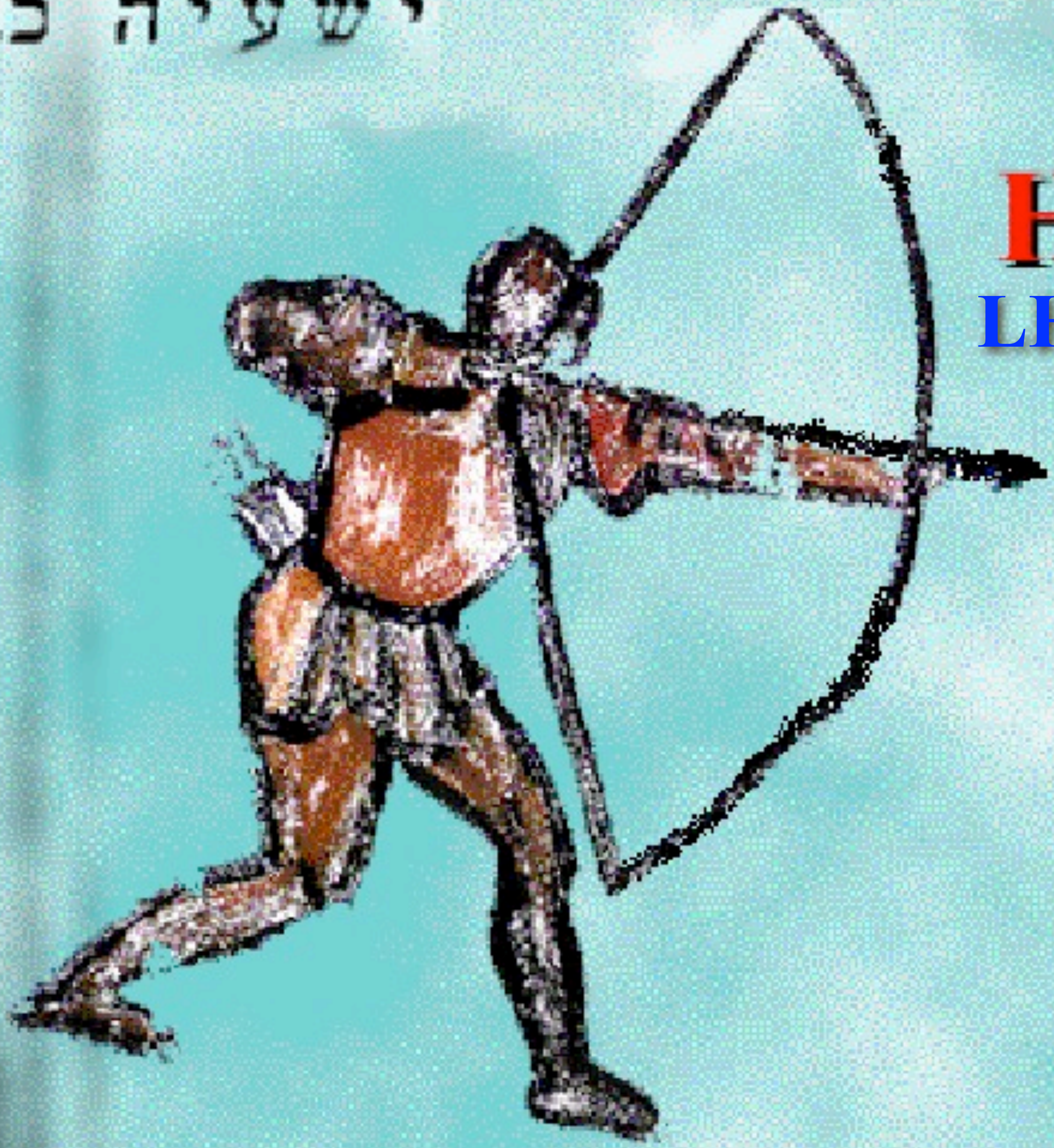
"וְעֵילָם נָשָׂא אַשְׁפָּה..."

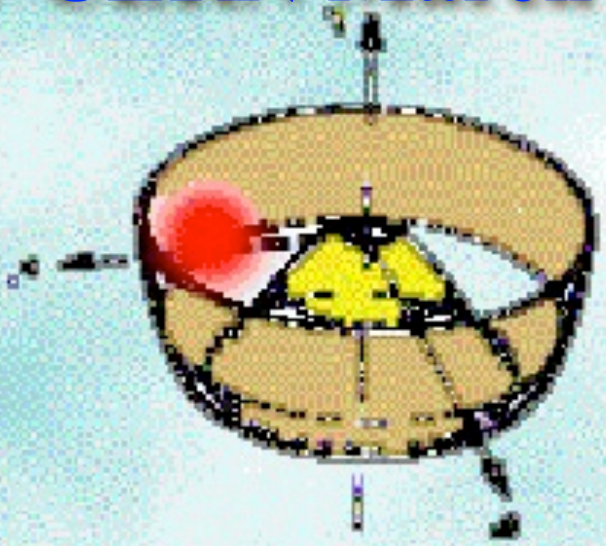
י ש ע י ה כב



Eilam Gross

Hunting the Higgs

LHC2TSP CERN March 2011



Thanks to many people
To name a few:
M. Kado, O. Silbert

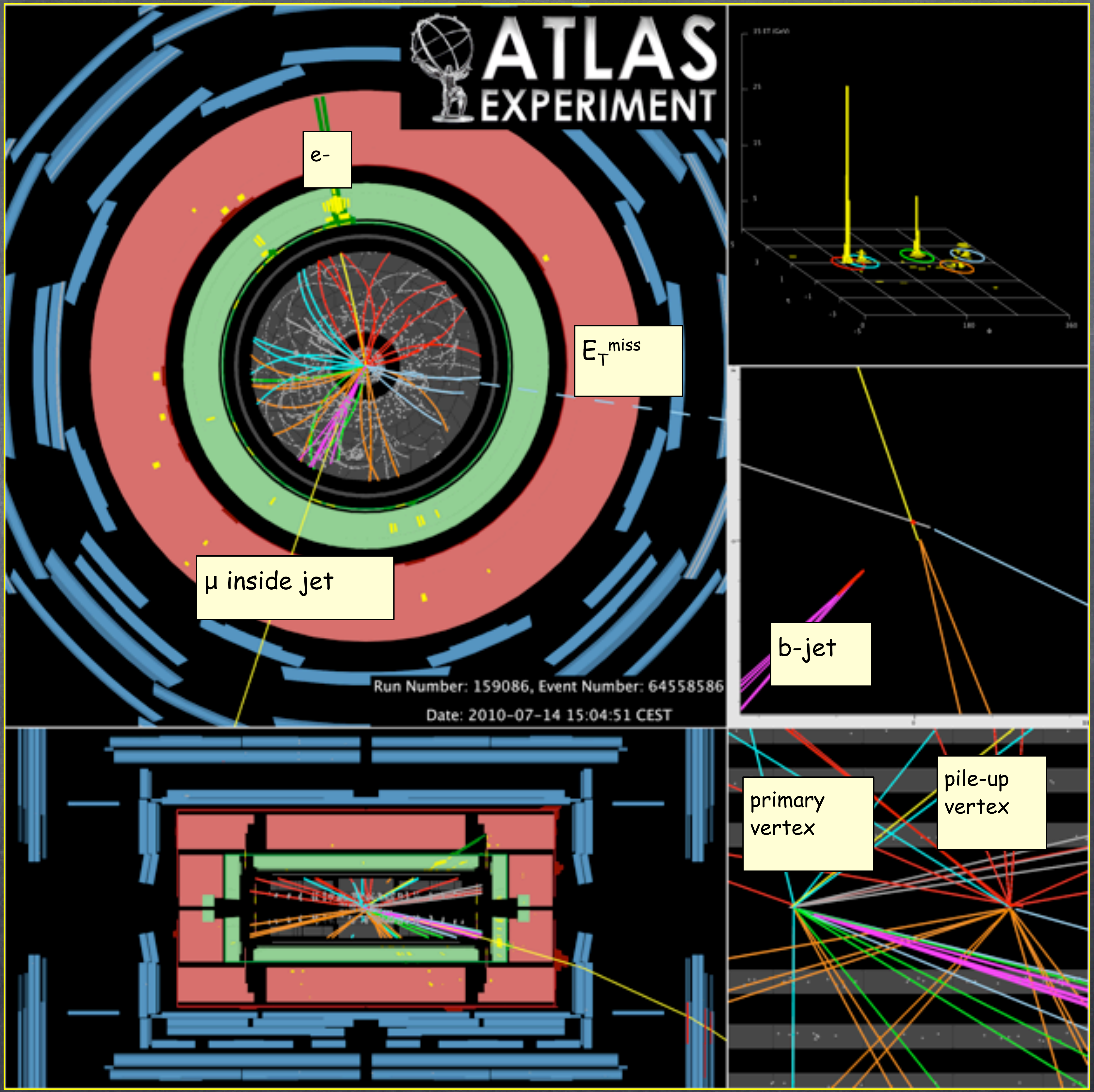
"And Eilam bare the quiver..."

Jesaia 22

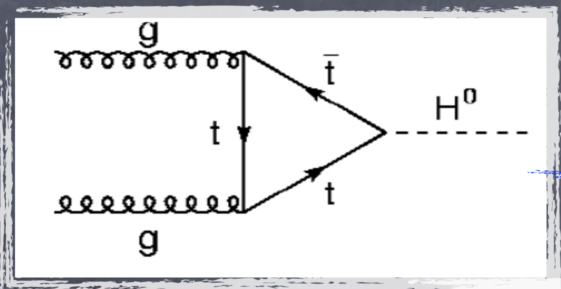

SUX 1

Physics Analysis Objects

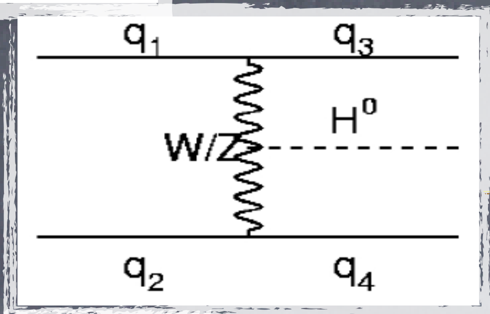
- Higgs searches require detailed understanding of all of the Physics objects:
  - electrons,
  - muons,
  - light-quarks (jets),
  - heavy flavours (charm, bottom-jets),
  - missing energy (E_T^{miss})

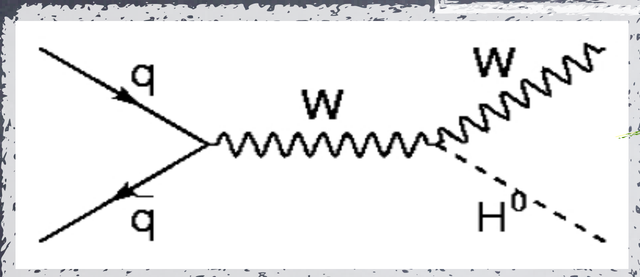


Higgs Production

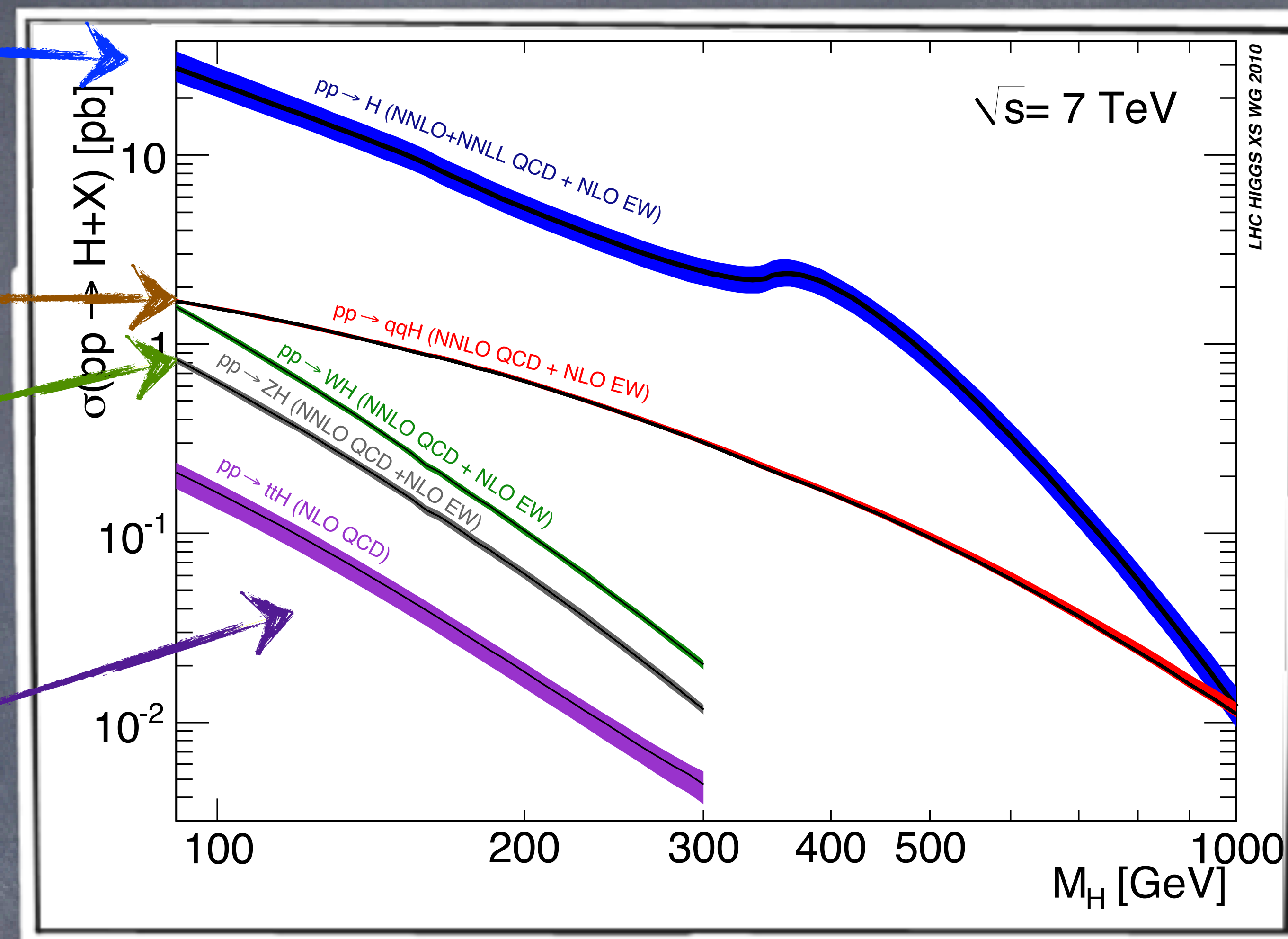


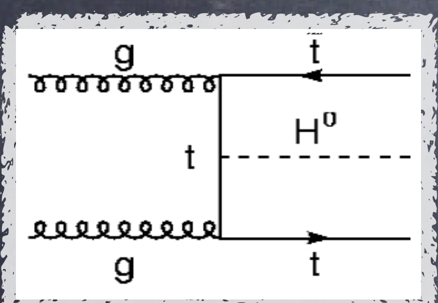
is x10 then





is even smaller, yet distinct



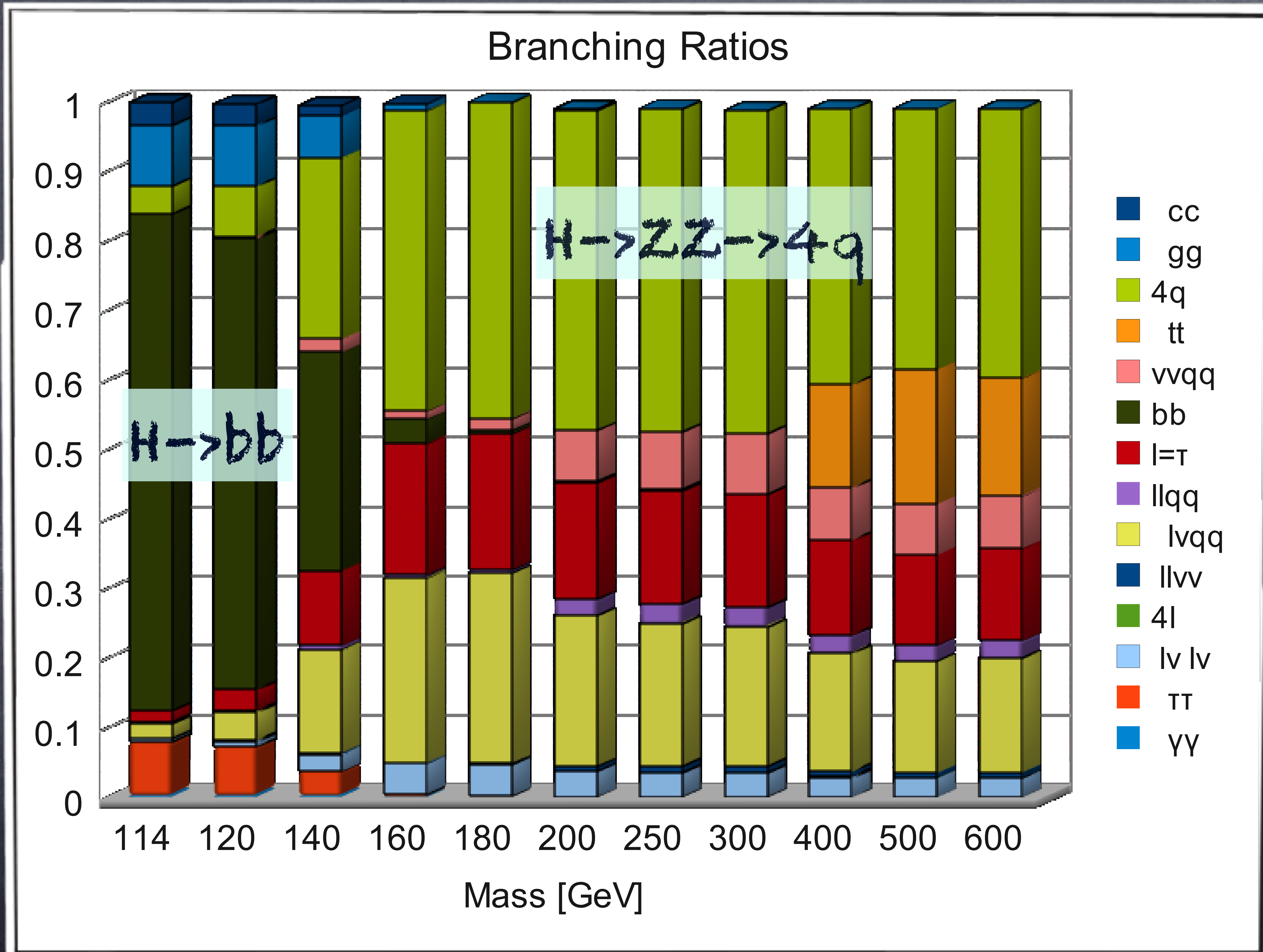


is the smallest and also difficult

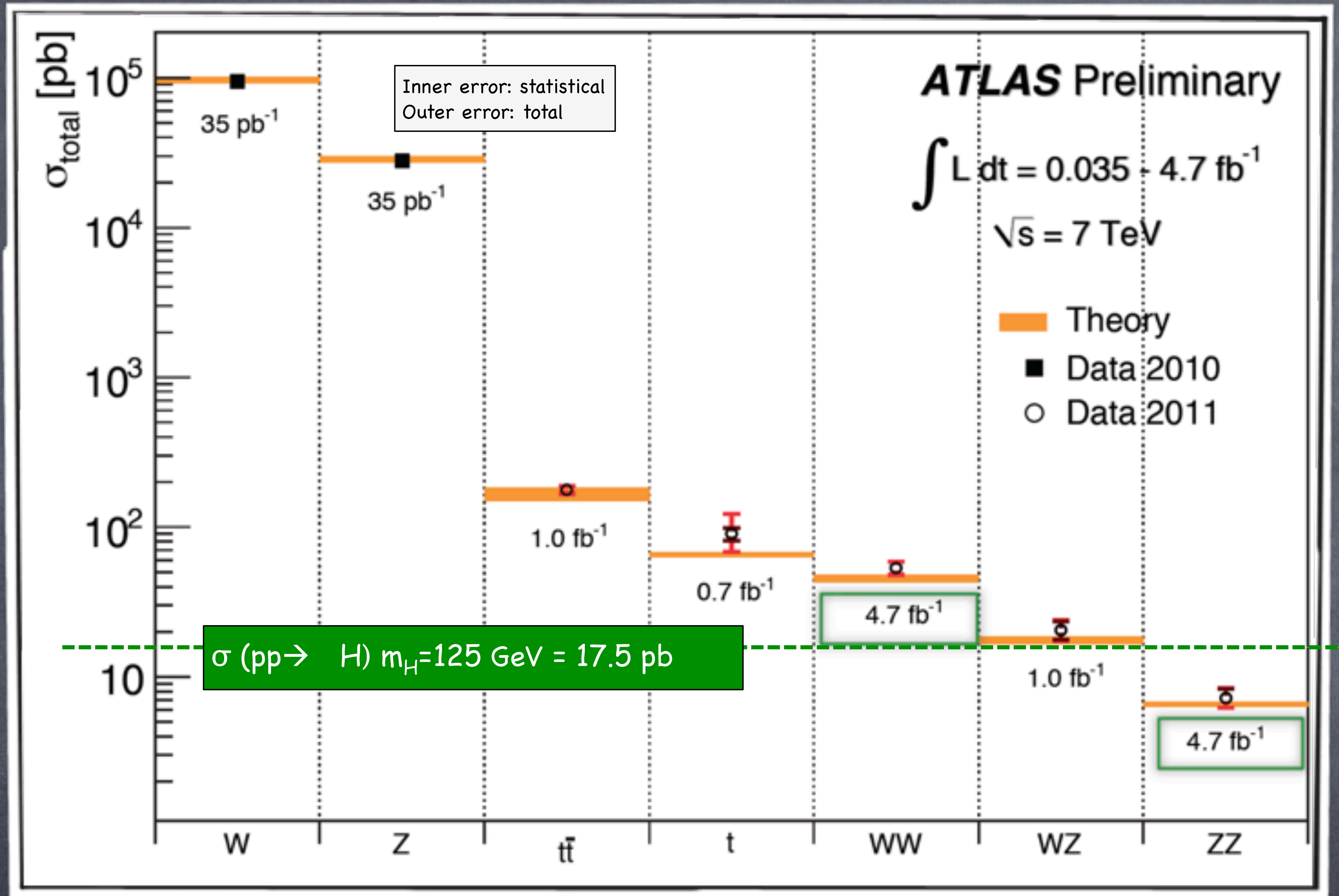
Typical size of uncertaint[illegible] alues depend on M_H):

	ggF	VBF	WH/ZH	$t\bar{t}H$
QCD scale:	$^{+12\%}_{-8\%}$	$\pm1\%$	$\pm1\%$	$^{+3\%}_{-9\%}$
PDF + α_s:	$\pm8\%$	$\pm4\%$	$\pm4\%$	$\pm8\%$
Mass line shape:	$(150\%) \times \left(\frac{M_H}{TeV}\right)^3$			

All Ingredients

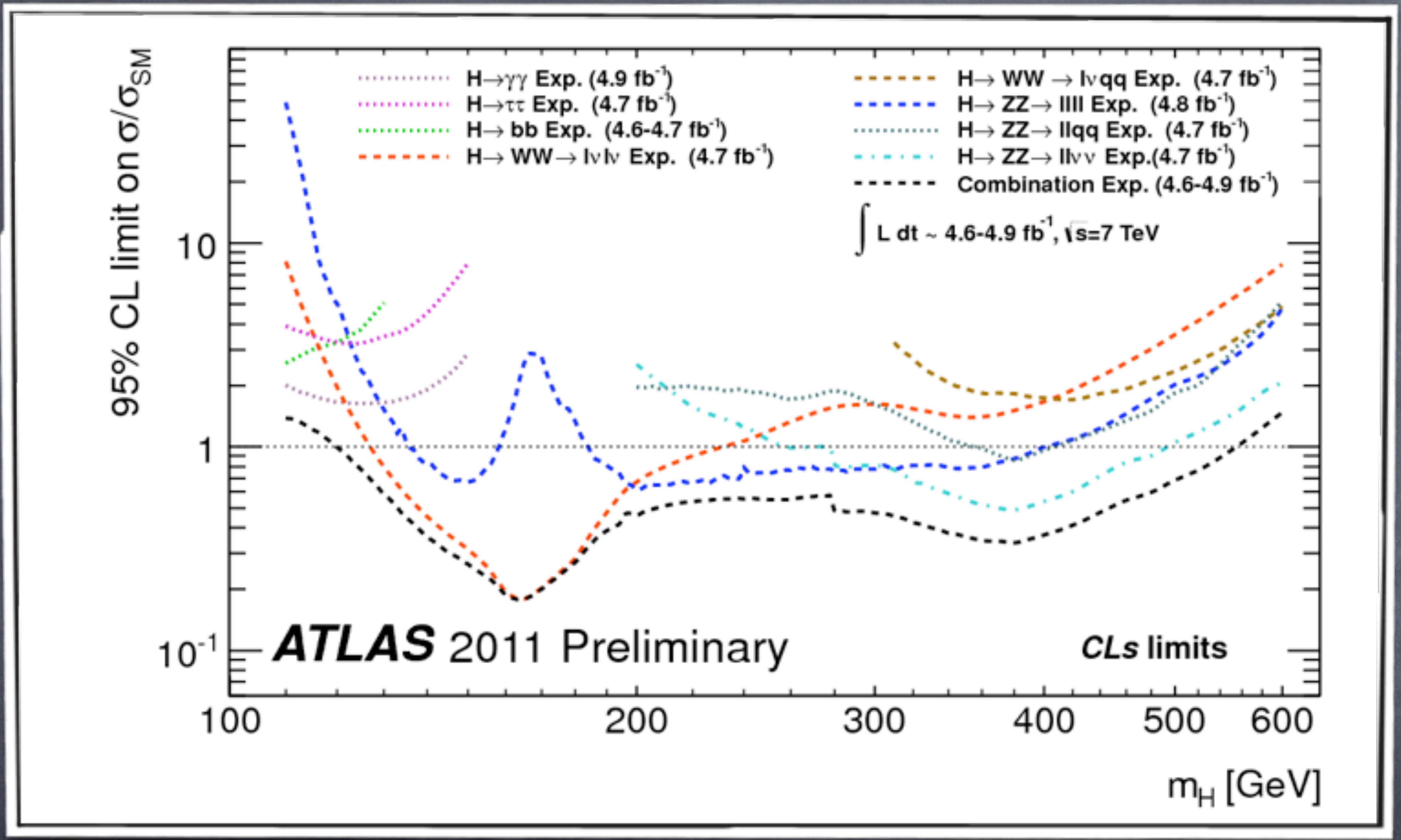


Elecroweak measurements are Higgs backgrounds



- Good agreement with theory , W, Z, tt become a challenge for theory
- Systematics dominate
- Higgs cross section same order of magnitude as Di-Boson production (WW,WZ,ZZ)

Combined Limit



- Low mass is completely dominated by γγ, then bb, ττ and a bit of WW
- High mass completely dominated by llνν

Channels Weight

$$\mu = \frac{\sigma}{\sigma_{SM}}$$

- Asymptotically *Cowan et. al. , EPJC 71 (2011) 1-19.*

$$\mu_{up,\exp,i}(\mathcal{L}_i) \to \mu_{up,\exp,i}(\mathcal{L}_0) = \mu_{up,\exp,i}(\mathcal{L}_i)\sqrt{\frac{\mathcal{L}_i}{\mathcal{L}_0}}$$

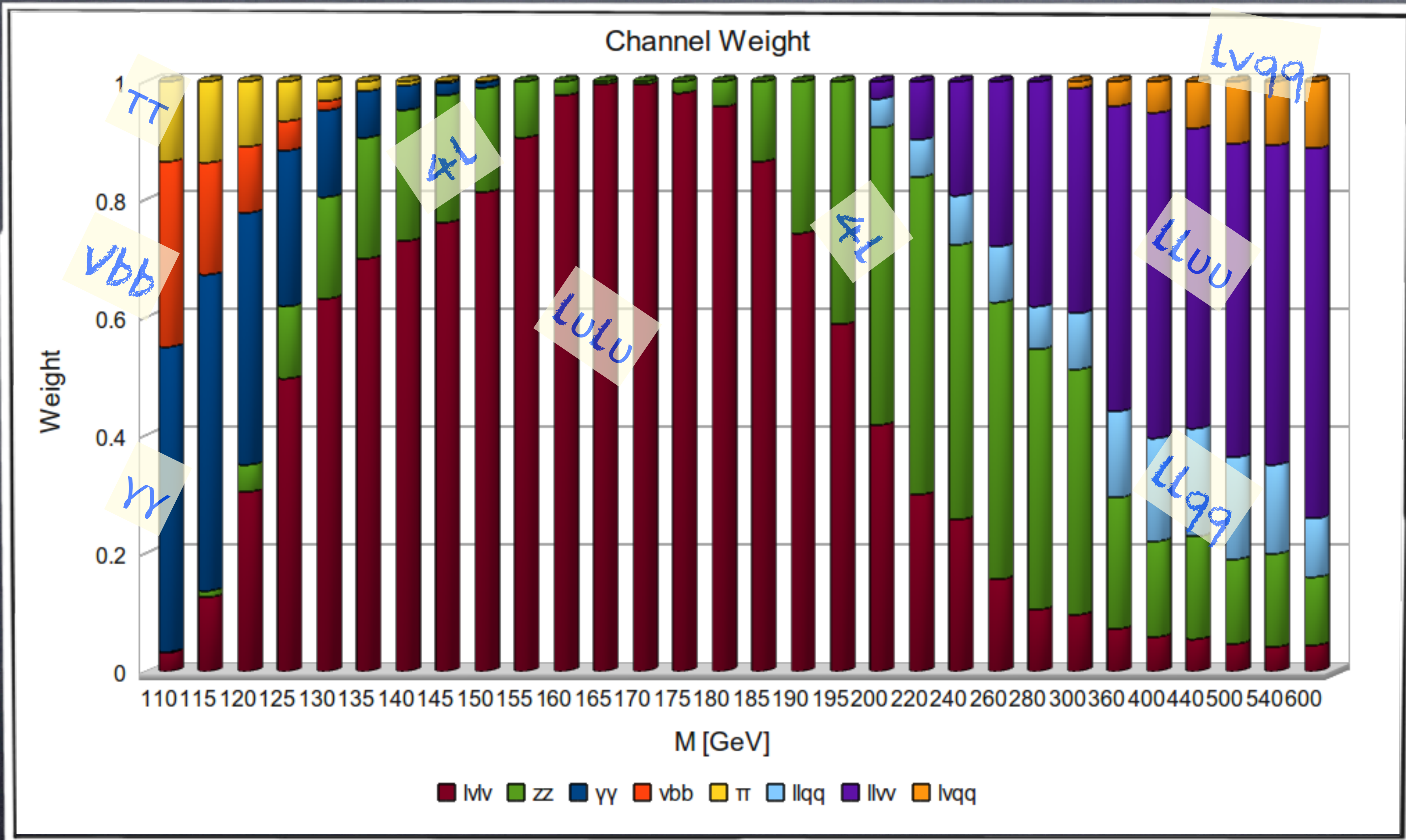
Luminosity normalized:

$$\mathrm{w}_i = \left(\frac{\mu_{up,\exp,C}}{\mu_{up,\exp,i}}\right)^2 = \left(\frac{\frac{1}{\mu_{up,\exp,i}}}{\sqrt{\sum\left(\frac{1}{\mu_{up,\exp,i}}\right)^2}}\right)^2 \to \frac{\left(s_i/\sqrt{s_i+b_i}\right)^2}{\sum_i\left(s_i/\sqrt{s_i+b_i}\right)^2}$$

If we normalize individual channels to the same luminosity,

the weight, w_i is independent of the luminosity

Channels Weight



A nano statistical interlude I

Understanding The Yellow and Green Bands

Exclusion: Profile Likelihood "vs" CLs

$$\mu = \frac{\sigma}{\sigma_{SM}(m_H)}$$

->CLs measures the compatibility of the data with the signal hypothesis.

->If CLs<5% the signal hypothesis is excluded at the 95% CL

->μ_{up} is the signal strength for which CLs=5%

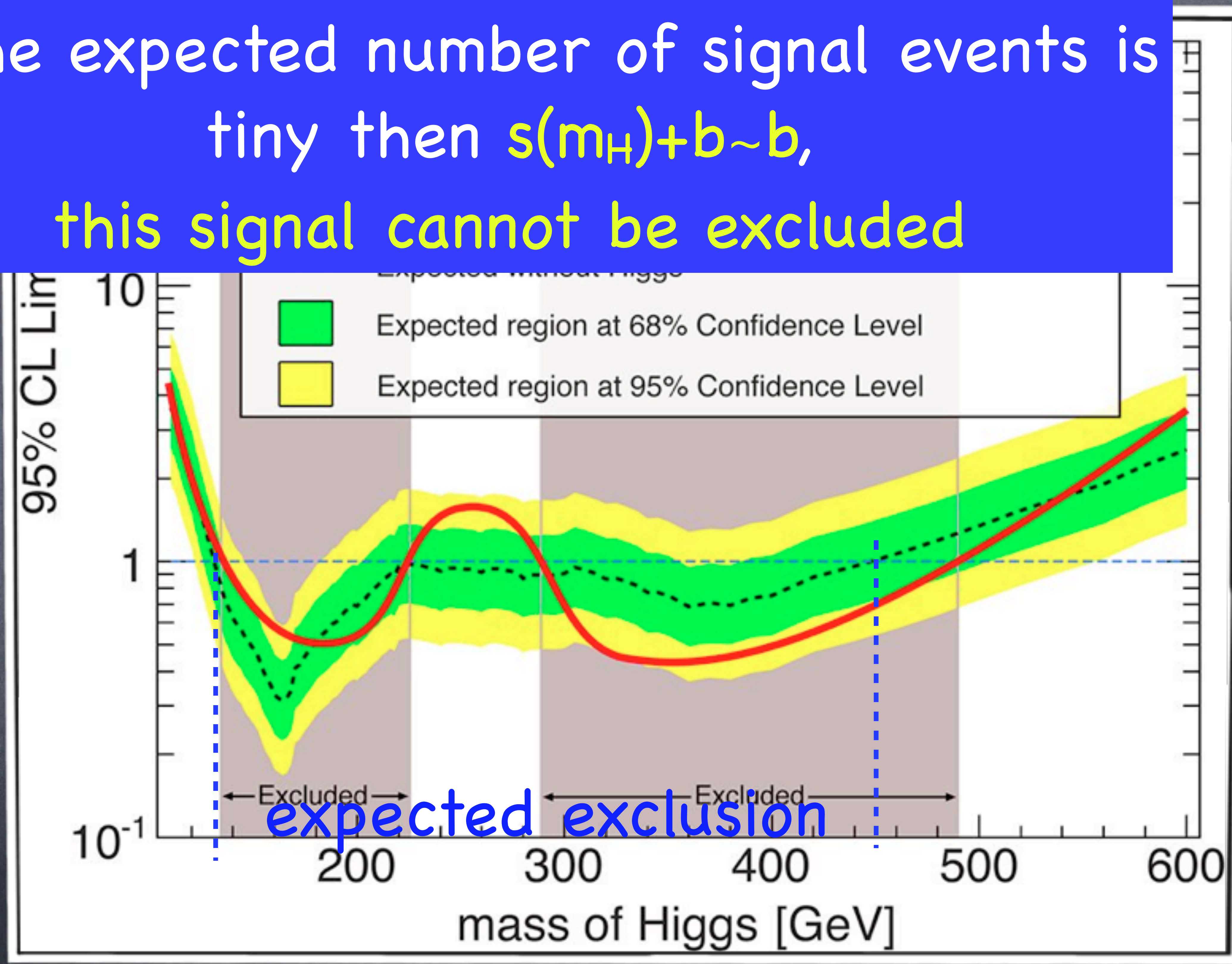
-> If $\mu_{up}<1 \Rightarrow \sigma(m_H)/\sigma_{SM}<1 \Rightarrow \sigma(m_H)<\sigma_{SM}$

$\Rightarrow m_H$ is excluded at the 95% Confidence Level

Understanding The Yellow and Green Bands

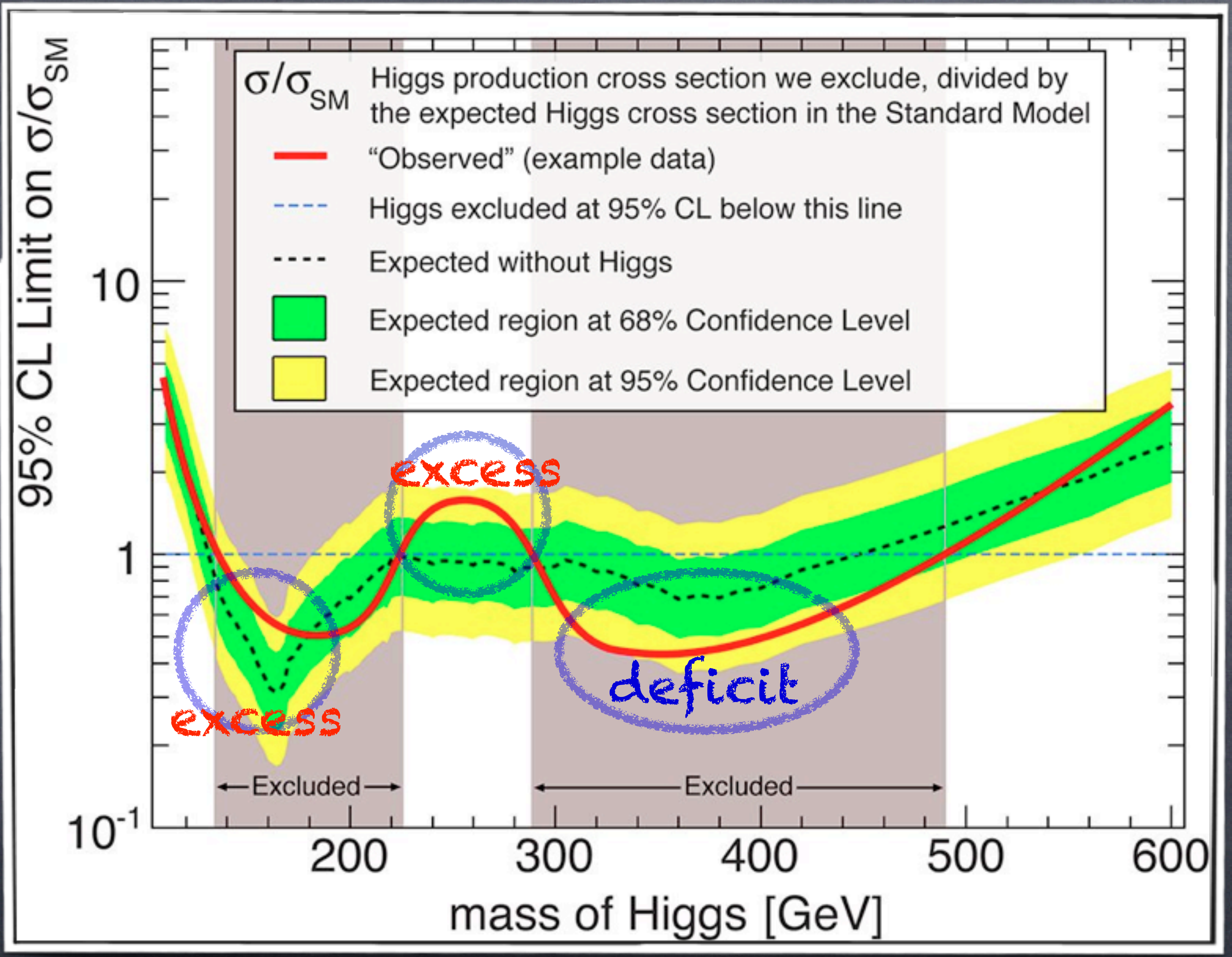
If the expected number of signal events is tiny then $s(m_H)+b \sim b$,
this signal cannot be excluded

$$\mu = \frac{\sigma}{\sigma_{SM}}$$



Understanding The Yellow and Green Bands

$$\mu = \frac{\sigma}{\sigma_{SM}}$$



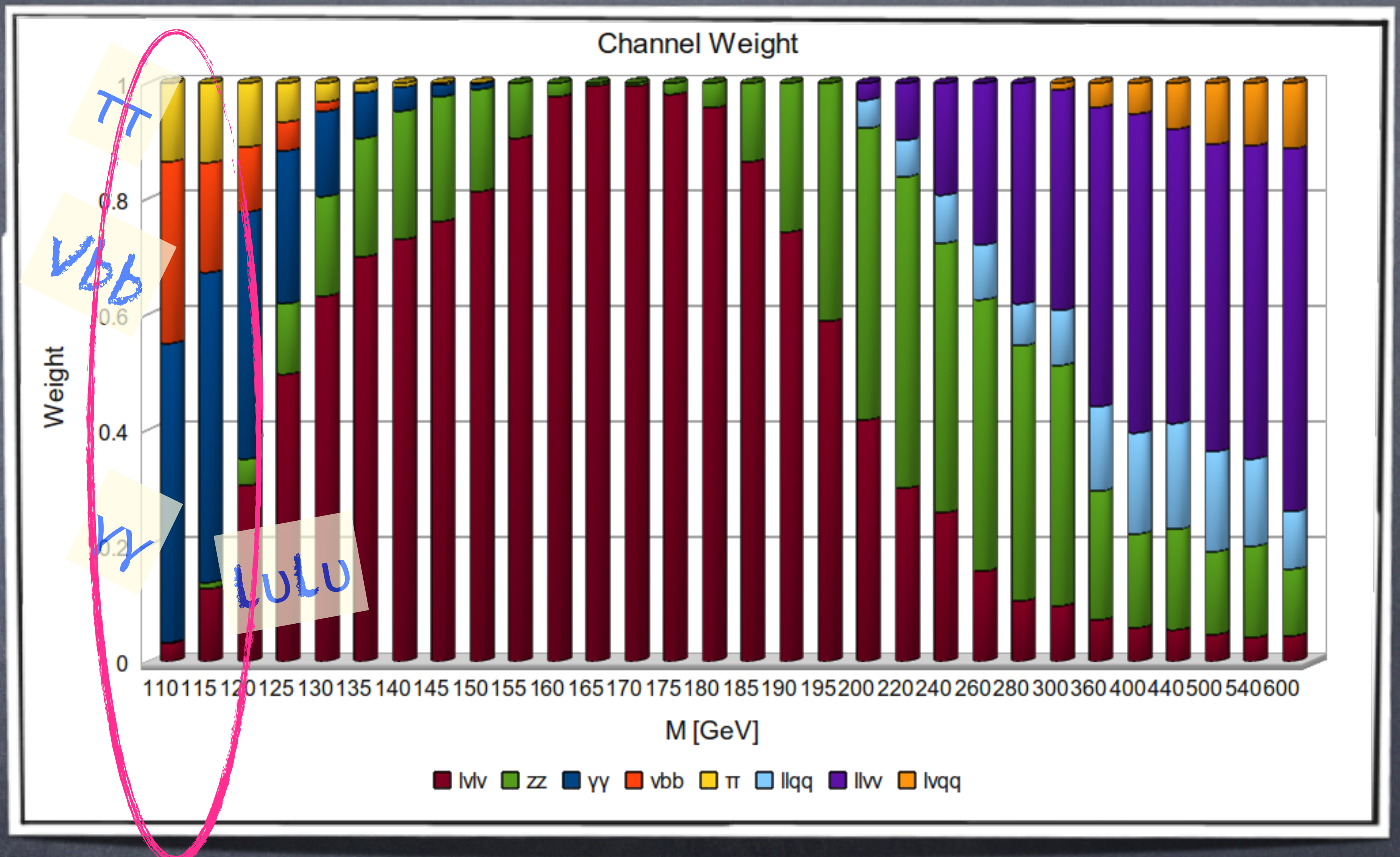
Probing low mass & the LEP Edge

- Probing 114-140 GeV
- Probing channels:

  H->γγ

  VH-> Vbb,

  H-> ττ



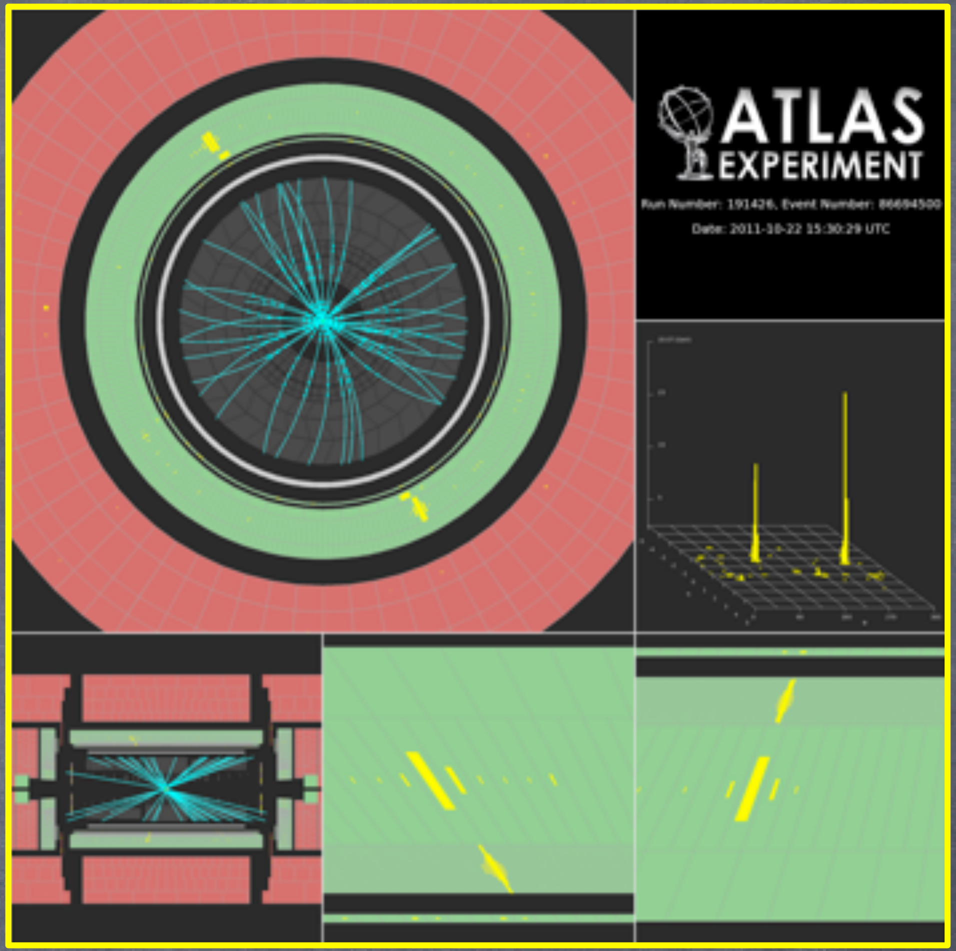
H->γγ Probing LEP 114 GeV

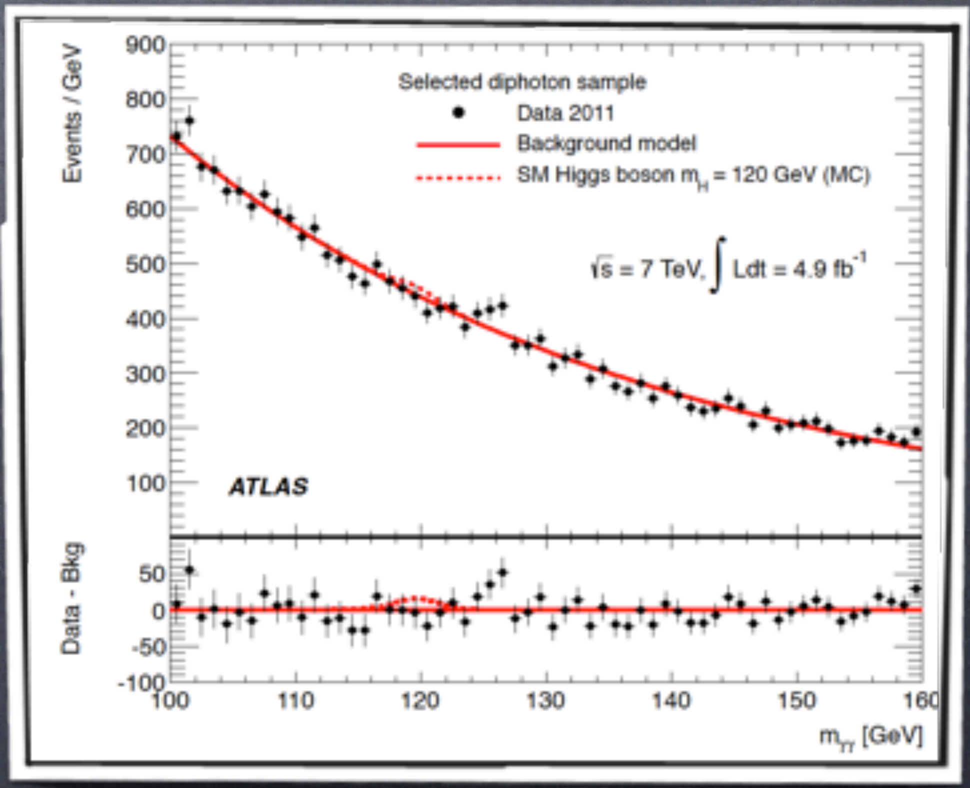
Clean signature: 2 energetic isolated photons->narrow mass peak
E^T (γ1, γ2) > 40, 25 GeV

A narrow peak is searched for over a large, smooth background.

Data are split into 9 categories based on direction of photons (detector region) , conversion mode (which affect γγ mass resolution, which is excellent)
and $p^T_{\gamma\gamma}$ perpendicular to γγ thrust axis

A fit is performed to the background side band under the BG only hypothesis (an exponential in EACH category)
(only data is considered)

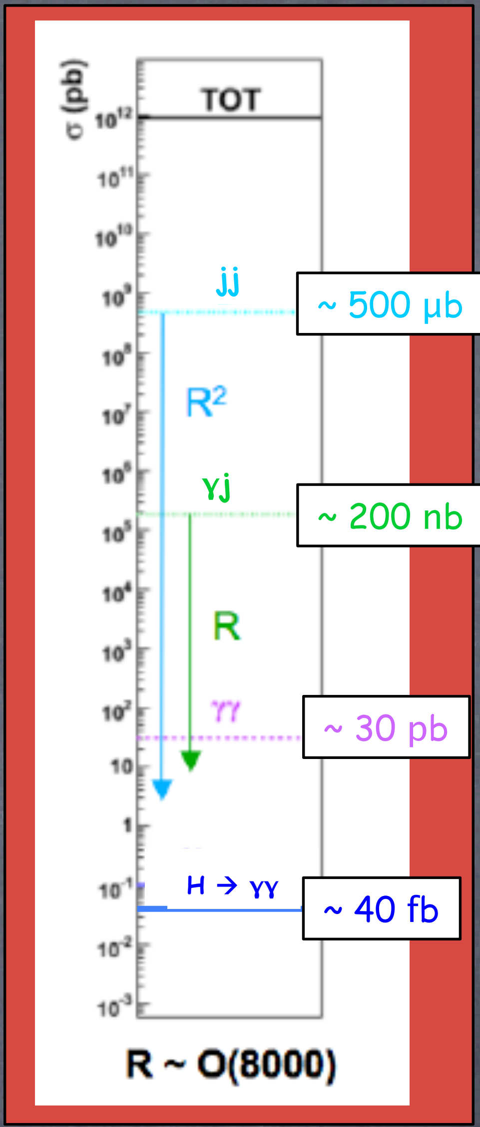




H->γγ Resolution

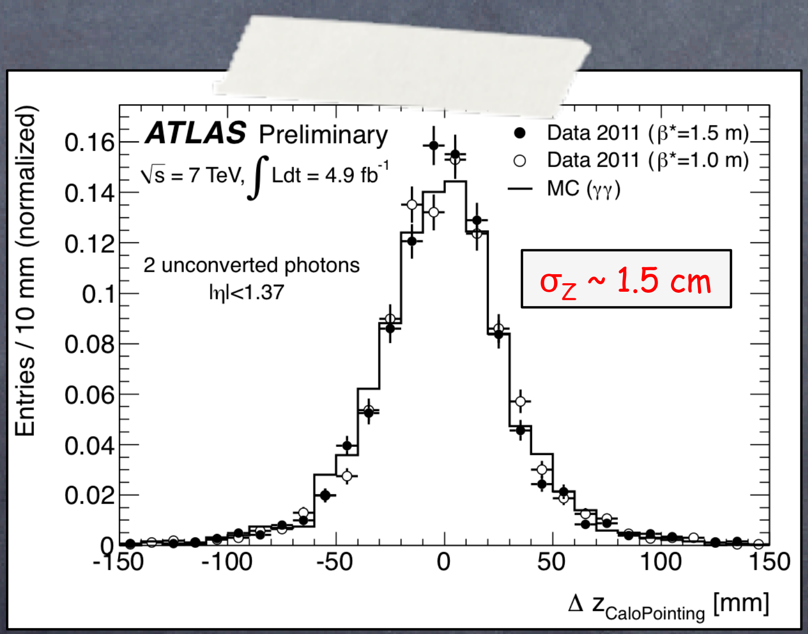
$$m^2_{\gamma_1\gamma_2} = 2E_{\gamma_1}E_{\gamma_2}\left(1 - \cos\measuredangle(\gamma_1,\gamma_2)\right)$$

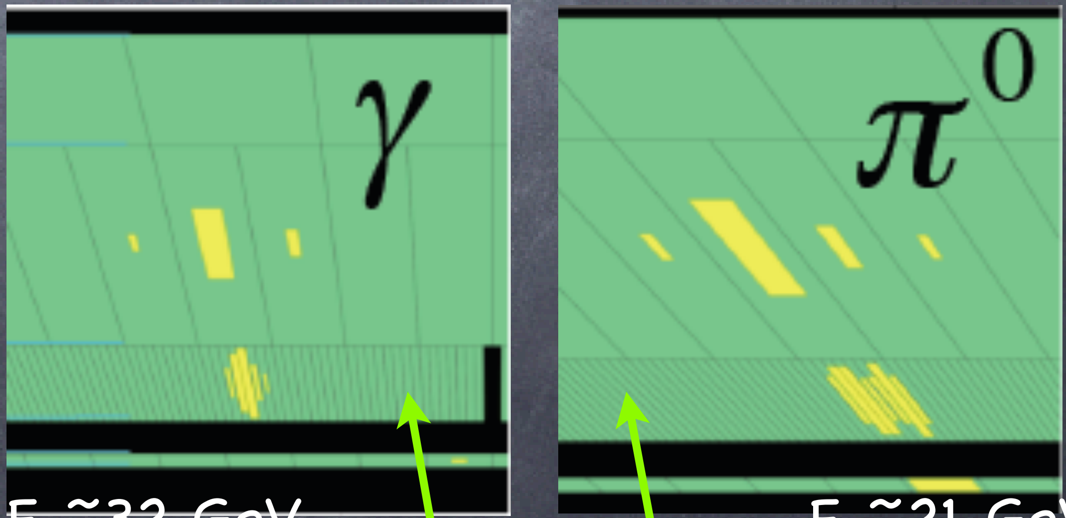
Needs a powerful γ/jet separation to suppress γj and jj background
with jet -> π^0 faking single γ



Due to ATLAS longitudinal and lateral EM calorimeter segmentation ATLAS has a pointing EM calorimeter geometry, enabling good γγ angular separation and better Z-vertex determination

This is crucial for high pile up and identifying fake photons from pions





E_T~32 GeV E_T~21 GeV

η strips

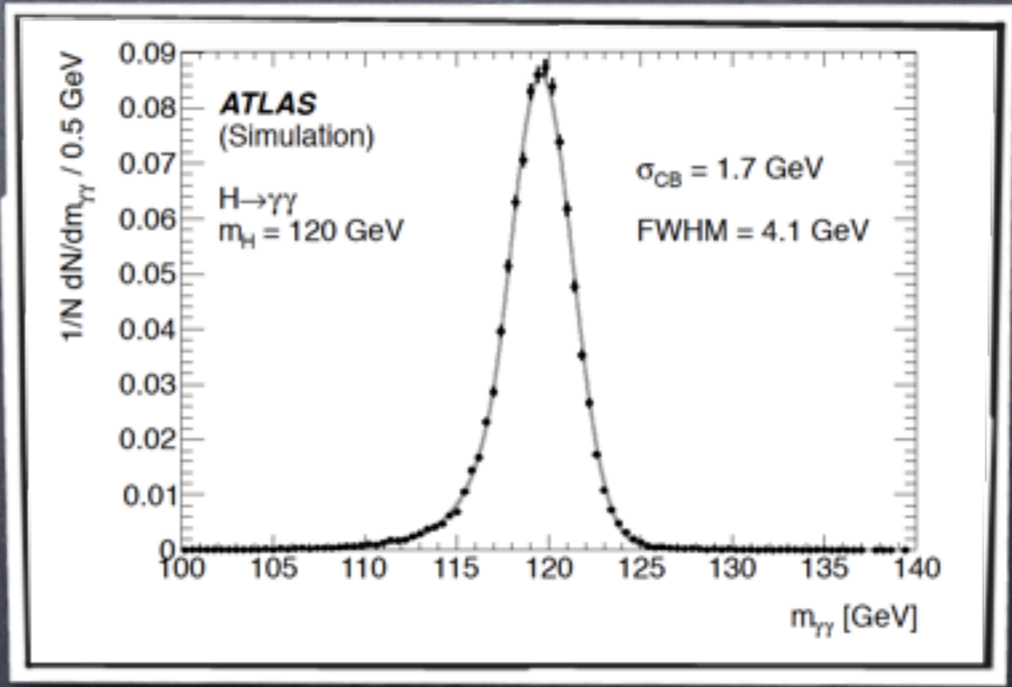
H->γγ Resolution

$$m^2_{\gamma_1\gamma_2} = 2E_{\gamma_1}E_{\gamma_2}\left(1 - \cos\measuredangle(\gamma_1,\gamma_2)\right)$$

Present understanding of calorimeter E response (from tag&probe Z->ee, J/ψ ->ee, W->eν data and MC):

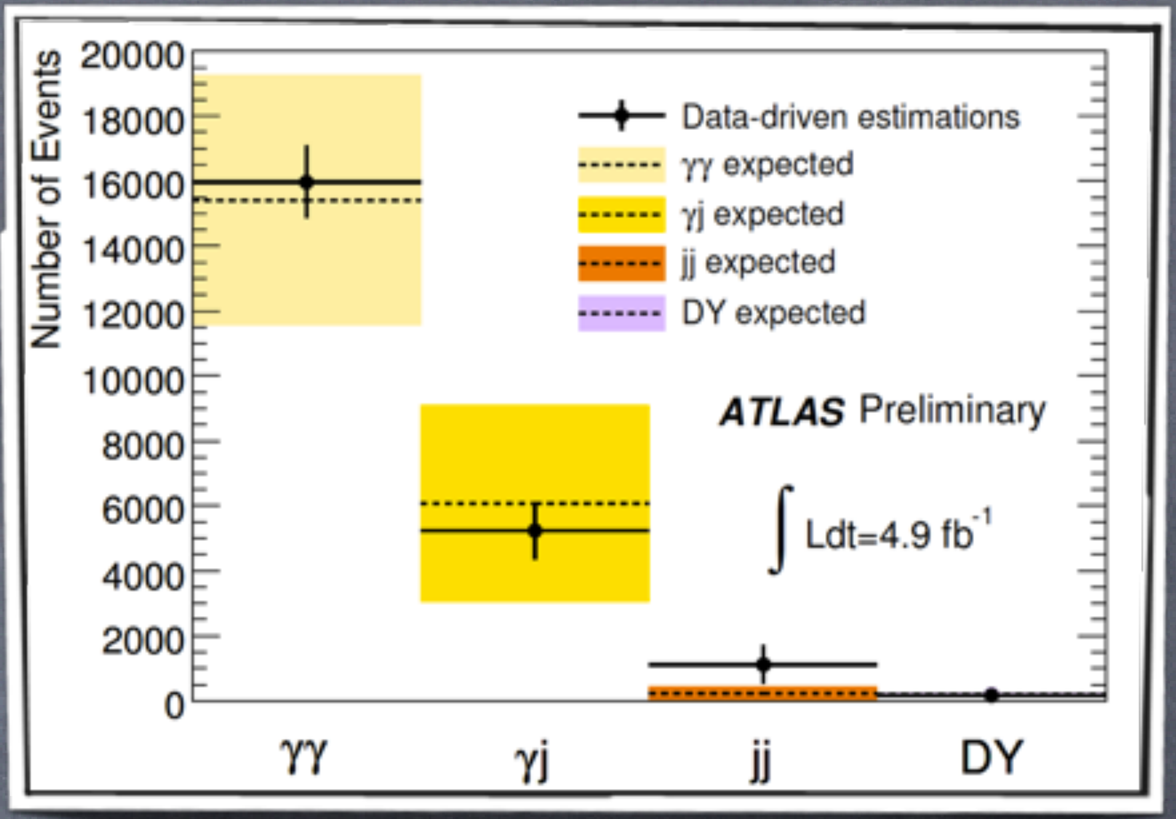
Energy scale at m_Z known to ~ 0.5%

m_H=120 GeV	σ ($m_{\gamma\gamma}$) GeV	Event fraction in ± 1.4 σ ($m_{\gamma\gamma}$)
All	1.7	80 %
Best category (unconverted central)	1.4	84%
Worst category (~10%) (≥ 1 γ converted, ≥ 1 γ near barrel/end-cap transition)	2.3	70%



H->γγ Background

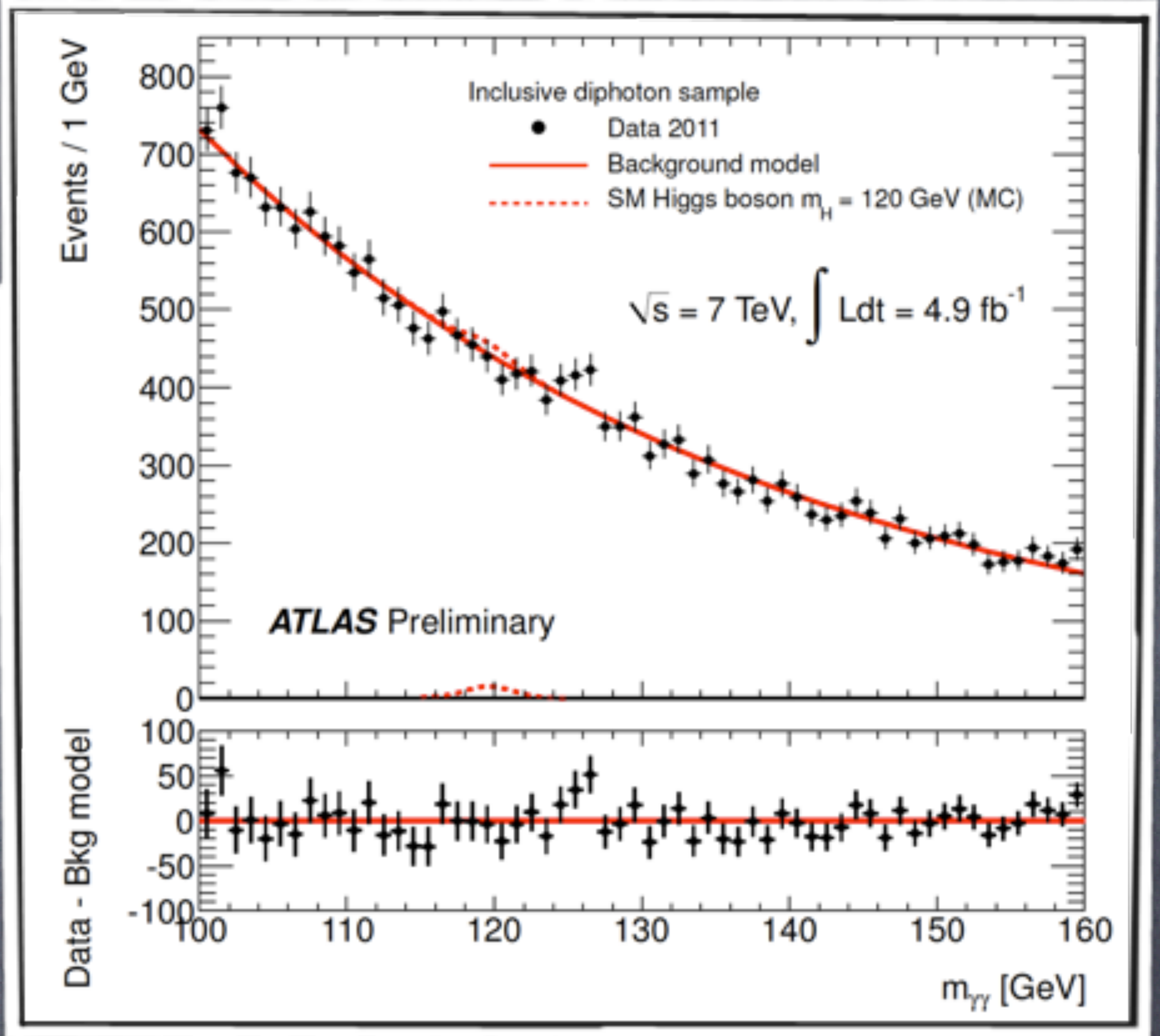
	Number of events	Fraction
γγ	16000 ± 1120	71 ±5 %
γj	5230 ± 890	23 ±4 %
jj	1130 ± 600	5 ±3 %
DY/Z	165 ± 8	0.7 ±0.1 %



- Search in the mass range $100<m_{\gamma\gamma}<160$ GeV
- Observed 22489 events of which 71% are γγ (determined from data control samples)

H->γγ Results

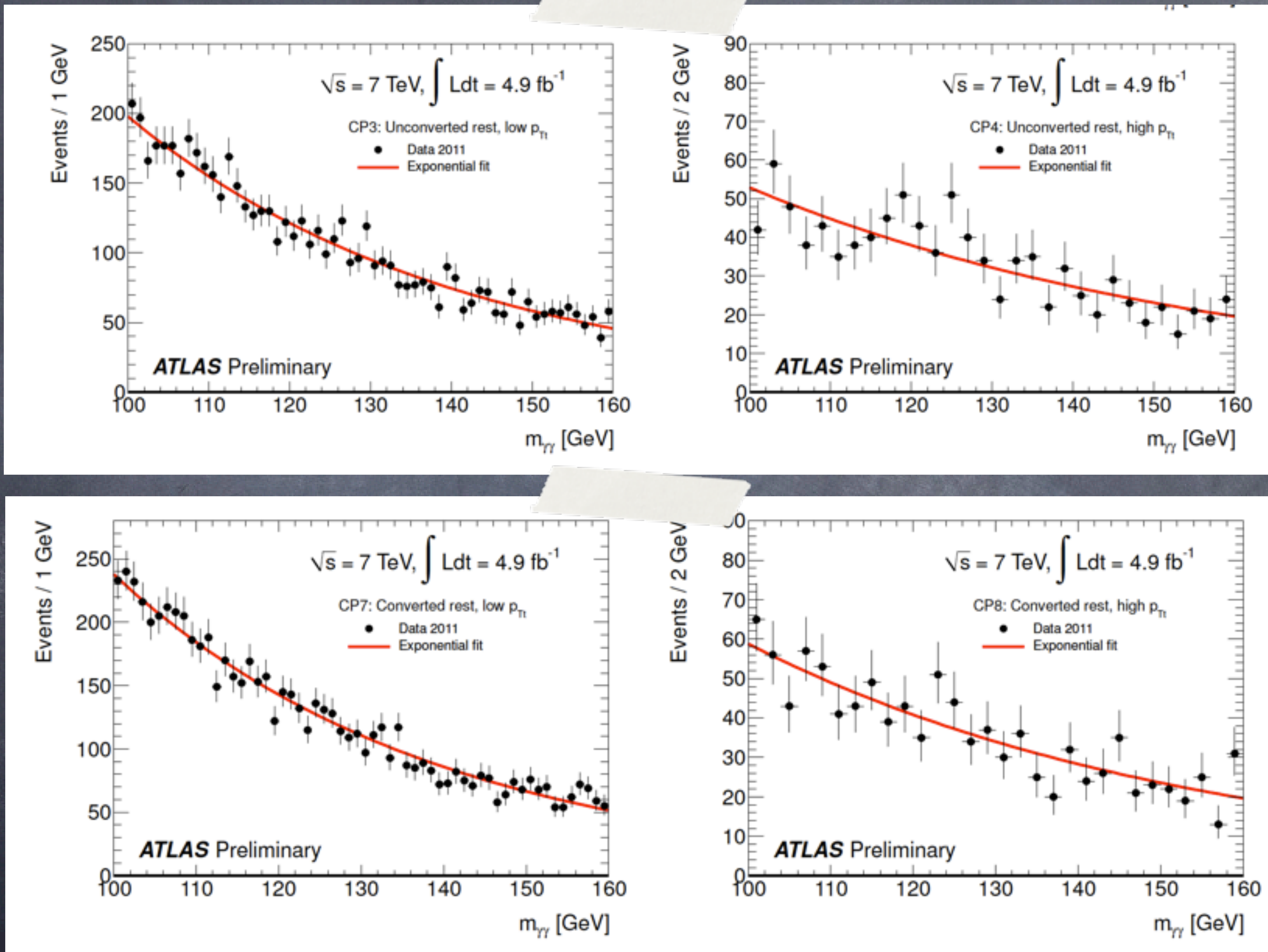
- ~22500 events observed in a mass window $100<m_{\gamma\gamma}<160$ GeV
- $m_{\gamma\gamma}$ was fit (per category) with exponential function for background plus a sum of Crystal Ball and Gaussian (for tails) for signal.
- Background was fitted from data
- ~70 signal events are expected in 4.9 fb^{-1} for m_H=125 GeV
- Out of ~22500 observed events, ~3000 expected in m_H=125 GeV mass window -> S/B~2% in signal mass window



Main systematic uncertainties

Expected signal yield	: ~ 20%
H→ γγ mass resolution	: ~ 14%
H→ γγ p_T modeling	: ~ 8%
Background modeling	: ±0.1-5.6 events

H->γγ Results

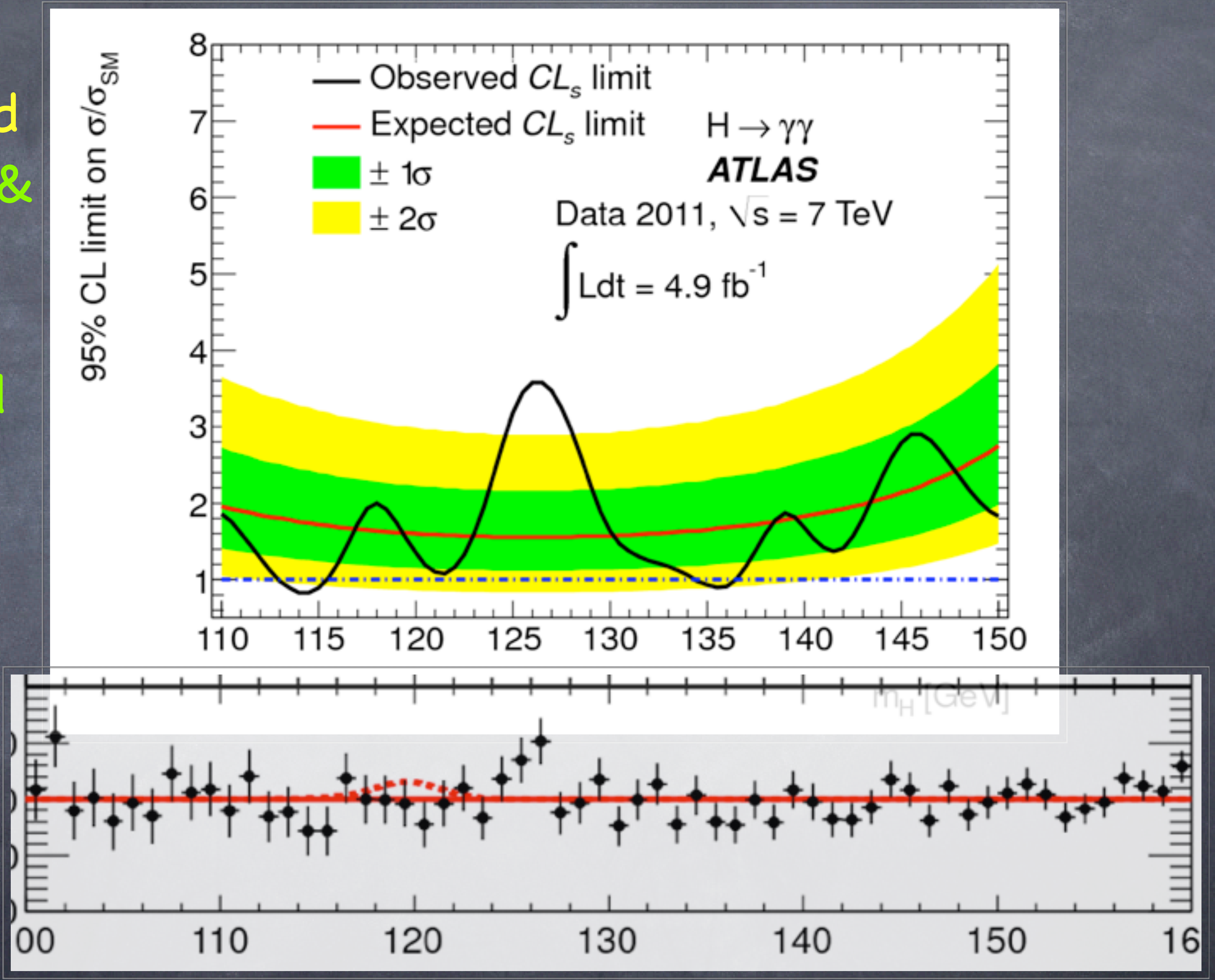


√s = 7 TeV, ∫ Ldt = 4.9 fb⁻¹
CP3: Unconverted rest, low p_Tt
Data 2011
Exponential fit
ATLAS Preliminary
Events / 1 GeV
m_γγ [GeV]
CP4: Unconverted rest, high p_Tt
Events / 2 GeV
CP7: Converted rest, low p_Tt
CP8: Converted rest, high p_Tt

H->γγ ATLAS Results

A SM Higgs Boson is excludd @ 113-115 GeV & 134.5-136 GeV due to a large downward fluctuation

Unable to exclude a Higgs Boson all over, in particular around 122-130 GeV



A nano statistical interlude II

Understanding p0 and the LEE (Look Elsewhere Effect)

Discovery: p_0

$$\mu = \frac{\sigma}{\sigma_{SM}(m_H)}$$

$$q_0 = -2\log\frac{max_{\{b\}}L(b)}{max_{\{\mu,b\}}L(\mu s(m_H)+b)}$$

->p_0 measures the compatibility of the data with the NO-HIGGS hypothesis.

->If p_0=0.025 the NO-HIGGS hypothesis is rejected at the 2σ level

$$p_0 = Prob(q_0 > q_0^{obs} \mid H_0)$$

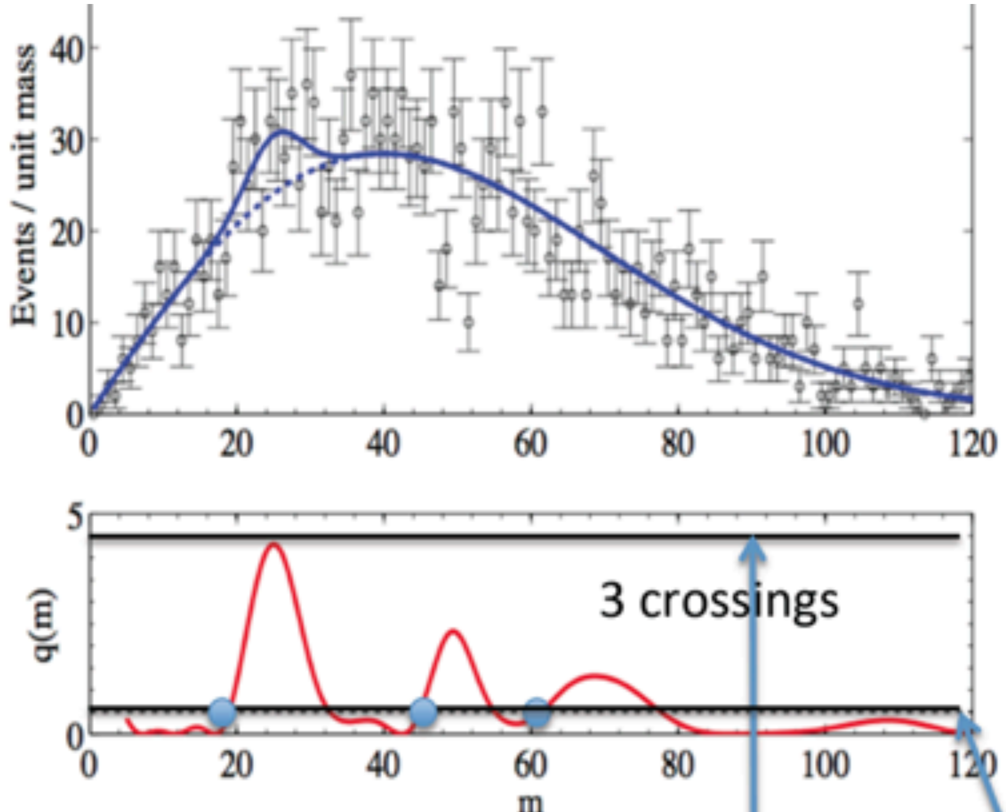
Discovery: Look Elsewhere Effect

- What is the probability to see such an excess (or more) ANYWHERE in the search mass range

$$p_{global} = p_{min} + N_0 e^{-Z_{max}^2/2}$$

☀ arXiv 1005.1892

E. Gross and O. Vitells, "Trial factors for the look elsewhere effect in high energy physics", *The European Physical Journal C - Particles and Fields* **70** (2010) 525–530.



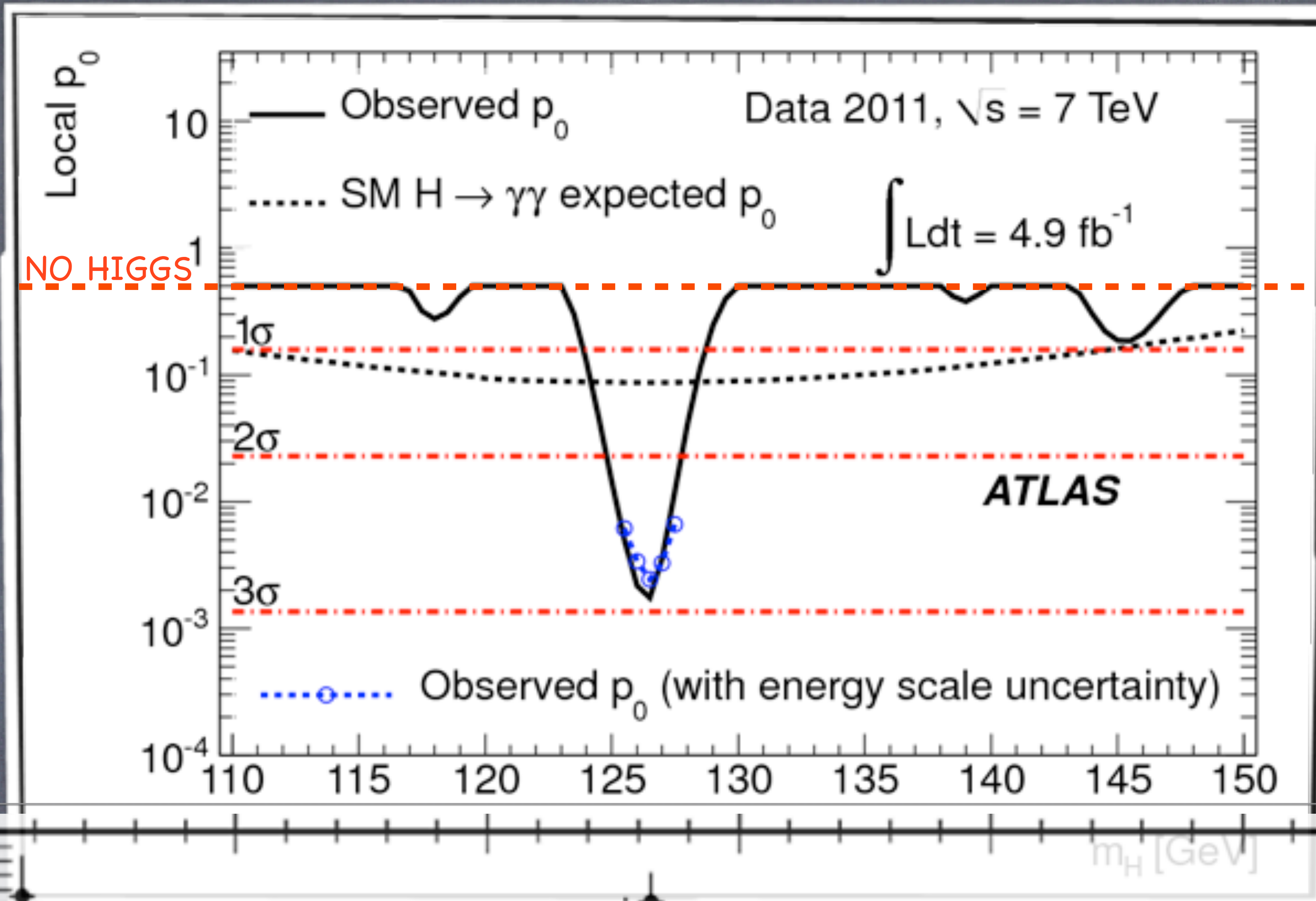
- Example:
  - q_{test}= 4.5 (2.1σ)
  - 3 crossings at 0.5σ
  - significance reduced to about 0.3σ
  - trials factor about 22

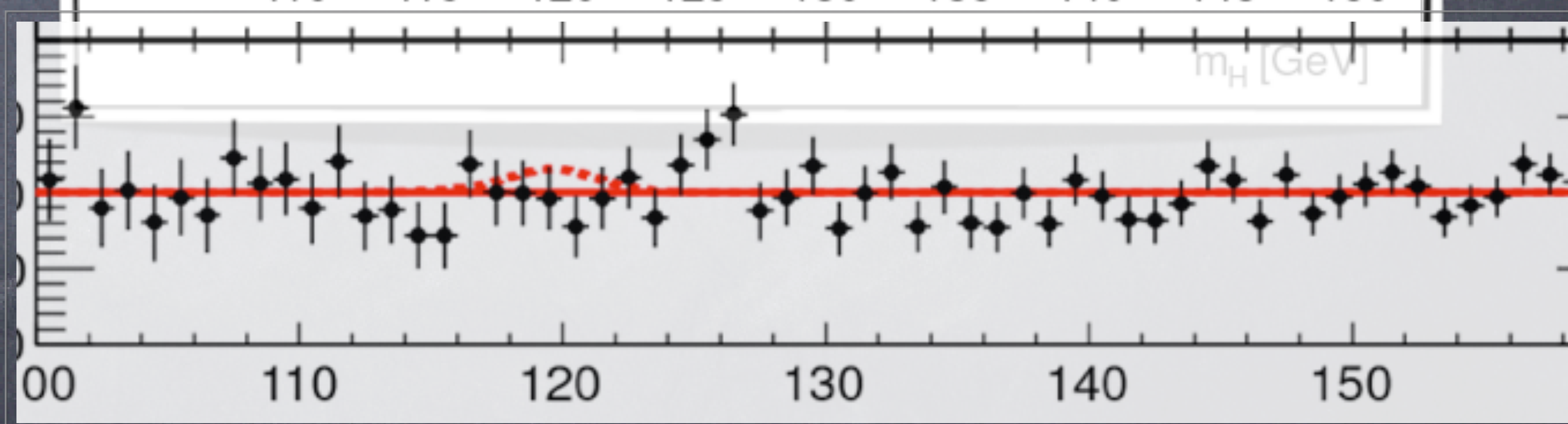
Local σ	Crossings	σ ref.	Trials factor	Global σ
3.5	3	1.0	47	2.3
5.0	3	2.0	290	3.8
7.0	3	2.0	400	6.1

$$p_0^{global} \cong p_0^{local} + \langle N(q_{ref}) \rangle \, e^{-(q_{test}-q_{ref})/2}$$

H->γγ ATLAS p_0 results

- ATLAS observes an excess of events with a maximum deviation from the background only expectation at 126.5 GeV.
- The significance of this excess is 2.8σ
- The significance to observe such an excess anywhere in the search mass range is reduced to 1.5σ

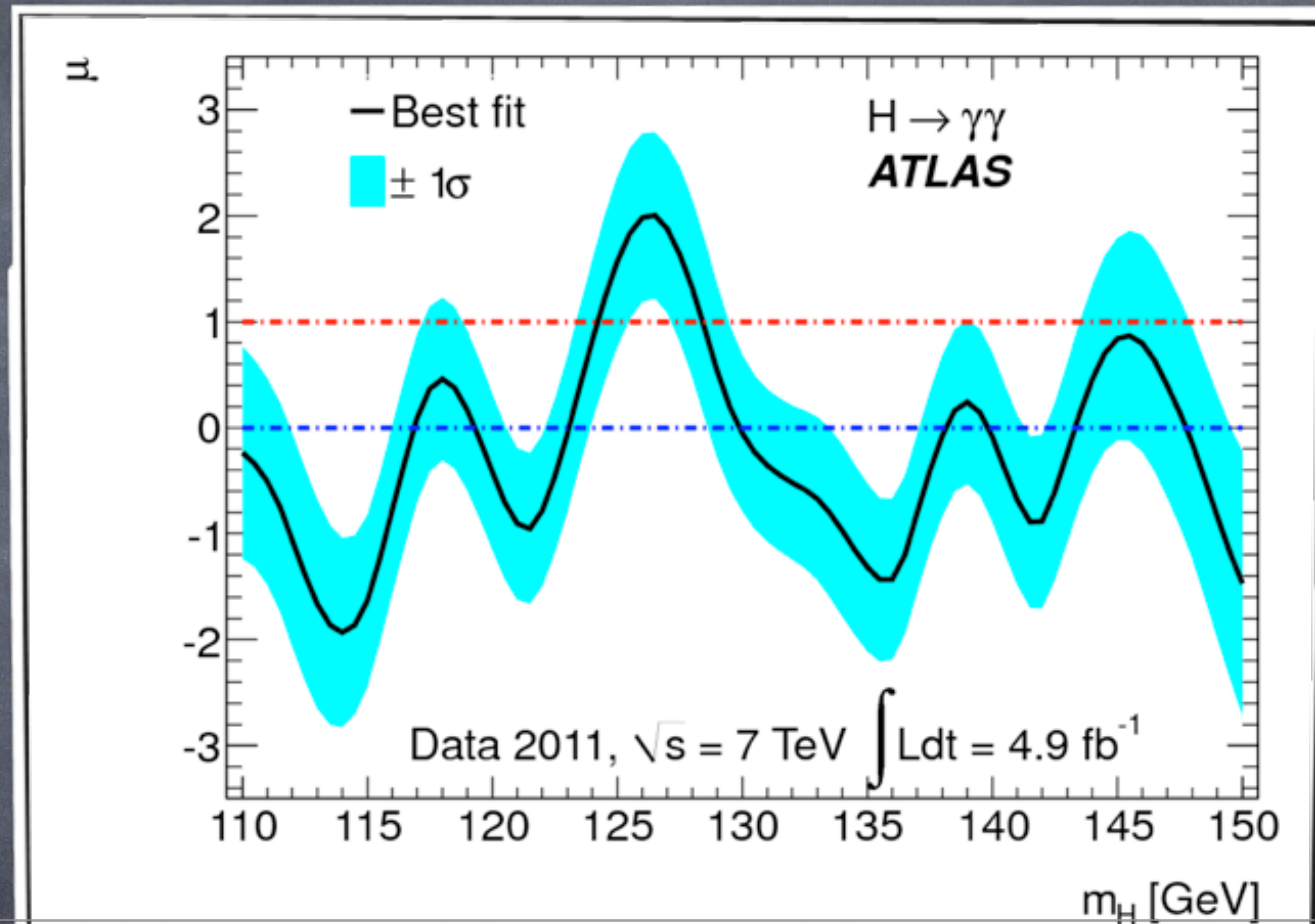


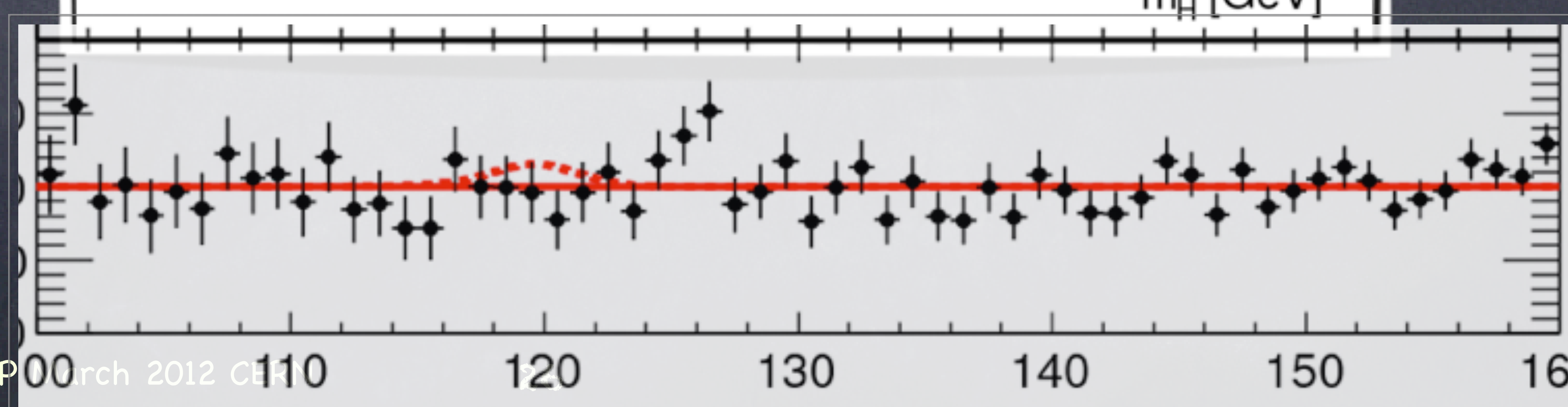


$\mu = \sigma / \sigma SM$ Signal Strength Fit

$$\hat{\mu} = \left\{ \mu \middle| L(\mu s(m_H) + b) = \max L(\mu, b) \right\}$$

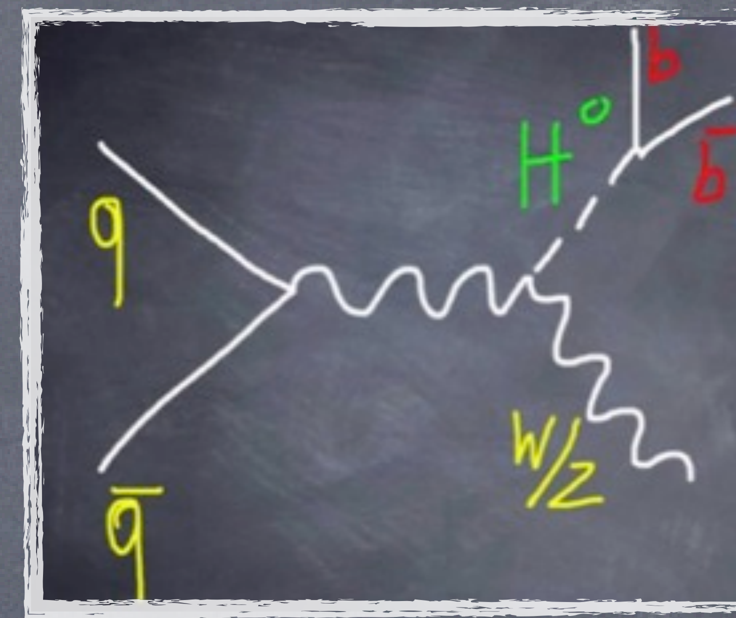
- For a SM Higgs ATLAS sees an excess of ~1.5σ

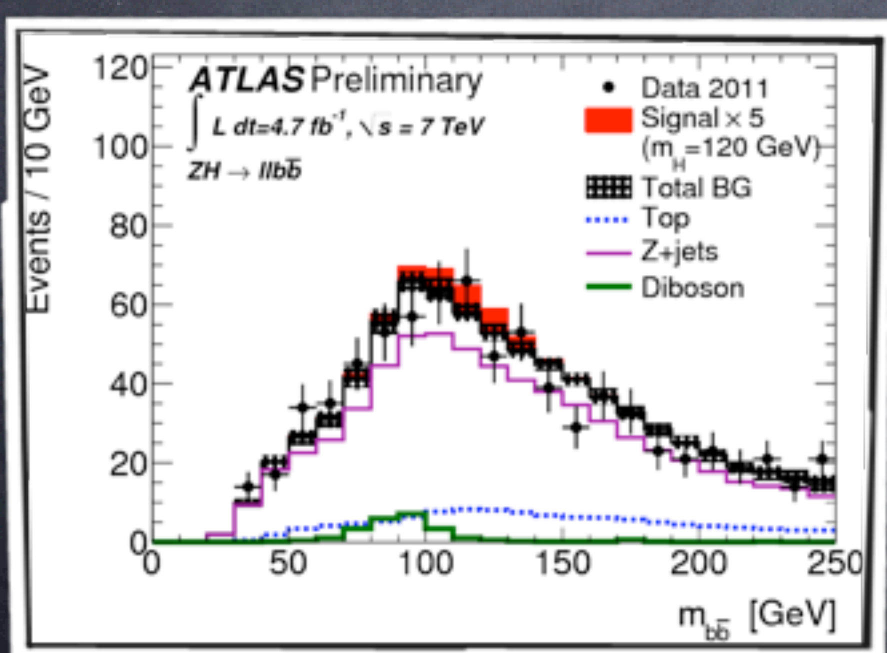


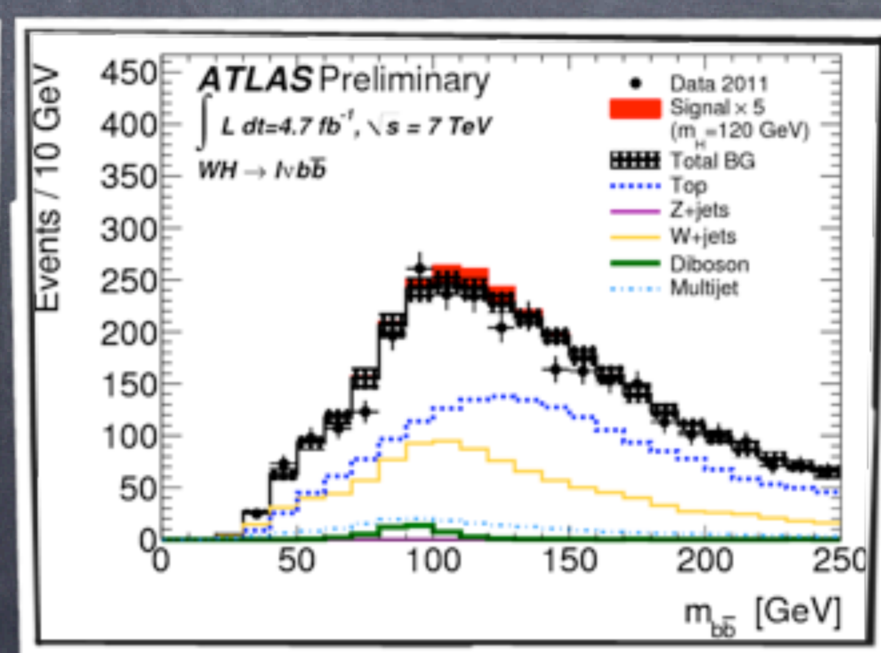


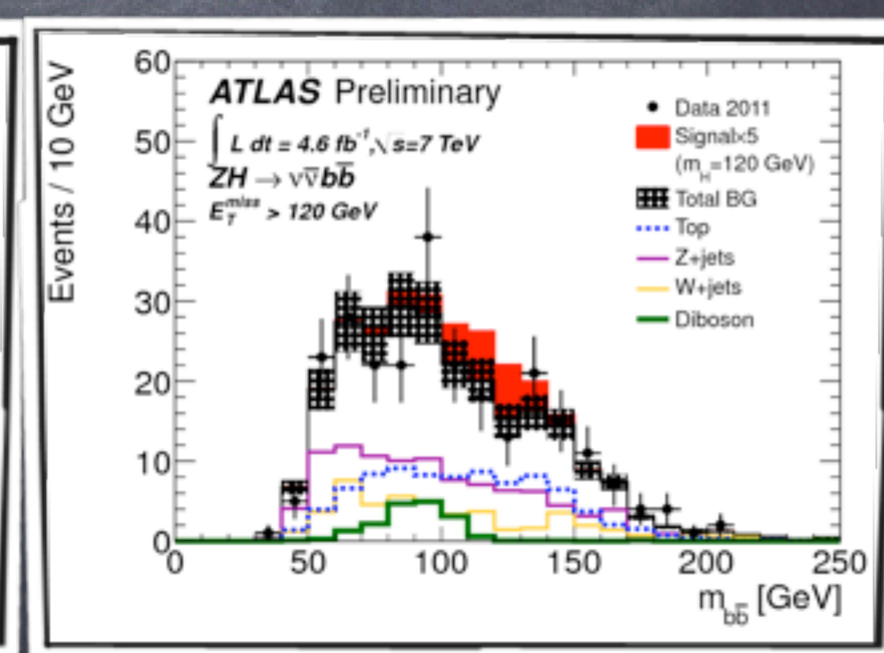
Probing Deeper: W/ZH->W/Zbb

- H->bb is the dominant decay of a low mass Higgs.
  It also extremely important to measure Higgs couplings.
- Multi-jet background kills its inclusive production
  (though there are hopes with boosted Higgs and jets substructure)
- W/ZH is feasible for low Higgs mass channels: lυbb,llbb and υυbb
- Signature : lepton,MET and b-tag
  (exactly two b-tag jets with E_Tb>45,25 GeV)
- Analysis is performed in p_{TW} (lvH), p_{TZ} (llH) and E_T^{miss} (vvH) , total of 4+4+3 bins
- m_{bb} as a discriminator, dominant Bacgrounds:
  Z+jets for ZH->llbb W+jets and tt for WH->lvbb Z+jets and tt for ZH->vvbb

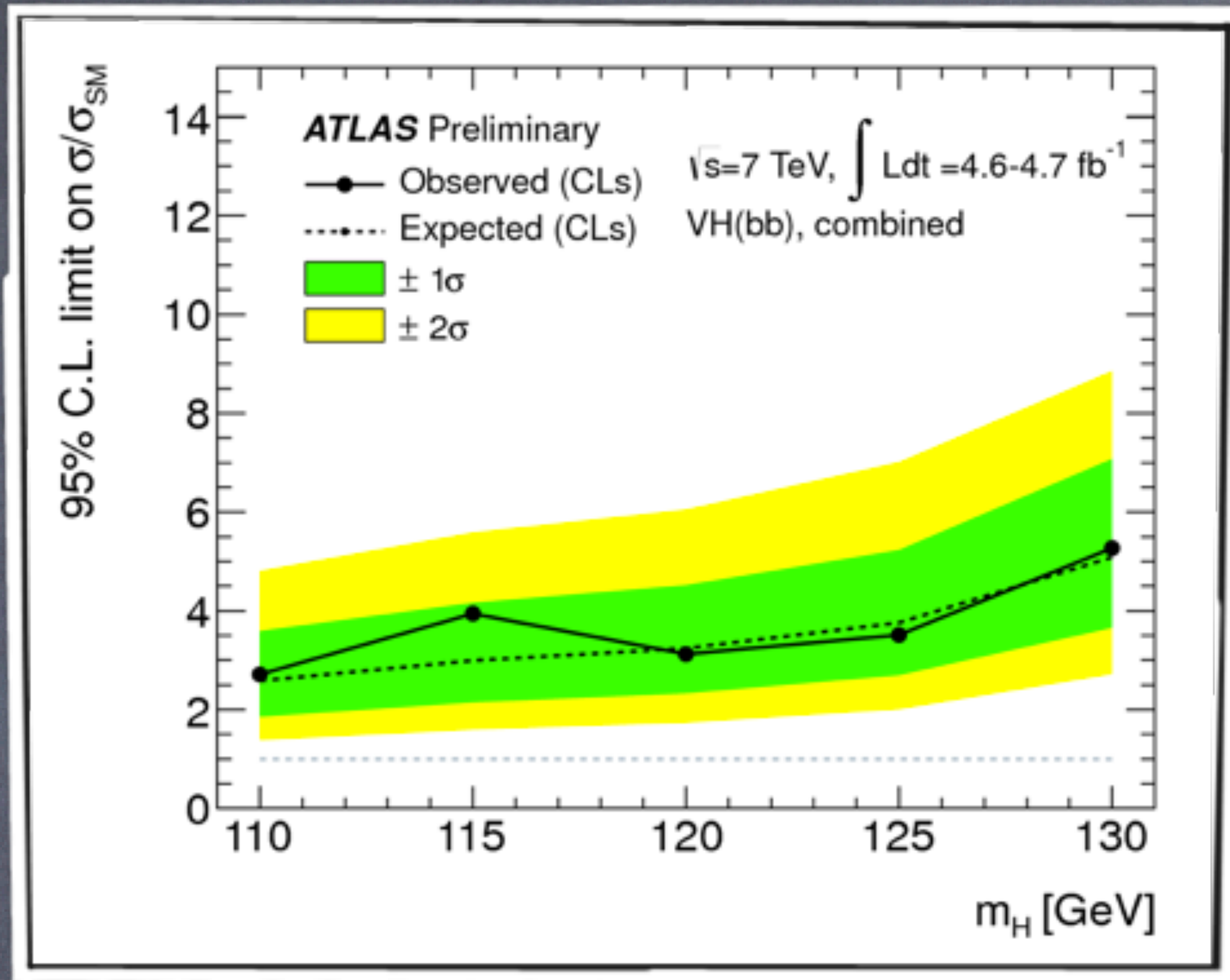








Probing Deeper: W/ZH->W/Zbb



Mass	ZH->llbb		WH->lvbb		ZH->vvbb		Combined	
	obs	exp	obs	exp	obs	exp	obs	exp
125	10.4	8.2	8.0	7.5	5.9	5.6	3.5	3.8

H->ττ

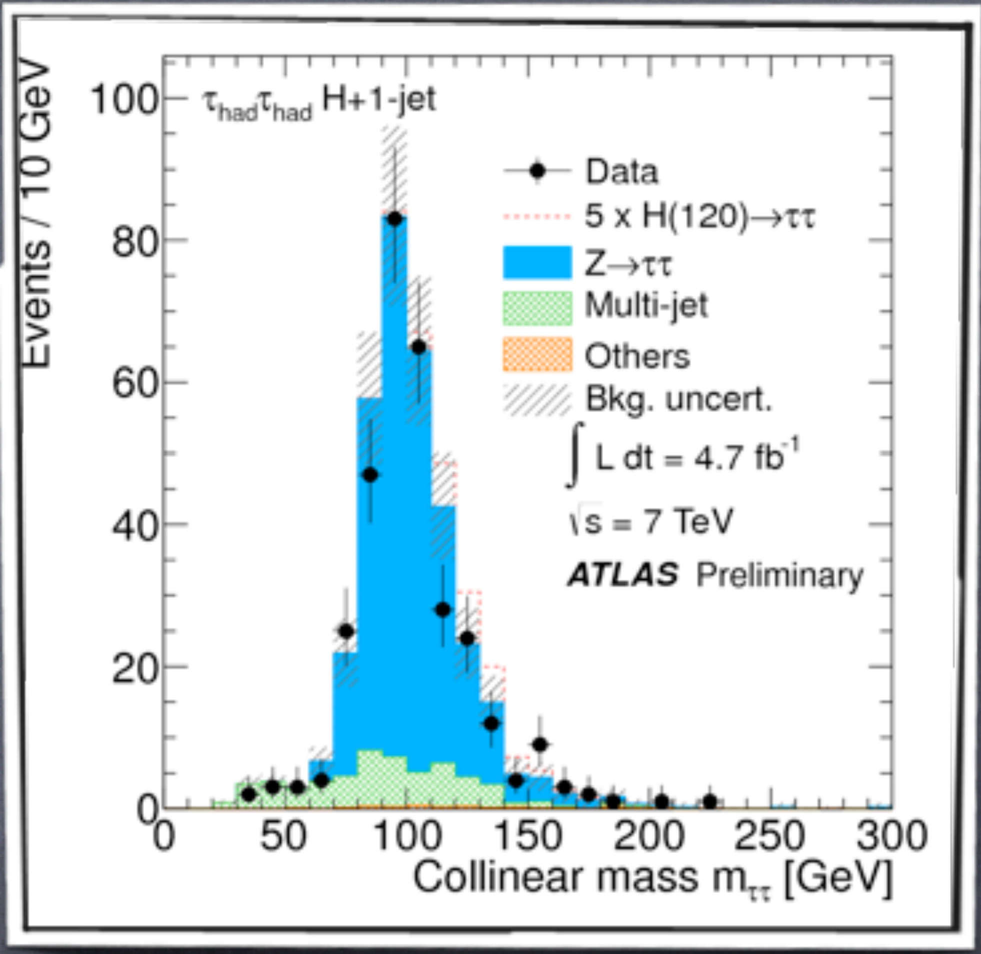
- 3 channels in 12 bins
  (0 jets, 1 jet, 2 jets VBF & VH)

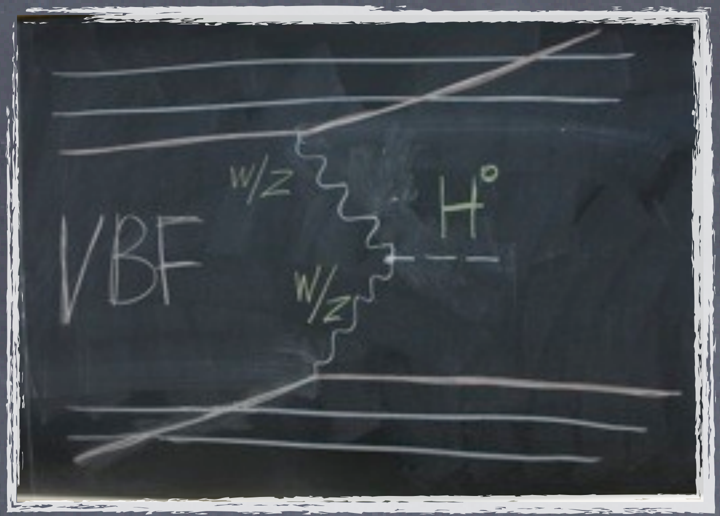
  H->$\tau_l\tau_l$+E_T^{miss} in 0 jets (eμ),1 jet, 2jets (VH,VBF)
  H->$\tau_l\tau_h$+E_T^{miss} in
  (l=e,μ)⊗(0 jets (2 E_T^{miss} bins),1-jet)⊕VBF
  H->$\tau_h\tau_h$+E_T^{miss} with ≥1 jet

- Discriminator $m_{\tau\tau}$
  (m_{eff}, colinear or MissingMassCalculator)
  Elagin et. al. NIM A654(2011)481

- Main background from Z->ττ, shape via embedding
  (Z->μμ replacing μ with a τ)

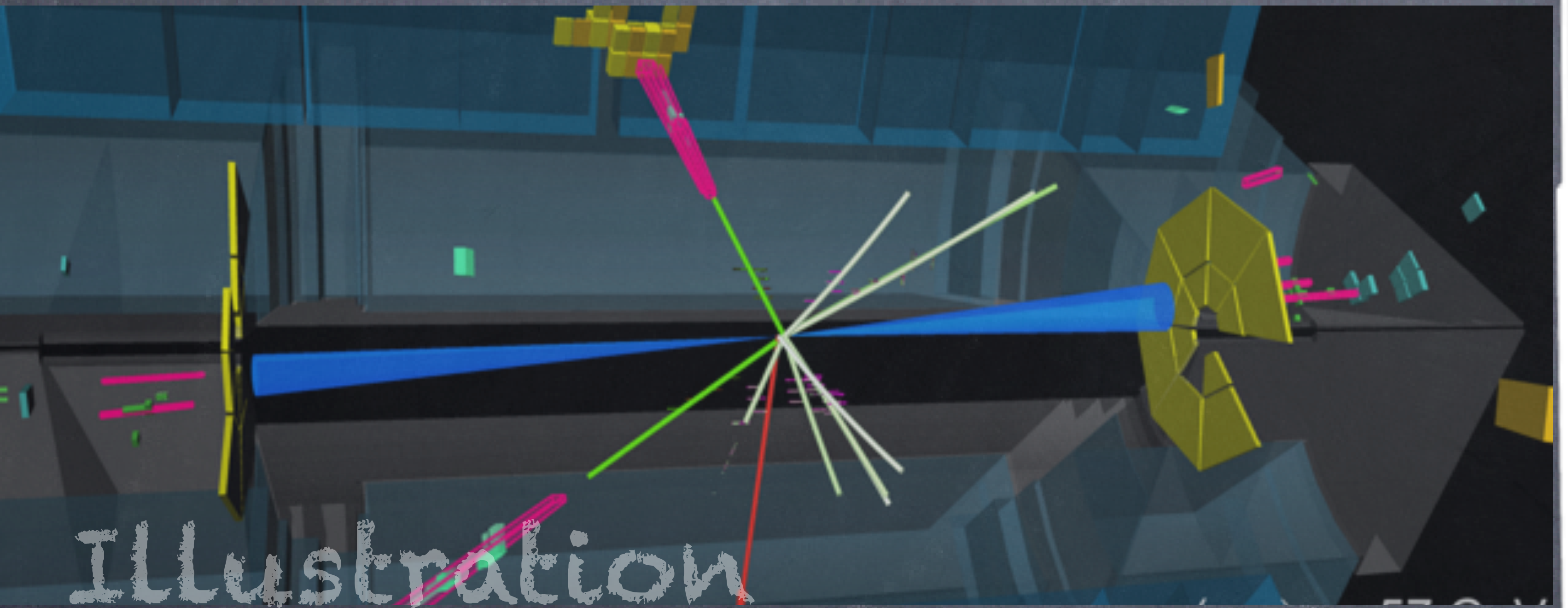
- Fake leptons and τ jets from data with an uncertainty of up to 40%

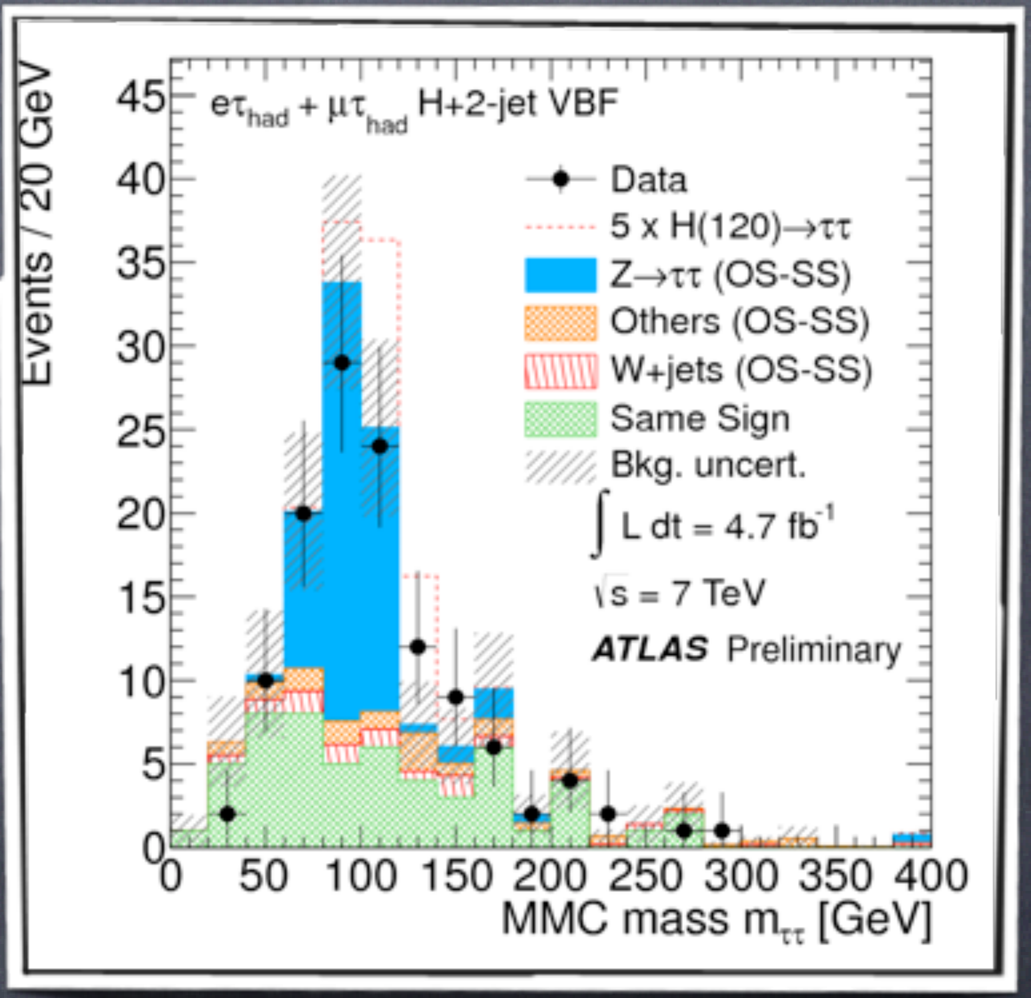




H->ττ

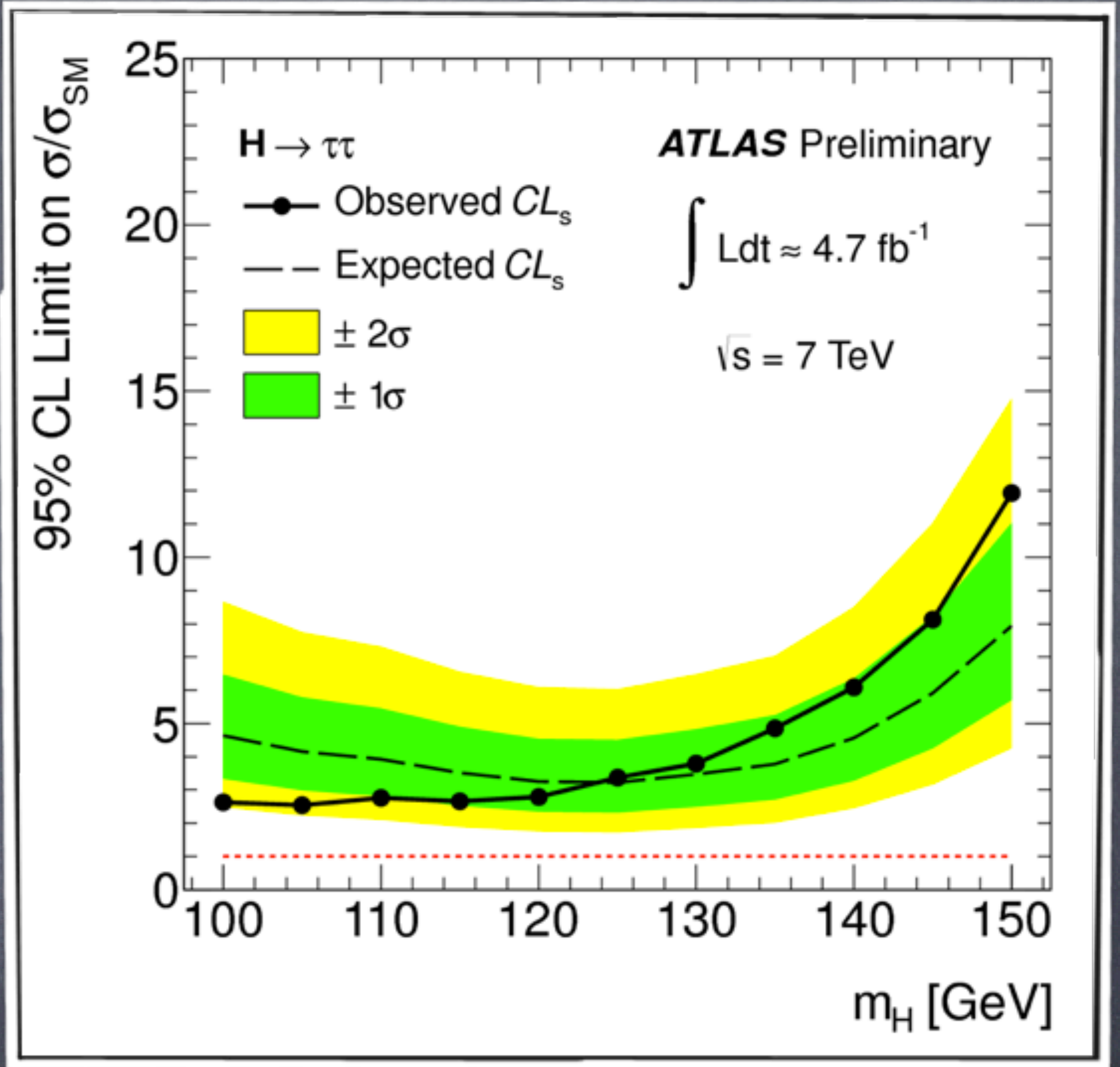
- VBF
  clean and sensitive
- 2 tagged back to back forward jets and two tagged taus





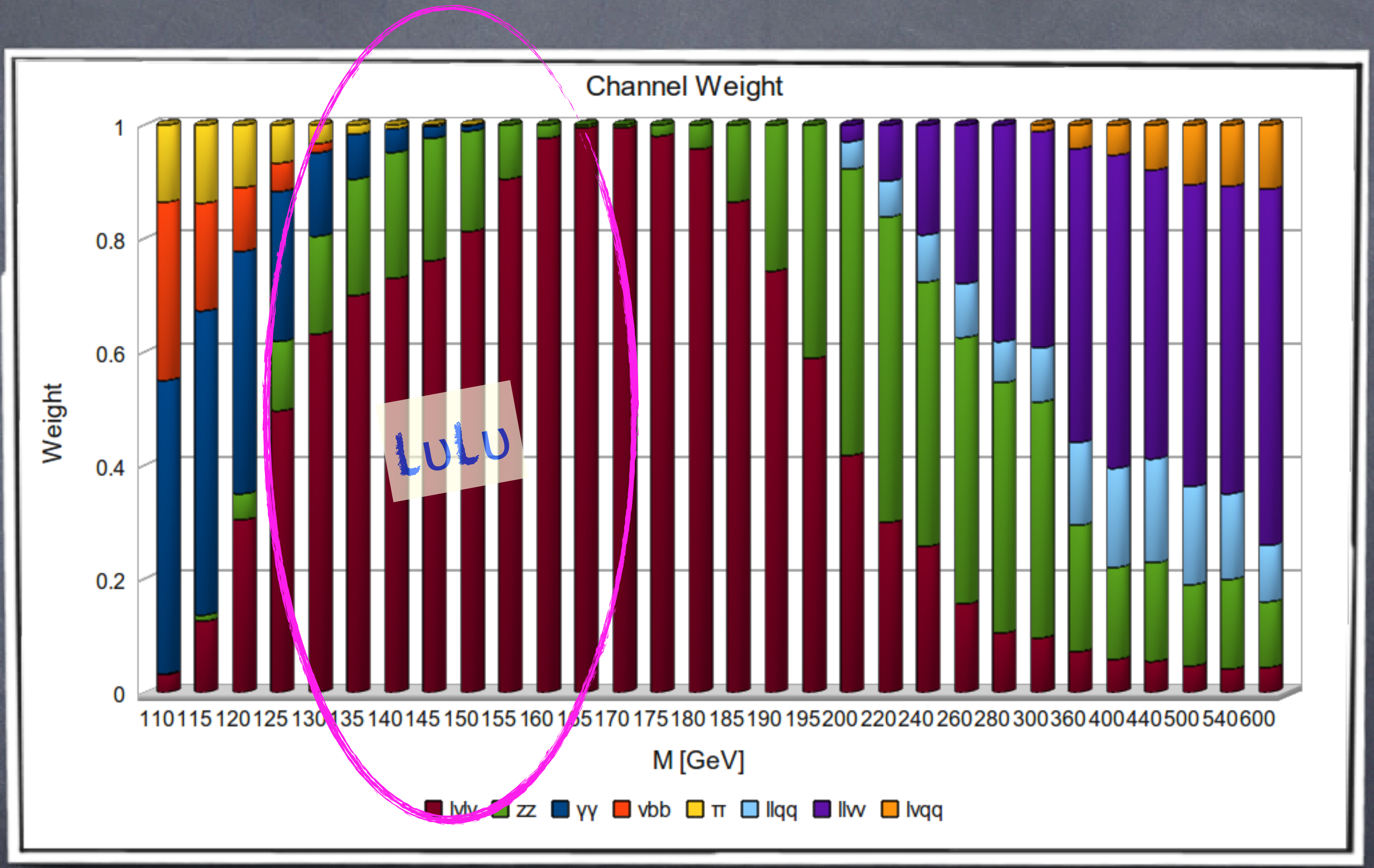
H->ττ

- Expected limit between $\sigma<(3.2\text{-}7.9)\times\sigma_{SM}$
- Most sensitive categories
  H+1j in $\tau_{had}\tau_{had}$,
  and
  2-jet VBF in $\tau_l\tau_l$ and $\tau_l\tau_{had}$
- Observed limit $\sigma<(2.5\text{-}11.9)\times\sigma_{SM}$



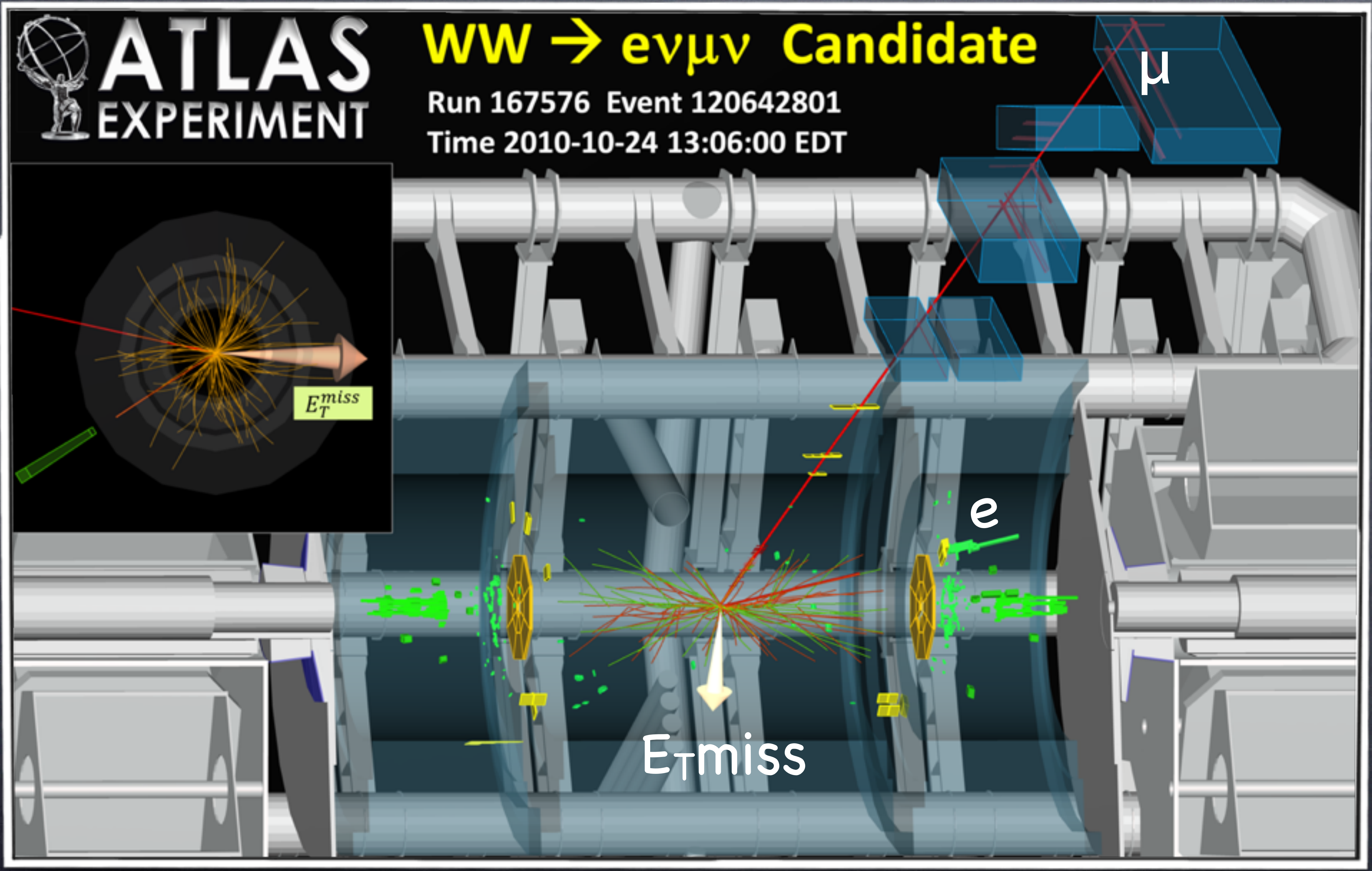
"TEVATRON++" mass region

- "TEVATRON++" mass region 140-200 GeV
- Probing channel: H->WW->lulu



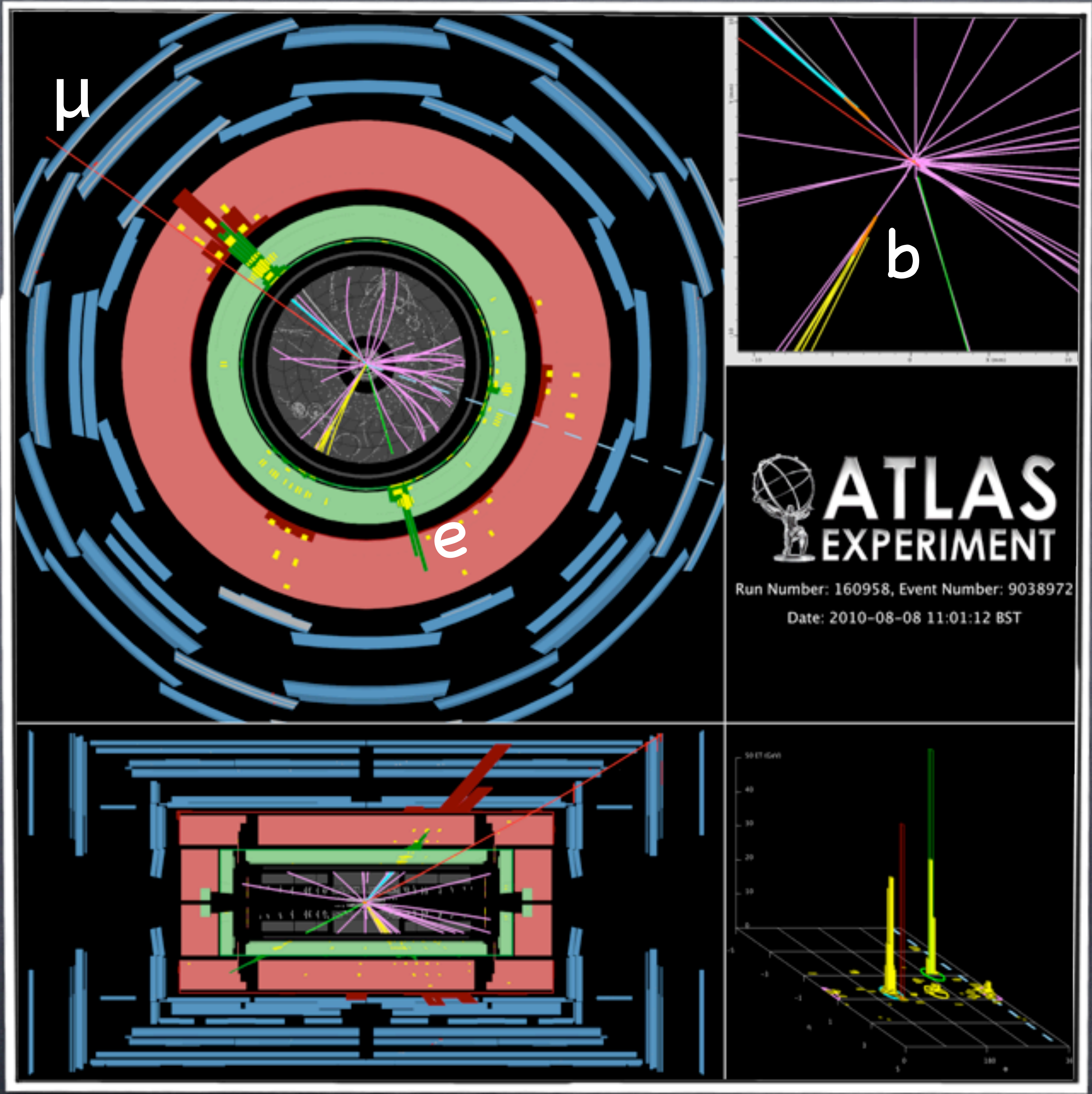
H->WW->lνlν: WW->eμ "Irreducible" BG

- WW can be reduced by exploiting the Higgs spin, require small $\Delta\Phi_{ll}$



H->WW->lνlν: tt->eμ background

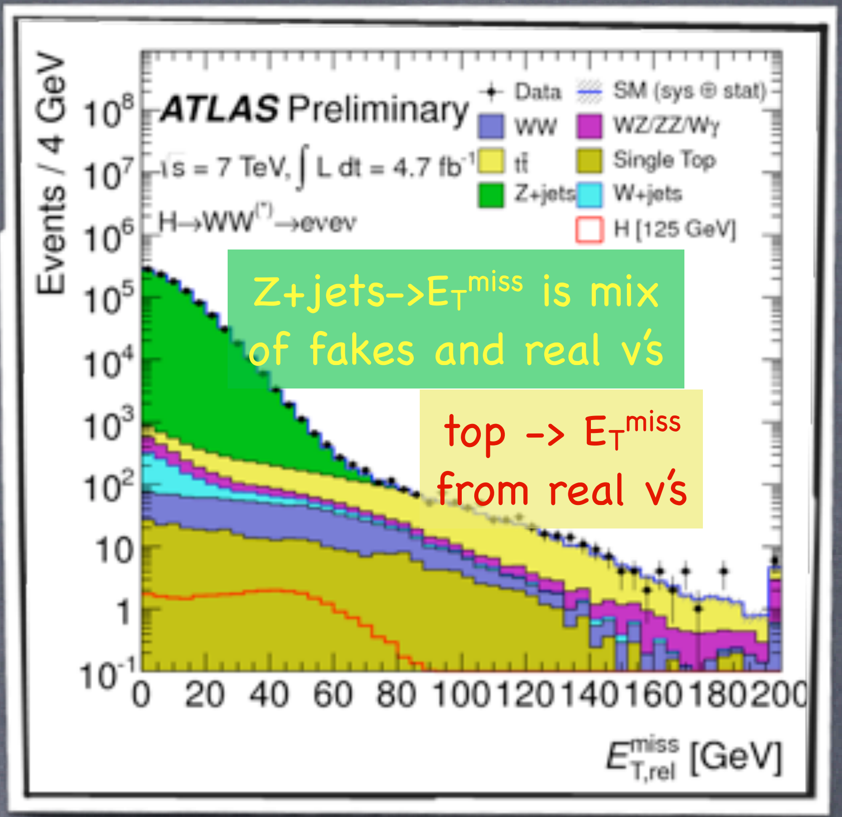
Event display of a top pair e-mu dilepton candidate with two b-tagged jets.
The electron is shown by the green track pointing to a calorimeter cluster, the muon by the long red track intersecting the muon chambers, and the missing ET direction by the dotted line on the XY view. The secondary vertices of the two b-tagged jets are indicated by the orange ellipses on the zoomed vertex region view.

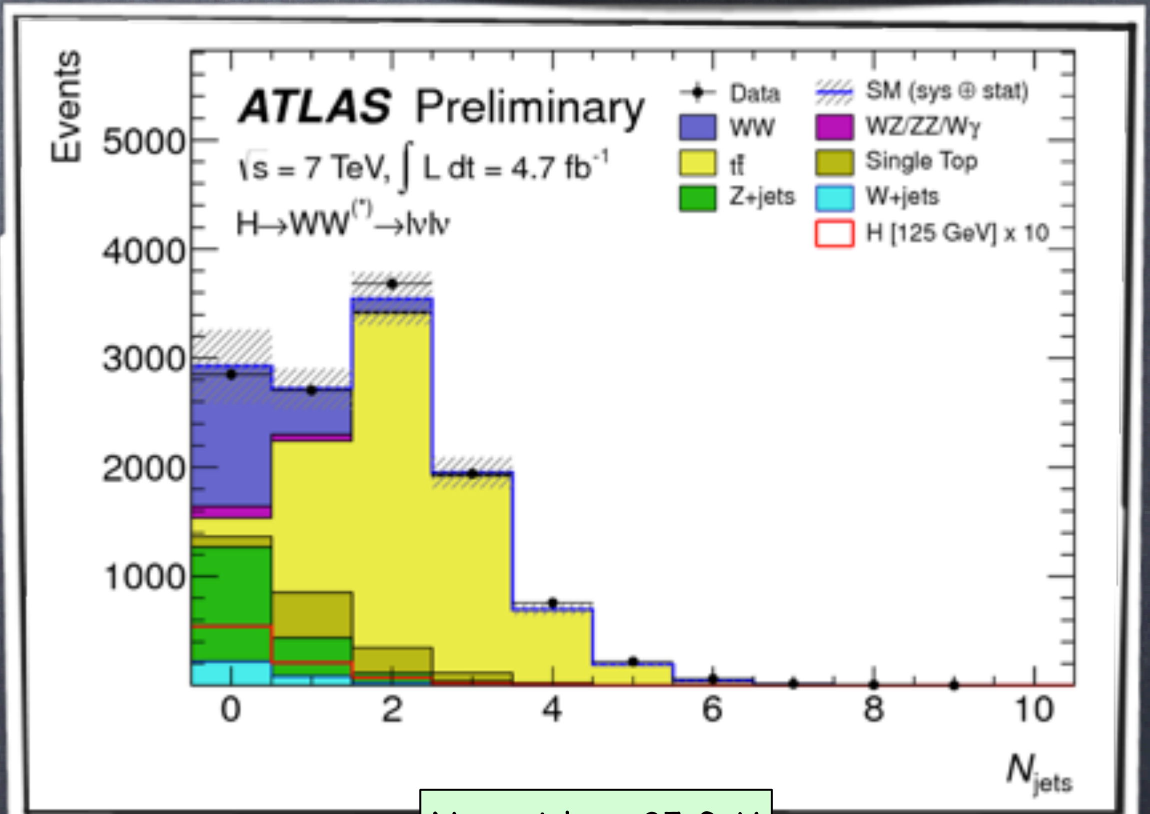


Reject by b-tag veto

H->WW->lνlν

- The cannel is challenging
  2 neutrinos- no mass reconstruction ->mT
- Signature: 2 high p_T opposite sign isolated leptons with large E_T^{miss}->Understanding of E_T^{miss} is crucial
- Main background from WW, top,
  Z+jets, W+jets ->Use of control regions to estimate fakes
- A control region is defined rich in the measured BG (e.g. WW or top), contaminations are being subtracted and then the BG is extrapolated to the signal region (mostly using MC)
  Example: b-tag is inverted to estimate Top BG
- -> large E_T^{miss}, m_{ll} incompatible with m_Z (DY),
  -> b jet veto (tt),
  ->Topological cuts against irreducible WW ($\Delta\Phi_{ll}$)
- Jet bins: +0j, +1, +2jet (VBF)
- Discriminating variable $m_T = \sqrt{(E_T^{ll} + E_T^{miss})^2 + (p_T^{ll} + p_T^{miss})^2}$





N_{jets} with p_T>25 GeV

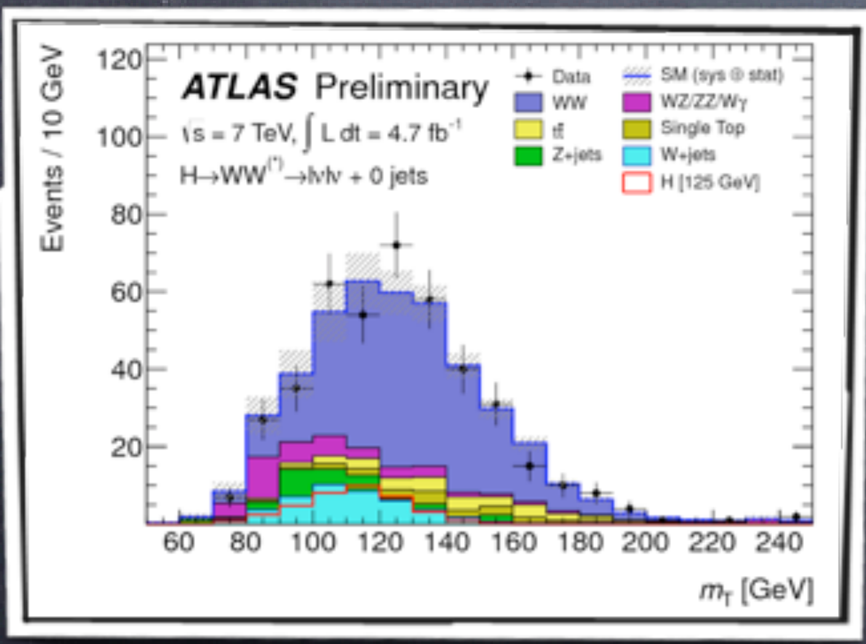
H->WW->lνlν Results

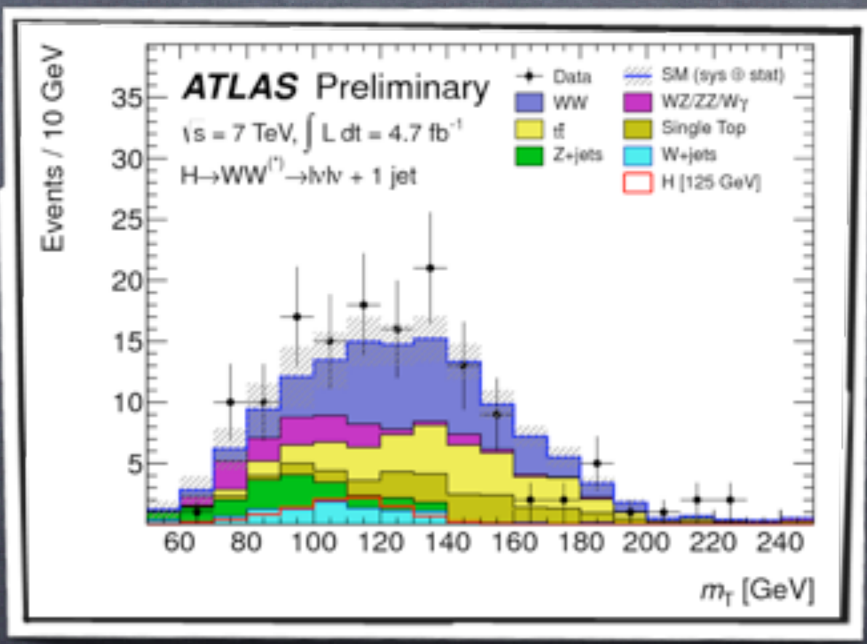
- After all cuts

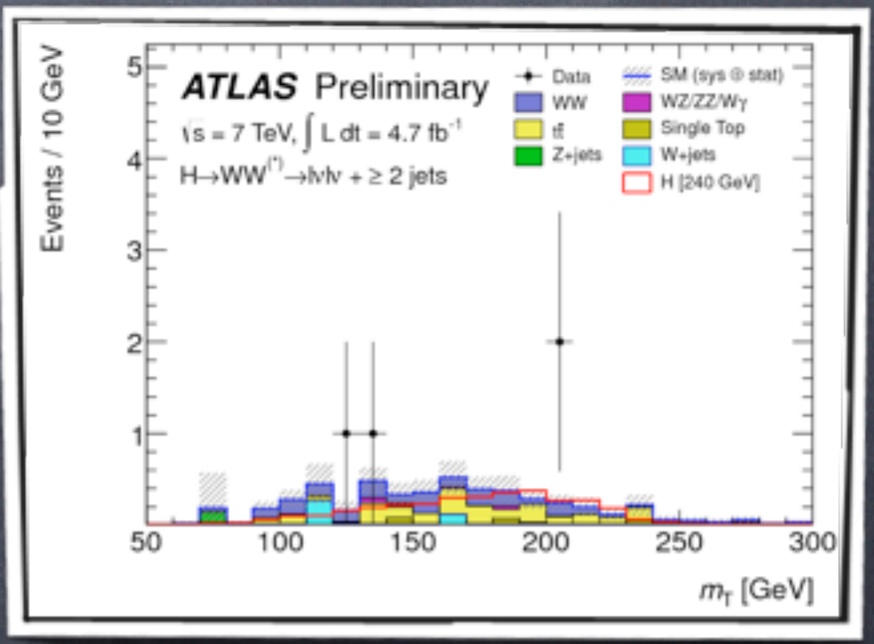
$$0.75 m_H < m_T < m_H$$

		Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	$Z/\gamma^* +$ jets	$W +$ jets	Total Bkg.	Obs.
0-jet	$m_H = 125$ GeV	25 ± 7	110 ± 12	12 ± 3	7 ± 2	5 ± 2	13 ± 8	27 ± 16	173 ± 22	174
	$m_H = 240$ GeV	60 ± 17	432 ± 49	24 ± 3	68 ± 15	39 ± 9	8 ± 2	36 ± 24	607 ± 63	629
1-jet	$m_H = 125$ GeV	6 ± 2	18 ± 3	6 ± 3	7 ± 2	4 ± 2	6 ± 1	5 ± 3	45 ± 7	56
	$m_H = 240$ GeV	23 ± 9	99 ± 22	8 ± 1	73 ± 27	35 ± 19	6 ± 2	7 ± 7	229 ± 55	232
2-jet	$m_H = 125$ GeV	0.4 ± 0.2	0.3 ± 0.2	negl.	0.2 ± 0.1	negl.	0.0 ± 0.1	negl.	0.5 ± 0.2	0
	$m_H = 240$ GeV	2.5 ± 0.6	1.1 ± 0.7	0.1 ± 0.1	2.6 ± 1.3	0.3 ± 0.3	negl.	0.1 ± 0.1	4.2 ± 1.7	2

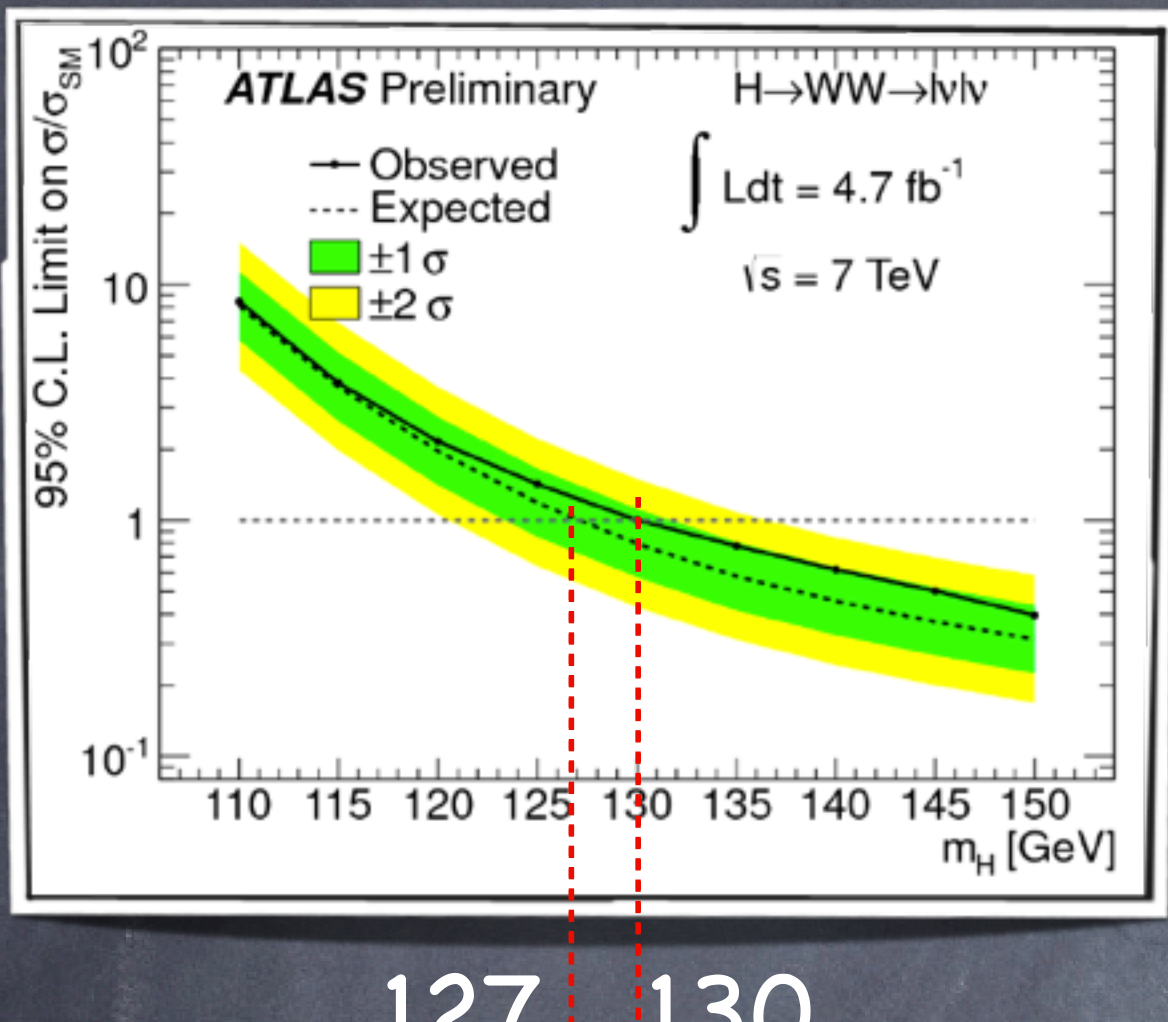
- Discriminating Variable $m_T = \sqrt{(E_T^{ll} + E_T^{miss})^2 + (p_T^{ll} + p_T^{miss})^2}$



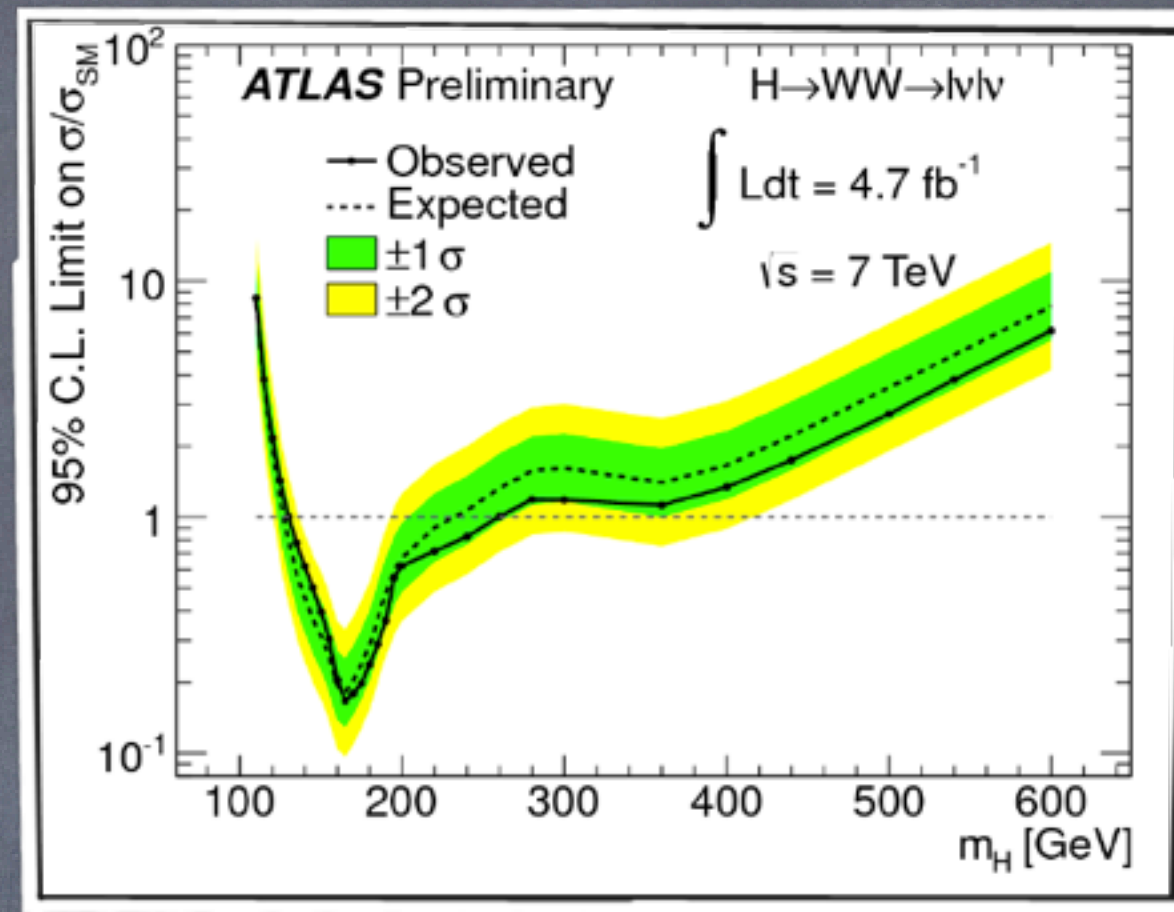




H->WW->lνlν (2.1 fb^{-1} ATLAS)



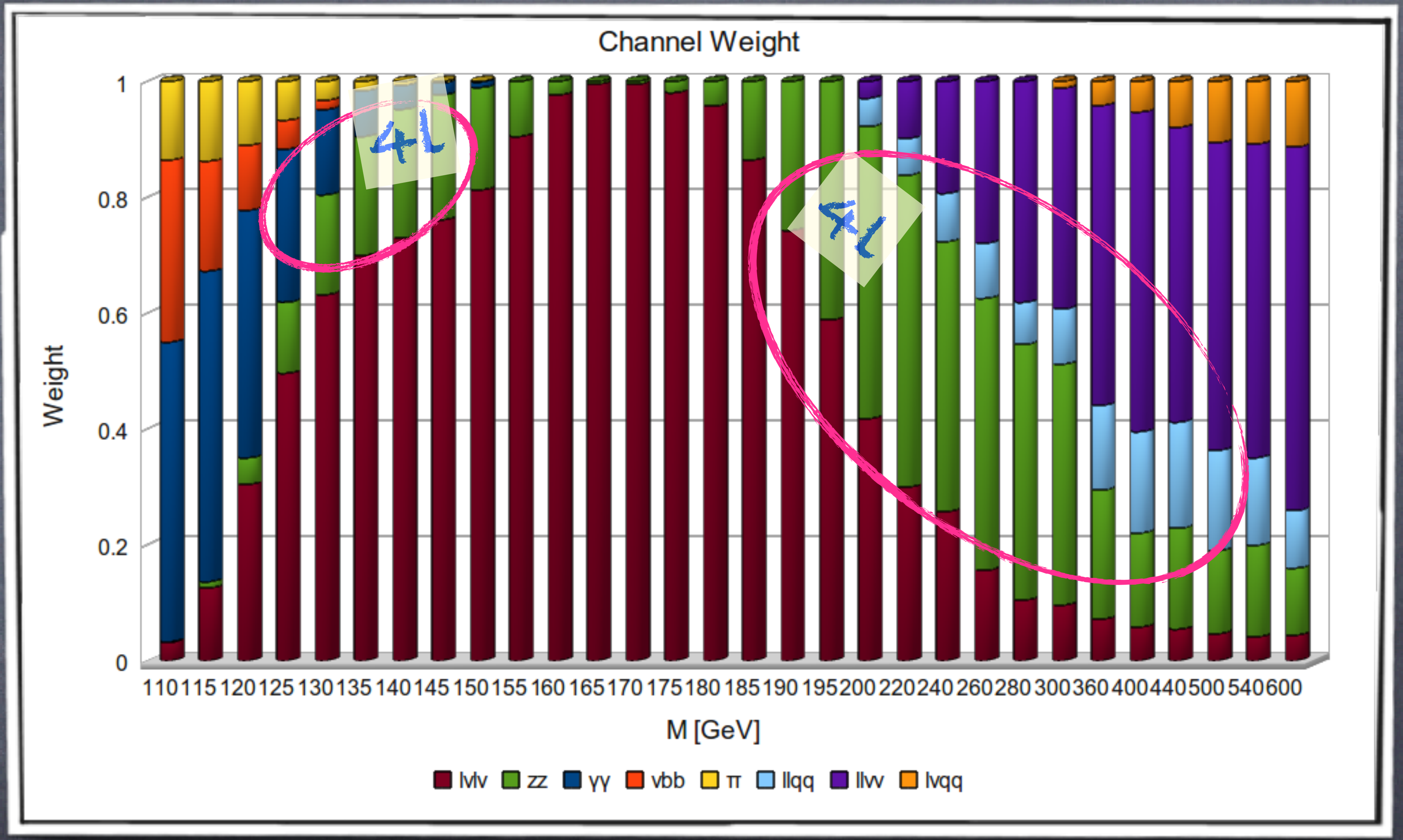
127 130



- ATLAS excludes (4.7 fb^{-1}) $130<m_H<260$ GeV
  (exp 127-234 GeV)

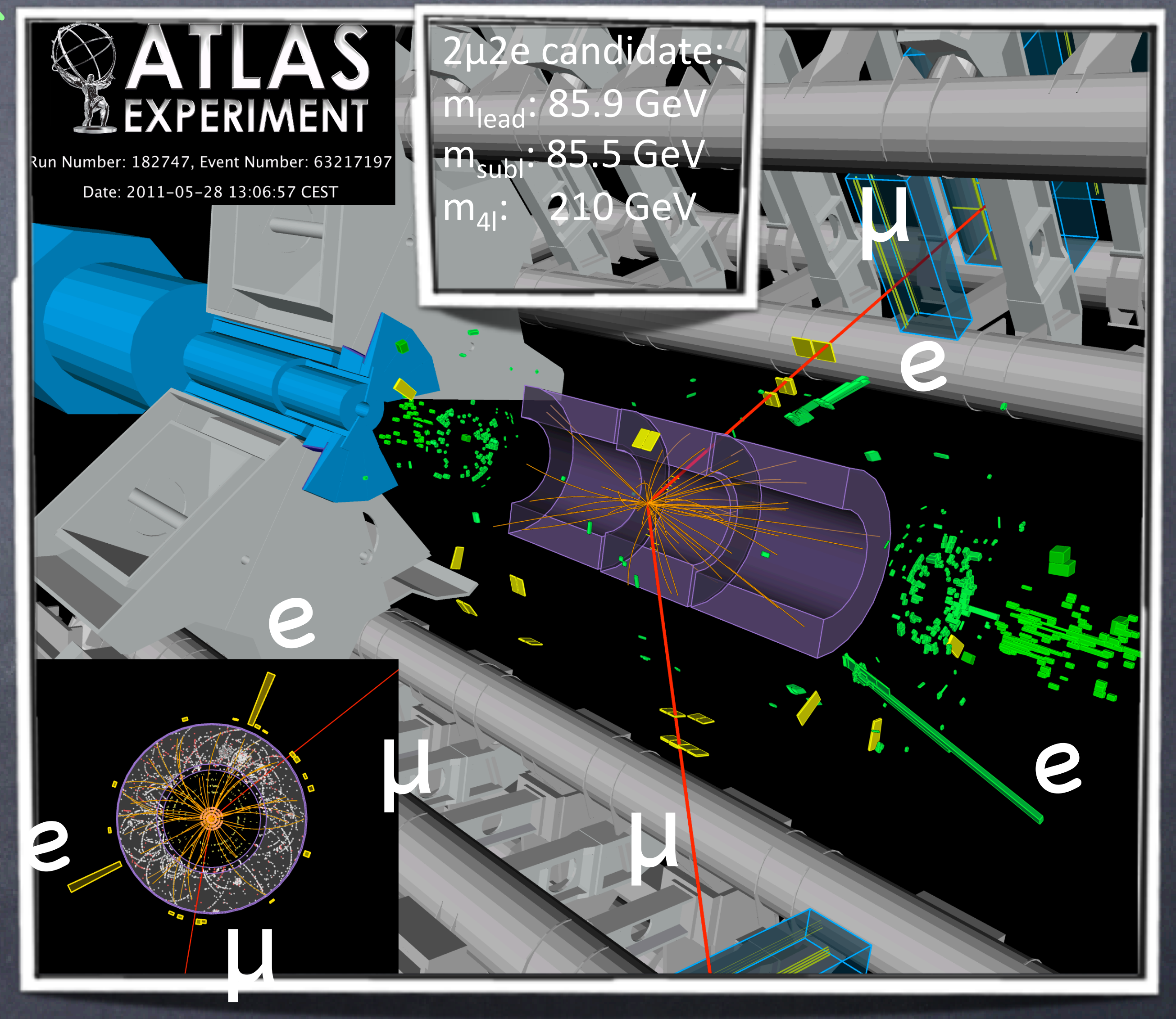
The Golden Channel - H->ZZ->4l

- Around 140 and above 200 GeV
- Probing channel: H->ZZ->4l



The Golden Channel: H->ZZ->4l

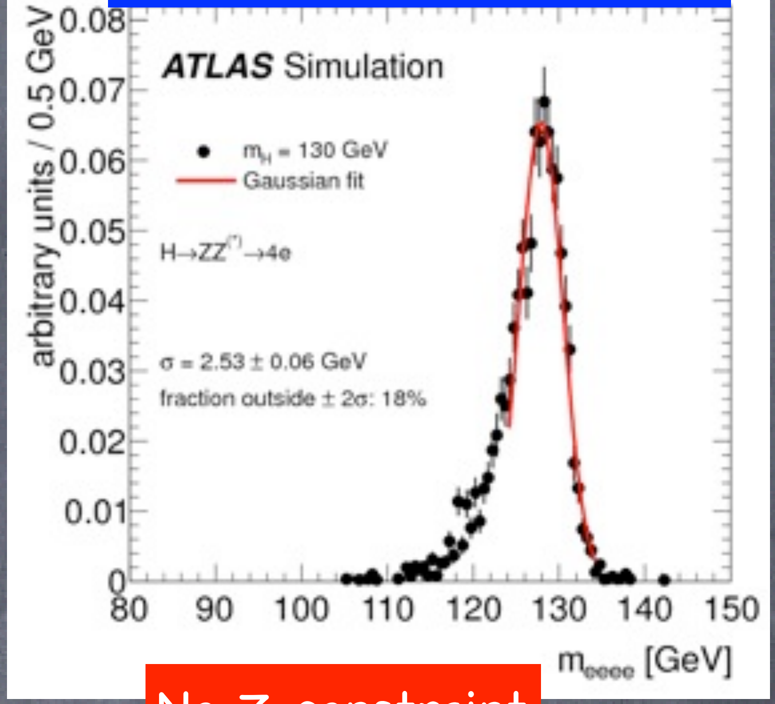
- CLEAN but very low rate (σ~2-5fb), yet probably most trustable
- All information is available, one can fully reconstruct the kinematics and the masses (m_{2l}, m_{4l})
- Signature: Two pairs of same flavor high pT opposite charged isolated leptons, one or both compatible with Z ->narrow peak
- Main backgrounds:
  - ZZ* (irreducible)
  - for $m_H<2m_Z$, Zbb, Z+jets, tt
- Suppress backgrounds with isolation and impact parameters cuts on two softest leptons



H->ZZ->4l experimental aspects

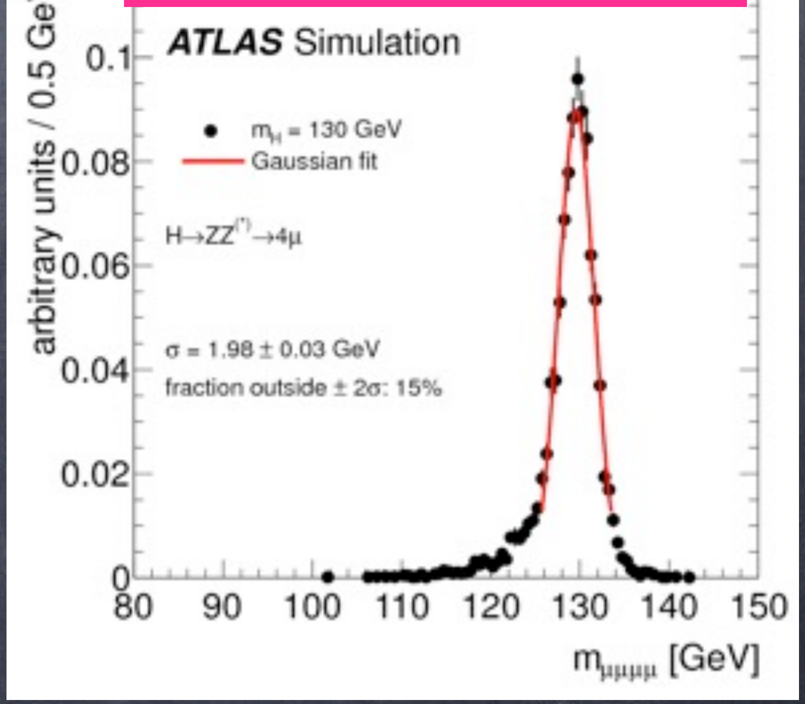
- Highly sensitive to lepton reconstruction and identification efficiency down to low momenta
- High electron efficiency (90-98%) from J/Ψ->ee, W->eν, Z->ee data
- Muon reconstruction efficiency >95%
- Z+jets (Z+bb) & tt BG estimated from data
- Reducible BG: tt, Zbb removed by isolation and small impact parameter (for $m_{4l}<2m_Z$) requirements

H->4e σ=2.5 GeV
82% of events within 2σ



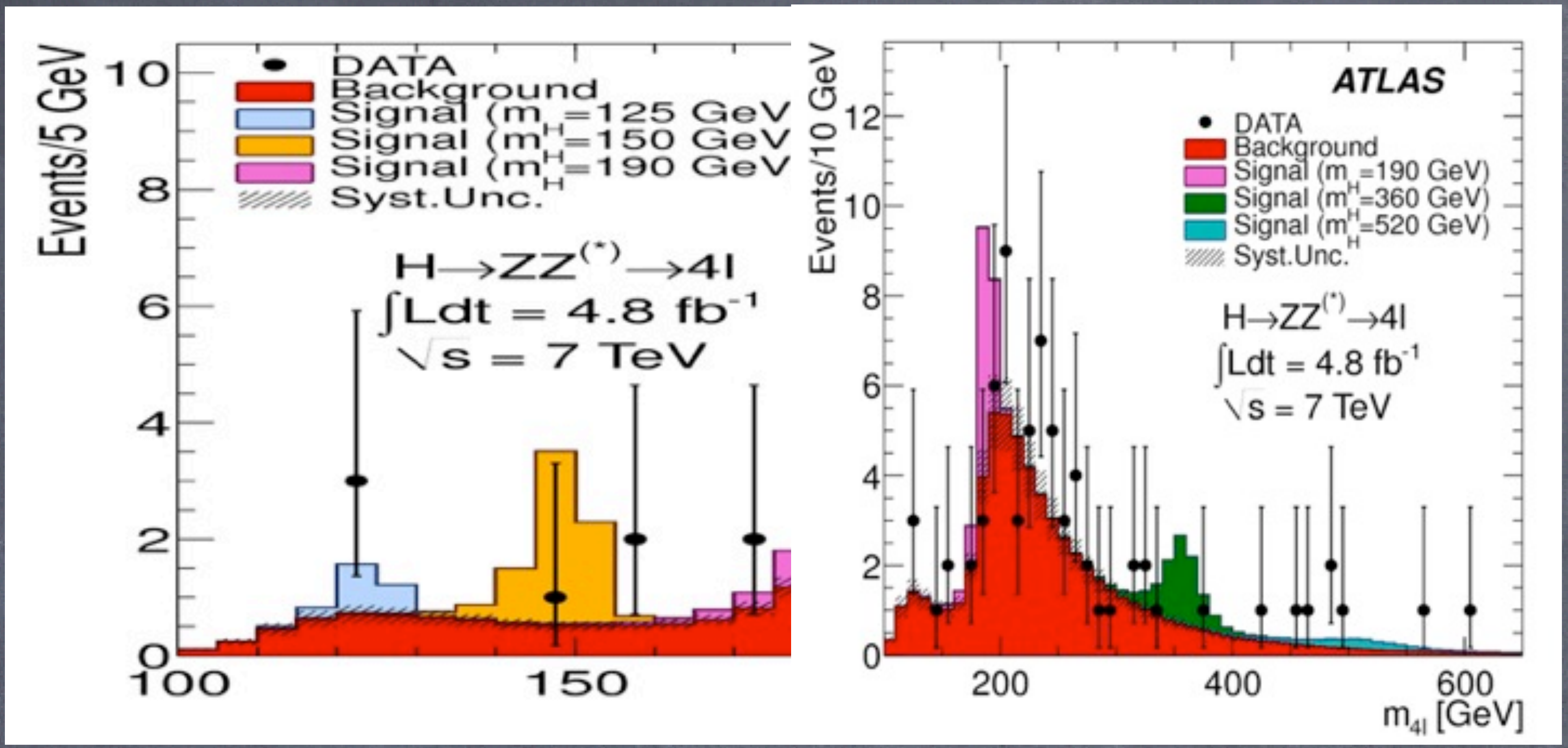
No Z constraint

H->4μ σ=2 GeV
85% of events within 2σ



H->ZZ->4l Results I

Low mass range (<180): Observed: 8 events,
3 4μ+
3 2e2μ+2 4e
Expected 9.3+-1.5

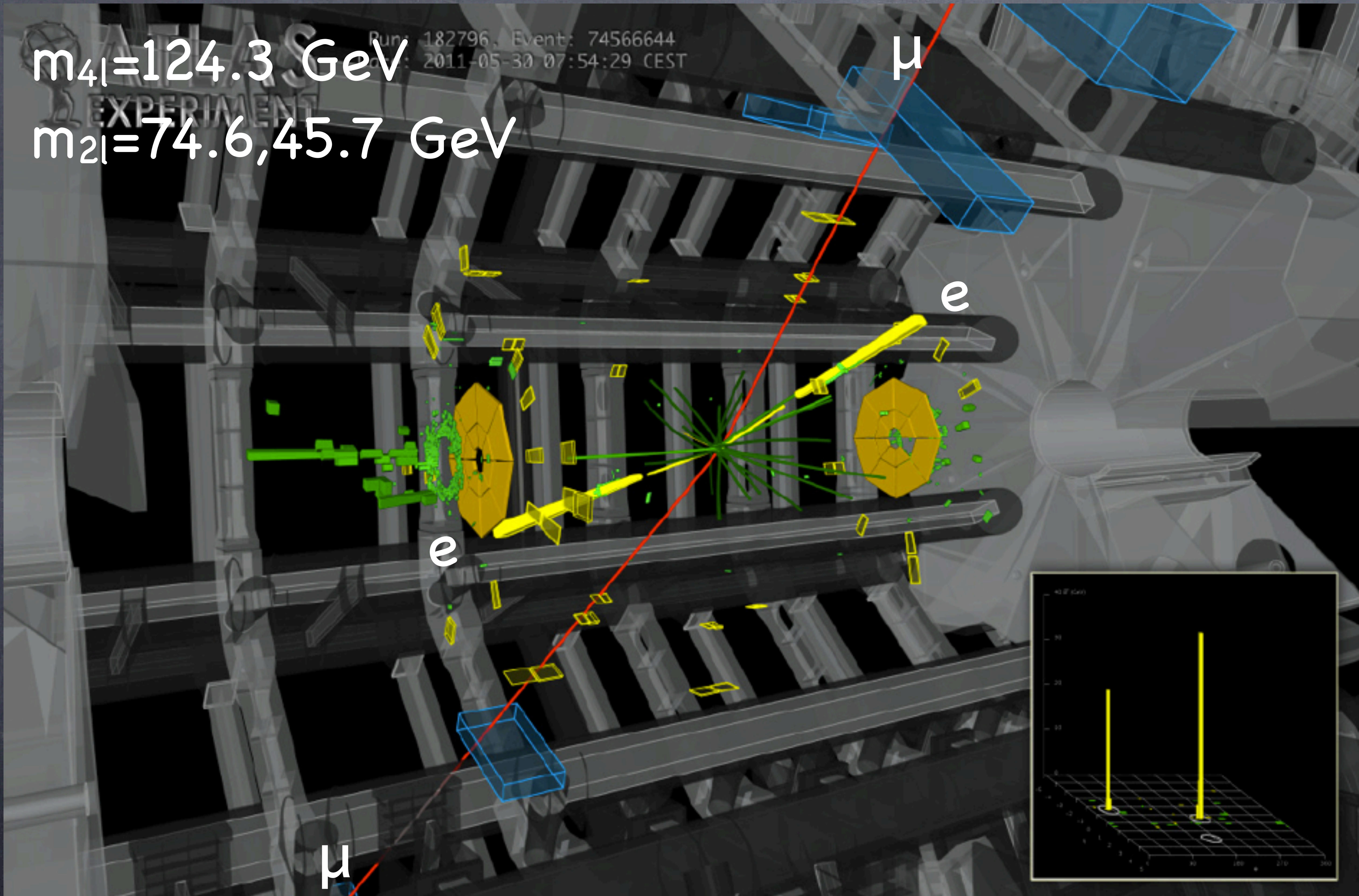


Full mass range: Observed: 71 events,
24 4μ+
30 2e2μ+
17 4e
Expected 62+-9

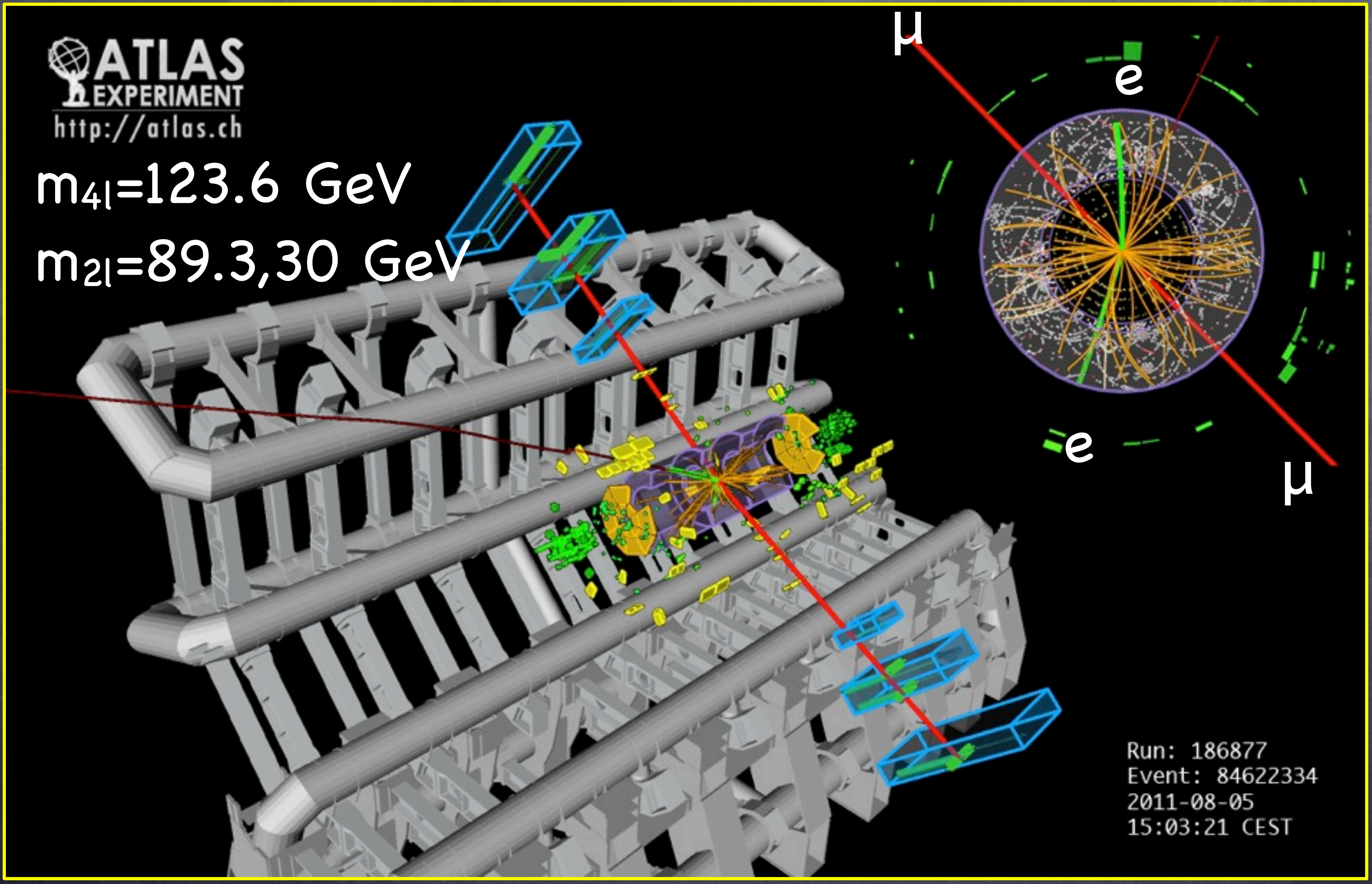
- In the interesting low mass region ATLAS observe 3 events, two 2e2μ (m=123.6,124.3 GeV) and one 4μ (m=124.6)
- In the region around 125 GeV (+-2σ) expect 1.5 BG evens from ZZ* (4μ,4e and 2e2μ) and Z+jets (4e)
- Expected m_H=125 GeV signal is 1.5 events with S/B~2(4μ),1(2e2μ) and 0.3(4e)

Main Systematic Uncertainties	
Higgs cross section	<2%
Zbb,Z+jets BG	40-45%
ZZ* BG	14%
E-efficiency	2-8%

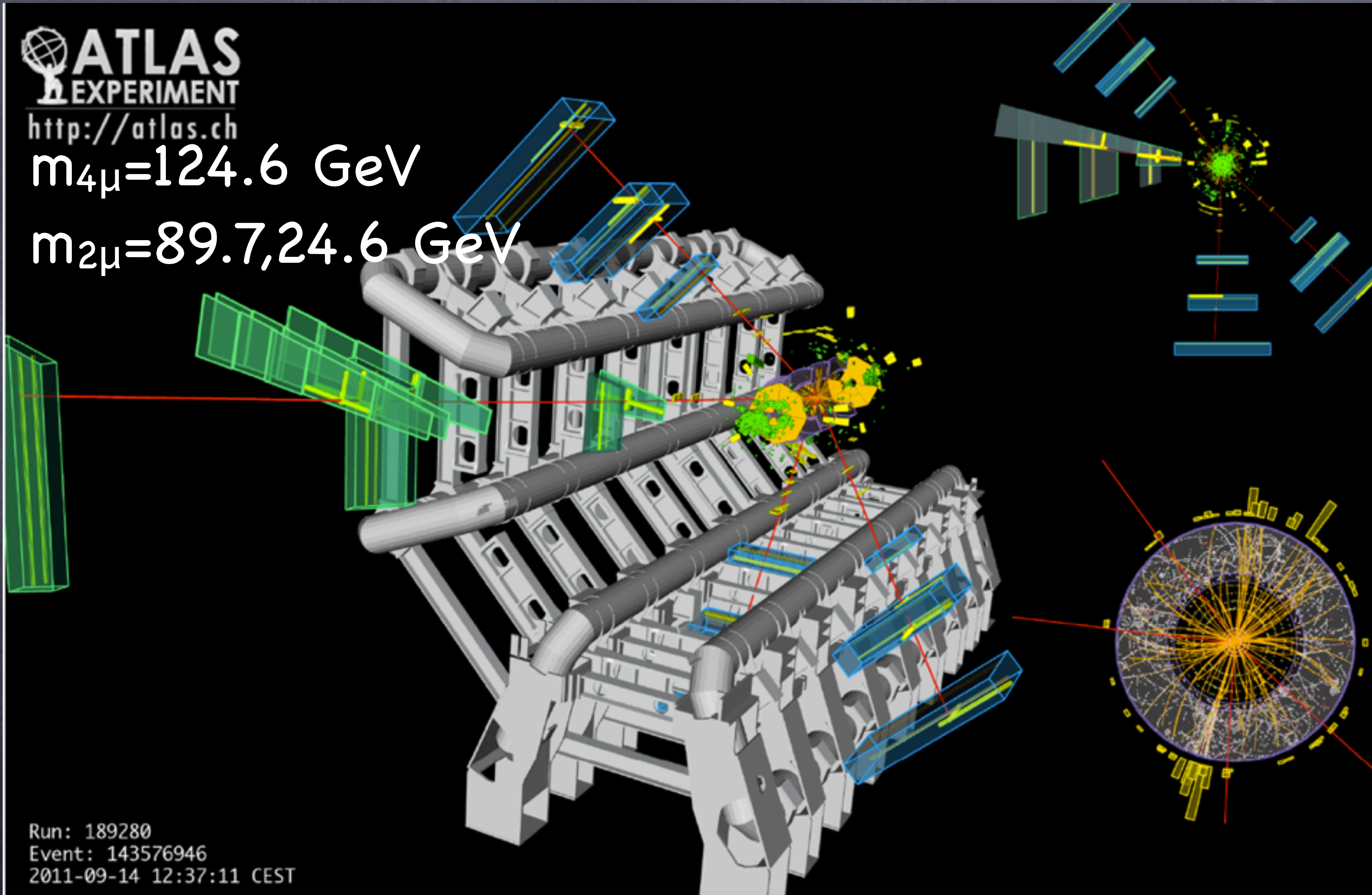
The Golden Channel: H->ZZ->4l



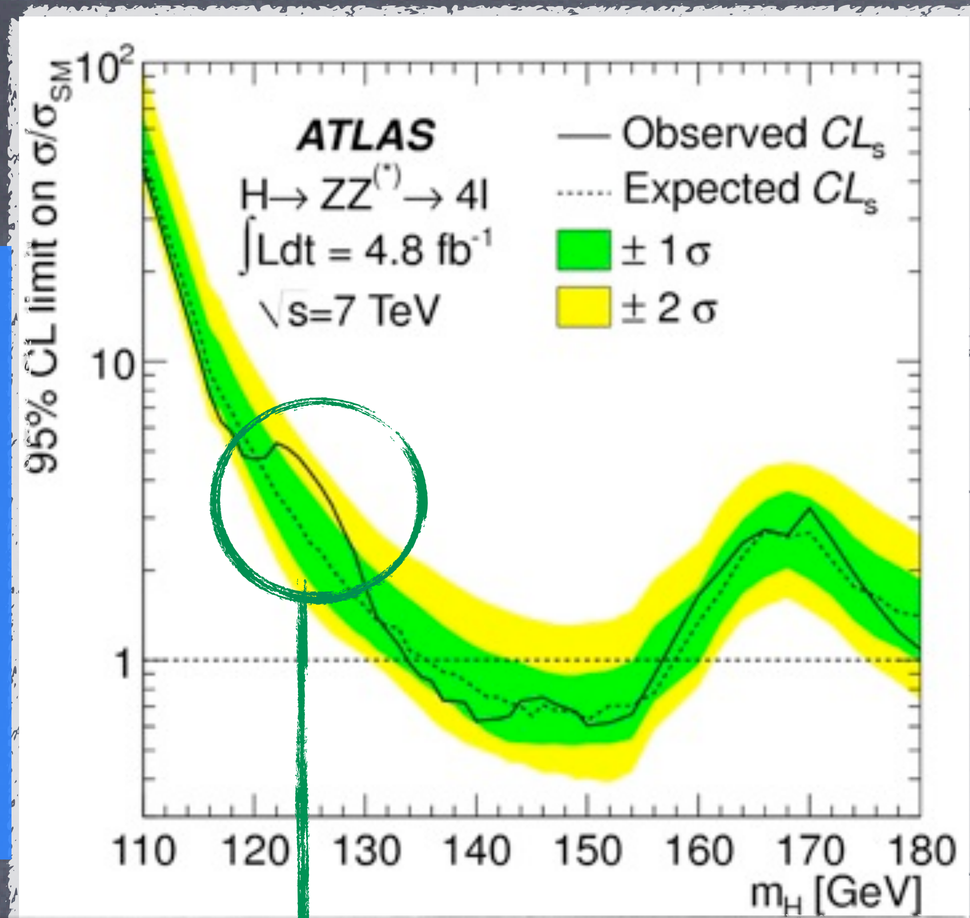
The Golden Channel: H->ZZ->4l

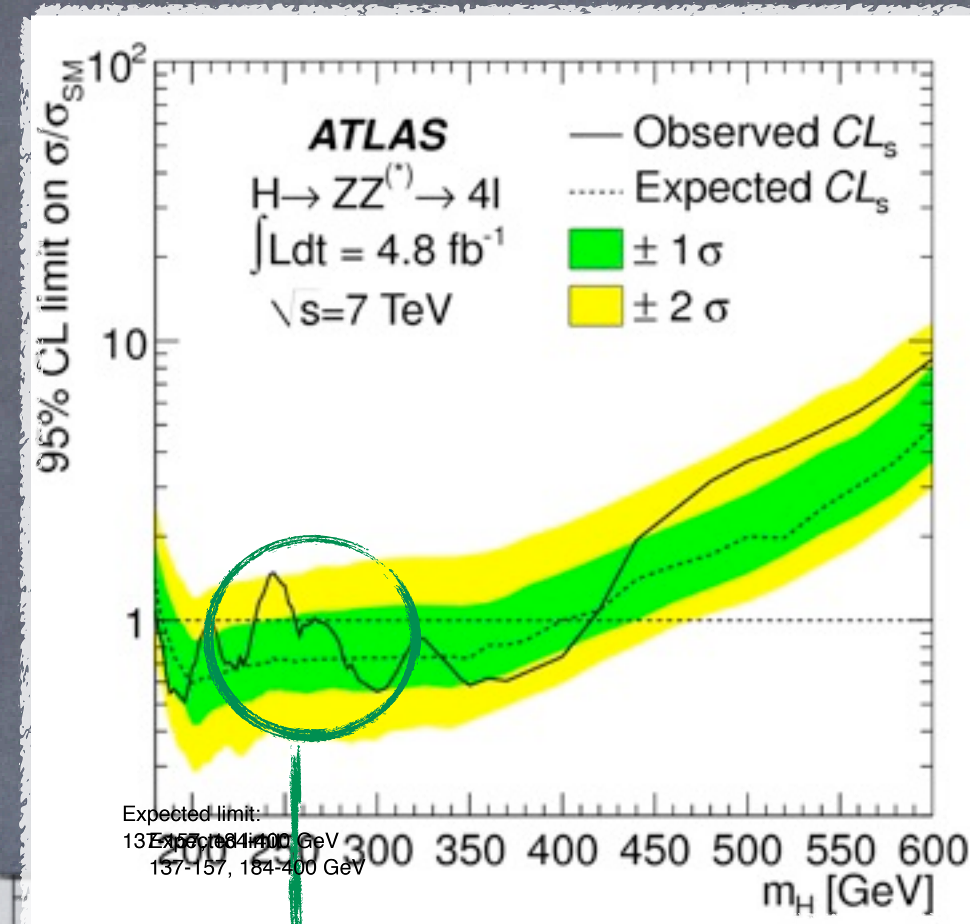


The Golden Channel: H->ZZ->4μ



H->ZZ->4l Limits





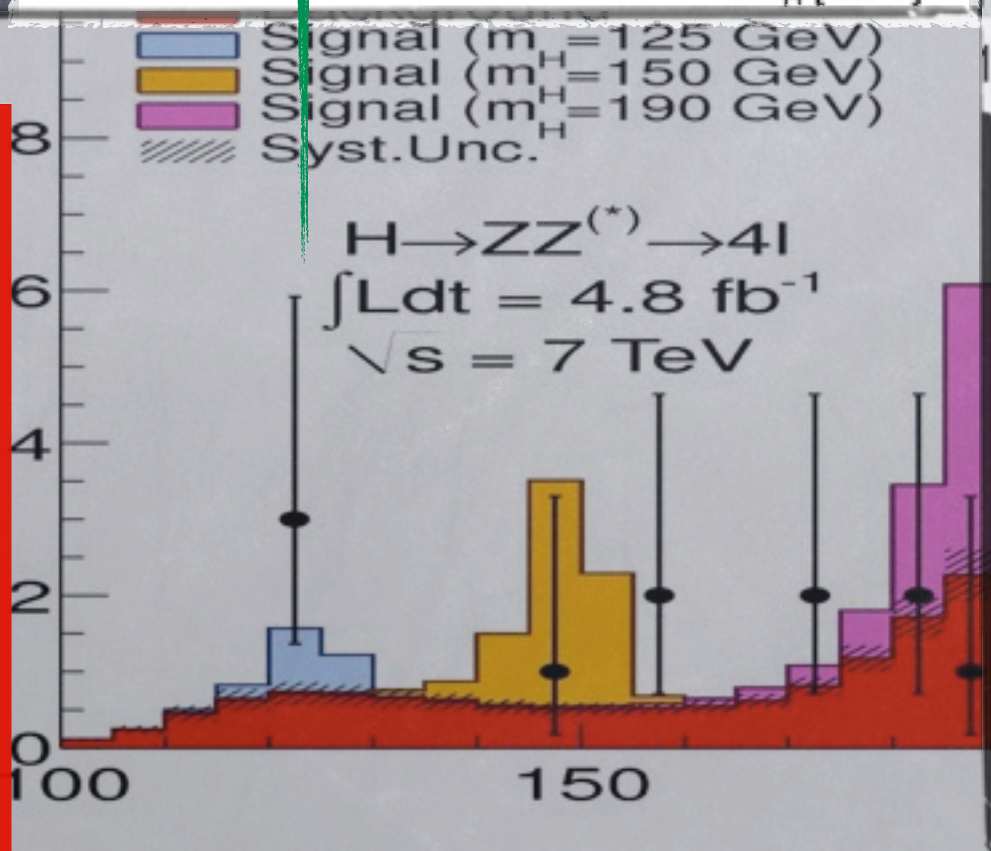
Expected Exclusion

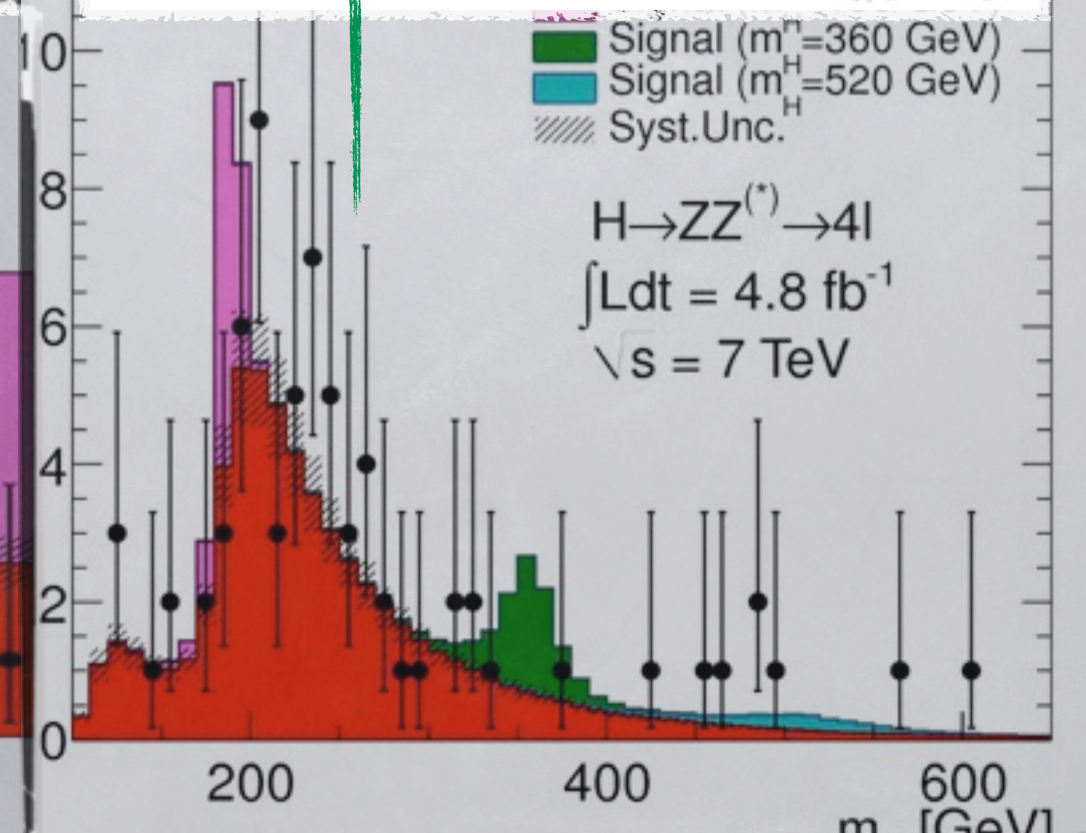
m_H=

137-157

184-400

GeV





Observed Exclusion

m_H=

134-156

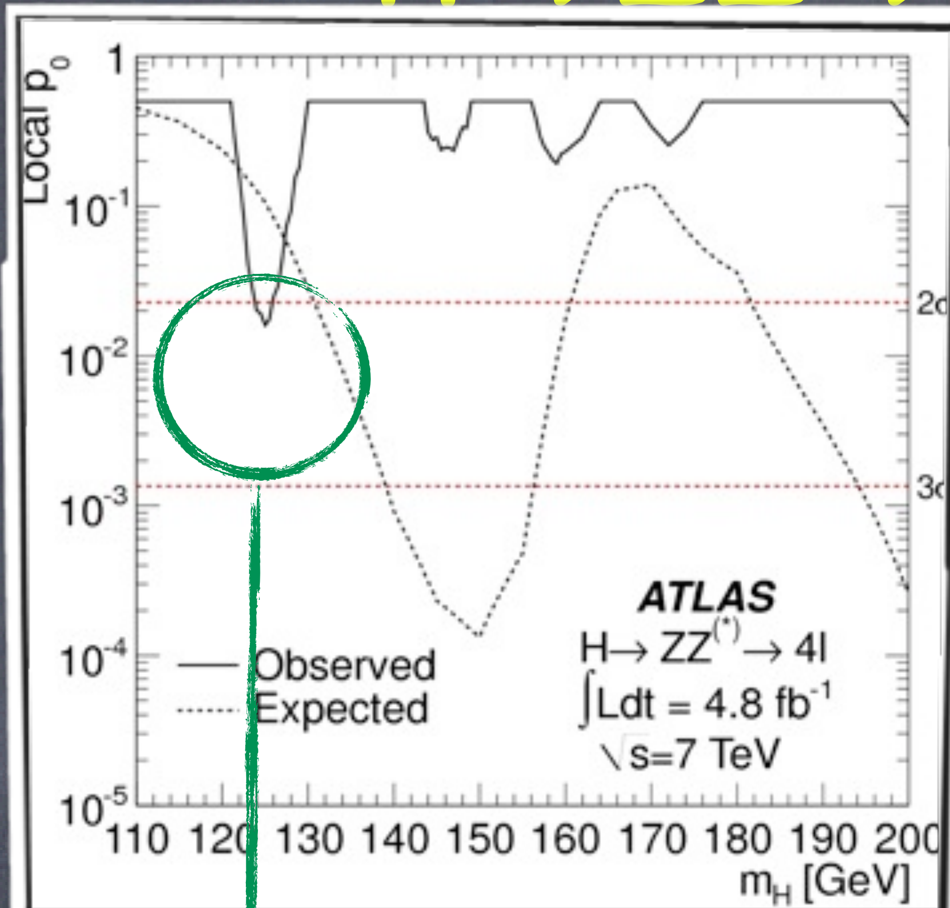
182-233,

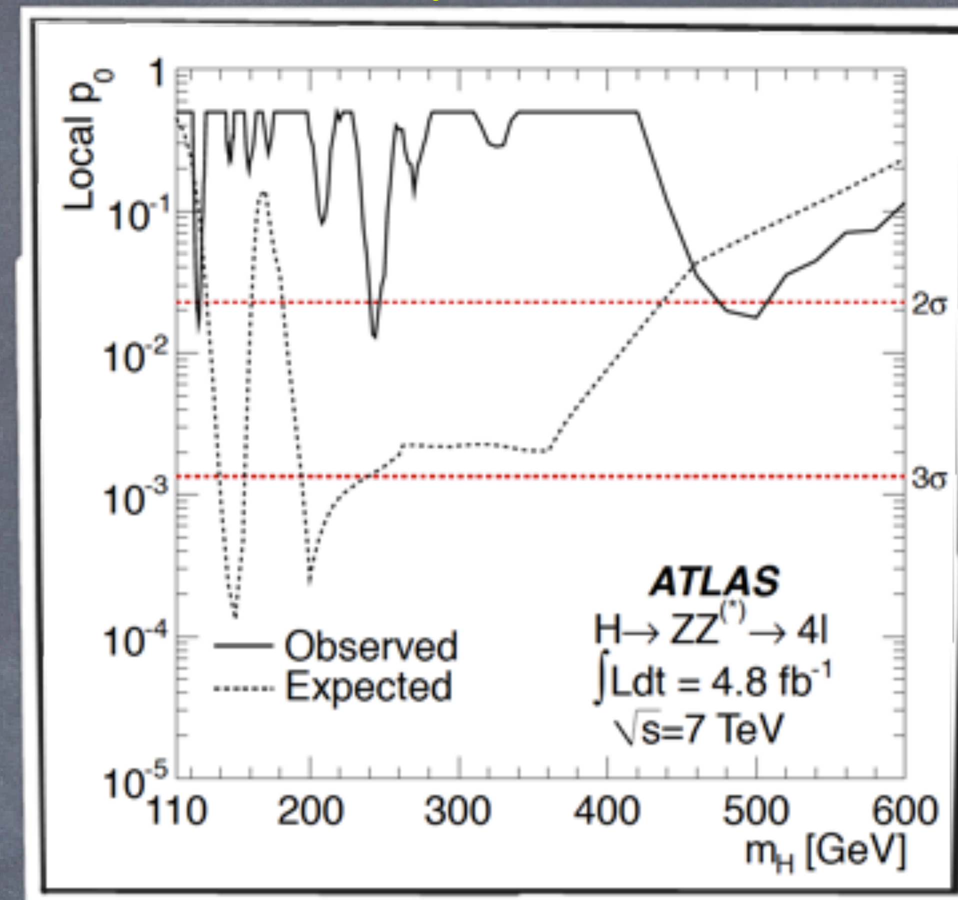
256-265

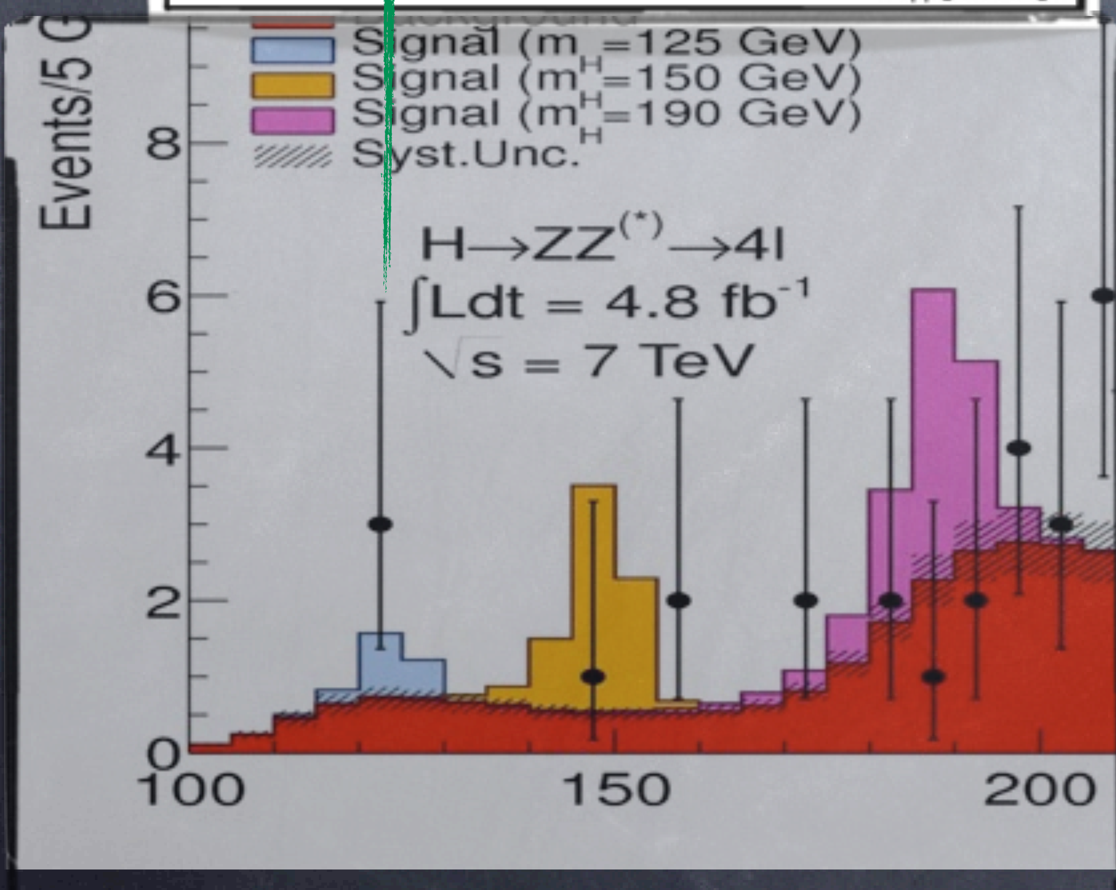
268-415

GeV

H->ZZ->4l ATLAS p_0





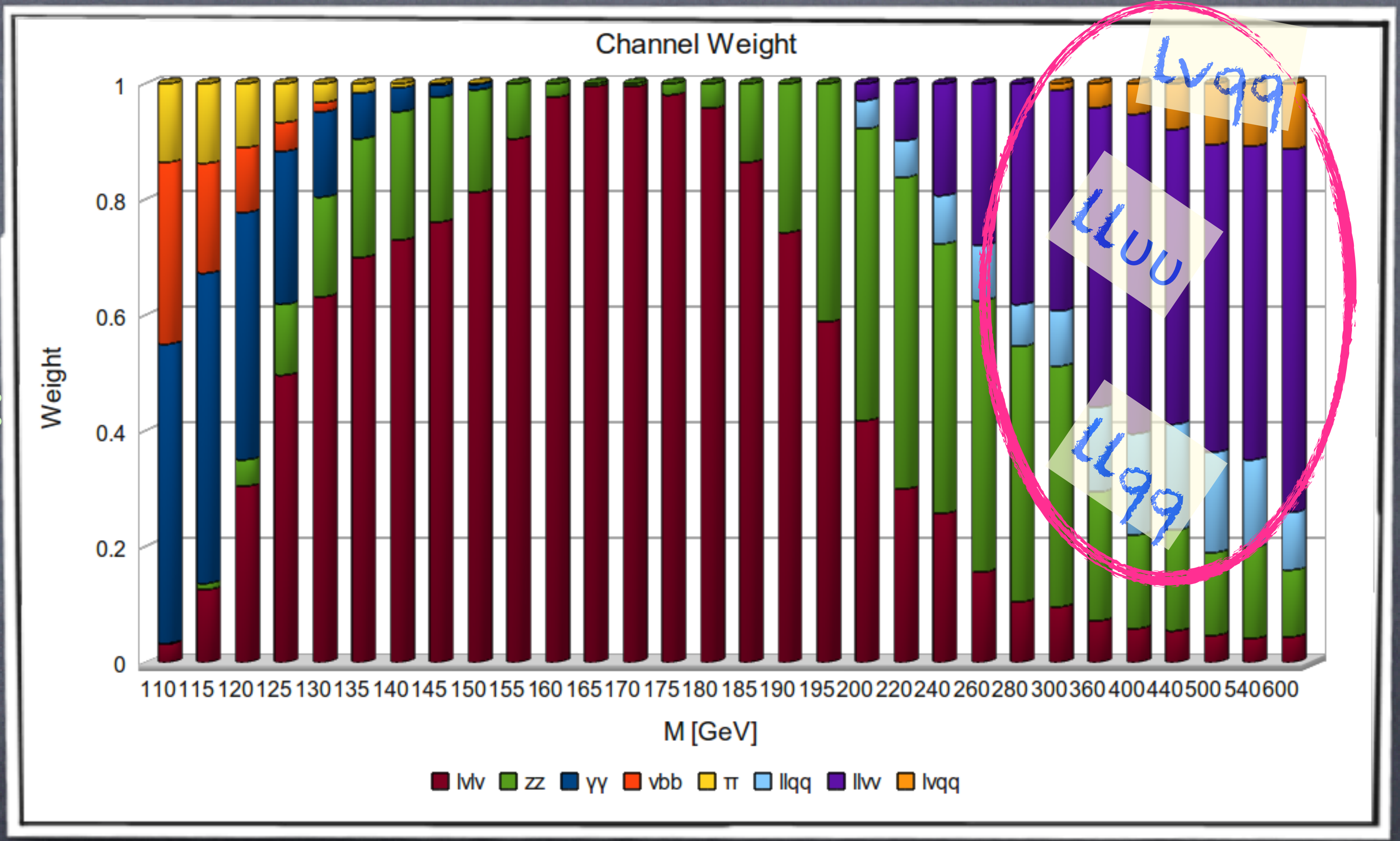


$m_{4\ell}$	125 GeV	244 GeV	500 GeV
Exp. w. signal	1.3σ	3.0σ	1.5σ
Observed	2.1σ	2.2σ	2.1σ

Look Elsewhere Effect is estimated over the full mass range to be O(50%)

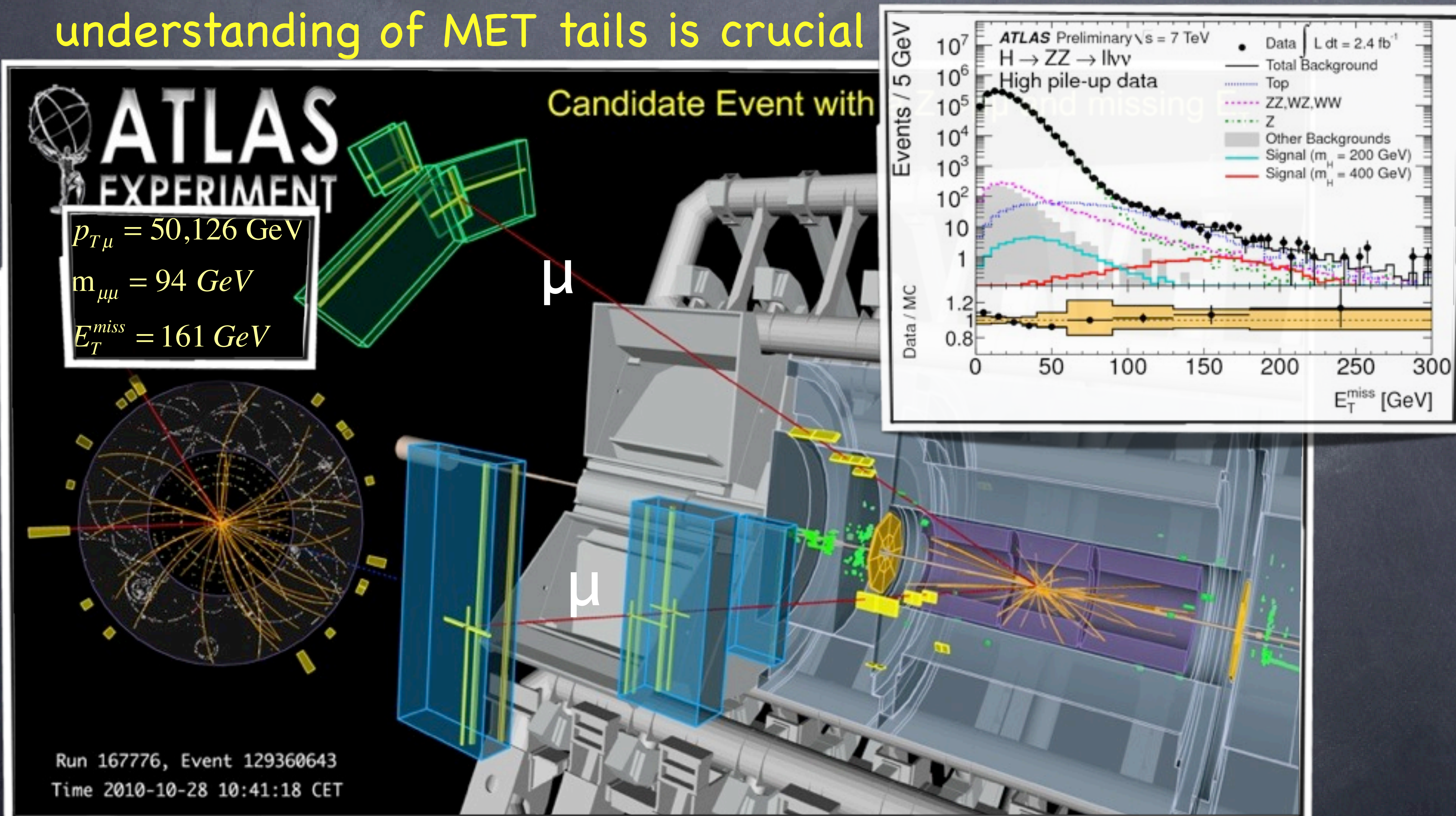
Heavy Higgses

- mH>300
- Probing channels:
  H->ZZ->llvv
  H->ZZ->llqq
  H->WW->lvqq



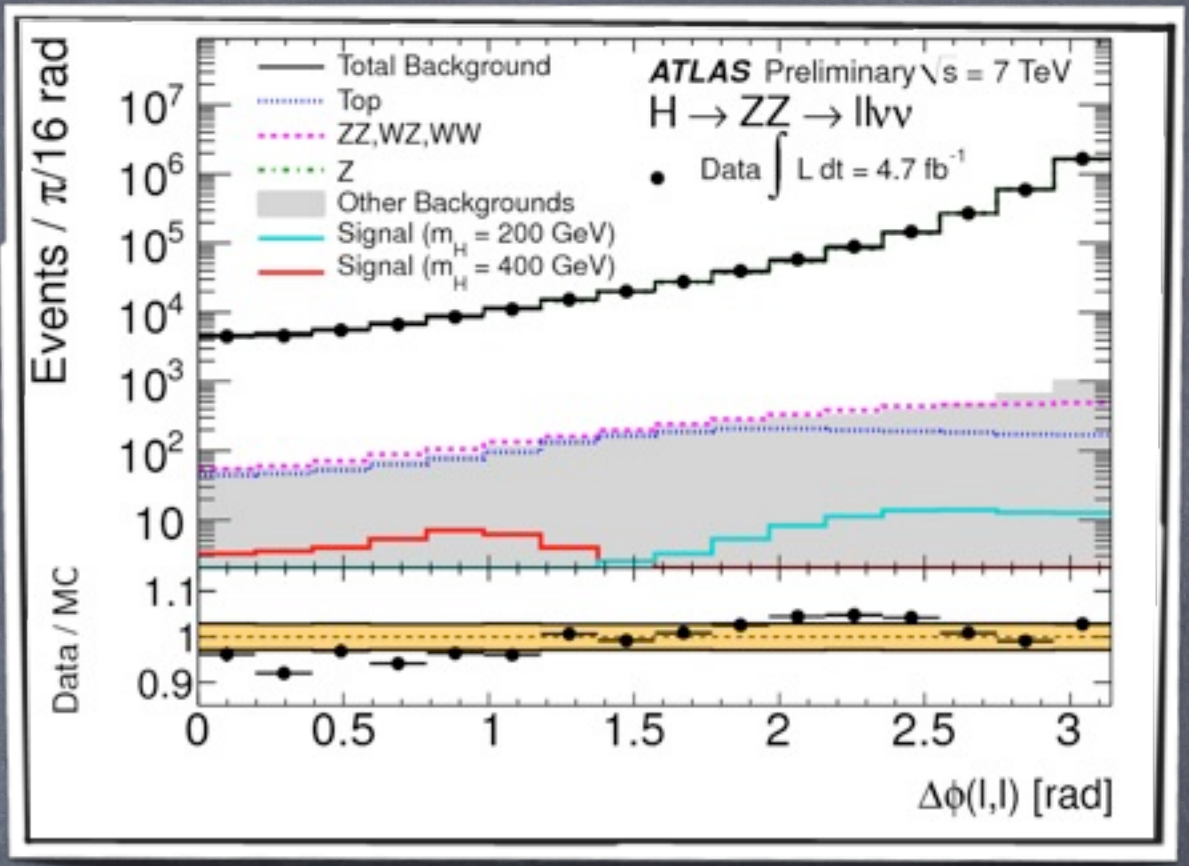
Heavier Higgs: H->llνν

- Signature: two high p_T opposite charged isolated leptons (with $m_{ll} \sim m_Z$) with high MET (both Z's are boosted for high m_H), understanding of MET tails is crucial



Heavier Higgs: H->llνν

- Main BG: irreducible di-Boson ZZ,WZ
- Reducible, measured or verified with data control samples: QCD, W/Z+jets (suppressed by MET) and top (rejected by anti b-tag)
- Discriminating variables: $\Delta\Phi_{ll}$,MET

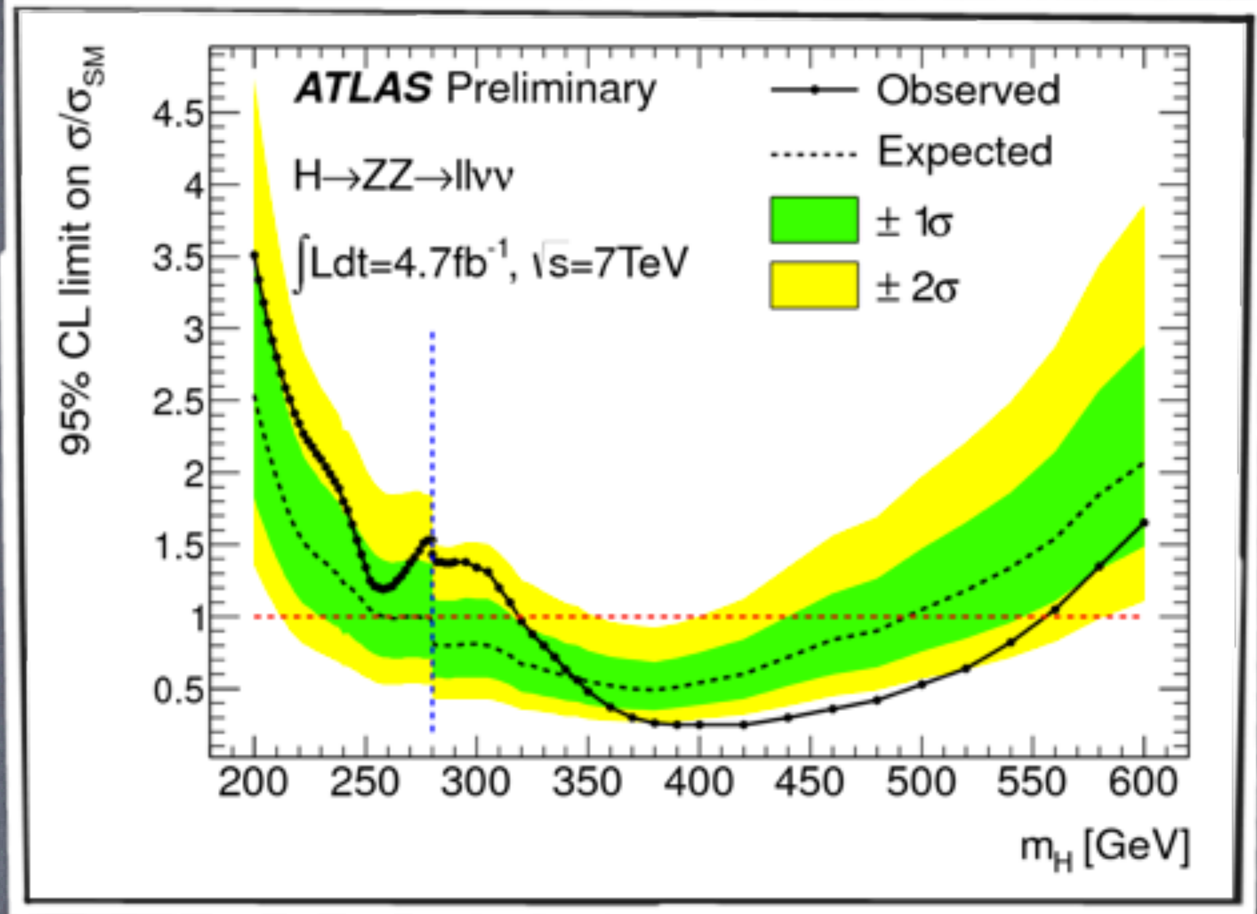


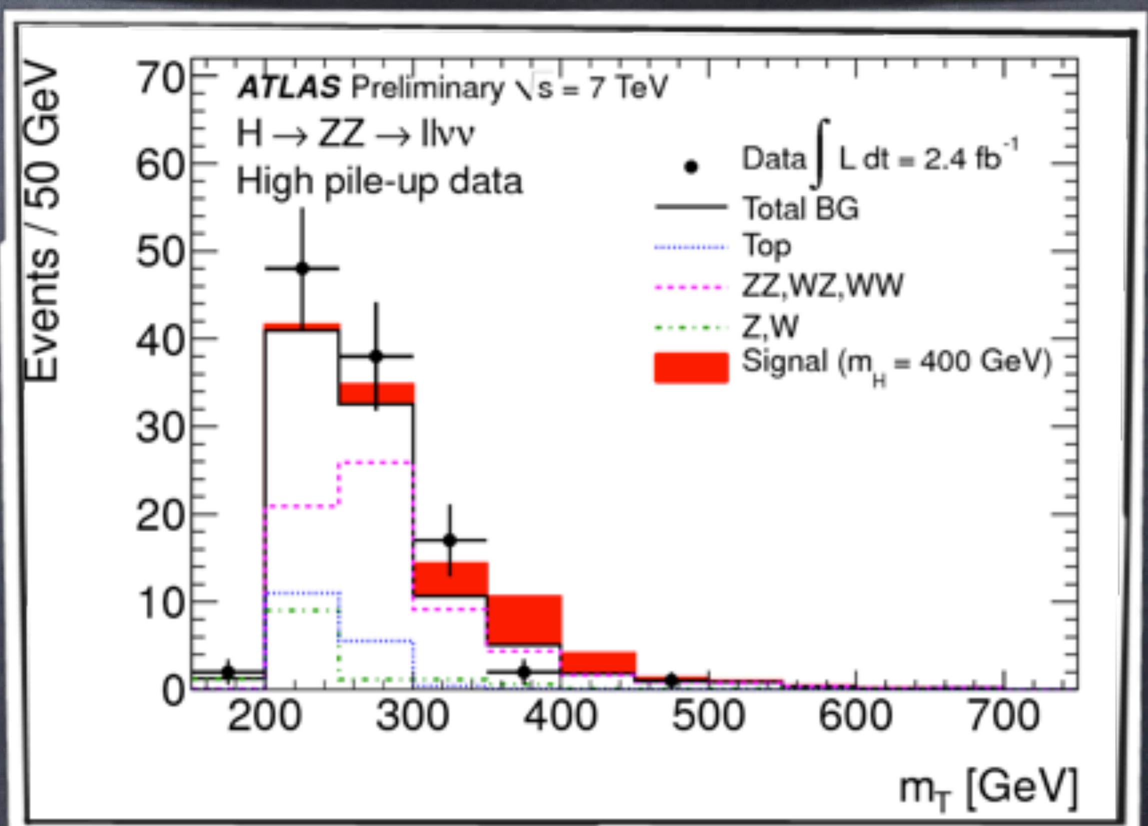
Heavier Higgs: H->llνν

- Transverse mass
  (two mass bins [≶280 GeV])

$$m_T^2 \equiv \left(\sqrt{\vec{p}_{TZ}^{\,2} + m_Z^2} + \sqrt{|\,\vec{p}_T^{\,miss}\,|^2 + m_Z^2}\right)^2 - (\vec{p}_{TZ} + \vec{p}_T^{\,miss})^2$$

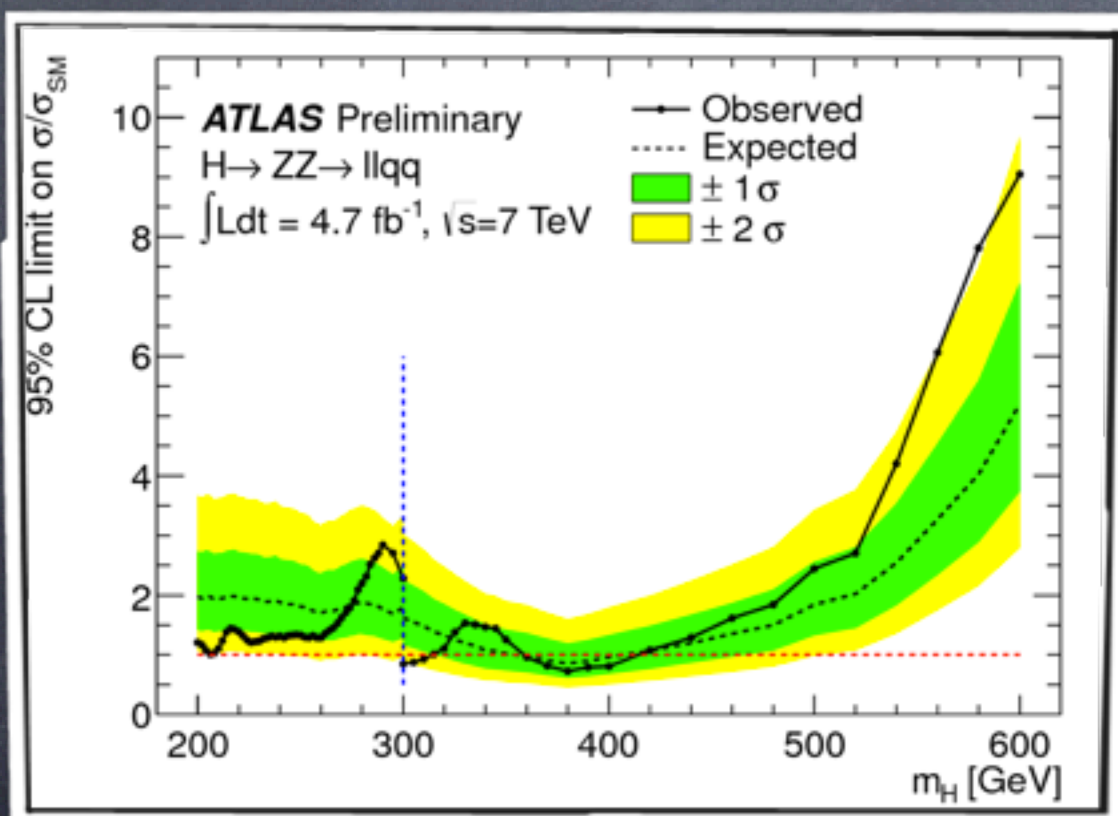
Obs: excl 350<mH<450
Exp: excl 260<mH<490

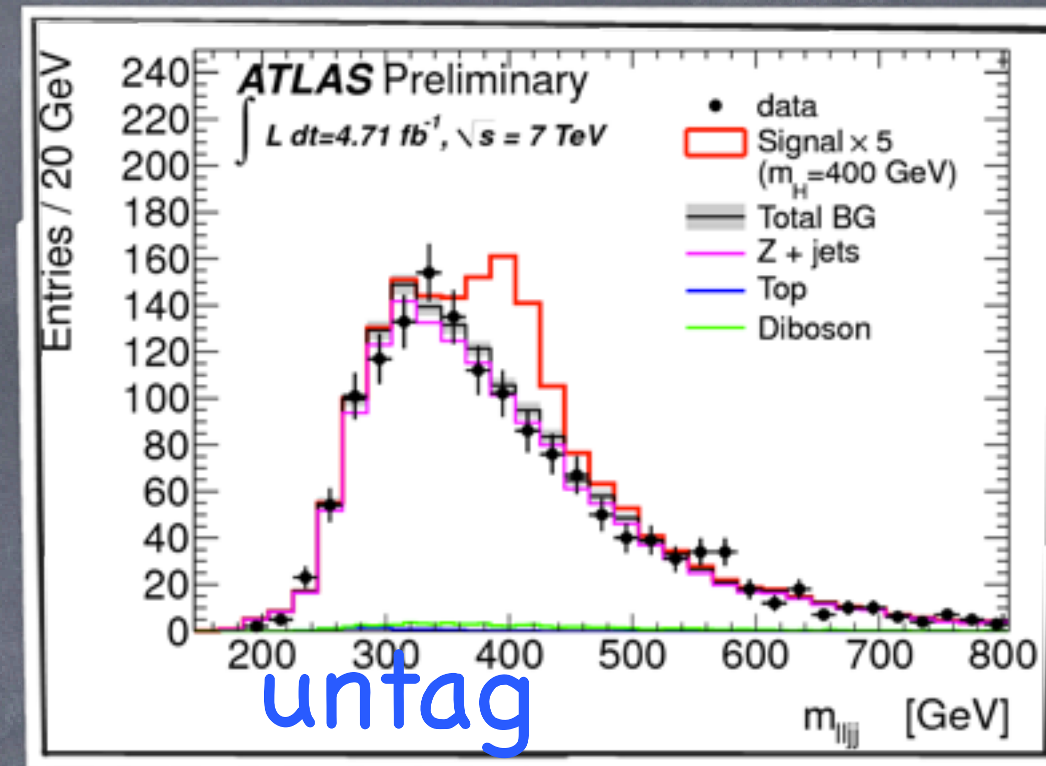


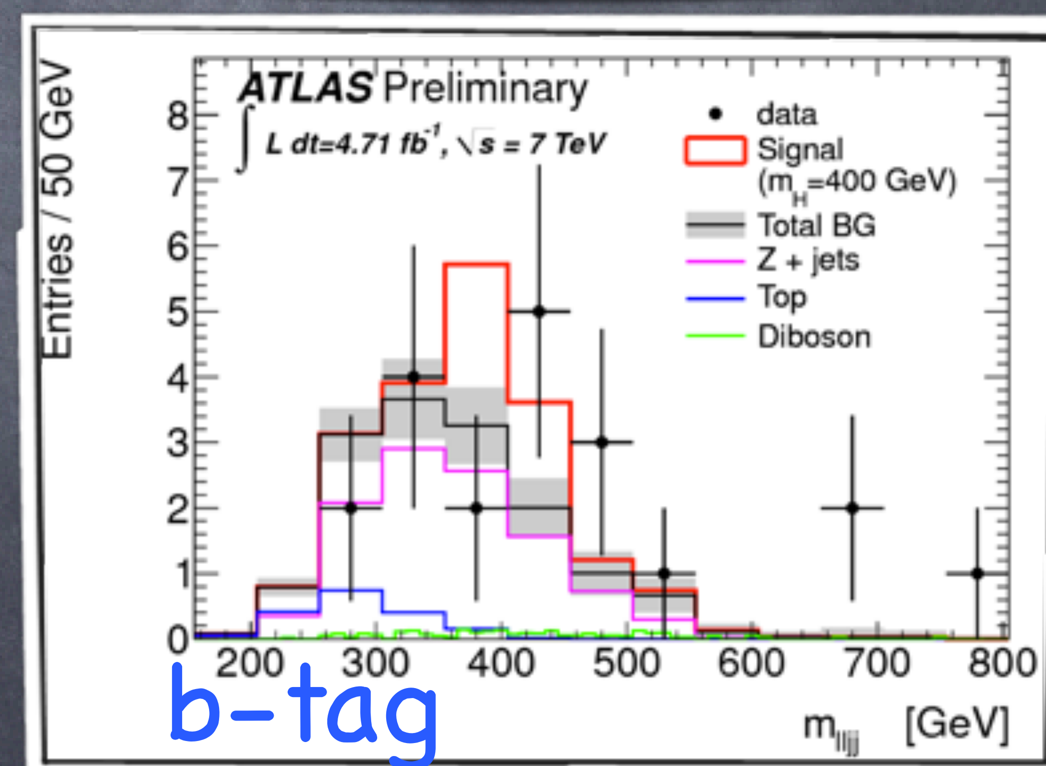


Heavier Higgs: H->llqq,llbb

- Highest rate, yet high Z+jets BG
- Clear signature:
  Exactly one pair of oppositely charged same flavor leptons and a pair of jets.
  both pairs compatible with a Z boson. Low MET
- Discriminating variable m_{lljj}



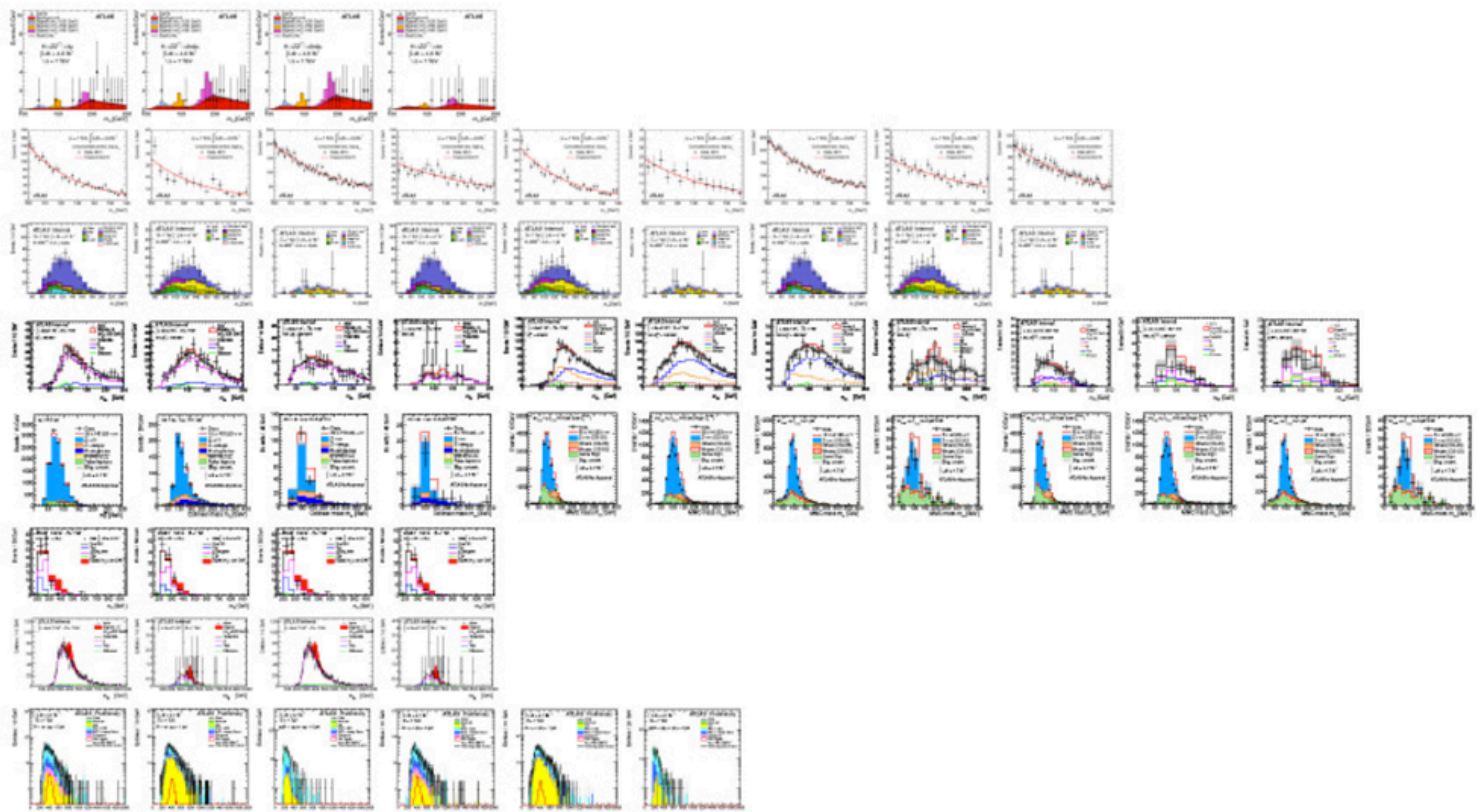




Obs: excl 300<mH<310,
360<mH<400

Exp: excl 360<mH<400

All for one - Combine forces

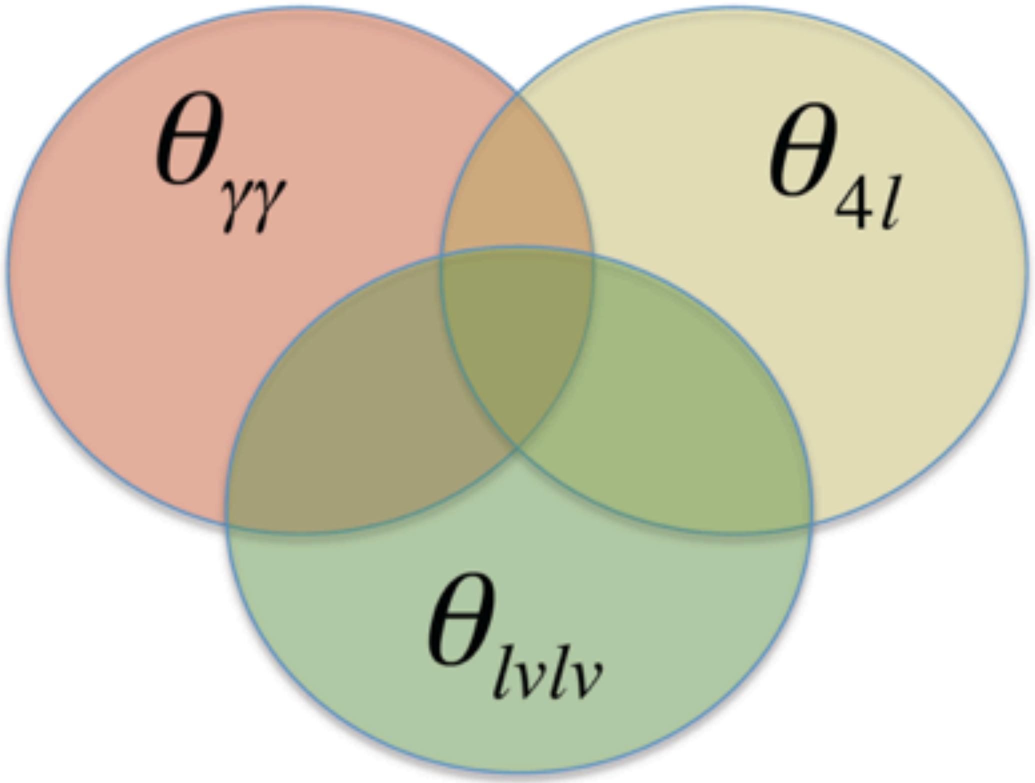


Disclaimer

- Correlated uncertainties (Jet energy scales, Luminosity etc... taken into account)
- When data driven methods are used, systematics are not correlated
- Theory uncertaintes are carefully taken into account across channels using the recommendation of the LHC cross section group

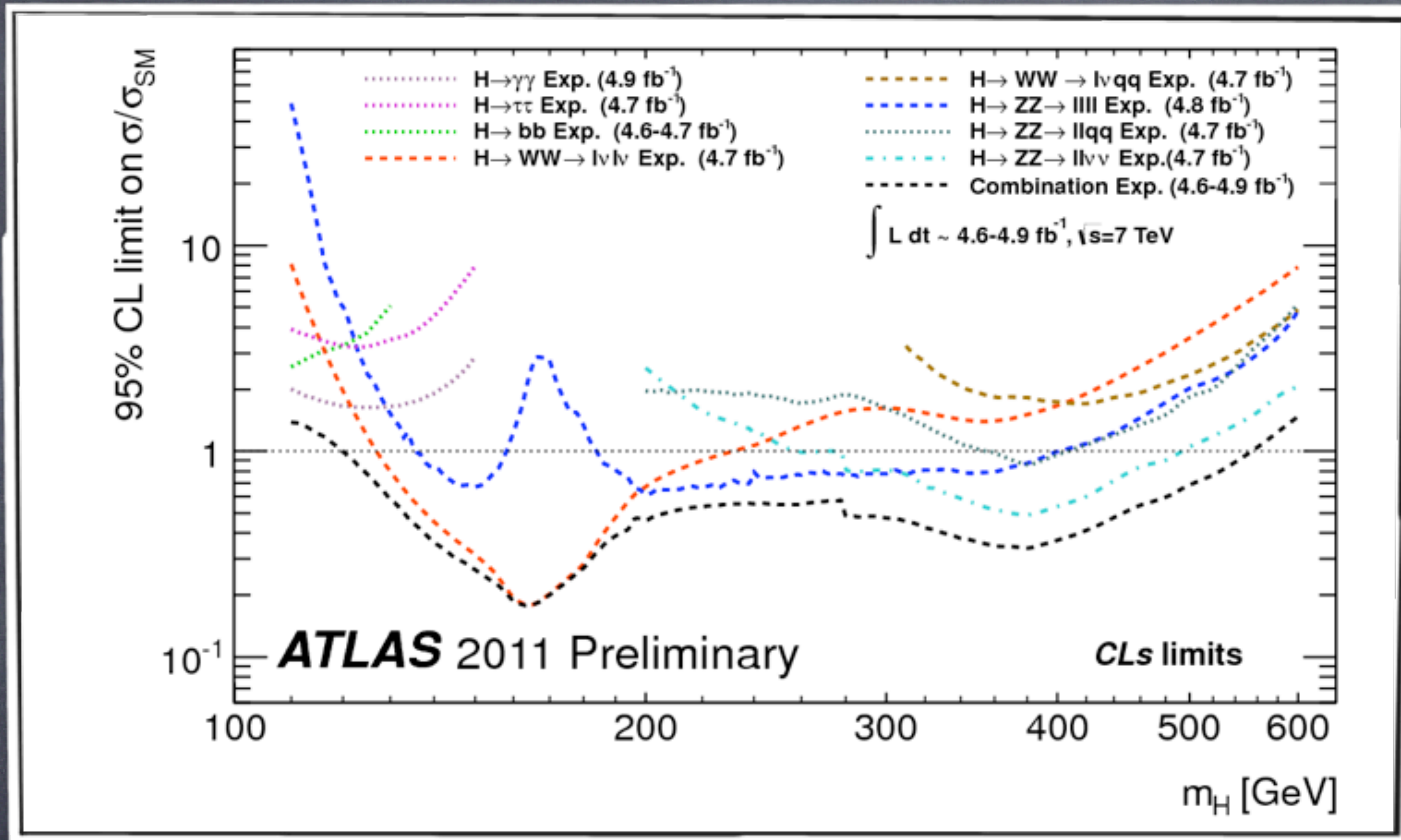
Combination : Use Correlations with Caution

$$L_{Combined}(\mu,\theta) = L_{\gamma\gamma}(\mu,\theta_{\gamma\gamma}) \times L_{4l}(\mu,\theta_{4l}) \times L_{l\nu l\nu}(\mu,\theta_{l\nu l\nu}) \times L_{\tau\tau}(\mu,\theta_{\tau\tau})$$



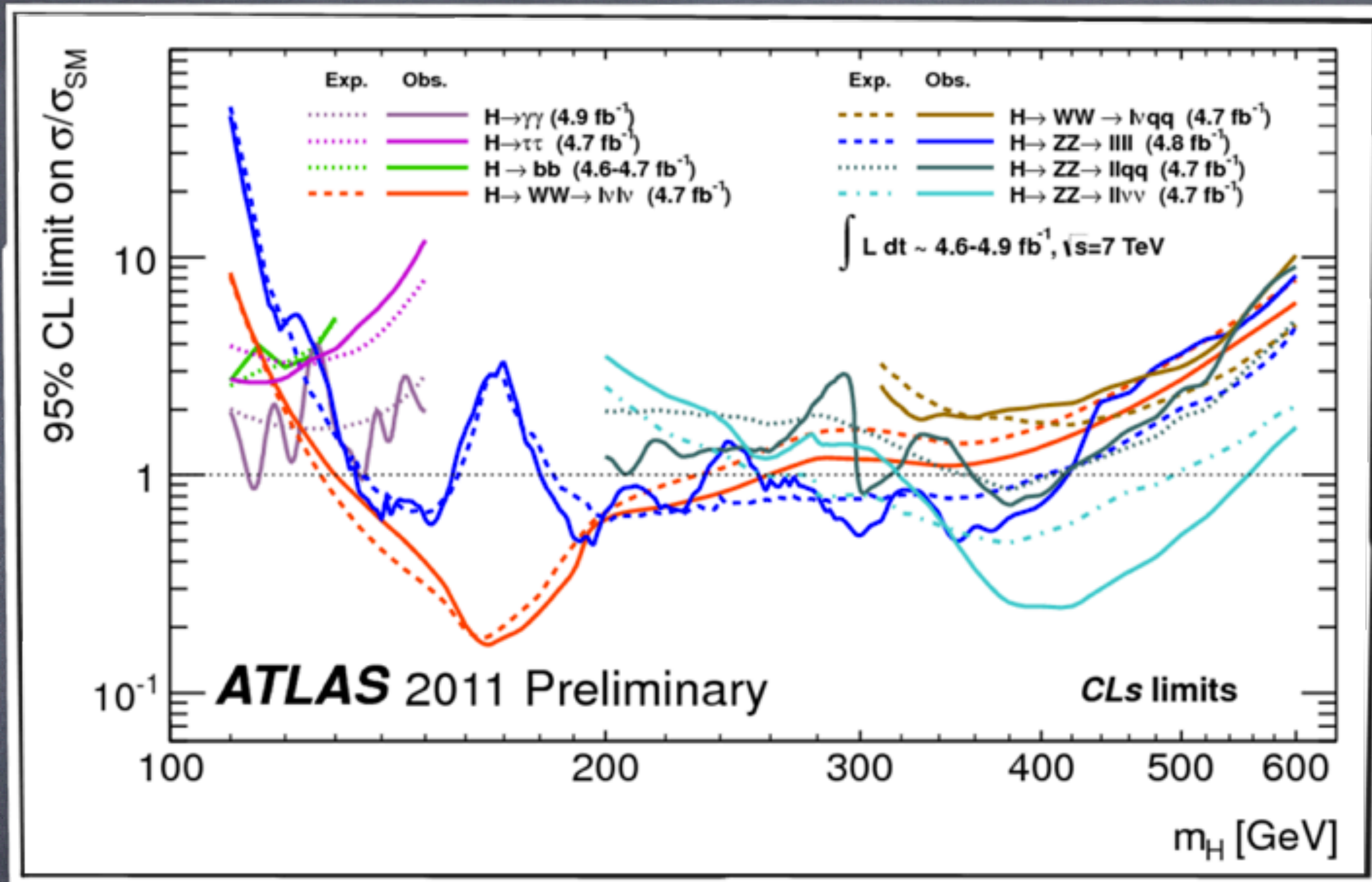
Need to very carefully check the interplay between correlated systematics...

Combined Limit



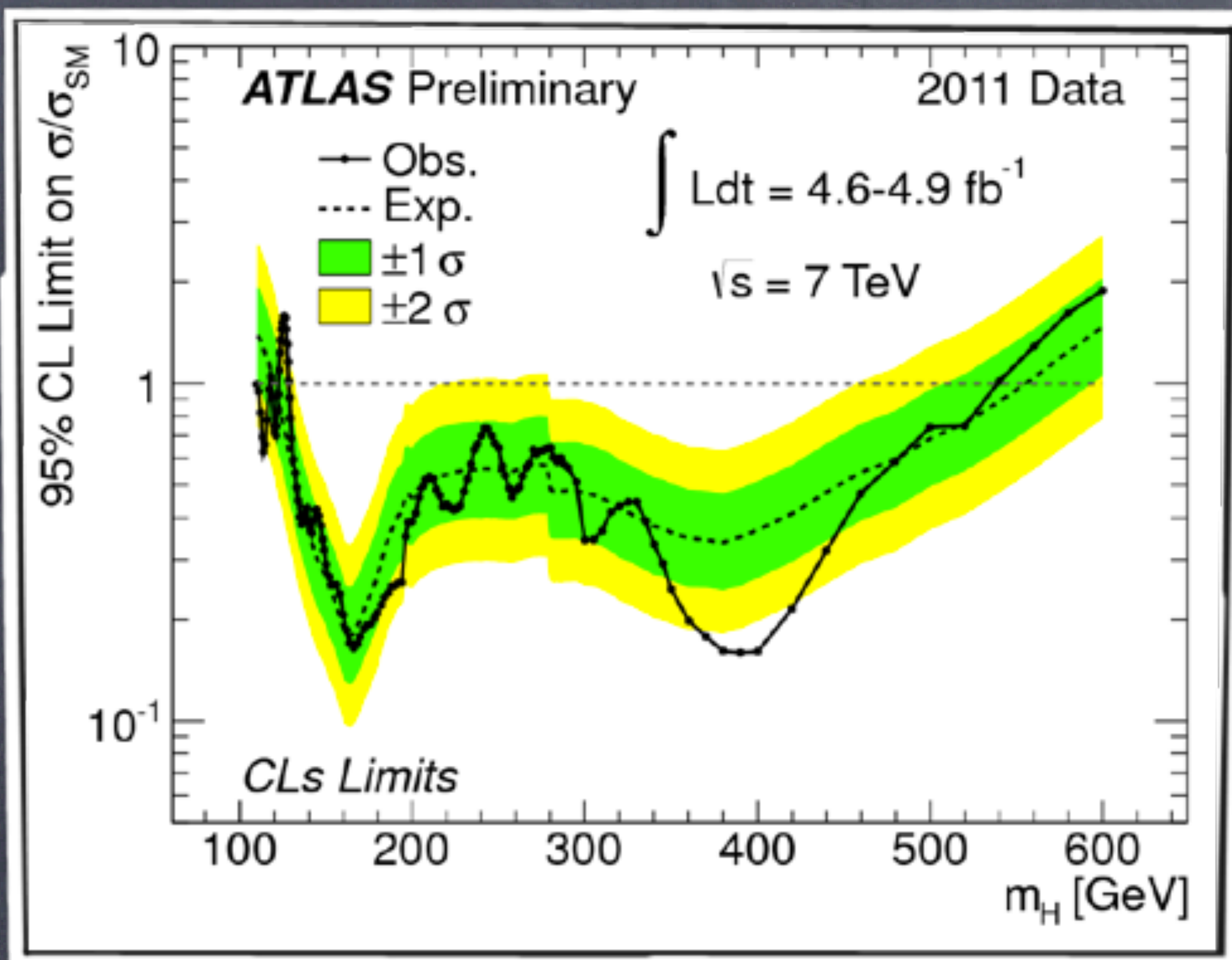
- Low mass is completely dominated by γγ, then ττ, bb and WW
- High mass completely dominated by llνν

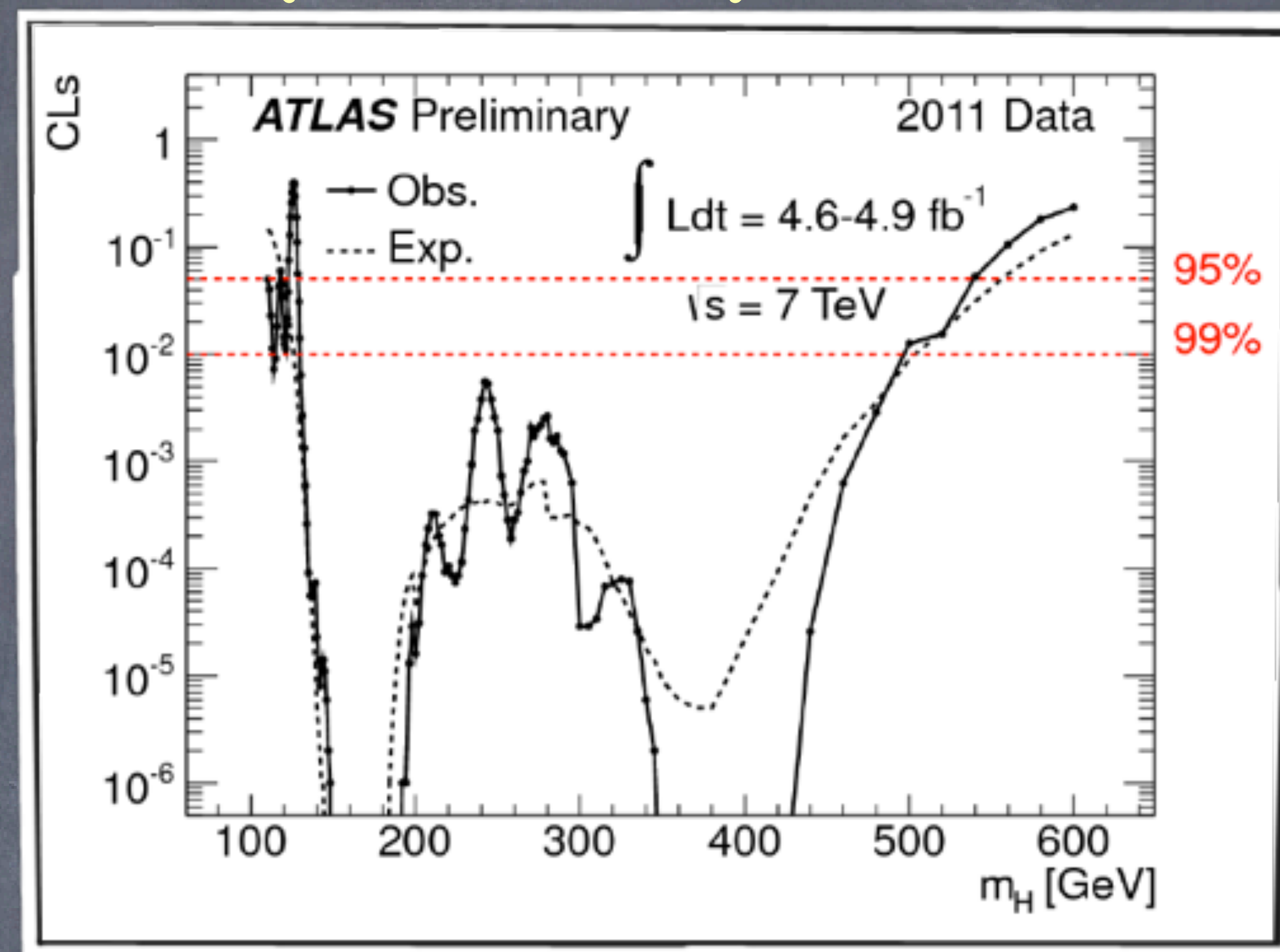
Combined Limit



- Low mass is completely dominated by γγ, then bb, ττ and WW
- High mass completely dominated by llνν

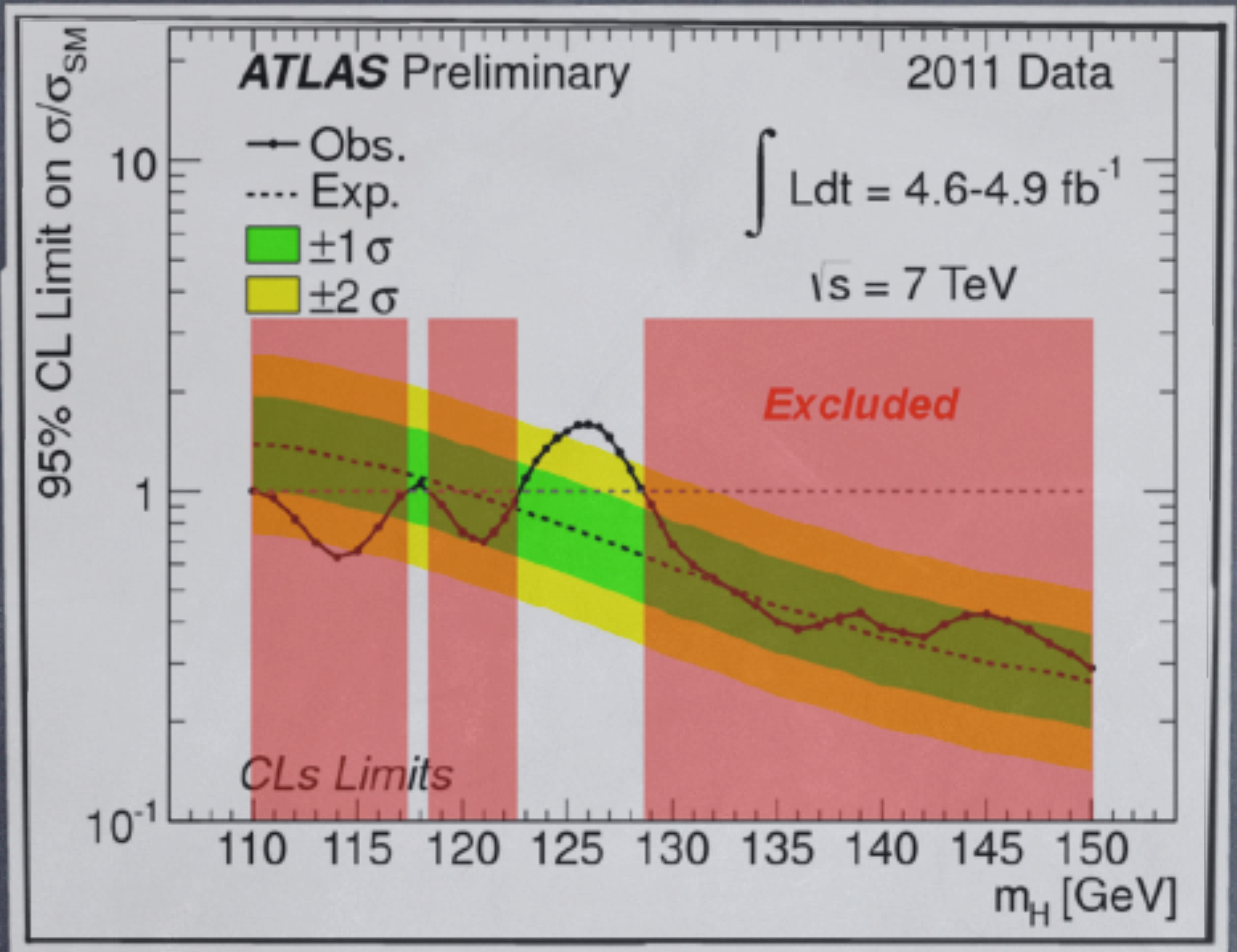
Combined Limit (ATLAS)

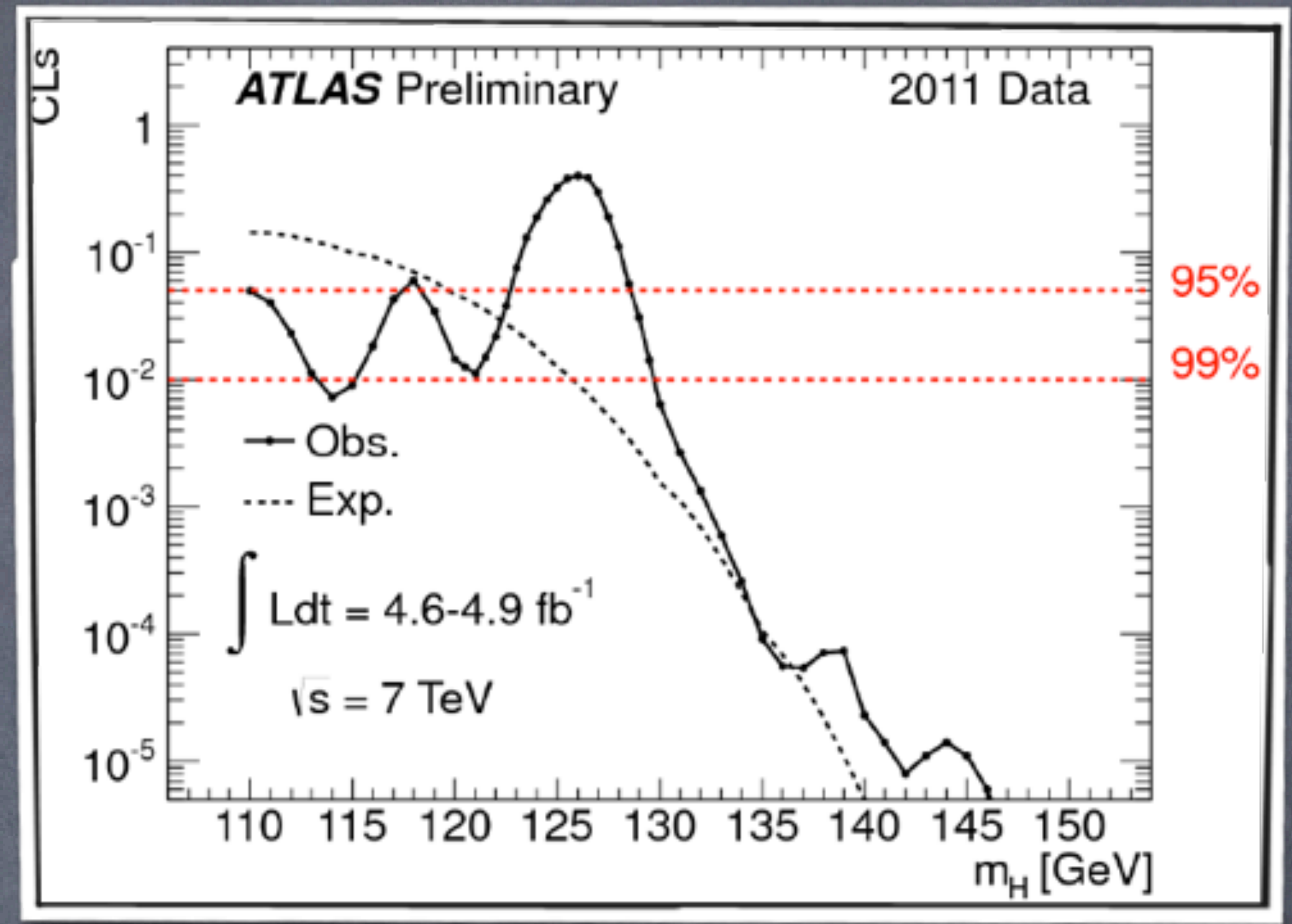




- ATLAS expected @ 95% Confidence Level 120<mH<555 GeV
- ATLAS excluded 95% Confidence Level $110<m_H<117.5$
  $118.5<m_H<122.5$
  $129<m_H<539$ GeV
- ATLAS excluded 99% Confidence Level $130<m_H<486$

Combined Limit





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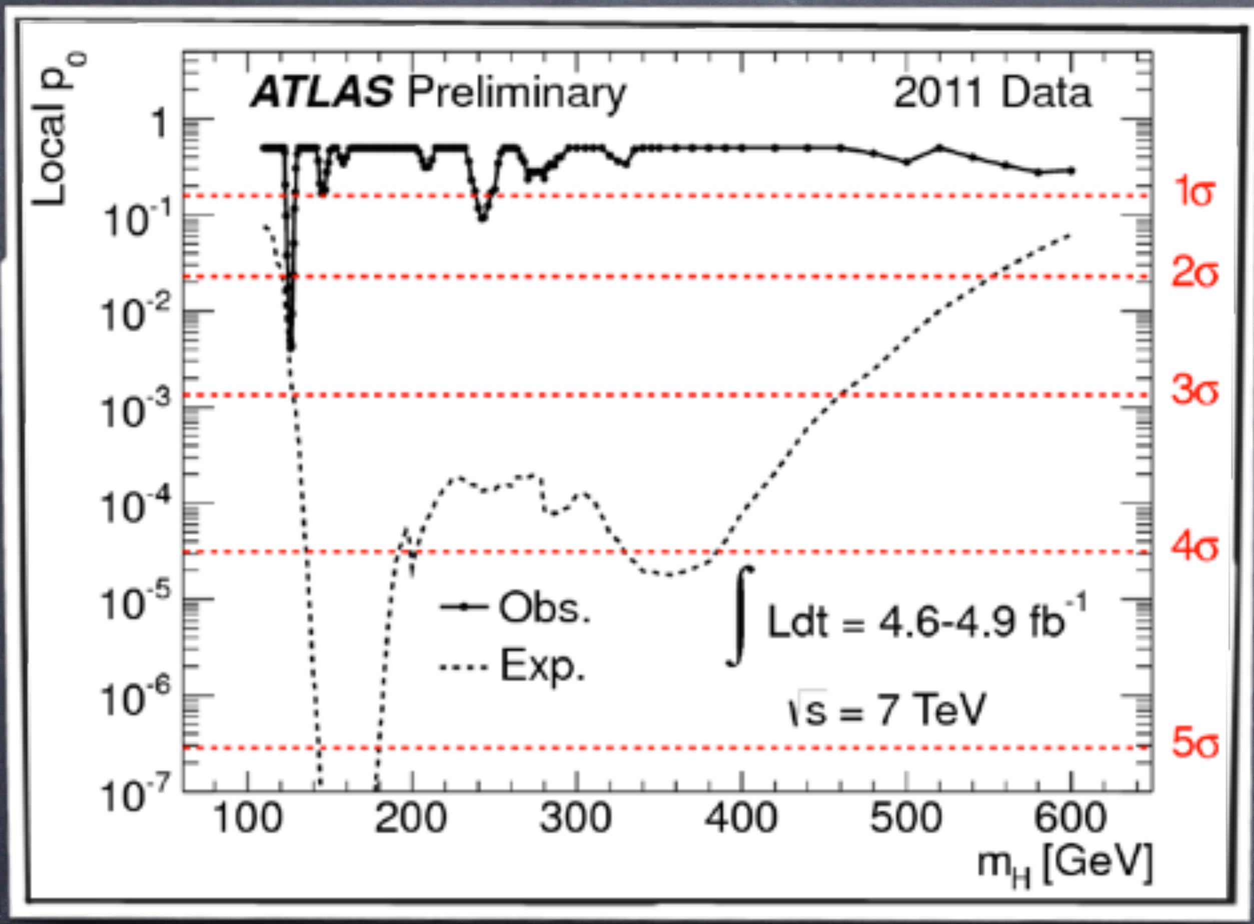
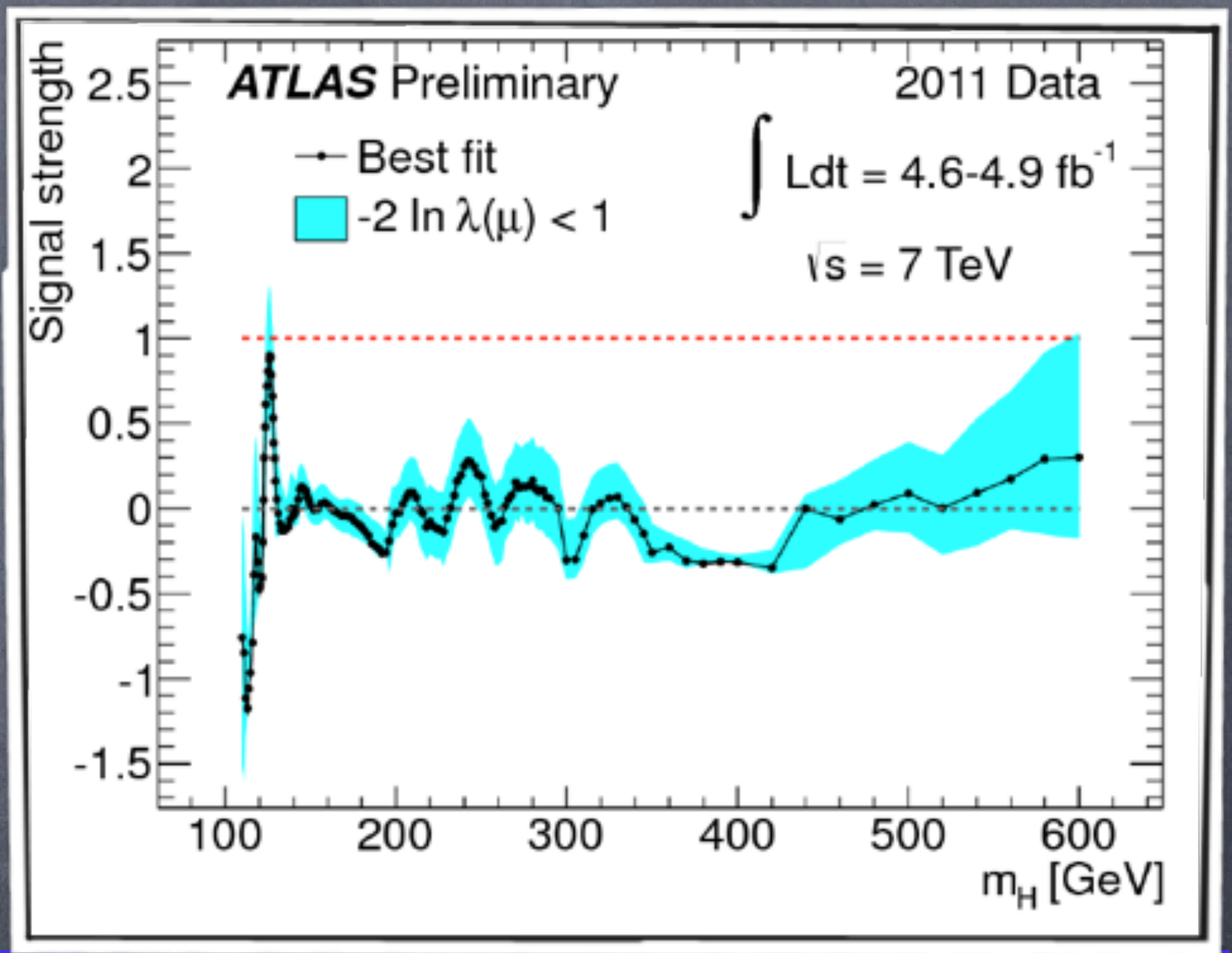
  $129<m_H<539$ GeV
- ATLAS excluded 99% Confidence Level $130<m_H<486$

ATLAS combined p_0 and $\hat{\mu}$

$$\mu = \sigma / \sigma SM$$

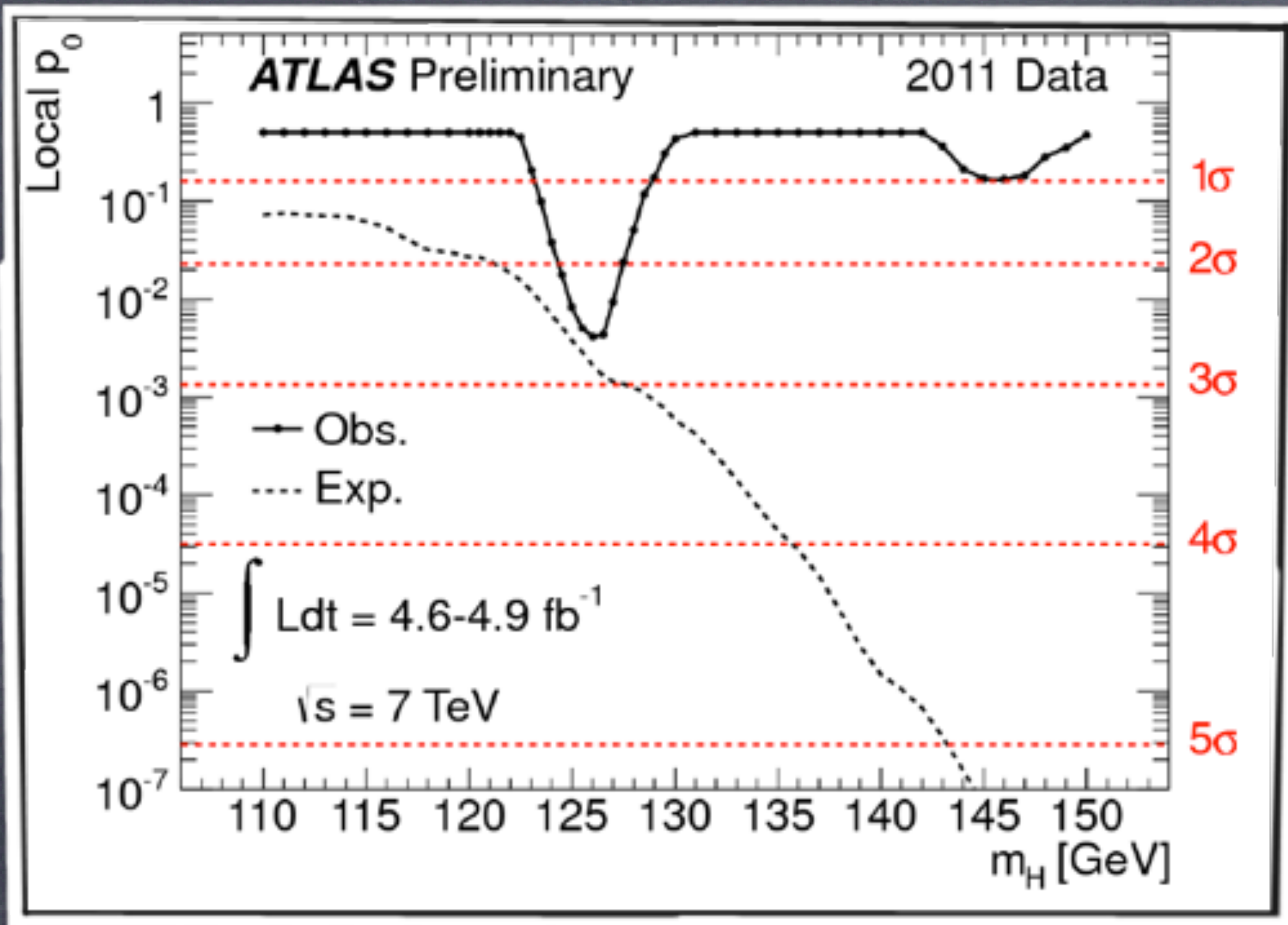
$$\hat{\mu} = \left\{ \mu \middle| L\left(\mu s(m_H) + b\right) = \max L(\mu, b) \right\}$$

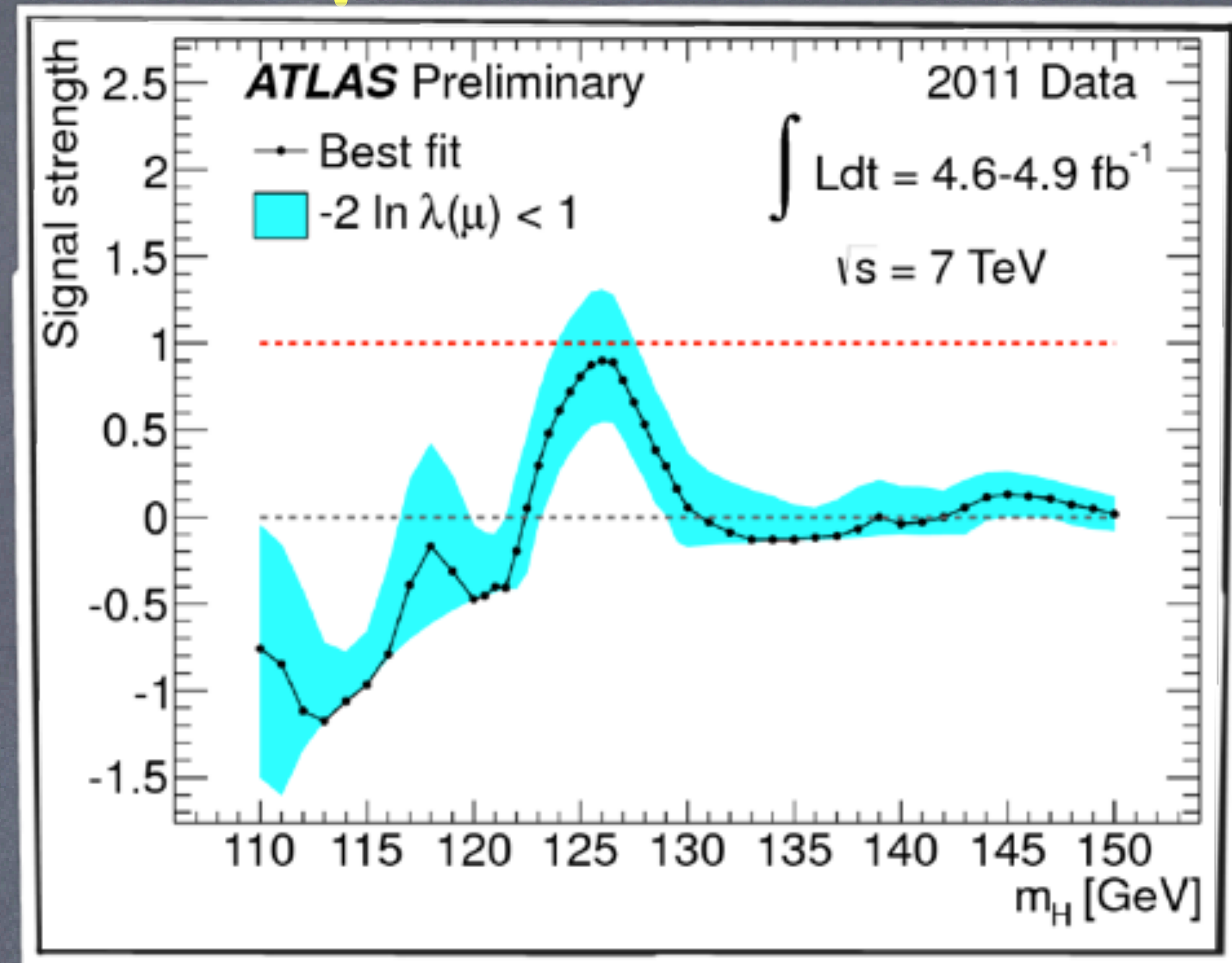




- There is an excess at the low mass that could be compatible with a SM light Higgs

ATLAS combined p_0 and $\hat{\mu}$



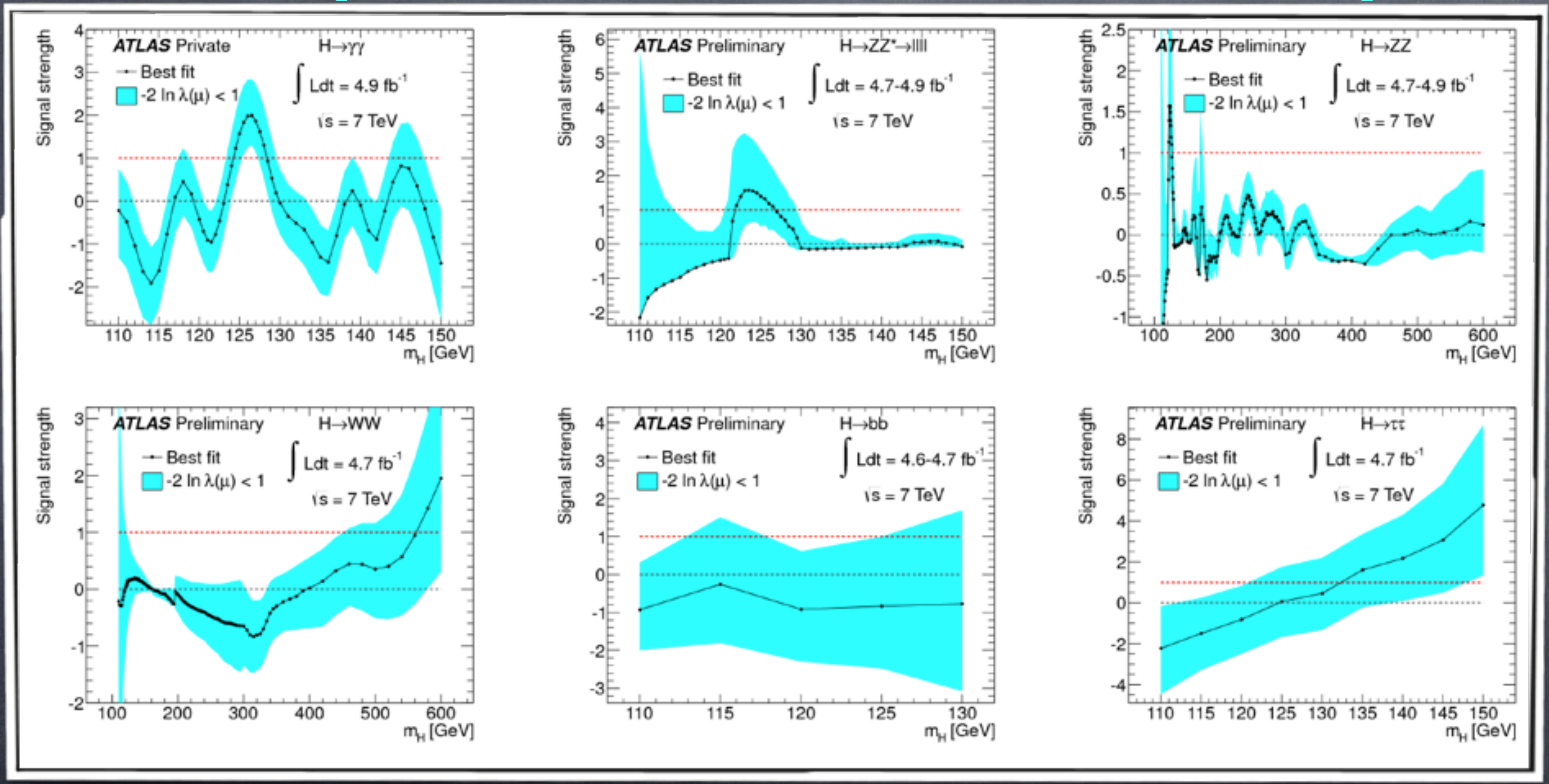


- There is an observed fluctuation at the level of 2.5σ (expected 2.9σ) at m_H=126 GeV
  with a best fit signal strength of $\hat{\mu} = 0.9^{+0.4}_{-0.3}$

- Global p_0: 10% with LEE over 110-146 GeV
  30% with LEE over 110-600 GeV

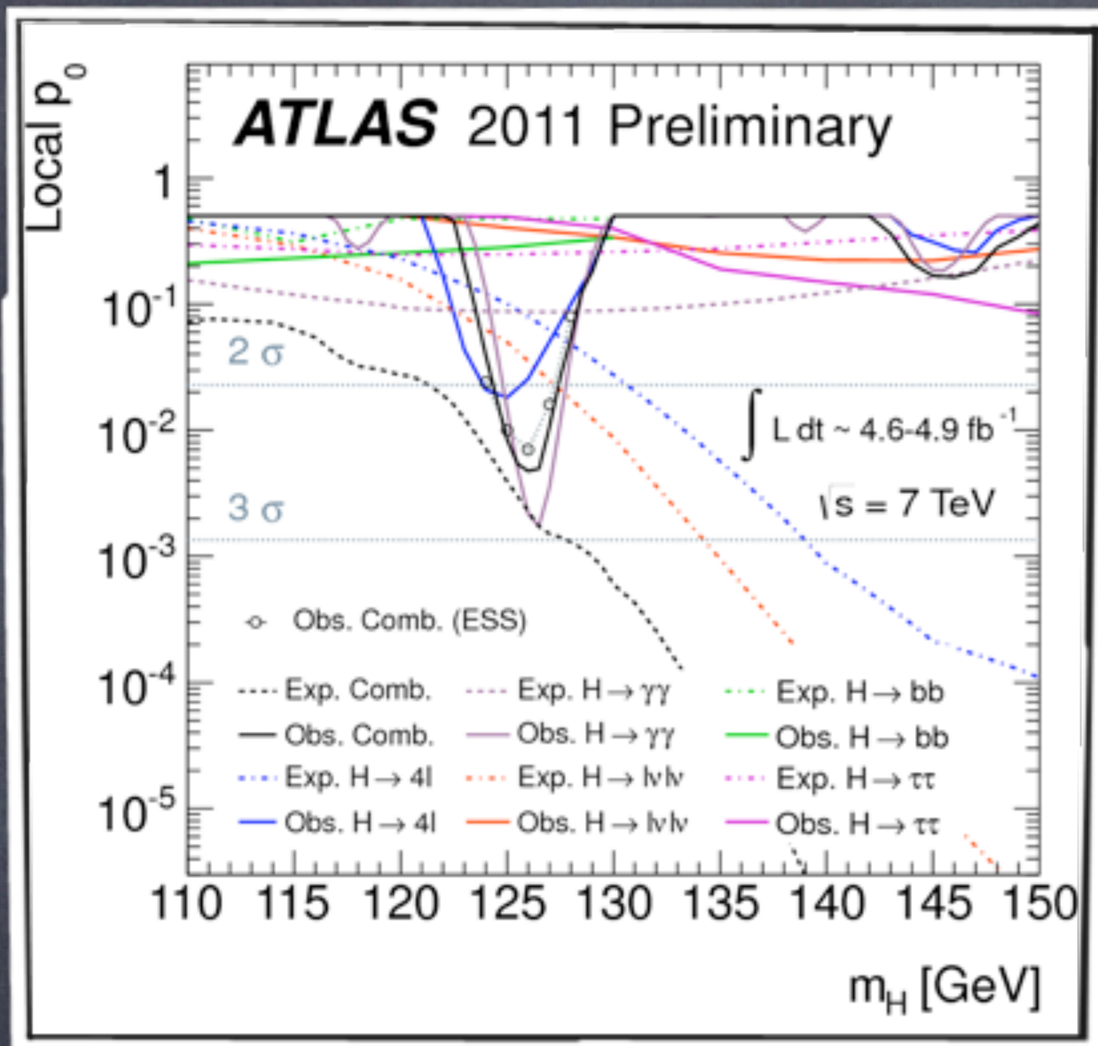
Combined ATLAS signal strength

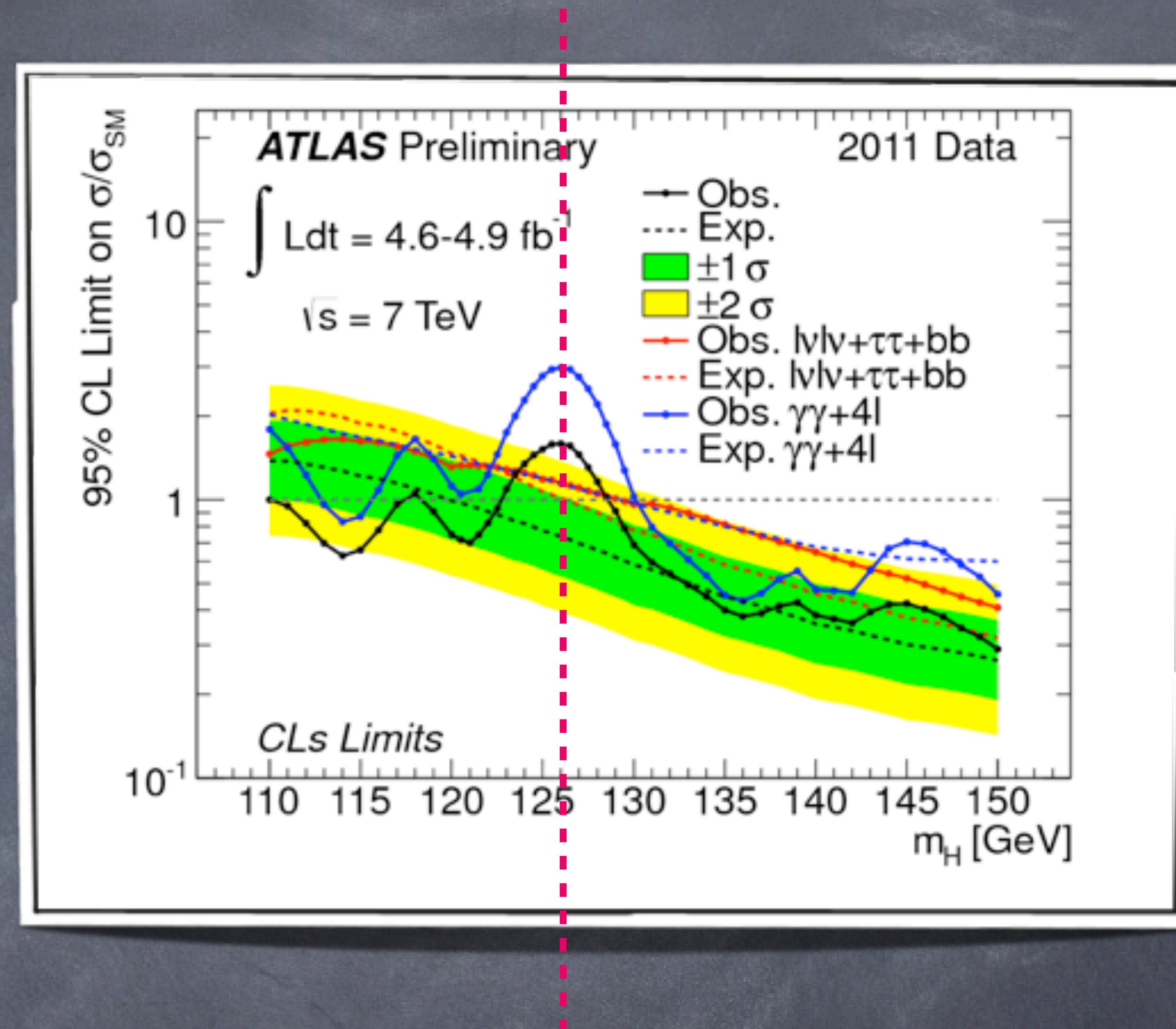
$$\hat{\mu} = \{\mu | L(\mu s(m_H) + b) = \max L(\mu, b)\}$$



The observed excess is driven by γγ at 126 GeV, it is larger than 1σ (γγ) from the SM value ($\hat{\mu}_{SM} = 1$) and within 1σ when combined $\hat{\mu} = 0.9^{+0.4}_{-0.3}$

Composition of Excess





- Excess is mainly composed of the high resolution channels,
  γγ (obs 2.8σ exp 1.4σ) and 4l (obs 2.1σ, exp 1.4σ)
- Excess is not seen in the low resolution channels WW->lvlv (obs 0.2σ, exp 1.6σ), bb and ττ.
- Combined local significance of 2.5σ (taking Energy Scale Systematics into account)

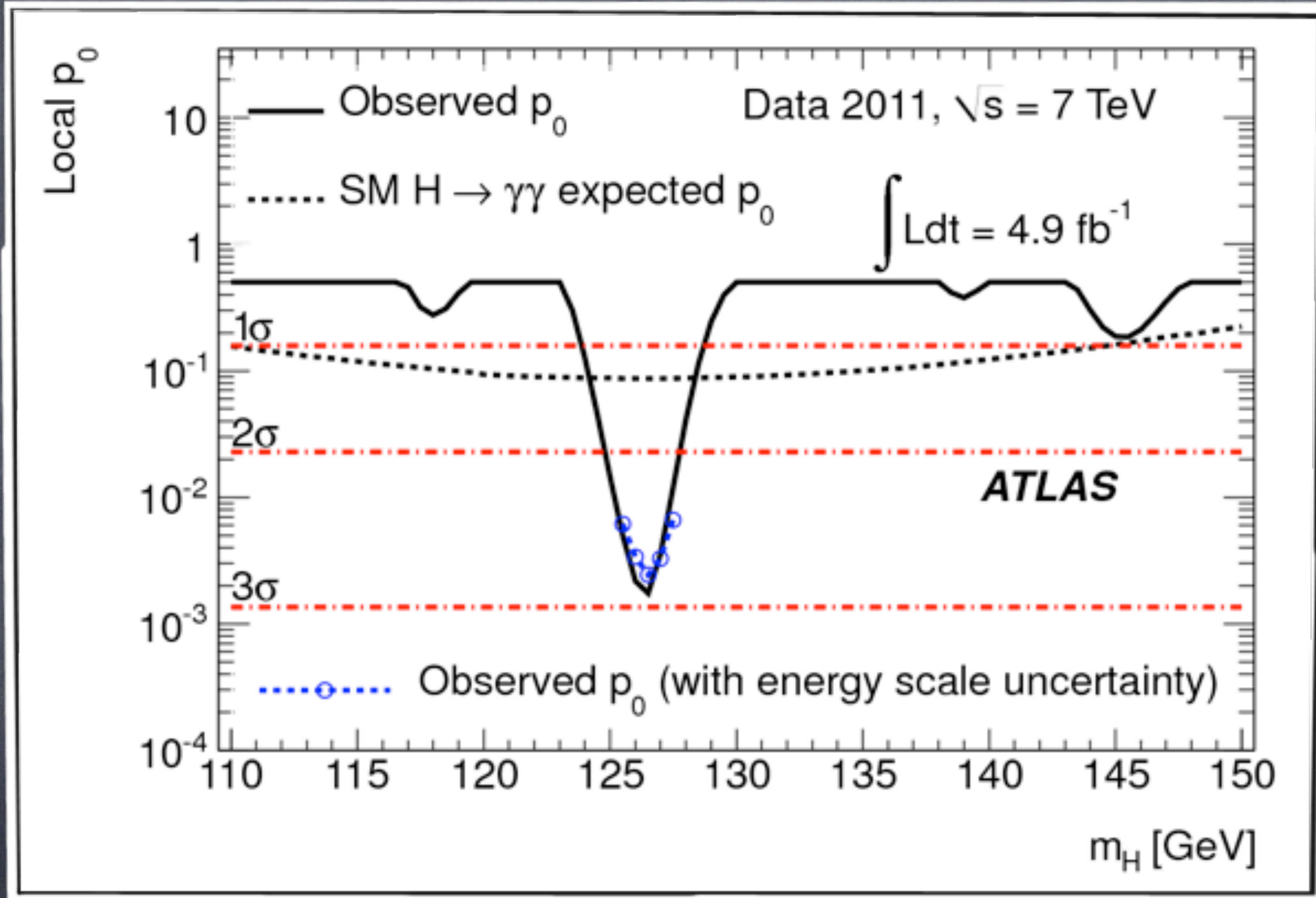
- The low resolution channels do not exclude 126 GeV Higgs

Conclusions ATLAS

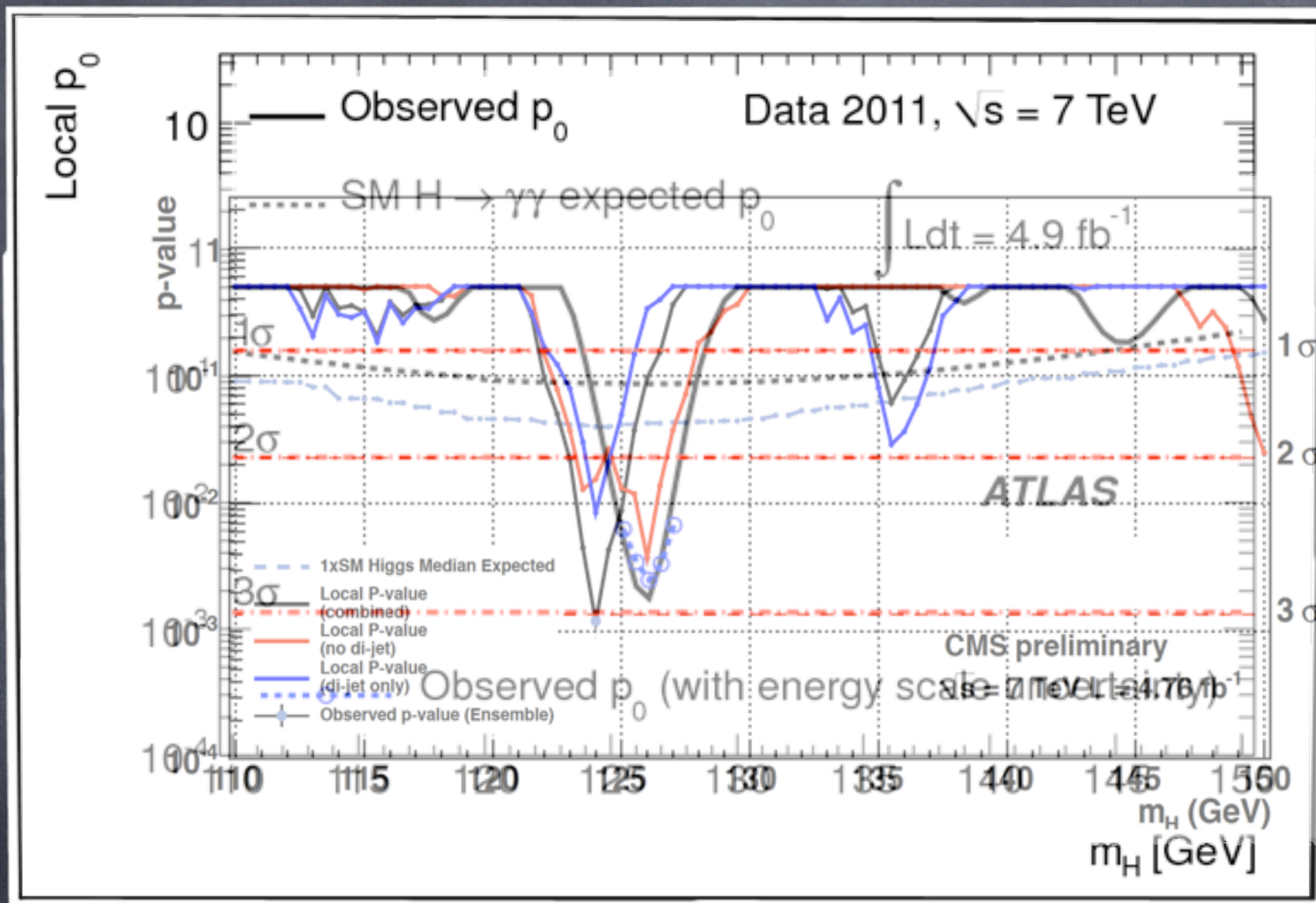
- ATLAS has done great in 2011 thanks also to a fantastic LHC machine
- ATLAS has reduced the living space for the light Higgs to about $122.5<m_H<129$ GeV, approaching the moment of truth
- An excess is seen around 126 GeV at the level of 2.5σ
- Need more data to conclude!

Forbidden Fruits

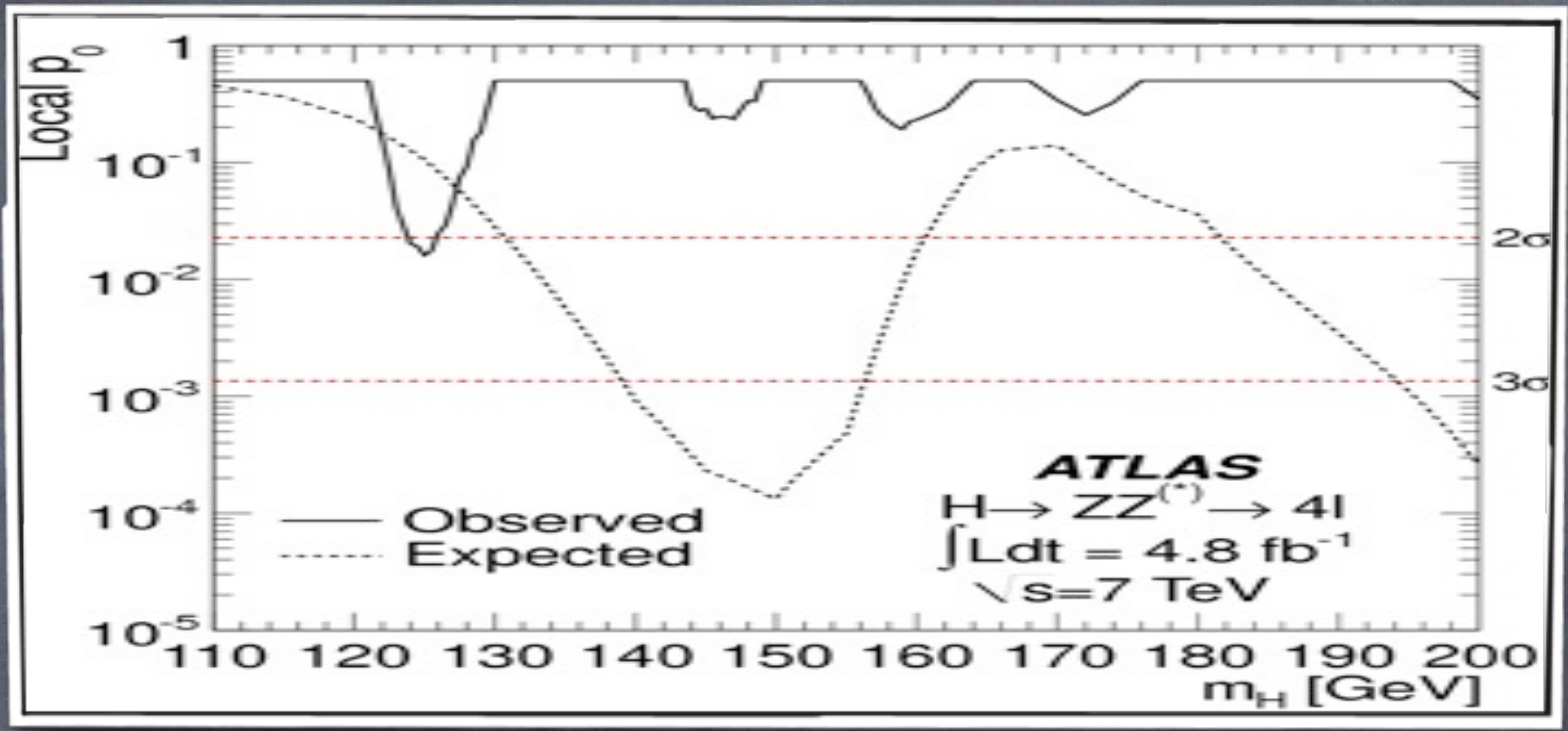
H->γγ ATLAS vs CMS p_0 results



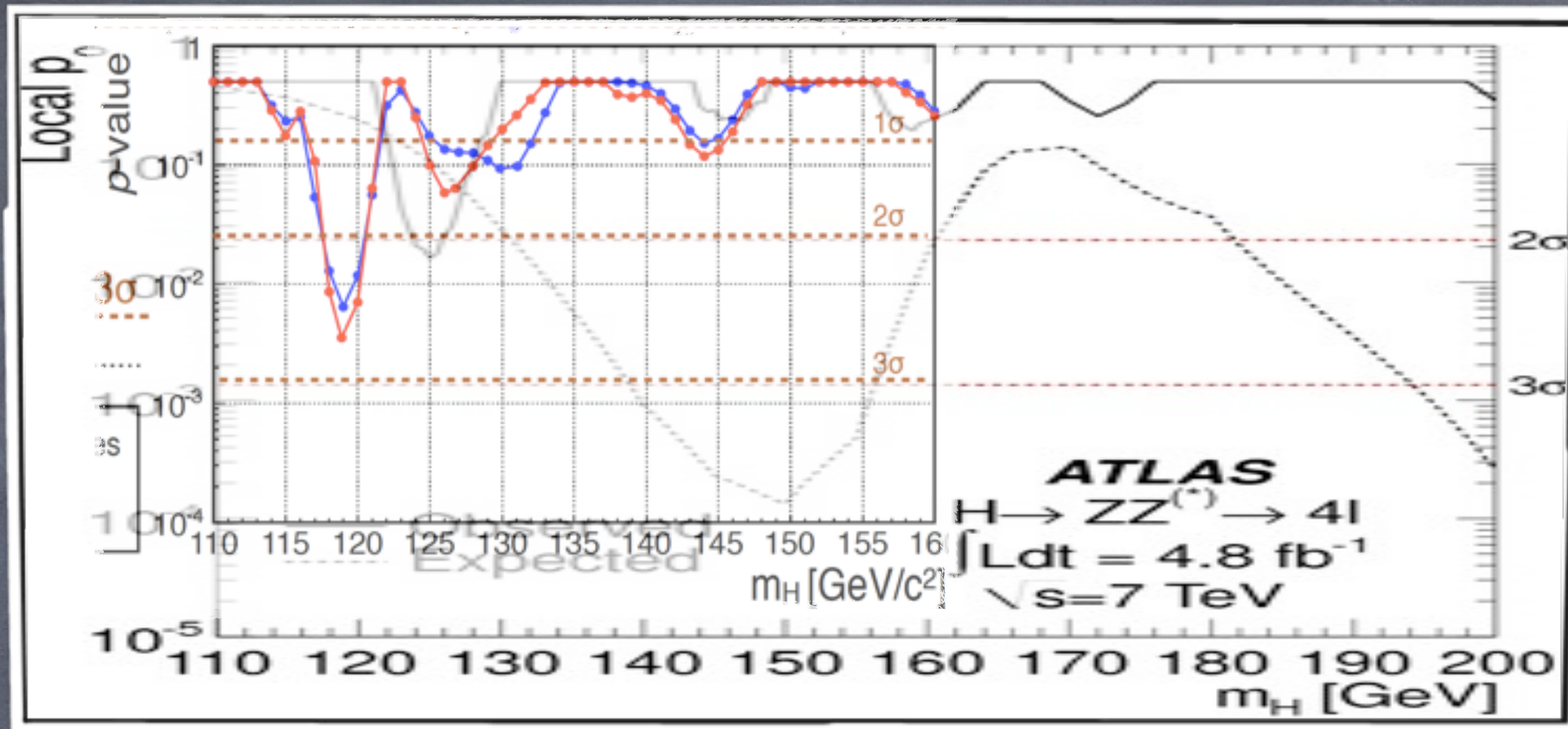
H->γγ ATLAS vs CMS p_0 results



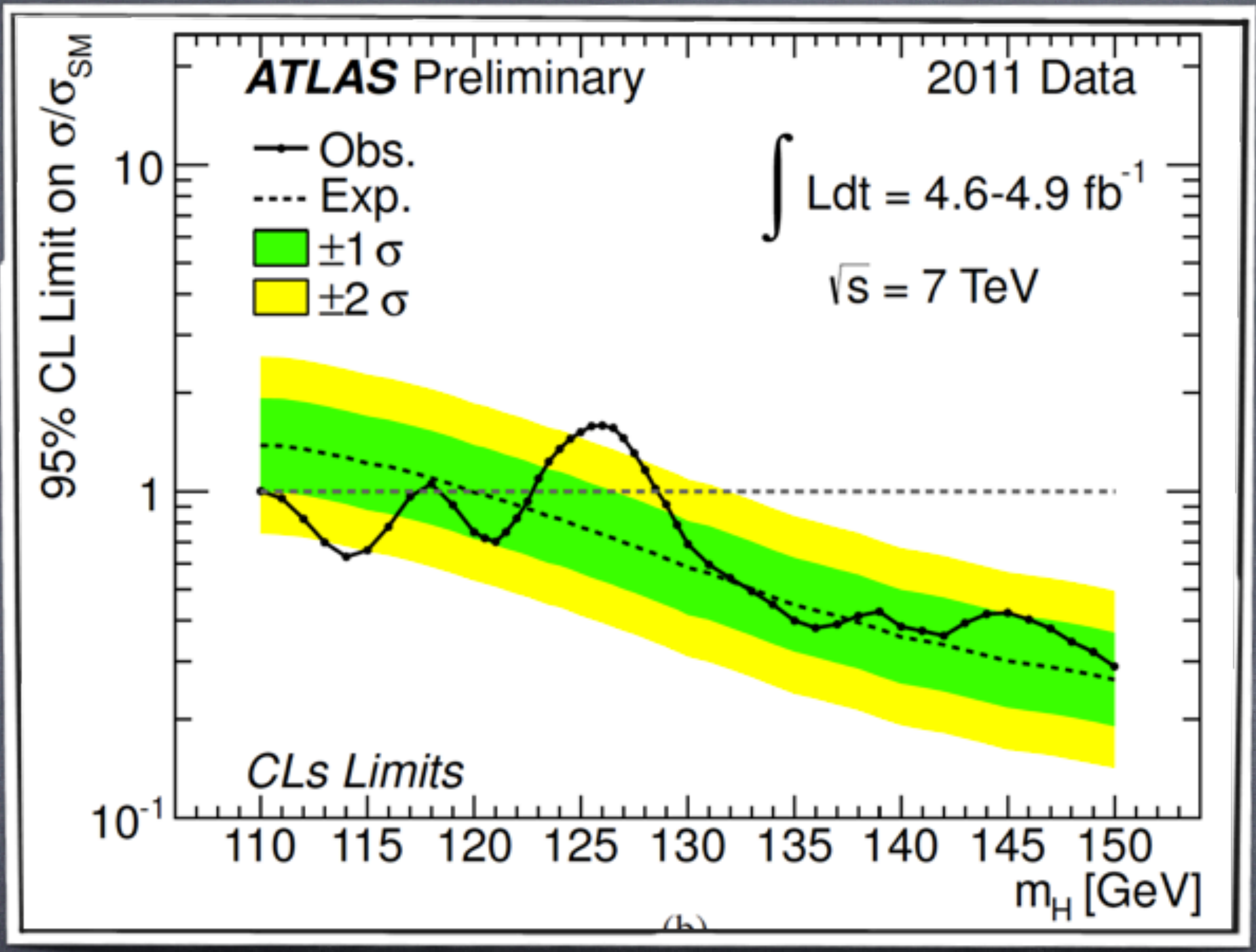
H->ZZ->4l p0 ATLAS vs CMS



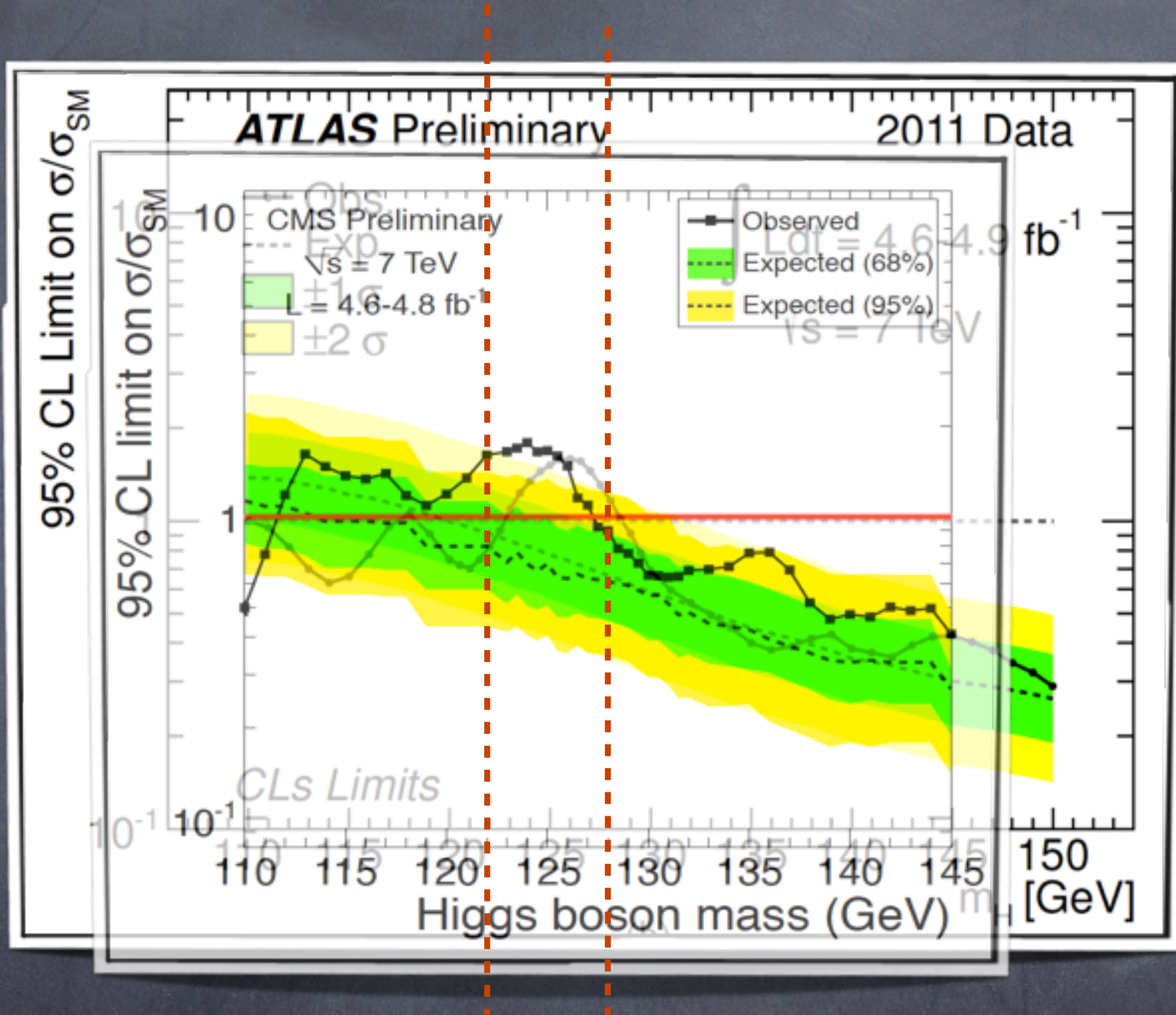
H->ZZ->4l p0 ATLAS vs CMS



Cmbined Limit CMS vs ATLAS



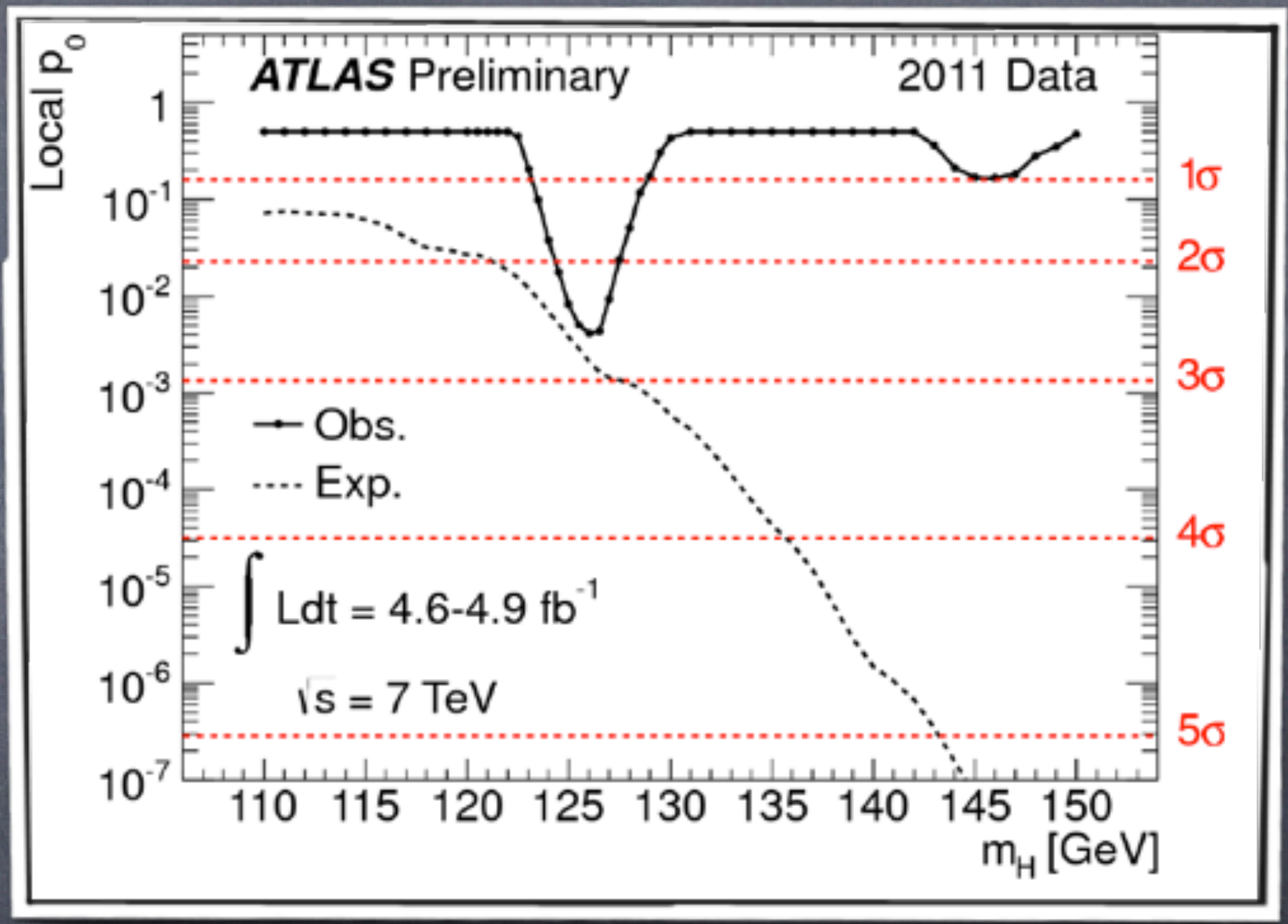
Combined Limit CMS vs ATLAS



- Not much living space for the Higgs to be, around 122-128 GeV

ATLAS vs CMS combined p_0

- ATLAS: local excess of 2.5σ at mH=126 GeV
-



ATLAS vs CMS combined p_0

- ATLAS: local excess of 2.5σ at mH=126 GeV
- CMS: local excess of 2.9σ at mH=125 GeV

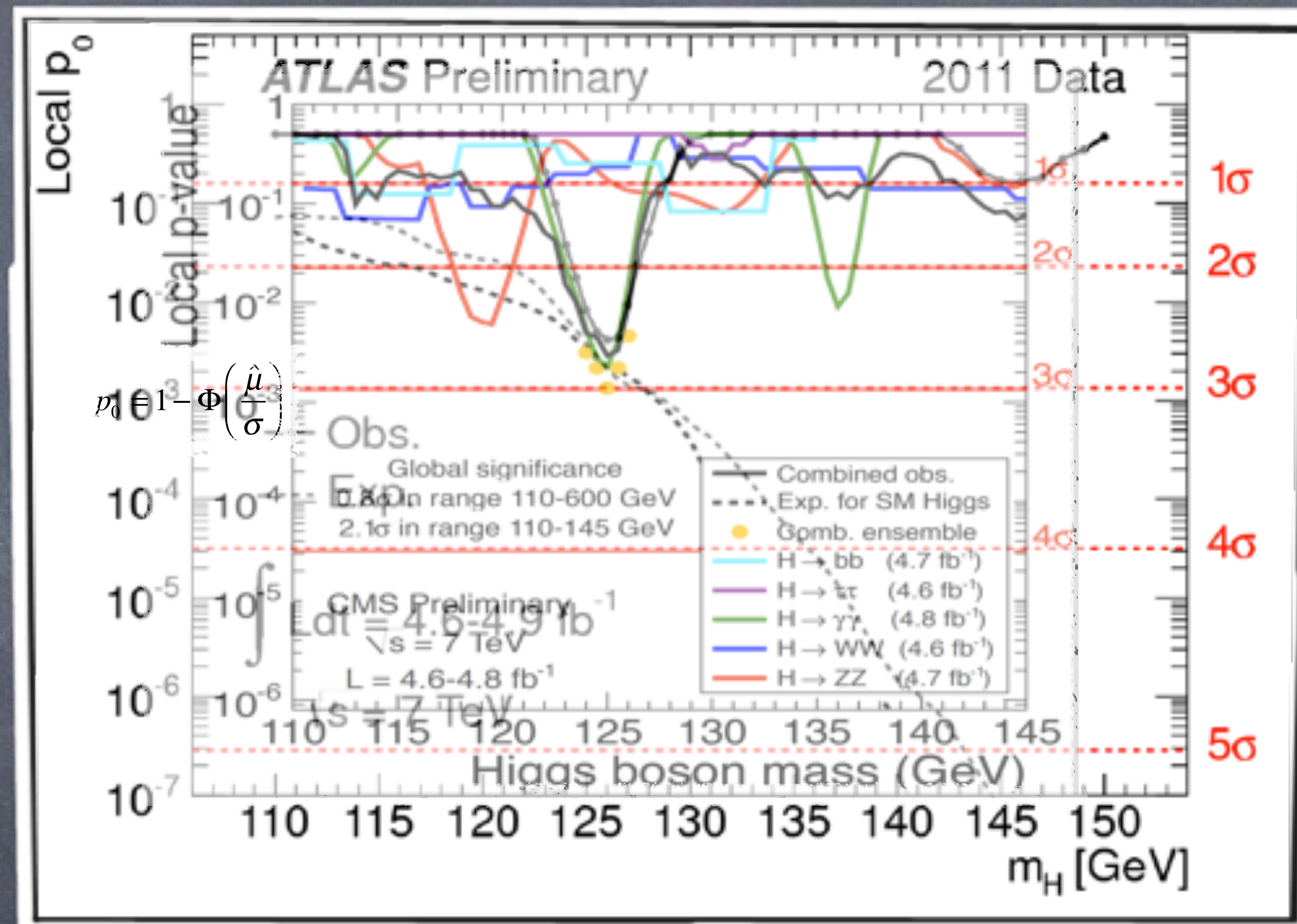
Cowan et. al. , EPJC 71 (2011) 1-19.

$$\mu_{up} = \hat{\mu} + \sigma\Phi^{-1}\left(1 - \alpha\Phi\left(\frac{\hat{\mu}}{\sigma}\right)\right)$$

$$\hat{\mu} = \frac{\hat{\mu}_1\sigma_1^{-2} + \hat{\mu}_2\sigma_2^{-2}}{\sigma_1^{-2} + \sigma_2^{-2}}$$

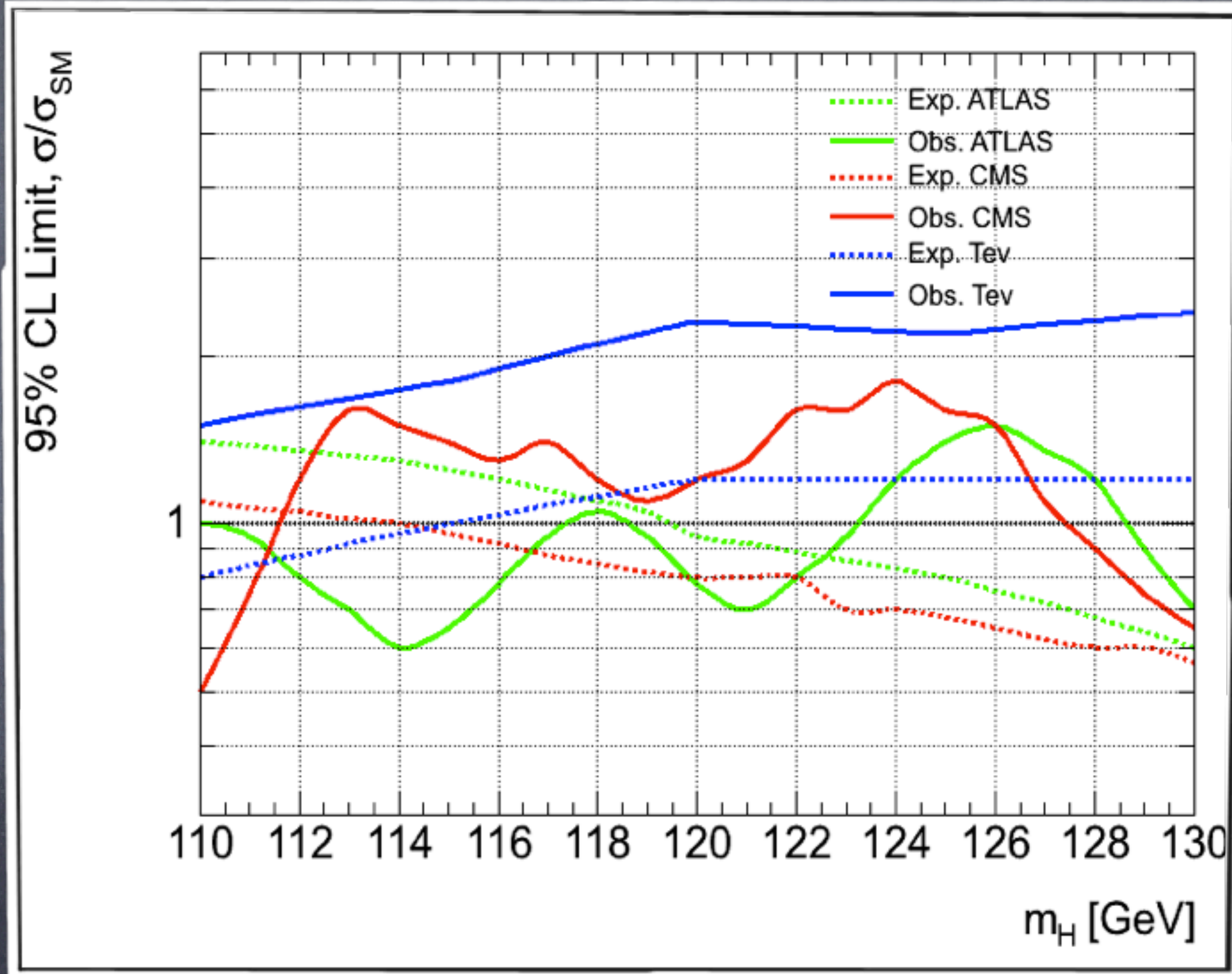
$$\sigma^{-2} = \sigma_1^{-2} + \sigma_2^{-2}$$

$$p_0 = 1 - \Phi\left(\frac{\hat{\mu}}{\sigma}\right)$$



ATLAS+CMS+TEVATRON

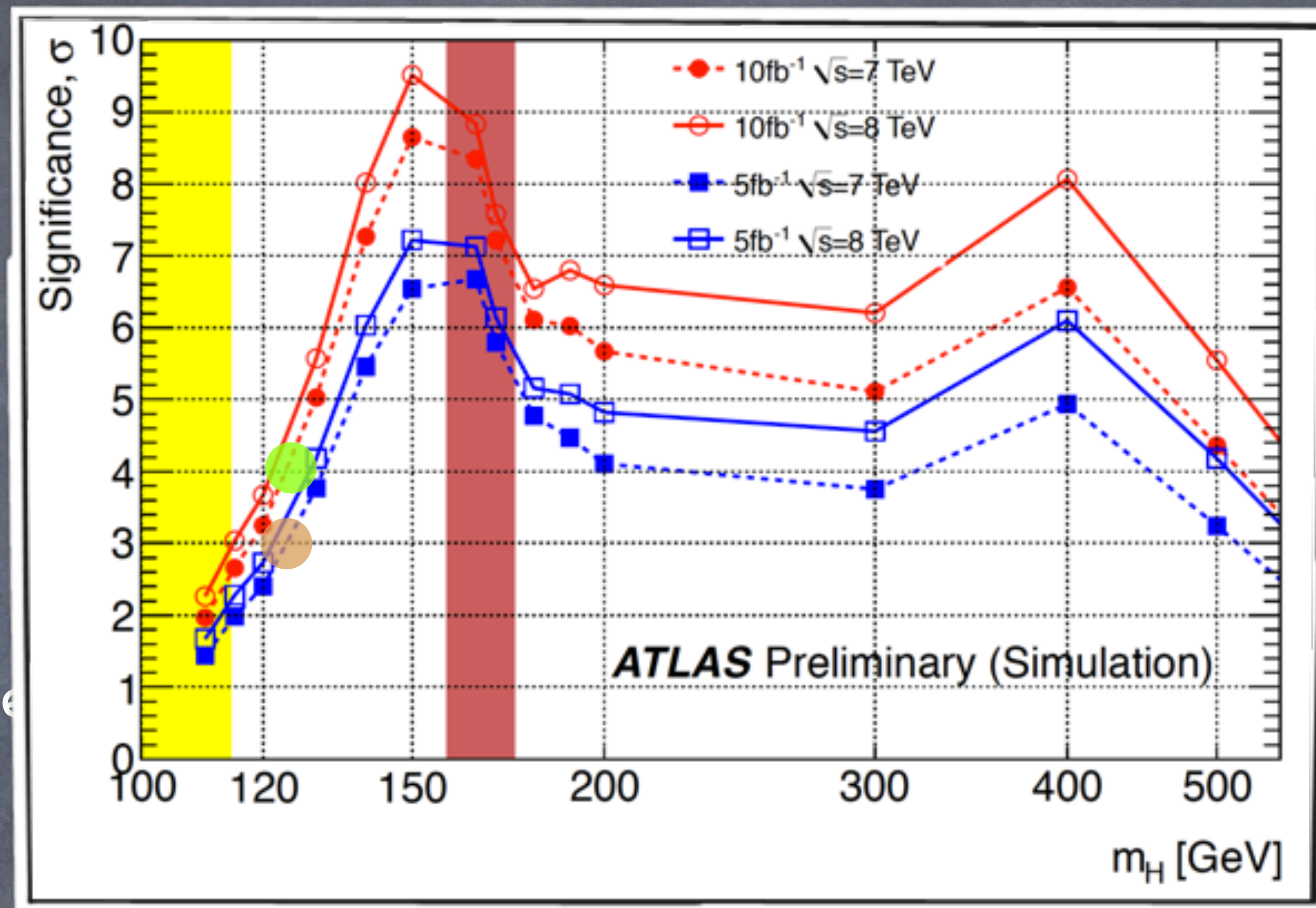
- ATLAS and CMS compensate each other except ~125 GeV
- TEVATRON pulls the combination a bit up
- The observed TEVATRON is too high to affect the combination, yet the expected is low, will reduce the 1σ band size and increase the exclusion significance



from B Murray

Projection into the Future (125 GeV)

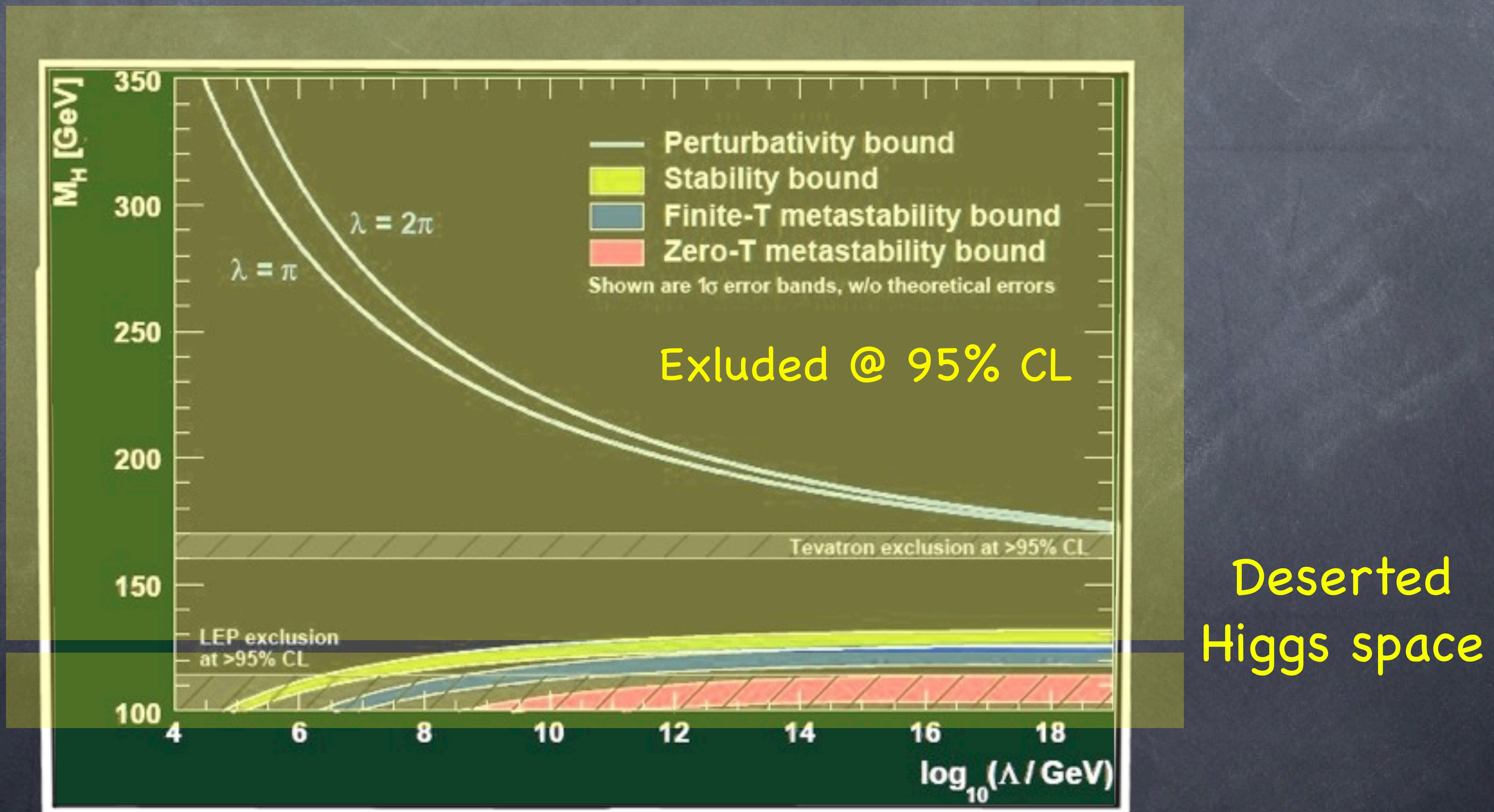
- ATLAS expected sensitivity with 5fb-1 @ 7TeV is 3σ (2.9σ with 4.6-4.9fb-1)
- 2xATLAS~ATLAS+CMS sensitivity with 5fb-1 @ 7TeV is 4σ
- Gain in sensitivity from 7->8 TeV is 10% in significance ~ 20% in luminosity
- ->Needs about 12 fb-1 @ 8TeV for 5σ discovery p/exp
- Since observed~expectation, we will certainly have a discovery sensitivity with >11 fb-1 @8 TeV per experiment



- Taking into account the 5fb-1 @ 7 TeV, we find that only 7-8fb-1 p/exp are needed to have a 5σ discovery sensitivity

Nightmare Scenario I: SM Higgs, period.

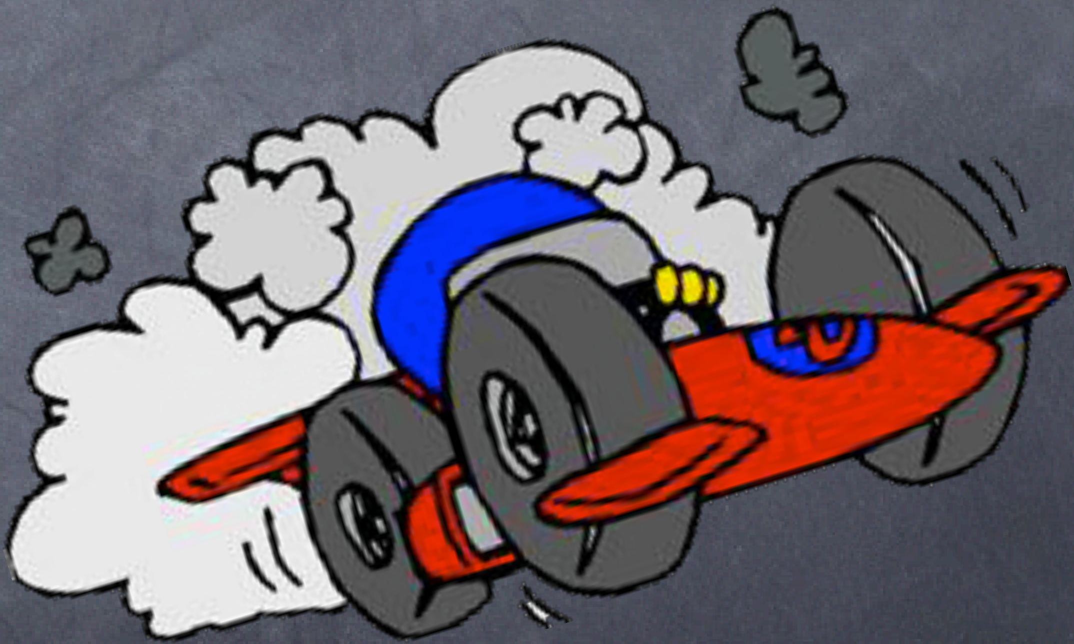
- Not much living space is left for the Higgs boson
- Looks like if there is a SM Higgs, it is either not Standard (i.e. not alone) or our vacuum is metastable



Ellis,Espinosa, Giudice, Hoecker, Riotto Phys.Lett. B679 (2009) 369-375
M. Lindner, Z. Phys. C 31, 295 (1986); M. Lindner, M. Sher and H. W. Zaglauer, Phys. Lett. B 228, 139 (1989);

Nightmare Scenario II: No Higgs

- Not much living space is left for the Higgs boson
- If there is no engine, how does the SM car drives so smooth and fast?



Conclusion (still to be rephrased)

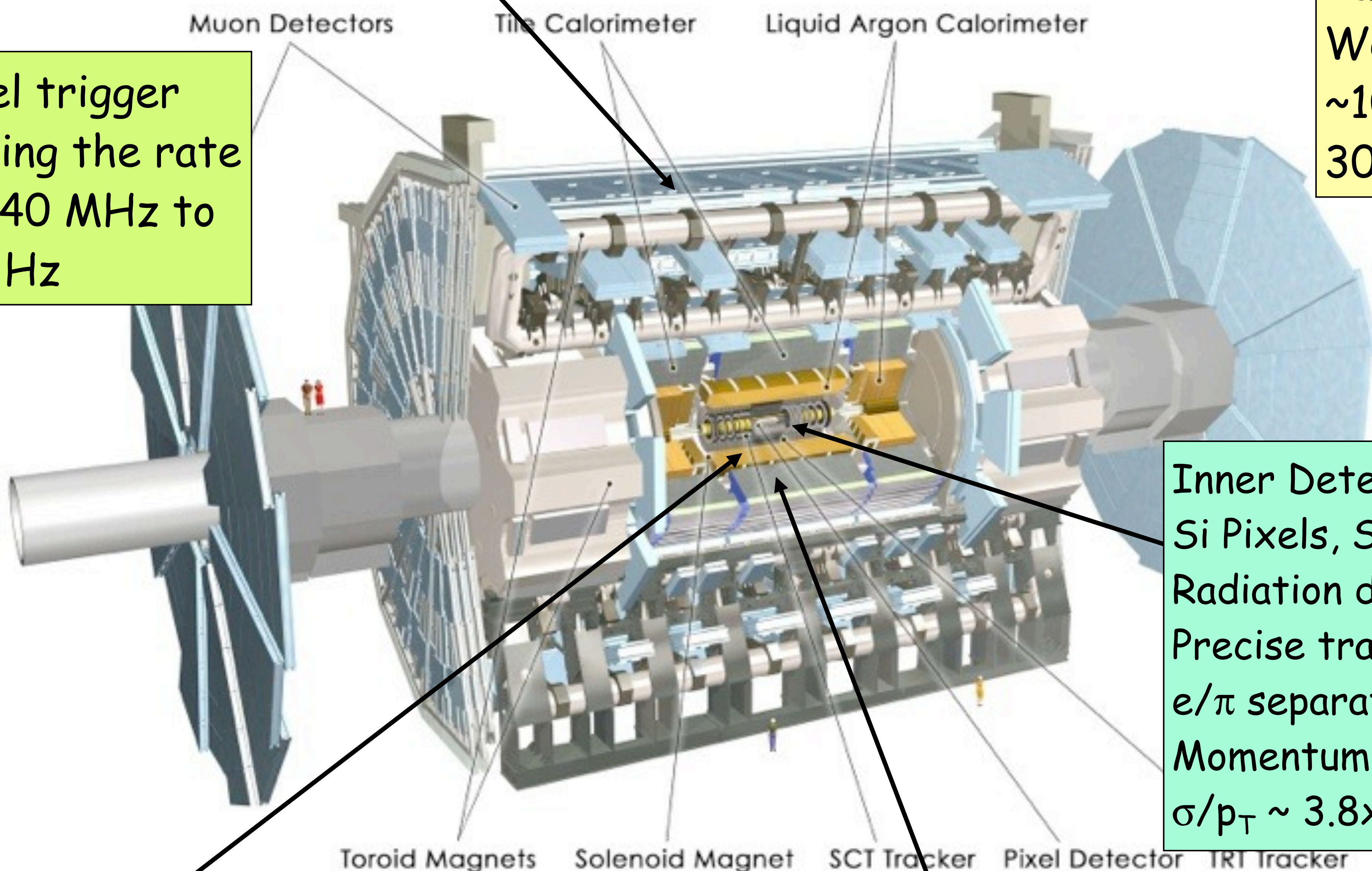
- 2011-2012 are the Higgs & LHC Miraculous Years
- The SM Higgs (if there) is probably light m_H~122-127 GeV
- I think from any point of view (SM, Exotic, SUSY, Higgs ......) this is the prime time for any High Energy Physicist ☺
- 2012 run as of April
  Over 12 fb-1/experiment of delivered luminosity is needed for:
  5σ discovery of a 125 GeV Higgs Boson (ATLAS or CMS alone)
  @E_{CM}=8 TeV OR 7-8 fb-1/experiment taking the 7 TeV results into account
- 10% sensitivity gain is E_{CM} goes up to 8 TeV which is equivalent to 20% gain in luminosity
-

Backup

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 1 TeV

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

3-level trigger reducing the rate from 40 MHz to ~200 Hz



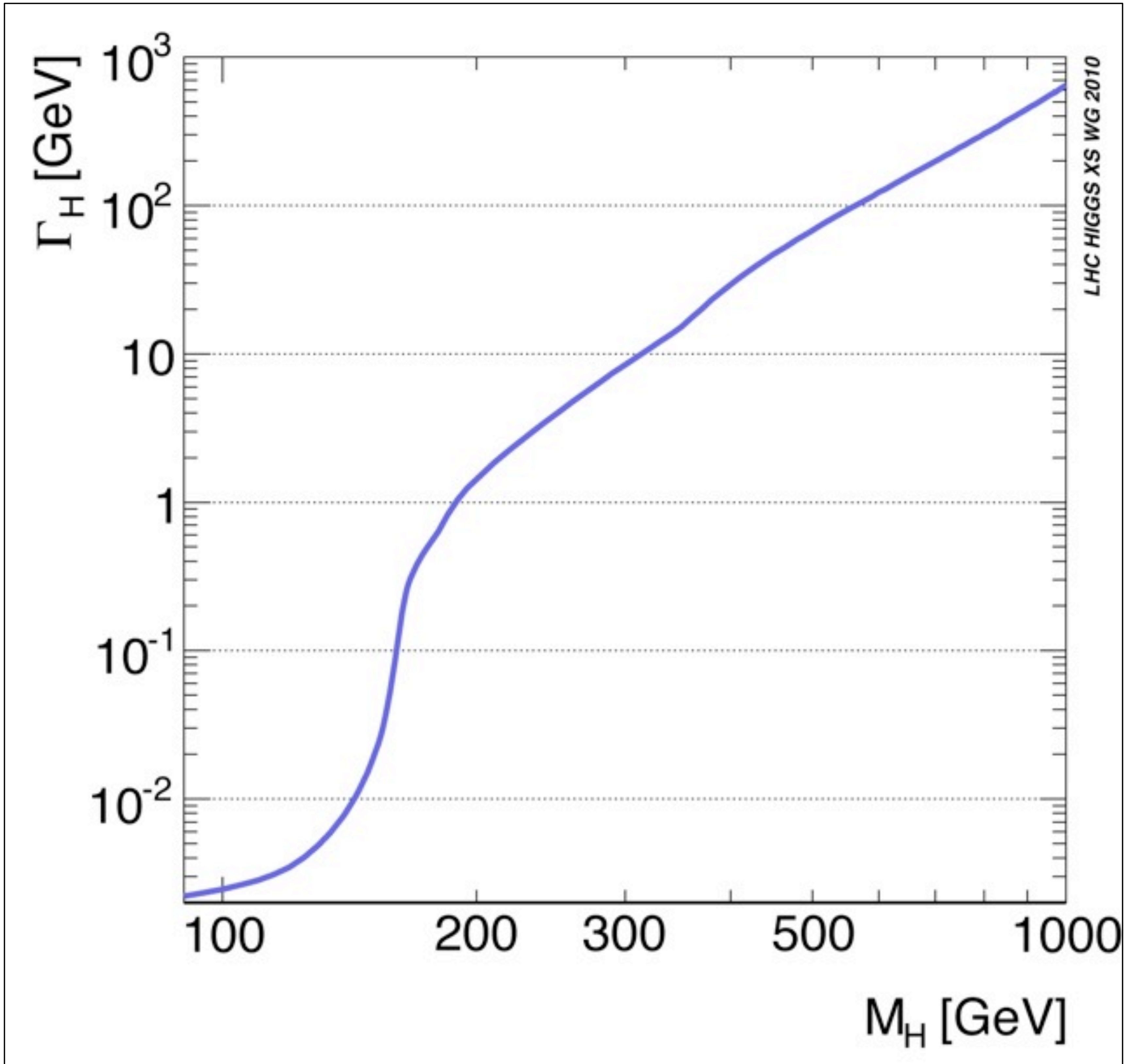
Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing,
e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\mathrm{GeV}) \oplus 0.015$

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

2011 Physics Proton Trigger Menu (end of run L = 3.3 10^{33} $cm^{-2}s^{-1}$)

	Offline Selection	Trigger Selection		L1 Rate (kHz) at 3e33	EF Rate (Hz) at 3e33
		L1	EF		
Single leptons	Single muon > 20GeV	11 GeV	18 GeV	8	100
	Single electron > 25GeV	16 GeV	22 GeV	9	55
Two leptons	2 muons > 17, 12GeV	11GeV	15,10GeV	8	4
	2 electrons, each > 15GeV	2x10GeV	2x12GeV	2	3.3
	2 taus > 45, 30GeV	15,11GeV	29,20GeV	7.5	15
Two photons	2 photons, each > 25GeV	2x12GeV	20GeV	3.5	5
Single jet plus MET	Jet pT > 130 GeV & MET > 140 GeV	50 GeV & 35 GeV	75GeV & 55GeV	0.8	18
MET	MET > 170 GeV	50 GeV	70GeV	0.6	5
Multi-jets	5 jets, each pT > 55 GeV	5x10GeV	5x30GeV	0.2	9
TOTAL				**<75**	**~400 (mean)**


Γ_H [GeV]
10^3
10^2
10
1
10^{-1}
10^{-2}
100
200
300
500
1000
M_H [GeV]
LHC HIGGS XS WG 2010