reduces the significance of (4l+γγ)



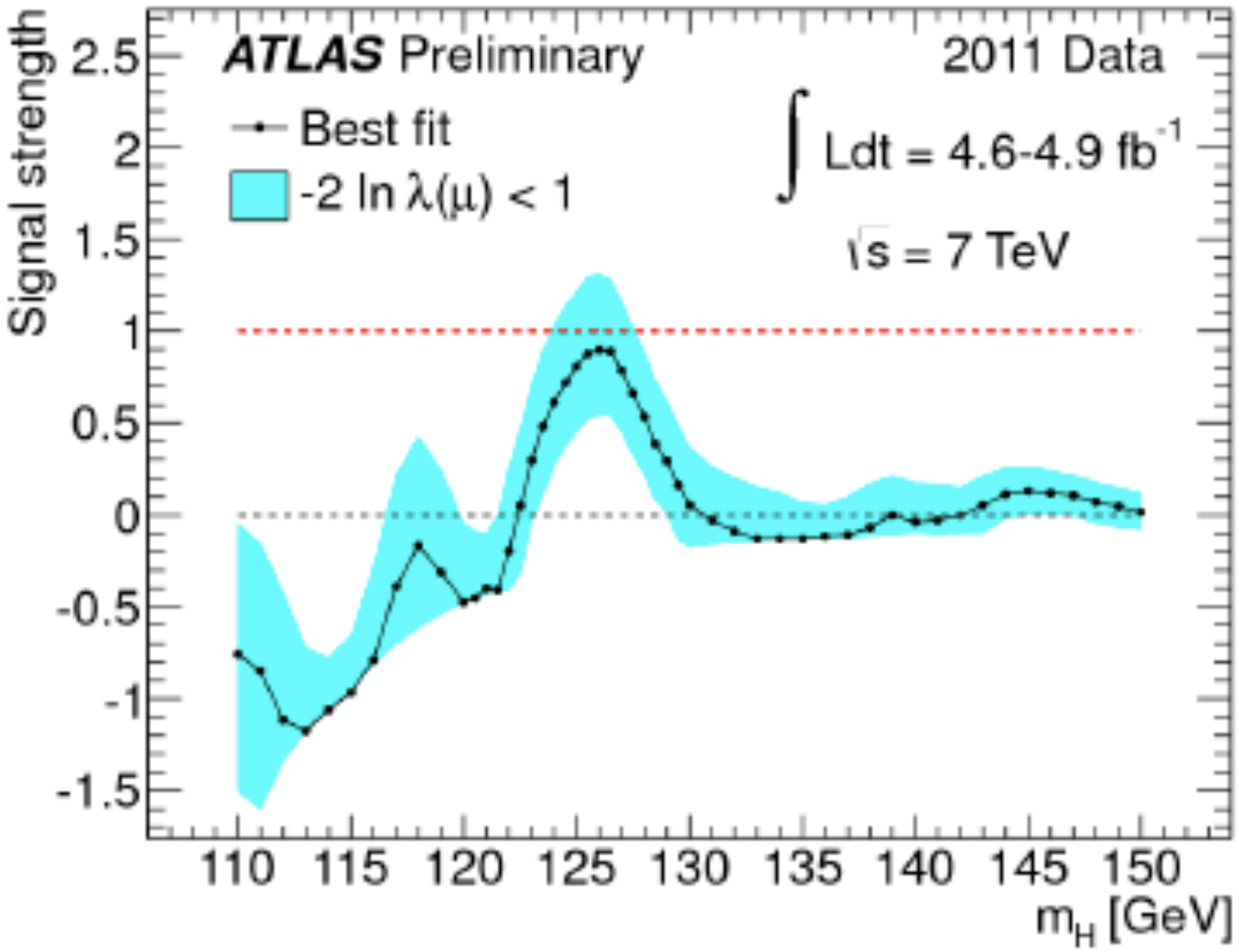
Lack of signal in γγ reduces the significance of 4 l



Is the excess seen in the region of 125 GeV compatible with SM Higgs cross section ?

Best fit value of μ

Best fit signal strength $\mu = \sigma/\sigma_{SM}$:



Standard Model
WITH Higgs

Standard Model
WITHOUT Higgs

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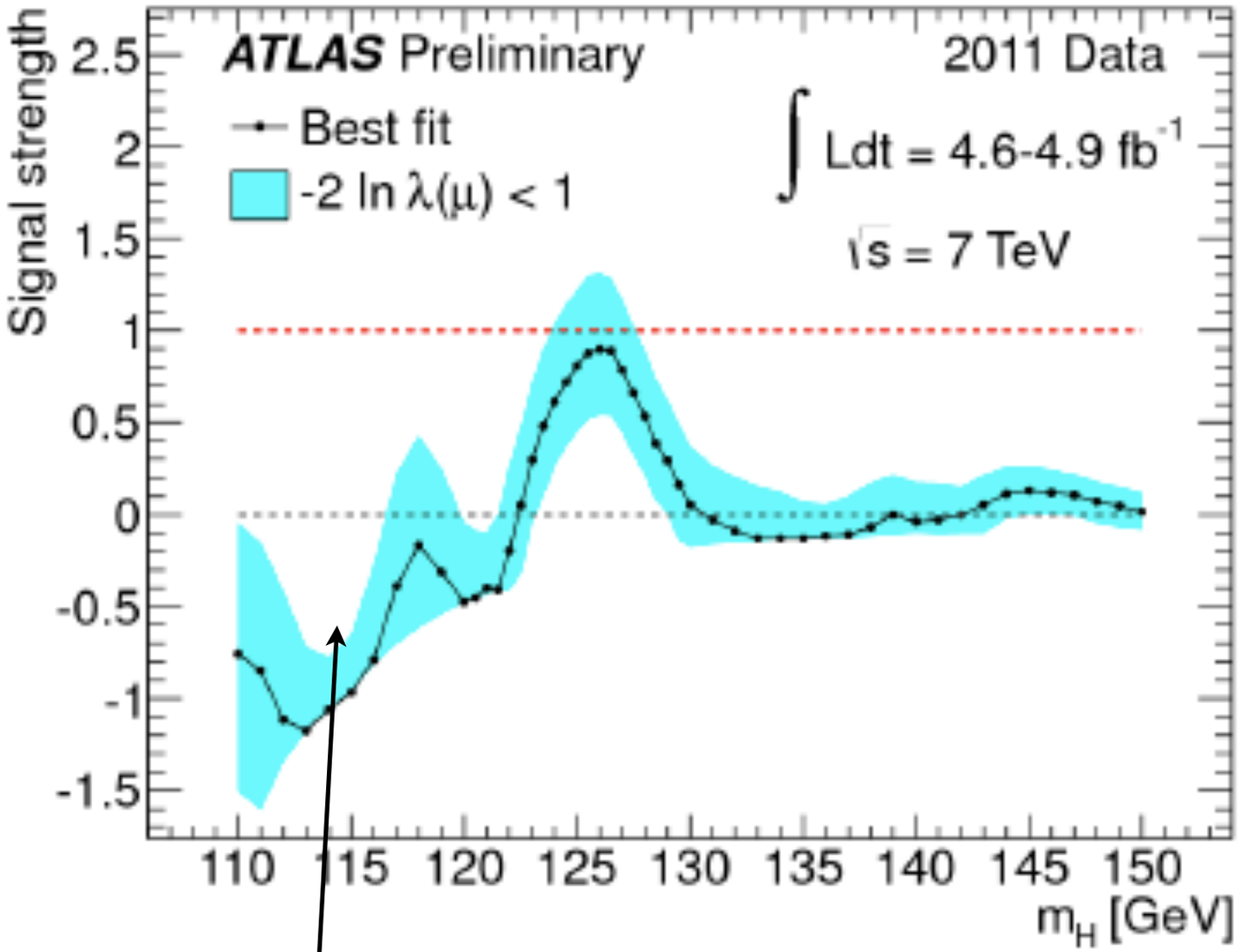
Best fit signal strength $\mu = \sigma/\sigma_{SM}$:



Standard Model
WITH Higgs

Standard Model
WITHOUT Higgs

Is the SM excluded here ?

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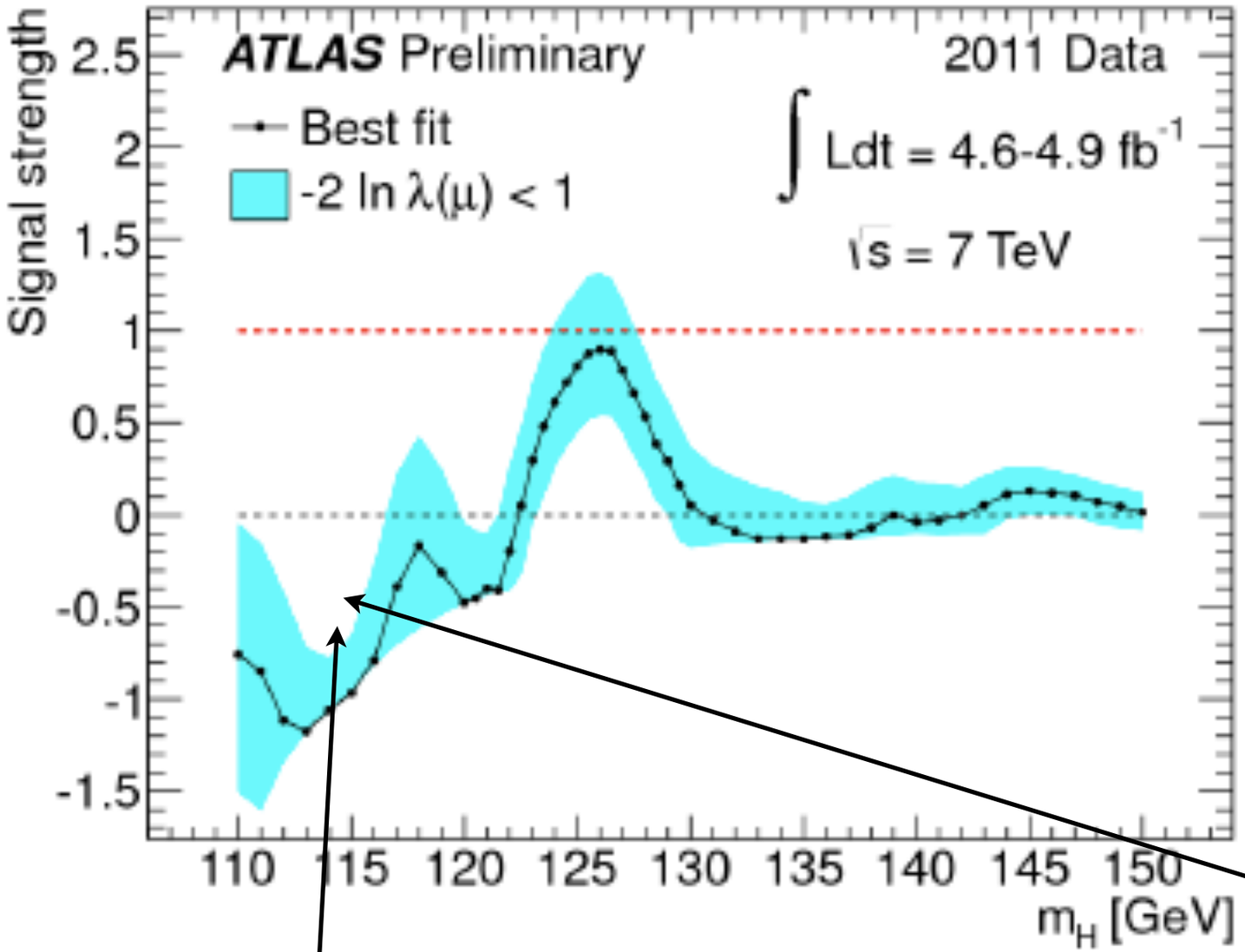
Best fit signal strength $\mu = \sigma/\sigma_{SM}$:



Standard Model
WITH Higgs

Standard Model
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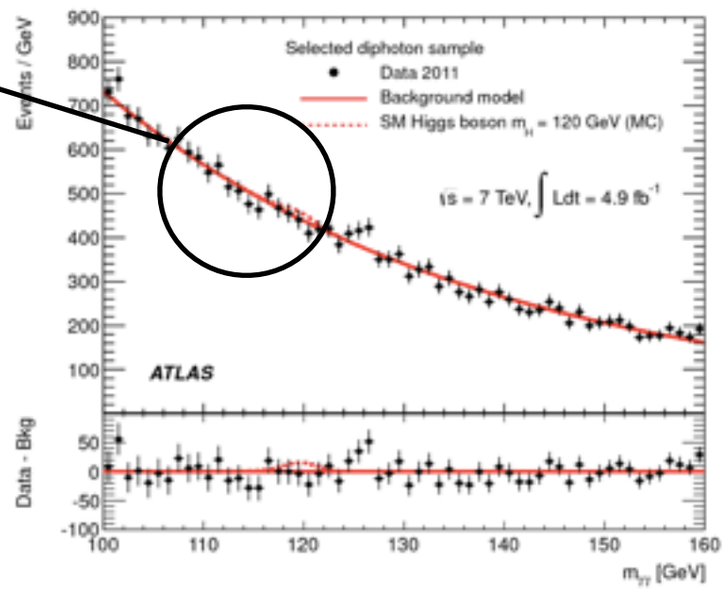

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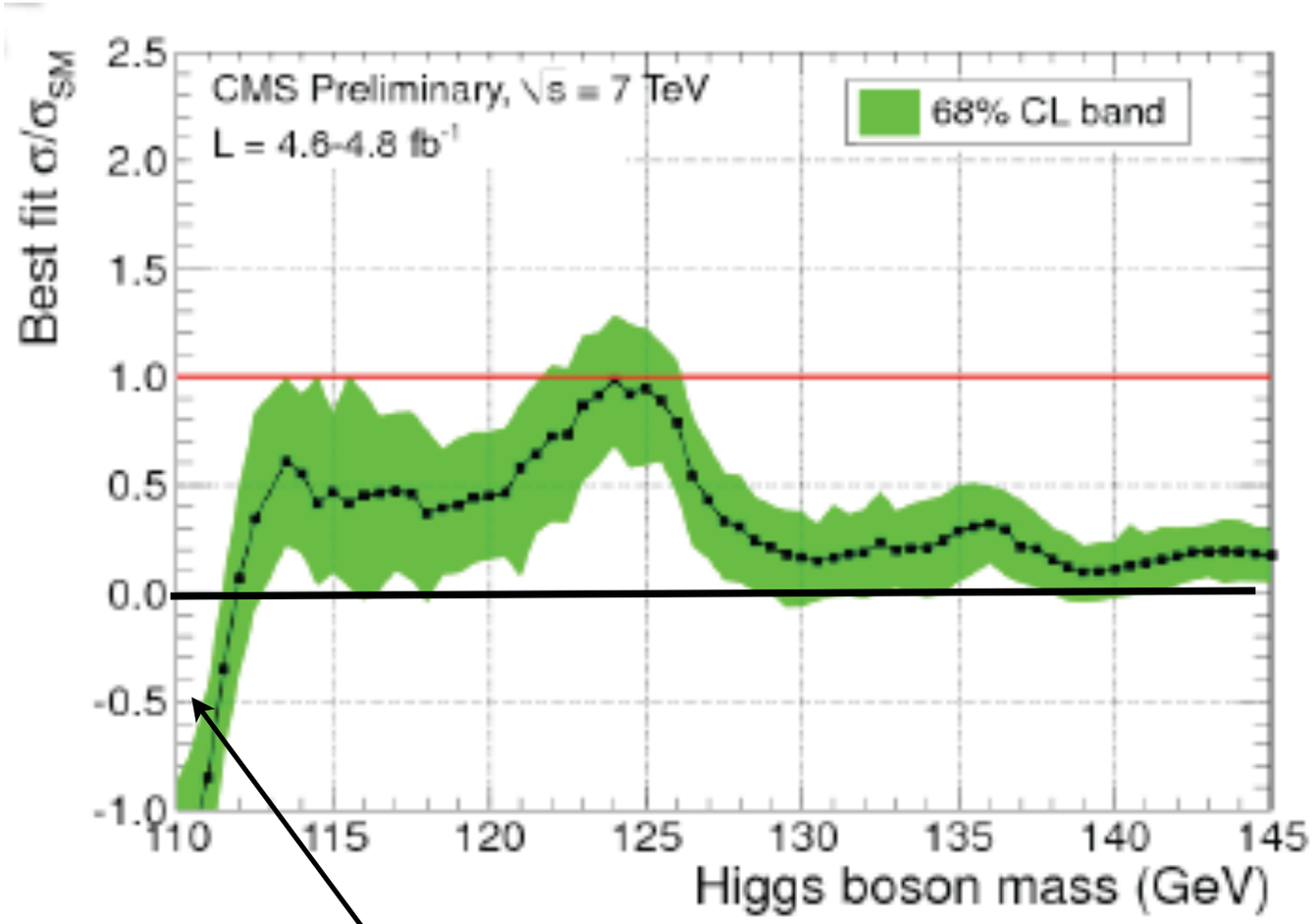
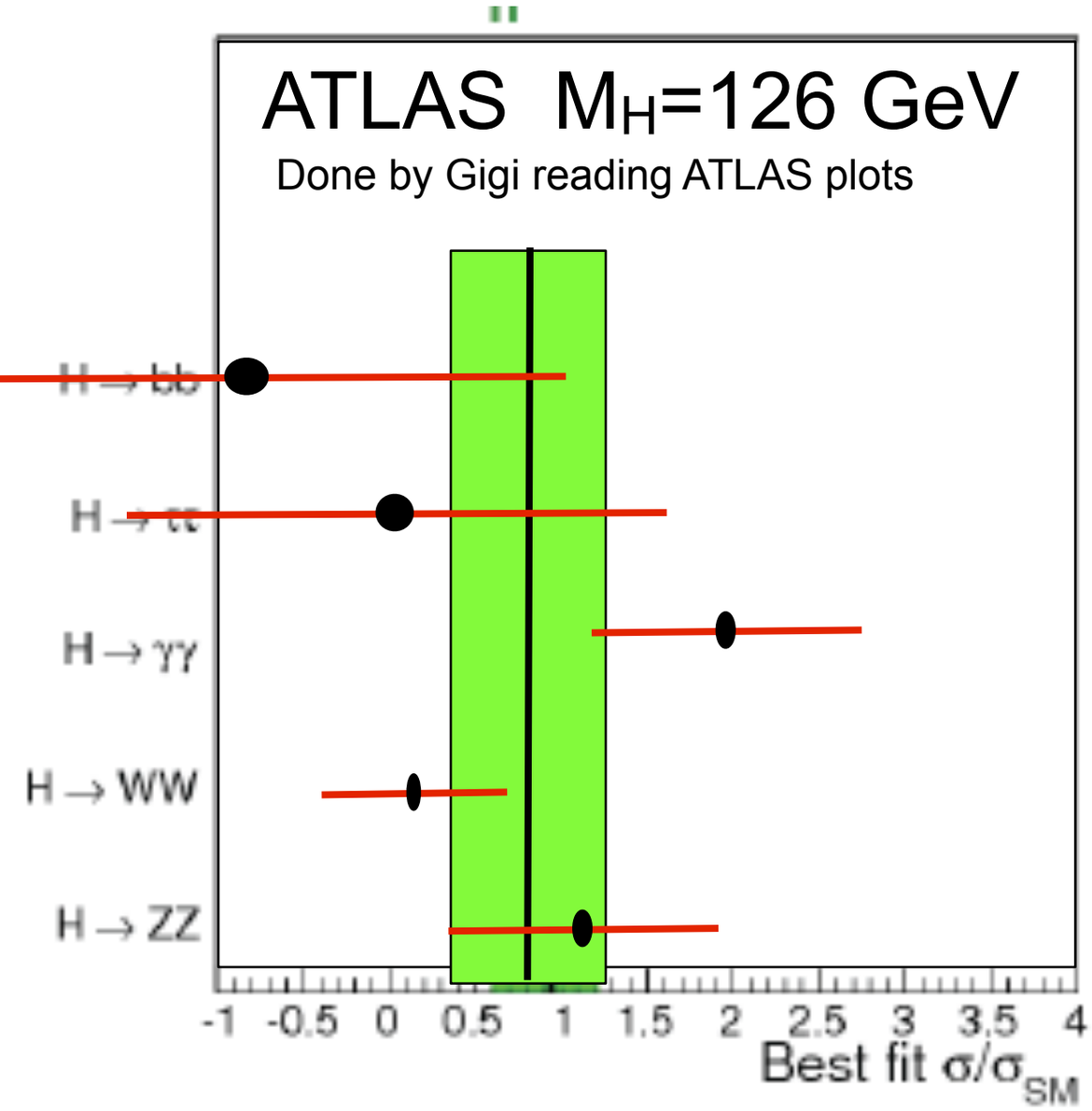


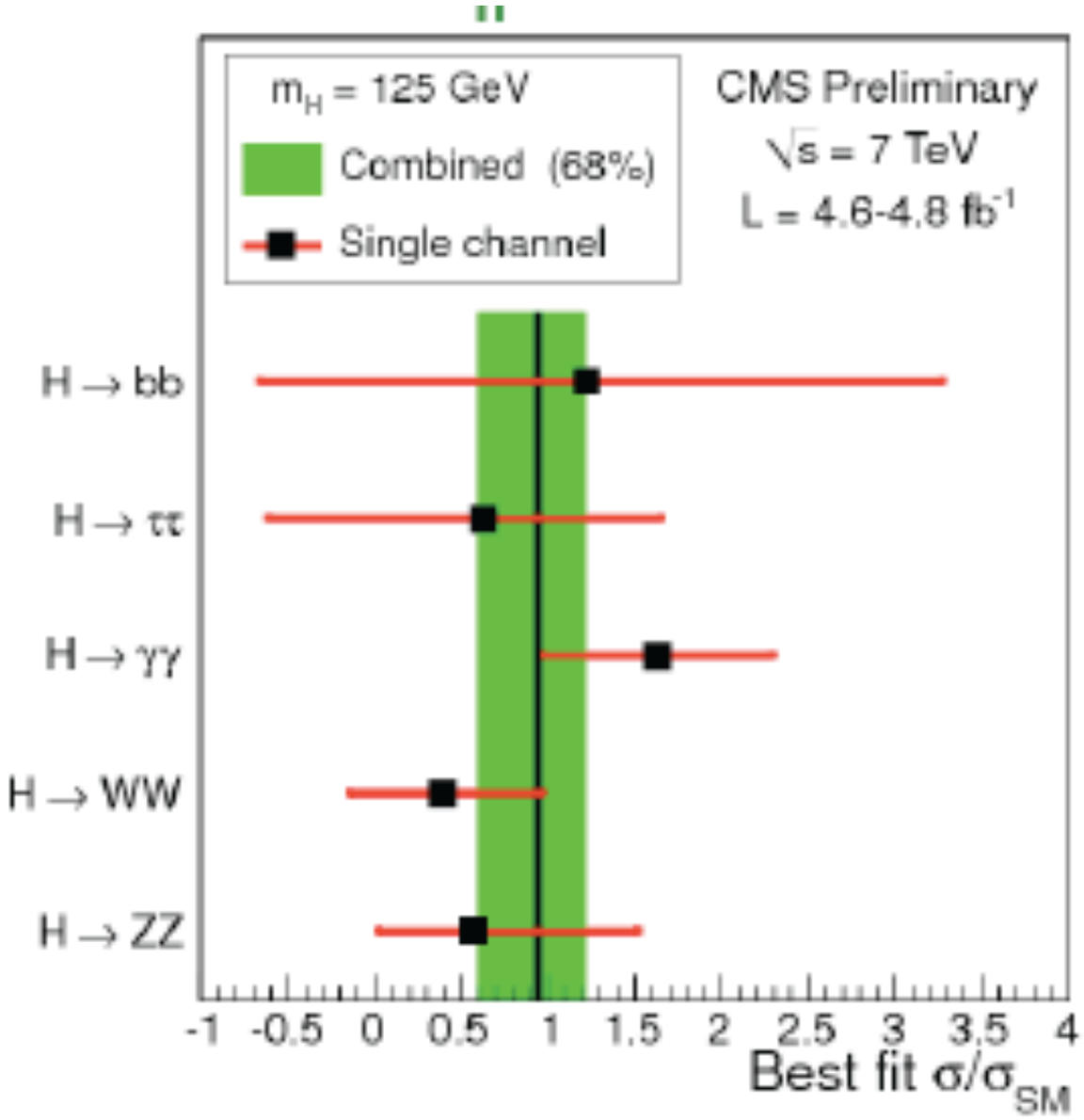
Standard Model
WITH Higgs

Standard Model
WITHOUT Higgs

Again fluctuations in γγ

Compatibility among different channels





Conclusion on LHC

- Tantalizing to see both experiments showing an excess at ~ 125 GeV.
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  - However WW , that has equal sensitivity, does not “confirm” the excess and is low in both experiments.

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  - The probability to see an excess anywhere at low mass in ATLAS/CMS is ~10%
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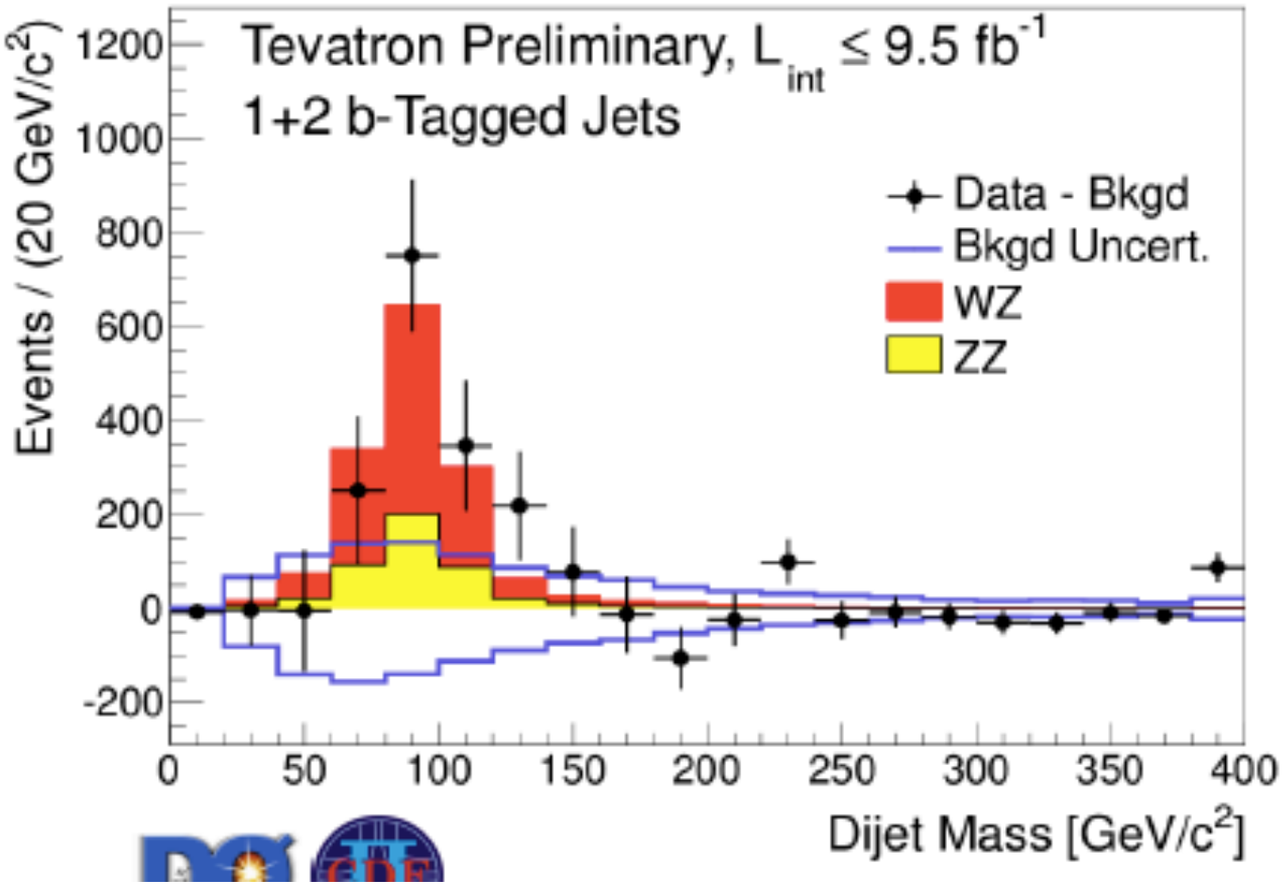
  - But....we see other unphysical fluctuations of the same size in the data in ATLAS and in CMS.
- The other channels are not inconsistent
  - However WW , that has equal sensitivity, does not “confirm” the excess and is low in both experiments.
- Some issues also on 4l events, but probably is just “small statistics” effects

Tevatron

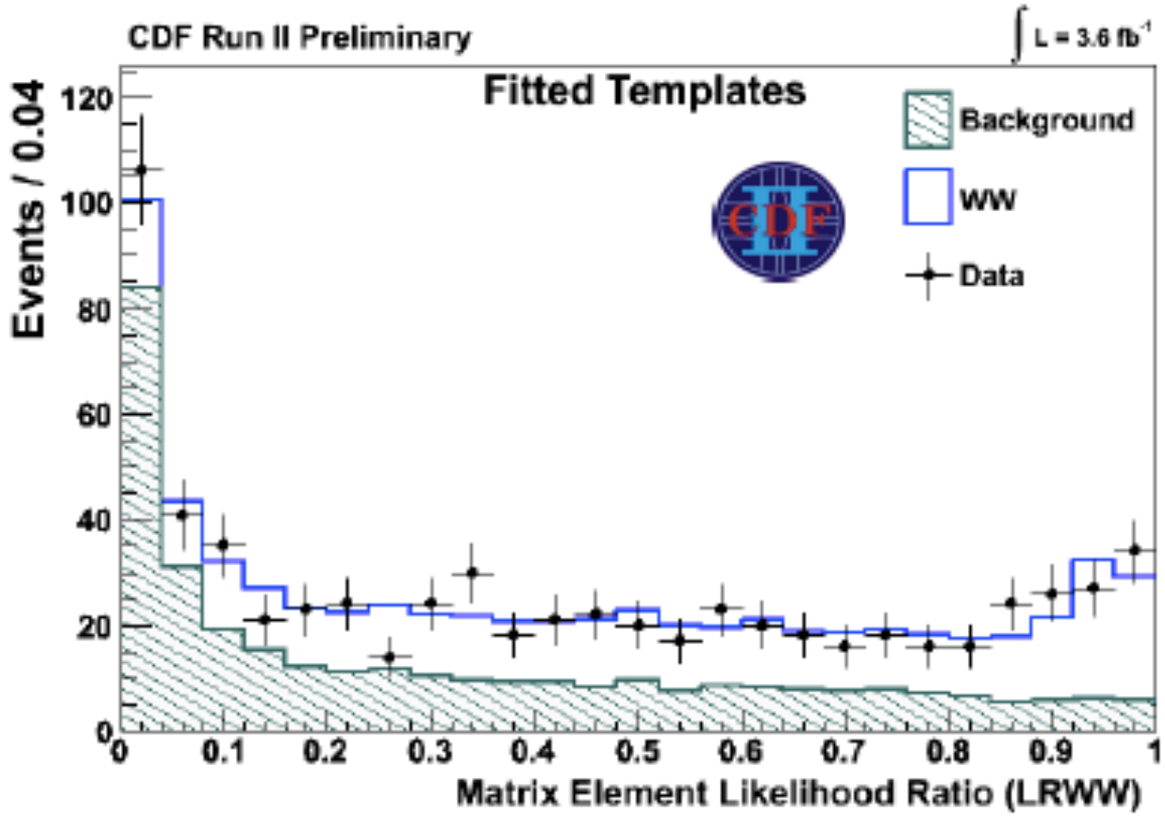
Validation of Higgs Searches

.....using Di-bosons and Z bb decays

$W/Z+Z\to bb$: $\sigma_{obs} = (1.01 \pm 0.21) \times \sigma_{SM}$



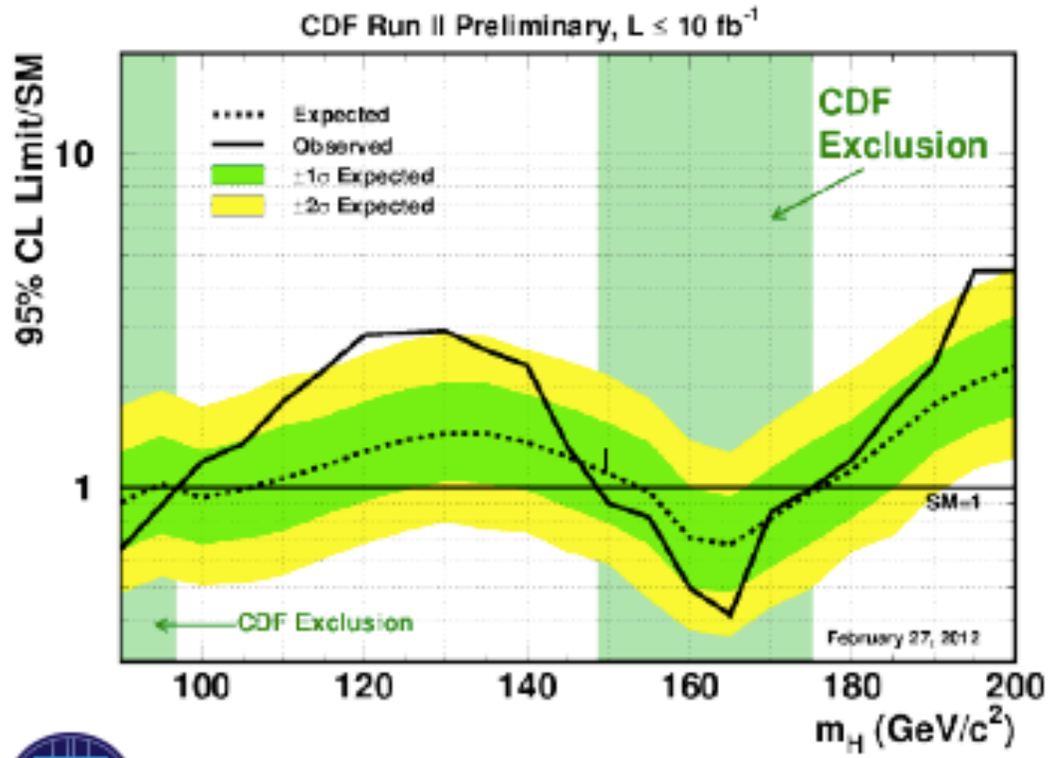
$WW\to l\nu l\nu$: $\sigma_{obs} = (1.07 \pm 0.16) \times \sigma_{SM}$

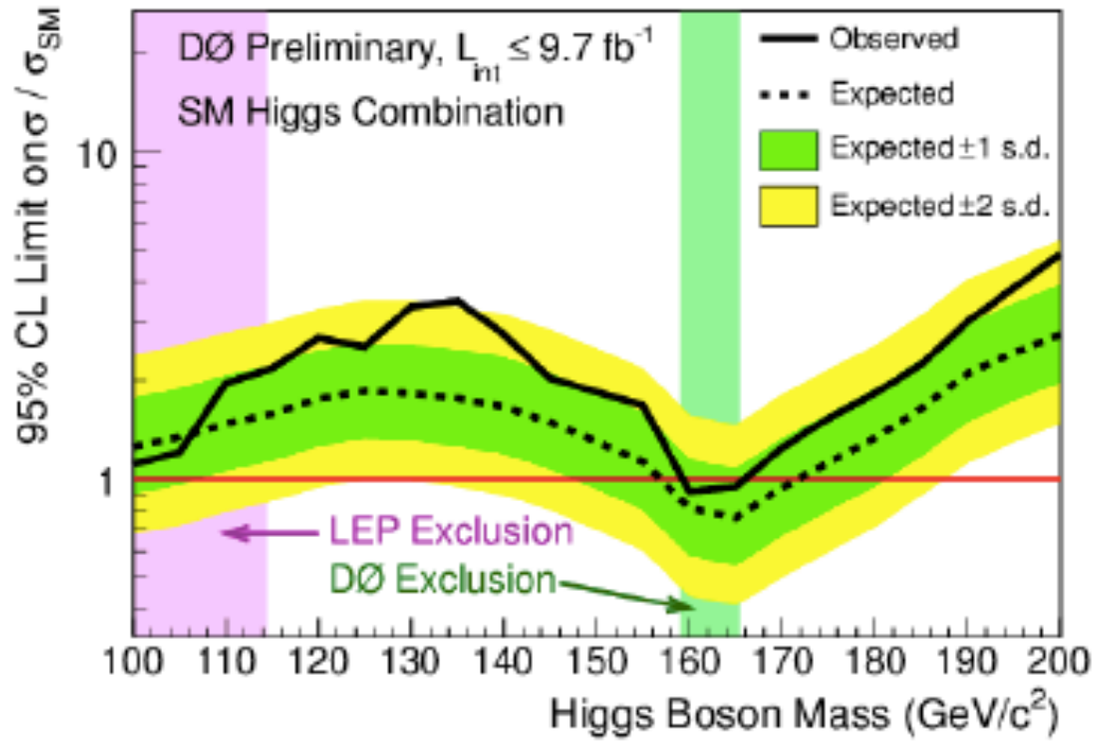


same analysis chain (very complex) as for Higgs searches

... new analyses with improved sensitivity

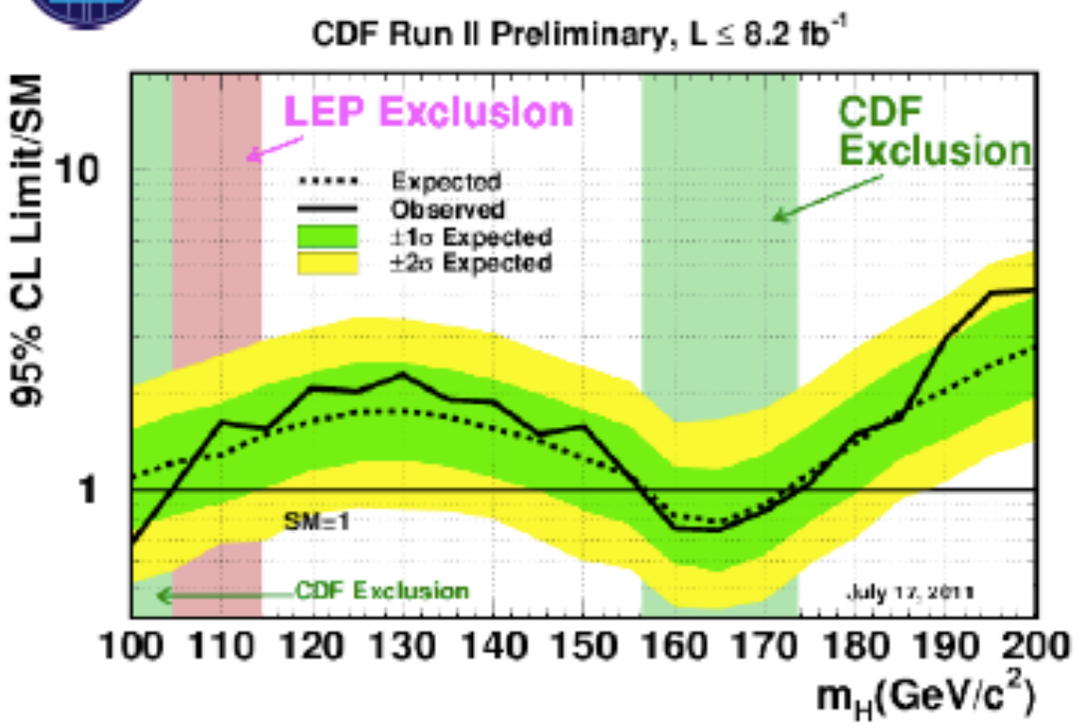
New Tevatron Results

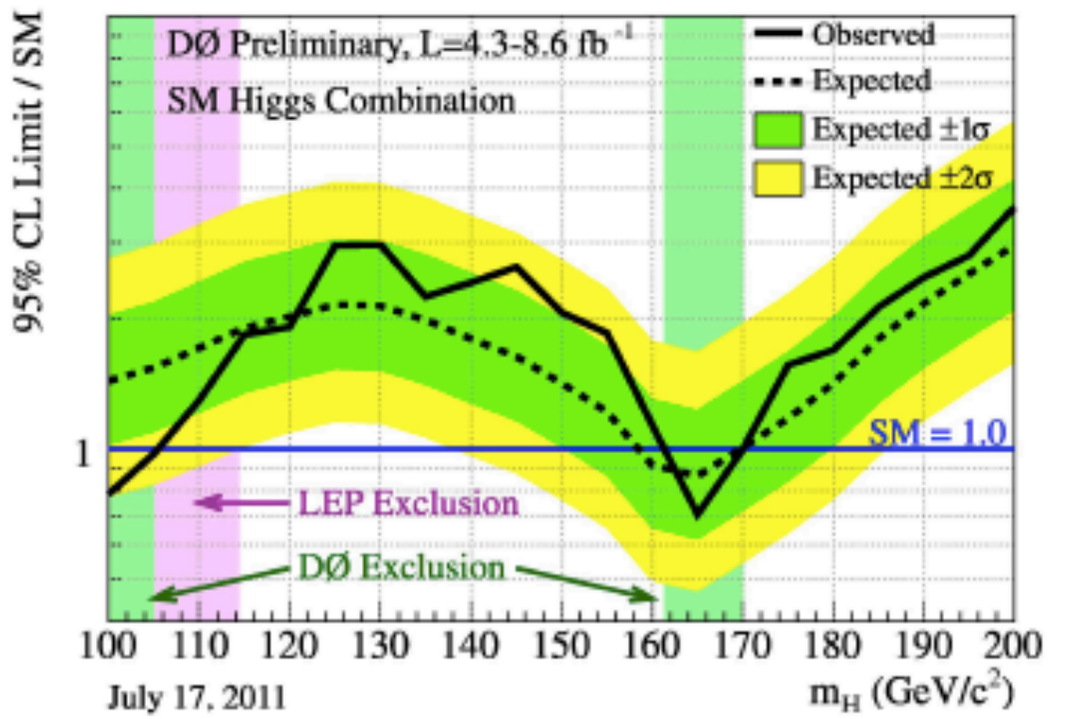




Winter 2012

Summer 2011

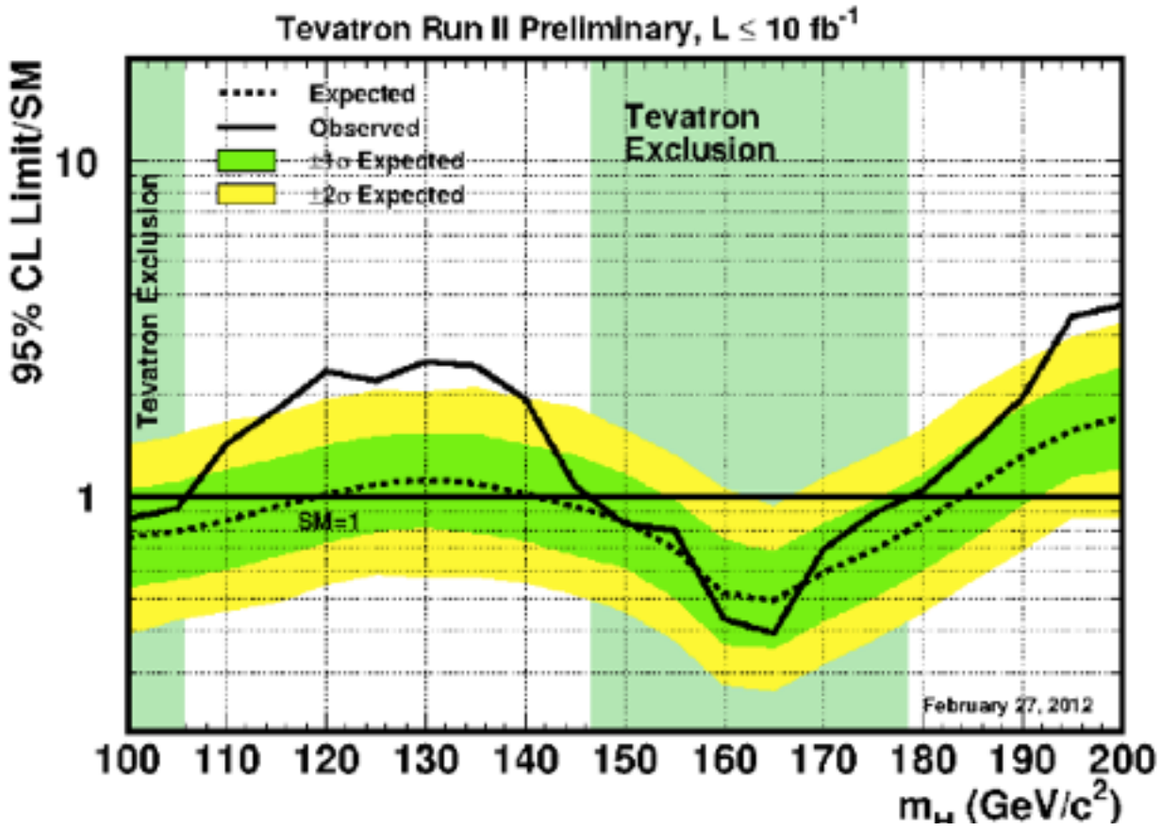




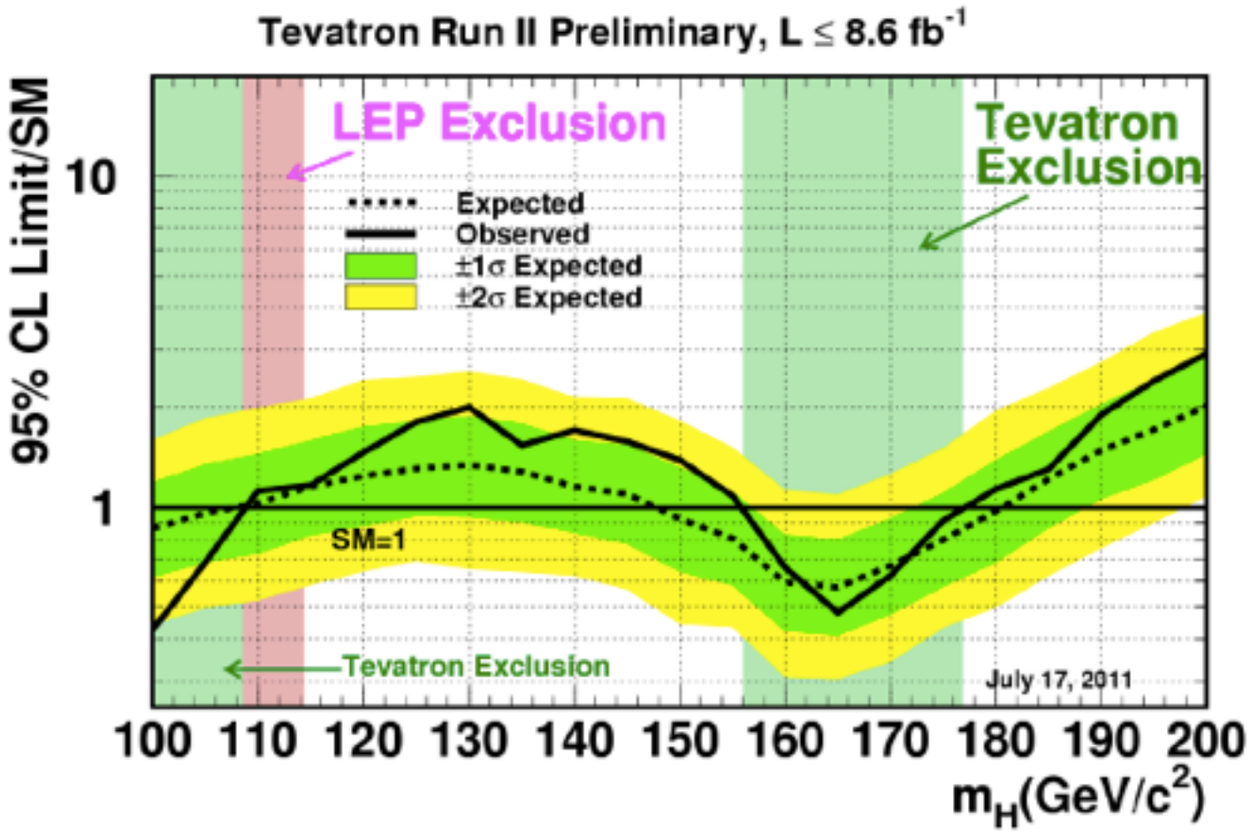
Combined Tevatron

Statistics

+20%

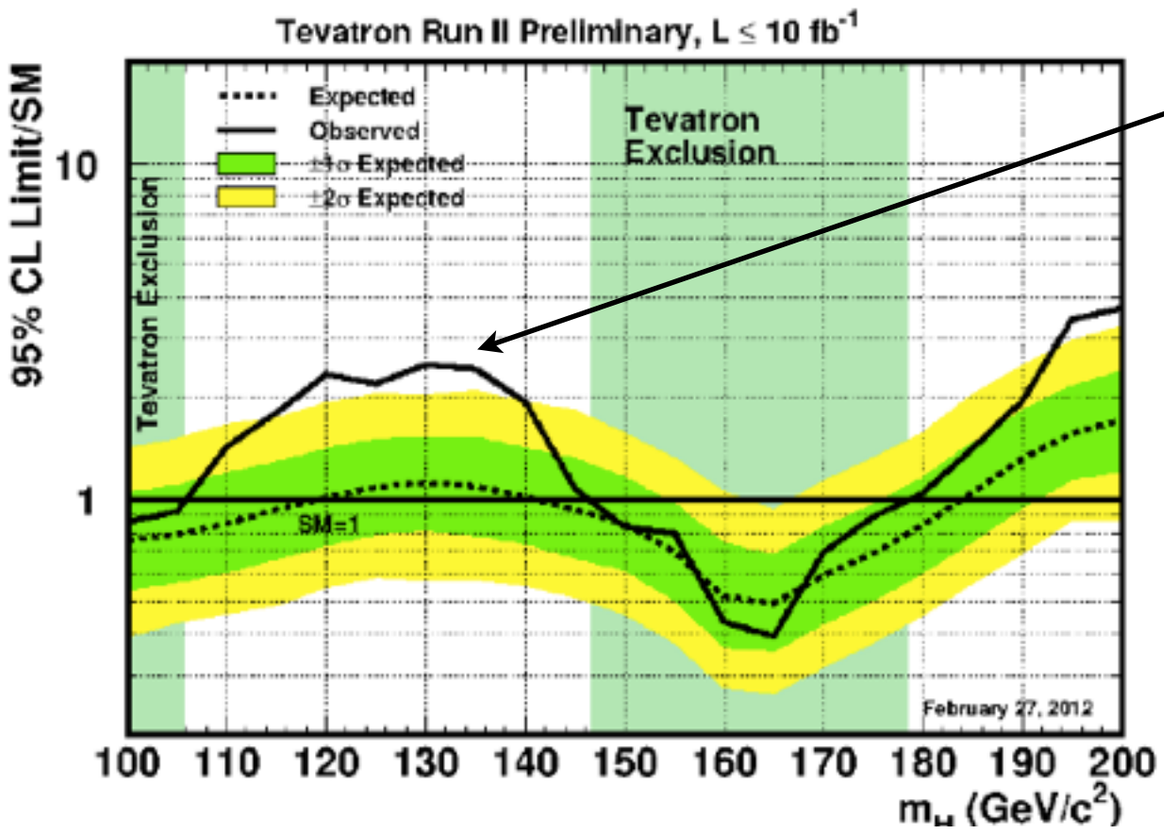


Winter 2012



Summer 2011

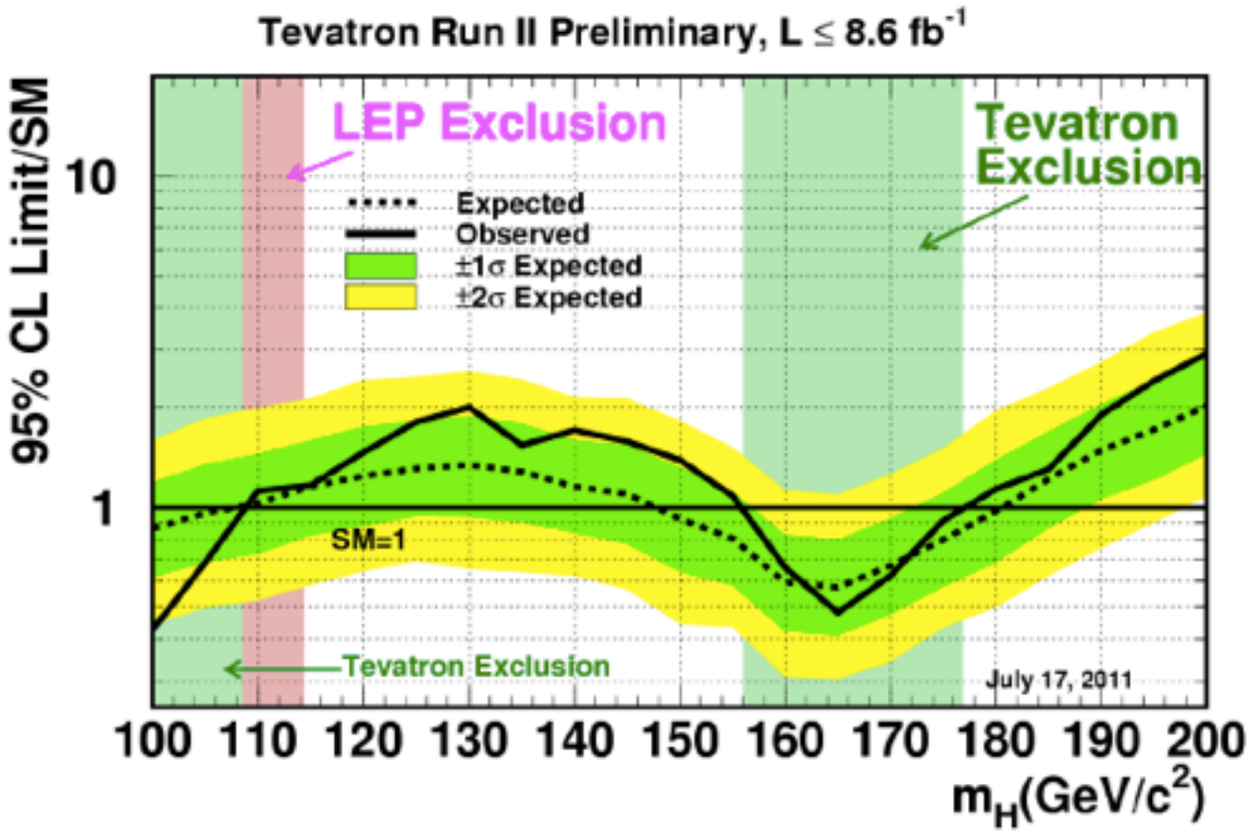
Combined Tevatron



2.2 σ effect once LLE is taken into account

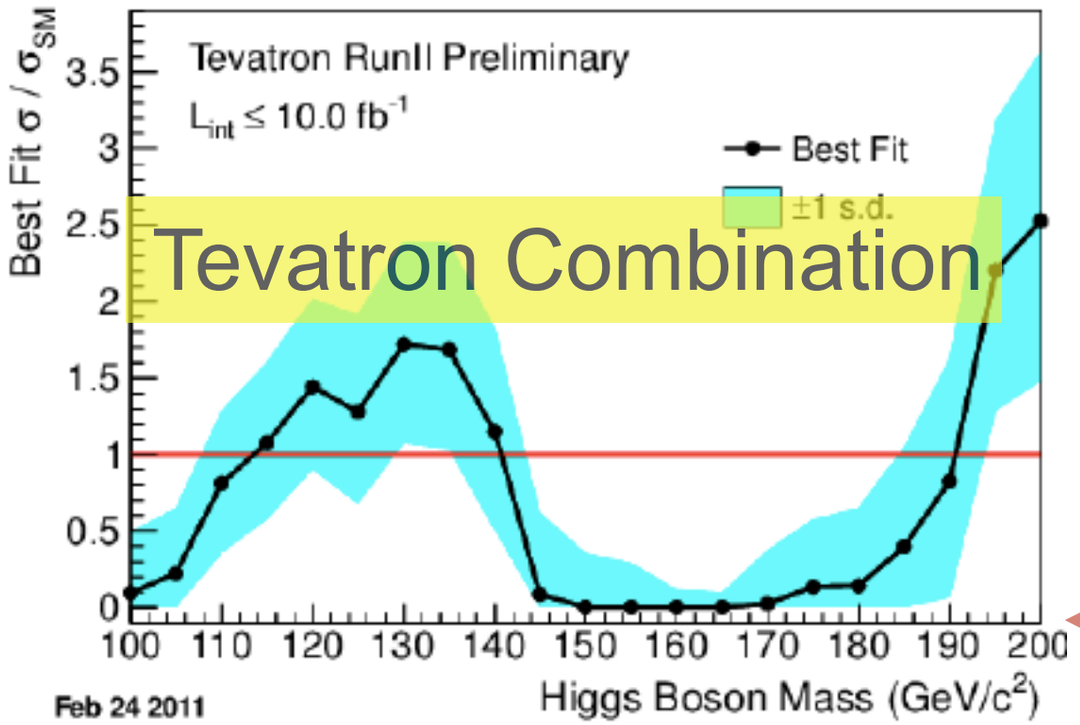
Winter 2012

Statistics +20%



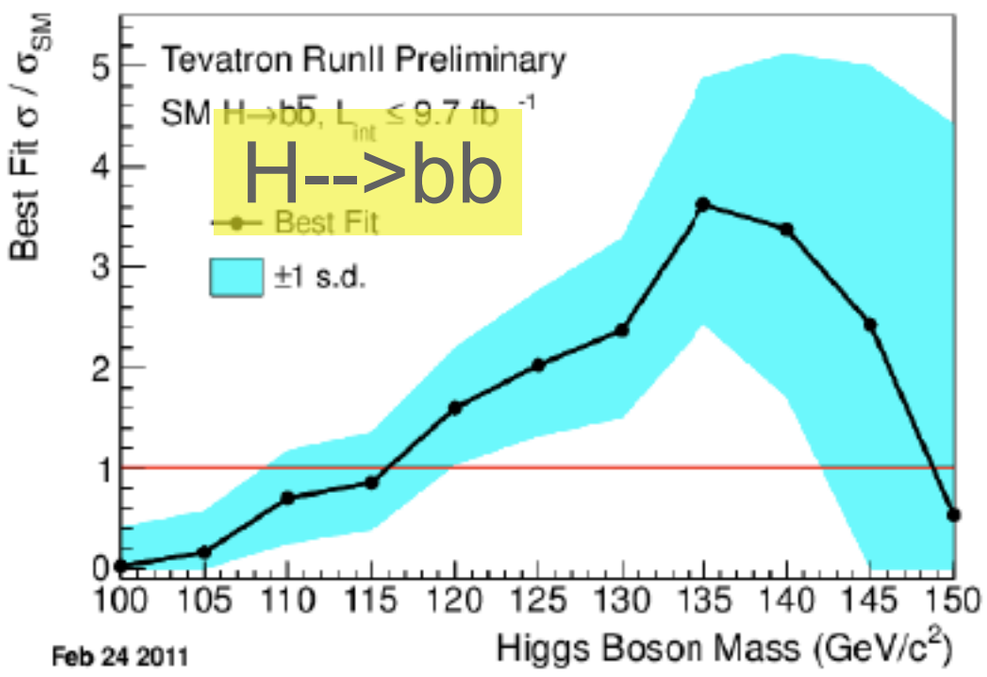
Summer 2011

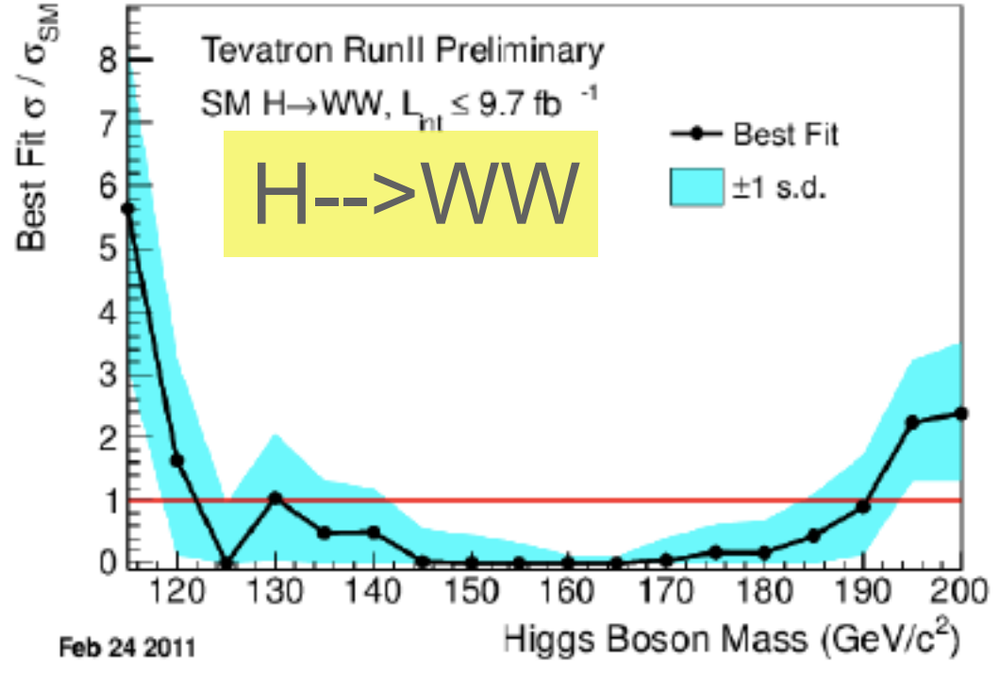
SM compatibility



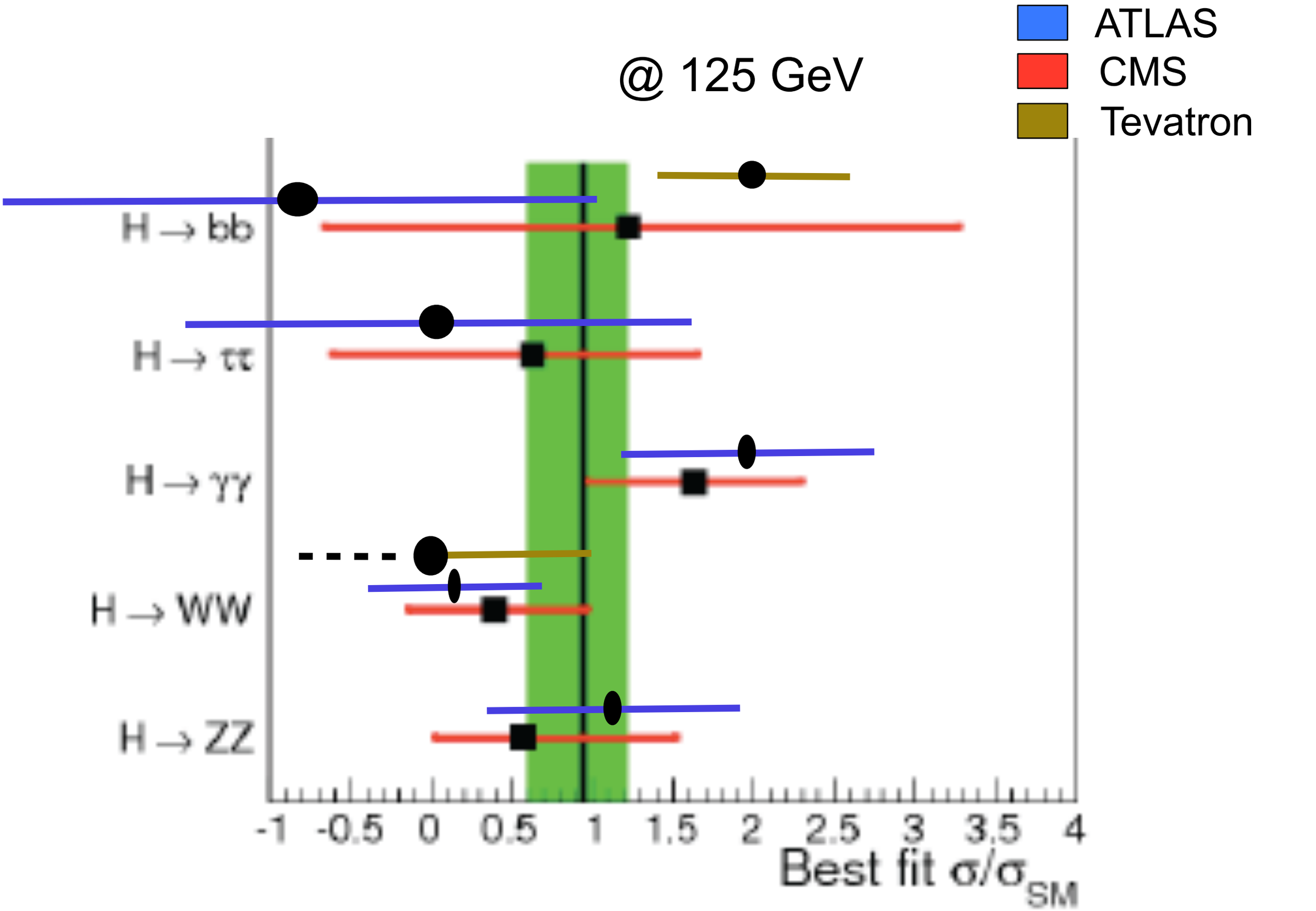
Compatibility with SM:
(1.6 ± 0.6) * SM @ 130
(1.4 ± 0.6) * SM @ 125

Not sure if in their case the fit can go negative





Compatibility among different channels



LHC will start again to take data at $\sqrt{s}$= 8 TeV in ~ one month. Aiming to collect x 4 the present integrated luminosity

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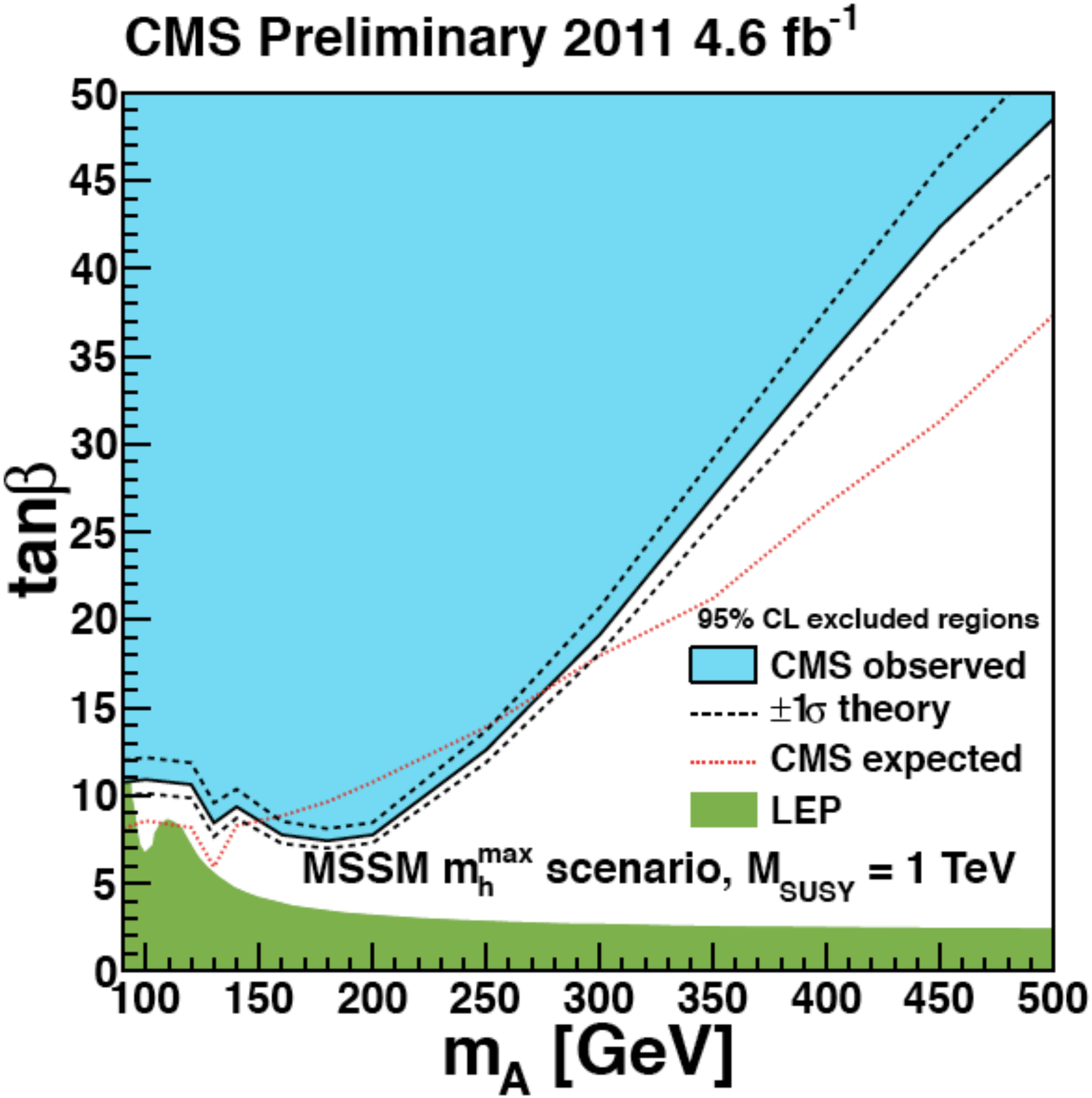
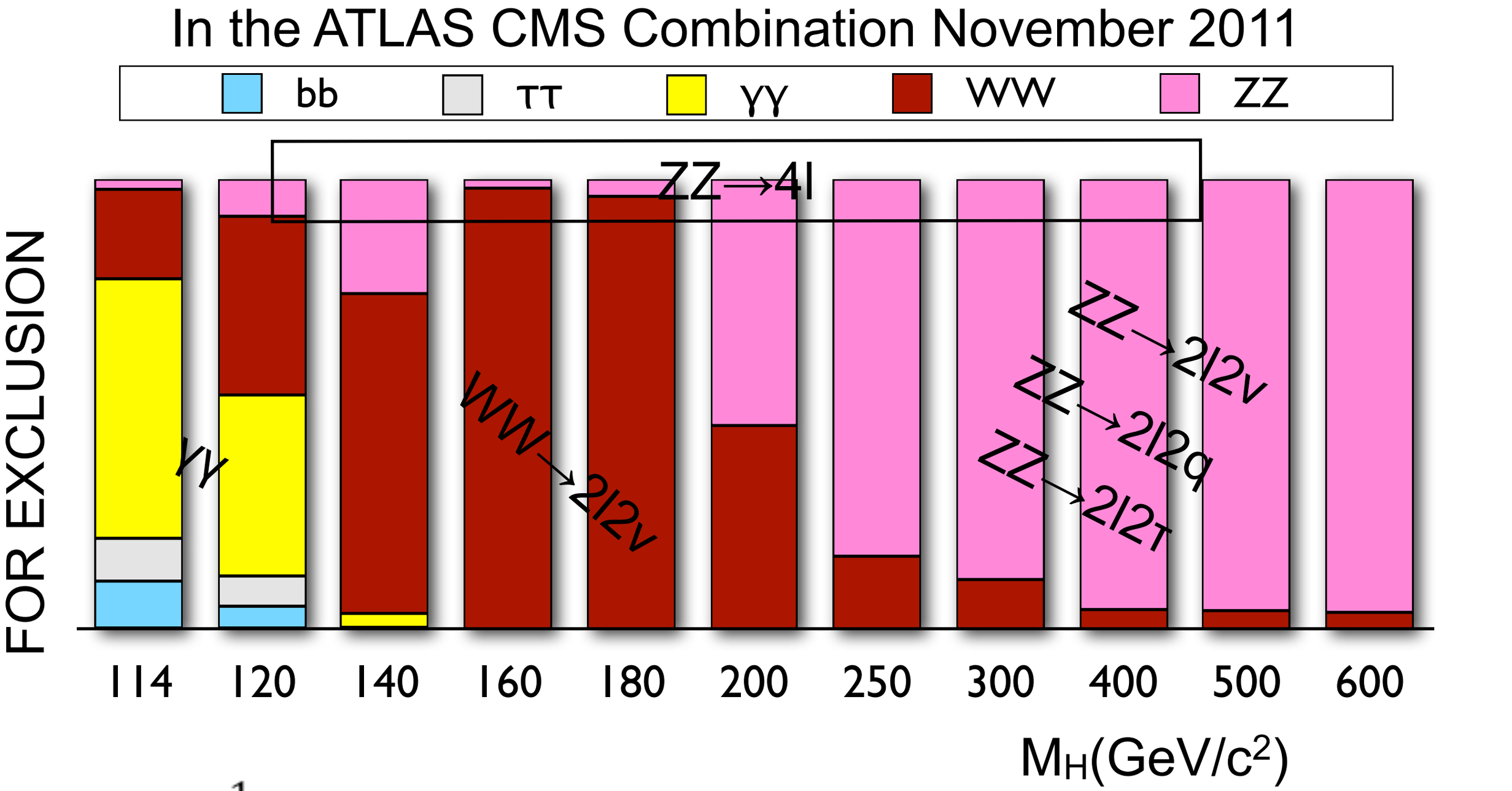
Thank You !

Tau Tau channel in MSSM



Weight of the individual channels



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

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