Higgs Physics at ATLAS
From the WW Perspective

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Seminar at CPPM (Marseille)

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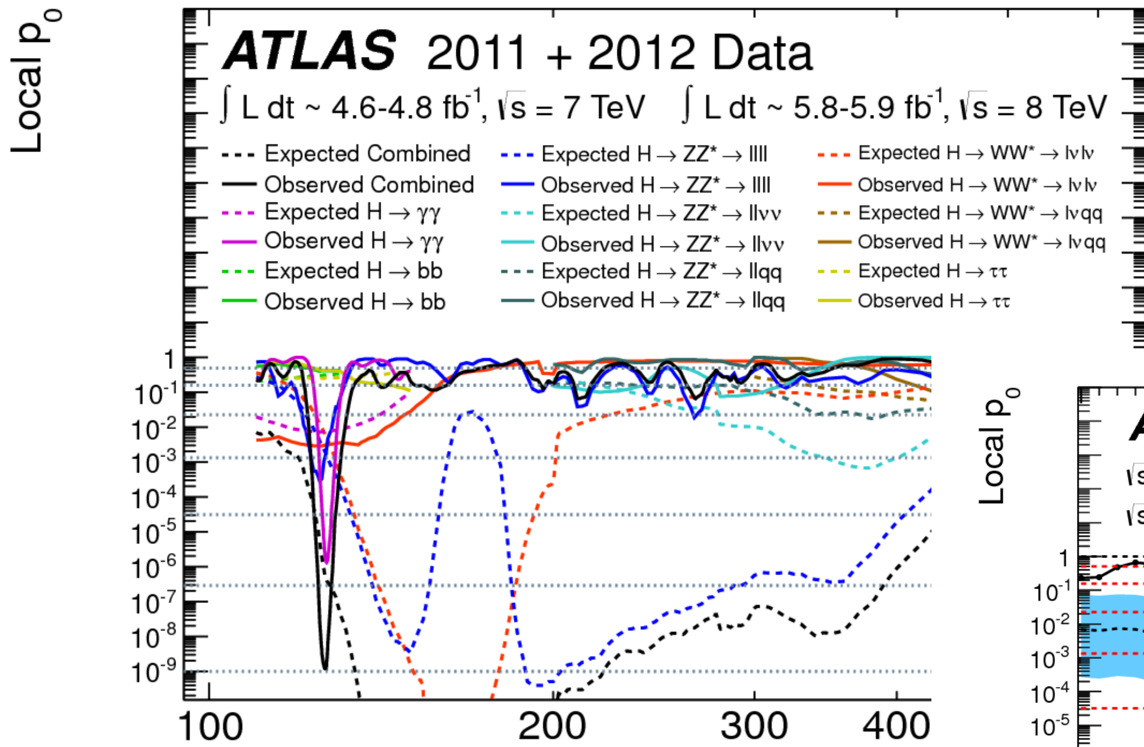
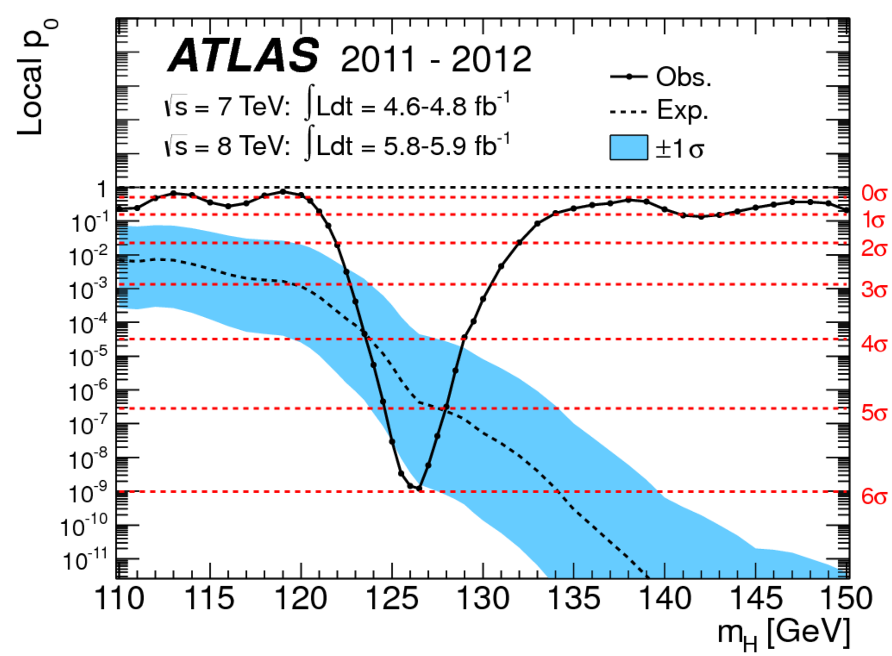
Discovery!

- After last winter's preamble, great excitement last summer





Overview

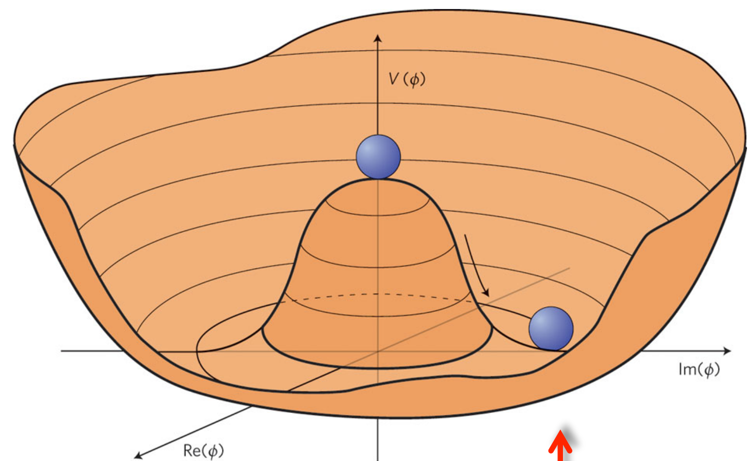
- History: this past summer's discovery, and why it was so long-sought
- Updated $H \to WW \to l\nu l\nu$ analysis
  - → *Motivation; role in the discovery*
  - → *Candidate event identification in light of detector and LHC*
  - → *Background estimation vs. systematic uncertainties*
- Latest results from ATLAS globally
- The way forward
- (Along the way: hints of results in the pipeline)

The History

The Higgs Mechanism

Gauge invariance does not allow fundamental particle masses: instead, generate masses through interaction with a scalar field

- → *Ground state is not zero-field*
- → *Breaks the electroweak symmetry*



$$L = \left[-\left(g_1 \frac{Y}{2} \right)^2 B_\mu B^\mu - g_1 g_2 \frac{Y}{4} \vec{\tau} \cdot \vec{W}_\mu B^\mu - g_2^2 \left(\frac{\vec{\tau}}{2} \cdot \vec{W}_\mu \right) \left(\frac{\vec{\tau}}{2} \cdot \vec{W}^\mu \right) \right] \phi^2$$

Interaction with nonzero field permeating space generates mass

- → *Minimal implementation: complex scalar doublet*
- → *Other possibilities exist*

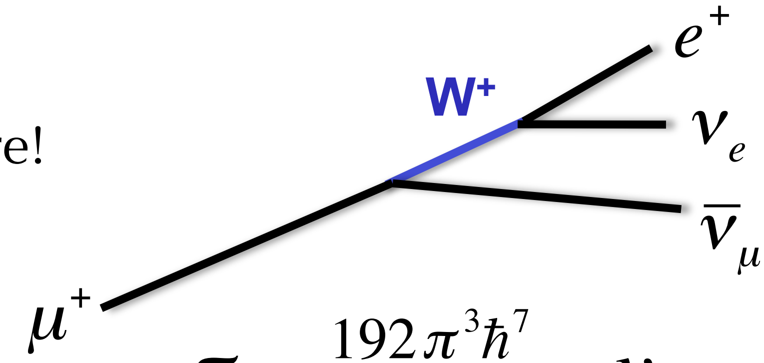
"vacuum expectation value"

$$\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \qquad \text{choose } \langle \phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}$$

Consequences of EWSB

- Vacuum expectation value enters electroweak interactions, can measure!
- Best constraints from muon decay

$$v = (\sqrt{2}\,G_F)^{-1/2} \approx 246\ \mathrm{GeV}$$



$$\tau_\mu = \frac{192\pi^3\hbar^7}{\mathbf{G_F^2}\, m_\mu^5 c^4} \propto v$$

- W and Z masses related by weak mixing angle θ_W

$$M_W = M_Z \cos(\theta_W) \qquad \cos(\theta_W) = \frac{g_2}{\sqrt{g_1^2 + g_2^2}}$$

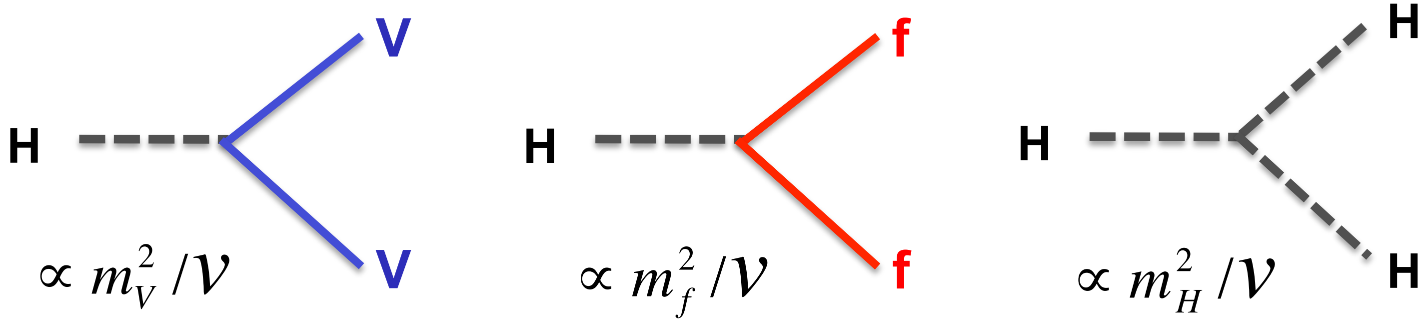
Electroweak symmetry breaking is experimentally verified

→ ***Strong evidence for the Higgs mechanism***

→ ***Question: what is the nature of the Higgs field?***

The Standard Model Higgs

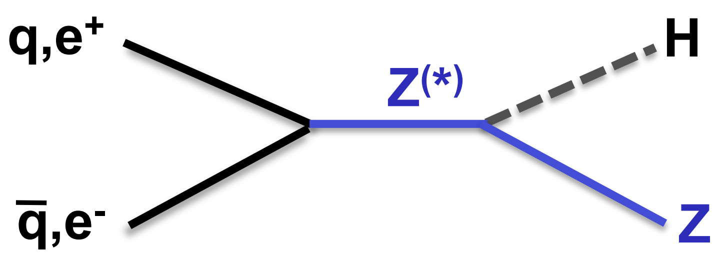
- Focus now on the **simplest** implementation: the Standard Model Higgs mechanism
- Four extra degrees of freedom in the complex scalar doublet field
  - → *Only 3 needed to give mass to the W and Z*
  - → *Fourth is a physical scalar: the Higgs boson*
- For every massive particle, an interaction with this new scalar
  - → *Interaction strength **determined** by particle mass and VEV* v
- Only thing not determined: the mass of the Higgs boson

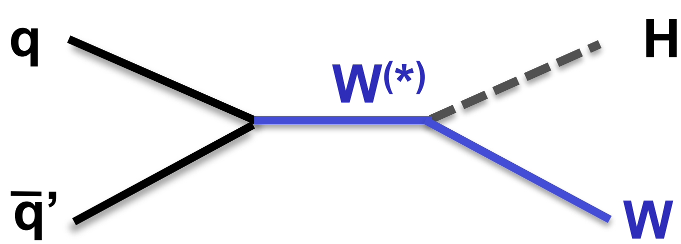


How to Make a Higgs Boson

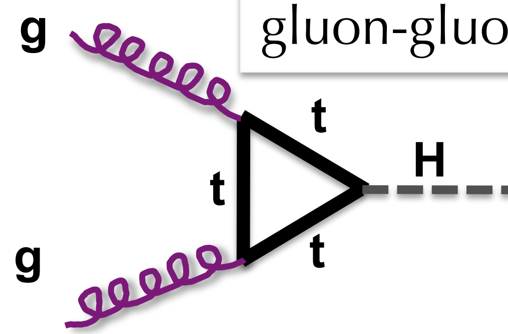
- Colorless particle ⇒ no (direct) strong production
- Recall: coupling strength ∝ m^2
  - → *Interactions go through the heaviest available particle*

associated production

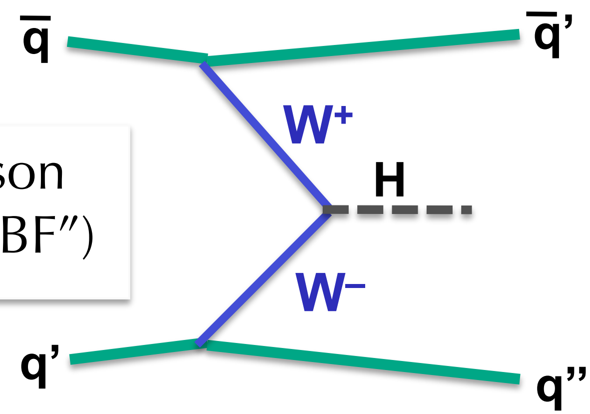




gluon-gluon fusion ("ggF")

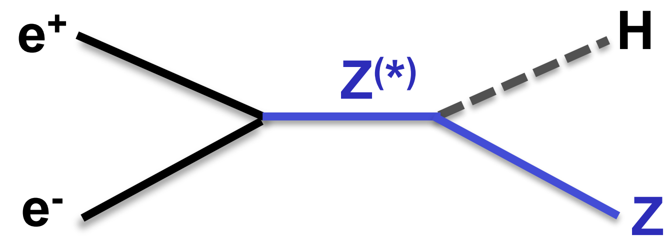


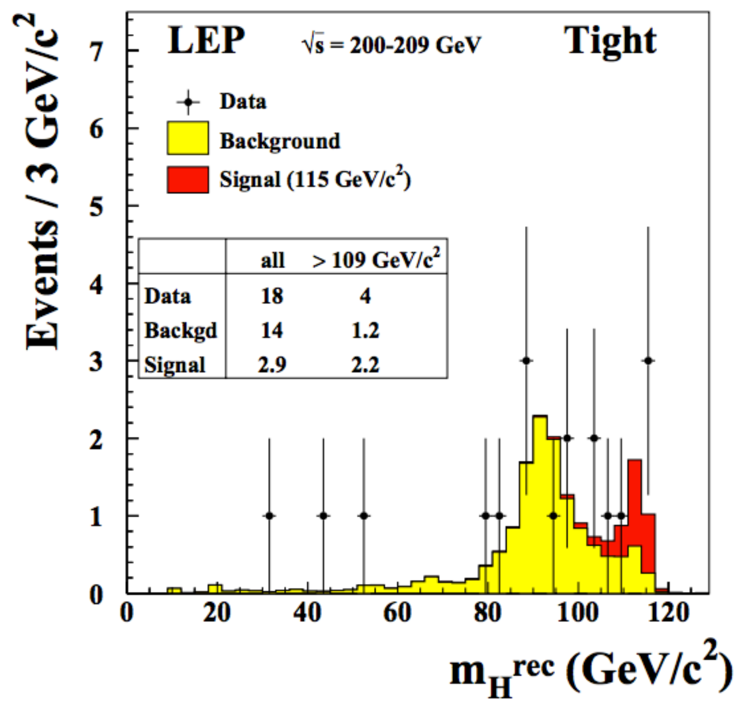
vector boson fusion ("VBF")



LEP: not quite enough energy

- Early high-mass search
- $m_H < m_Z$ ruled out by non-appearance in Z decay
- LEP: e^+e^- collisions at $\sqrt{s}$ = 189-209 GeV
- **Four experiments' combined direct bound m_H > 114.4 GeV**
  - → *(209 – 91 = 118)*
- In the end, limited by machine energy
- Did not quite reach expected BG-only limit of 115.3 GeV

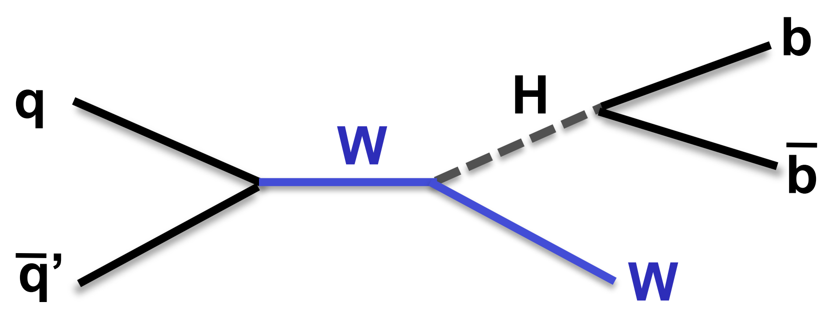




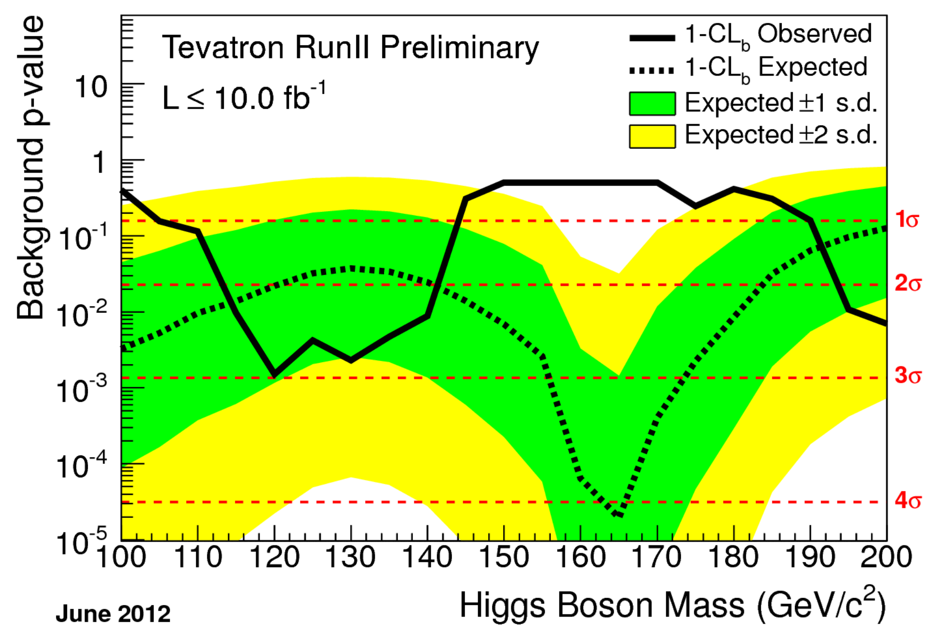
Tevatron: almost…

- 2 TeV proton-antiproton
- Cross section for ggF @ 125 = 0.95 pb

  → *compare 20 pb at LHC*



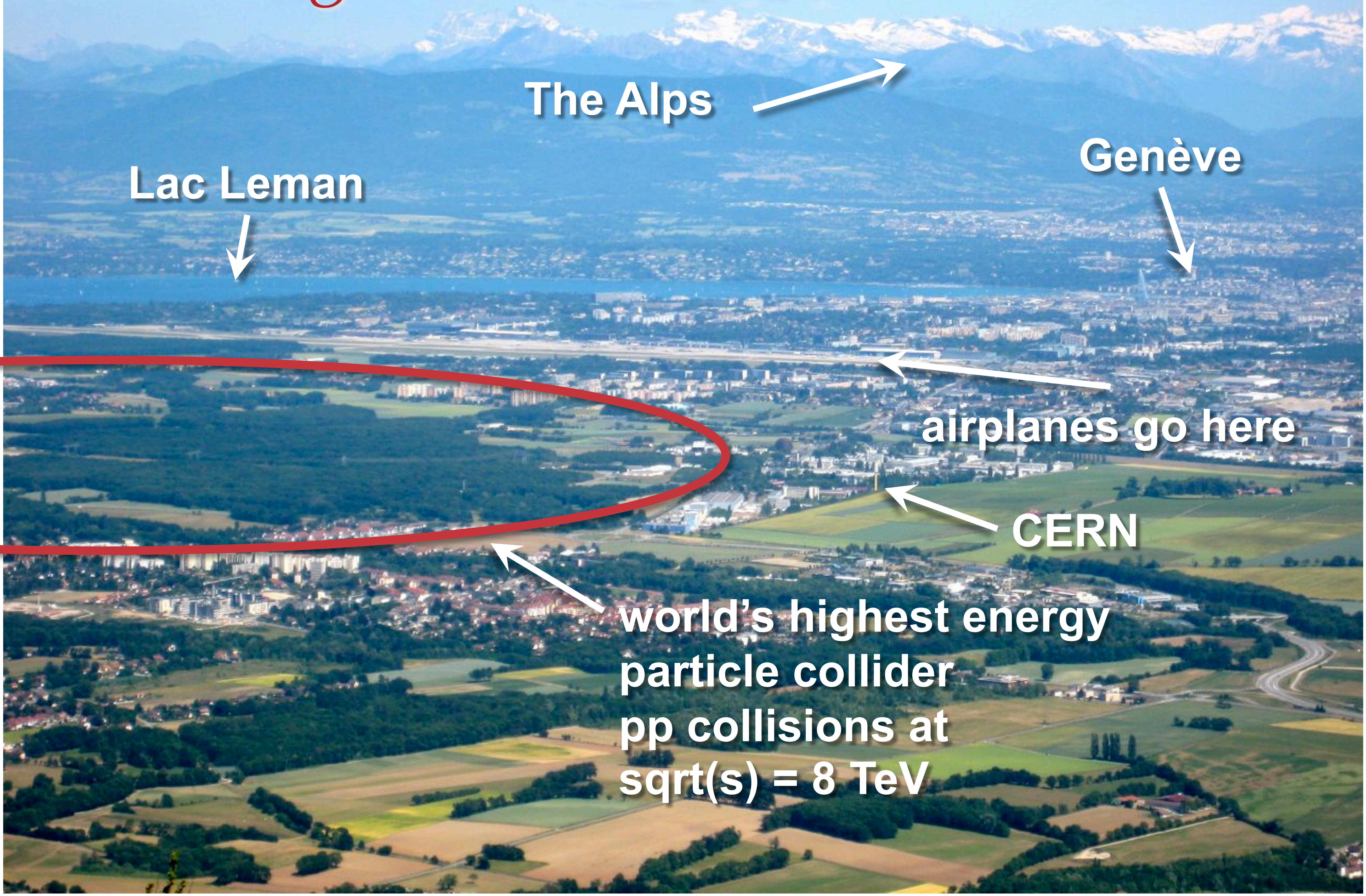
- Added sensitivity at low mass from associated production searches (σ_{WH} = 0.13 pb)



- Final combined CDF+D0 Run II significance 2.5σ (2.9σ considering bbbar alone)

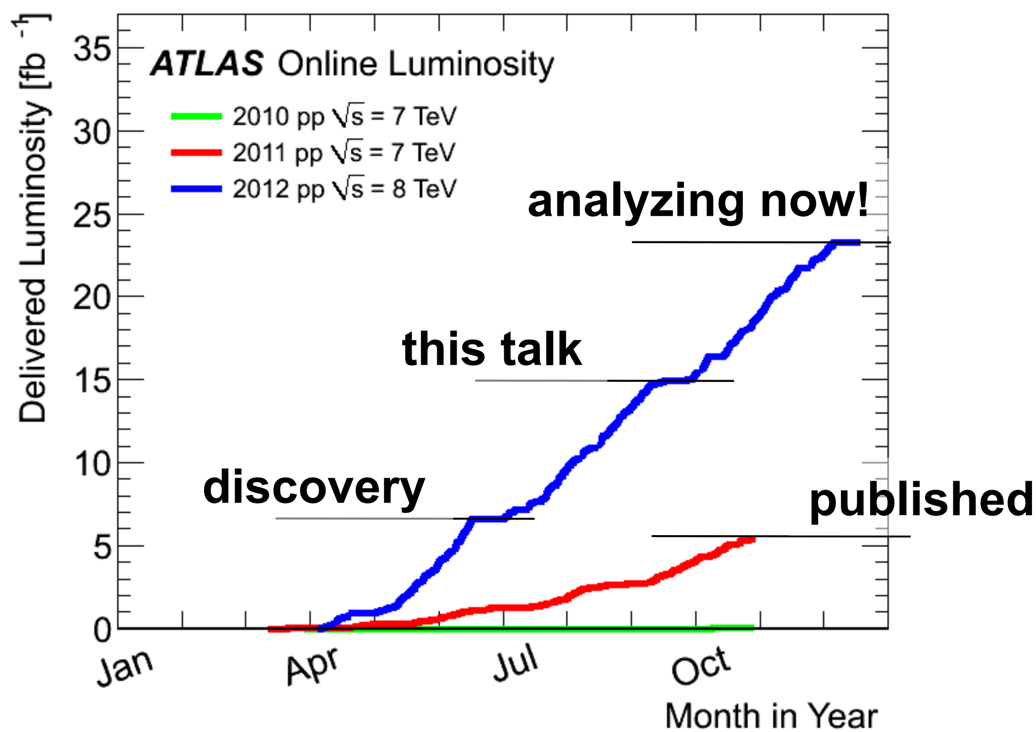
The Machine

The Large Hadron Collider at CERN



An Unprecedented Dataset

- Opened the throttle: **> 20 fb^{-1}** for analysis at 8 TeV (2011: $\approx$ 5 fb^{-1} at 7 TeV)
- **2012 Instantaneous luminosity record = 7.7 x 10^{33} cm^{-2}s^{-1}** (2011: 3.7 x 10^{33} cm^{-2}s^{-1})
- **1380 colliding bunches** (2011: 1331)
- **up to 1.5x10^{11} p/bunch** (~ same in 2011)



The ATLAS Detector

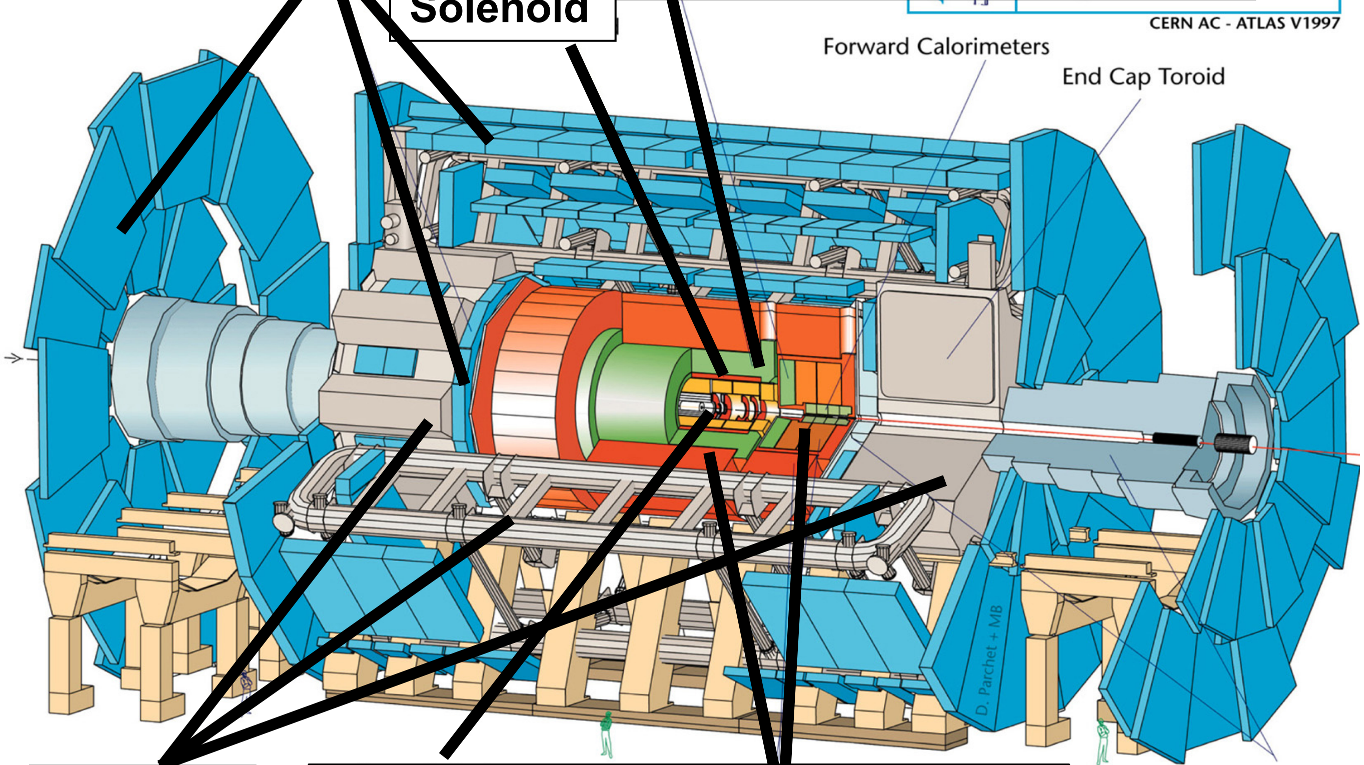
Muon Detectors: large radii for precise momentum measurement

Precision: Drift tubes (MDT) and Cathode Strip Chambers (CSC)

Trigger: Resistive Plate Chamber (RPC) and Thin Gap Chamber (TGC)

iquid Argon (LAr) with lead absorber

Solenoid



Toroids

Inner Detector (tracking):

Pixels (silicon)

SCT (silicon strip

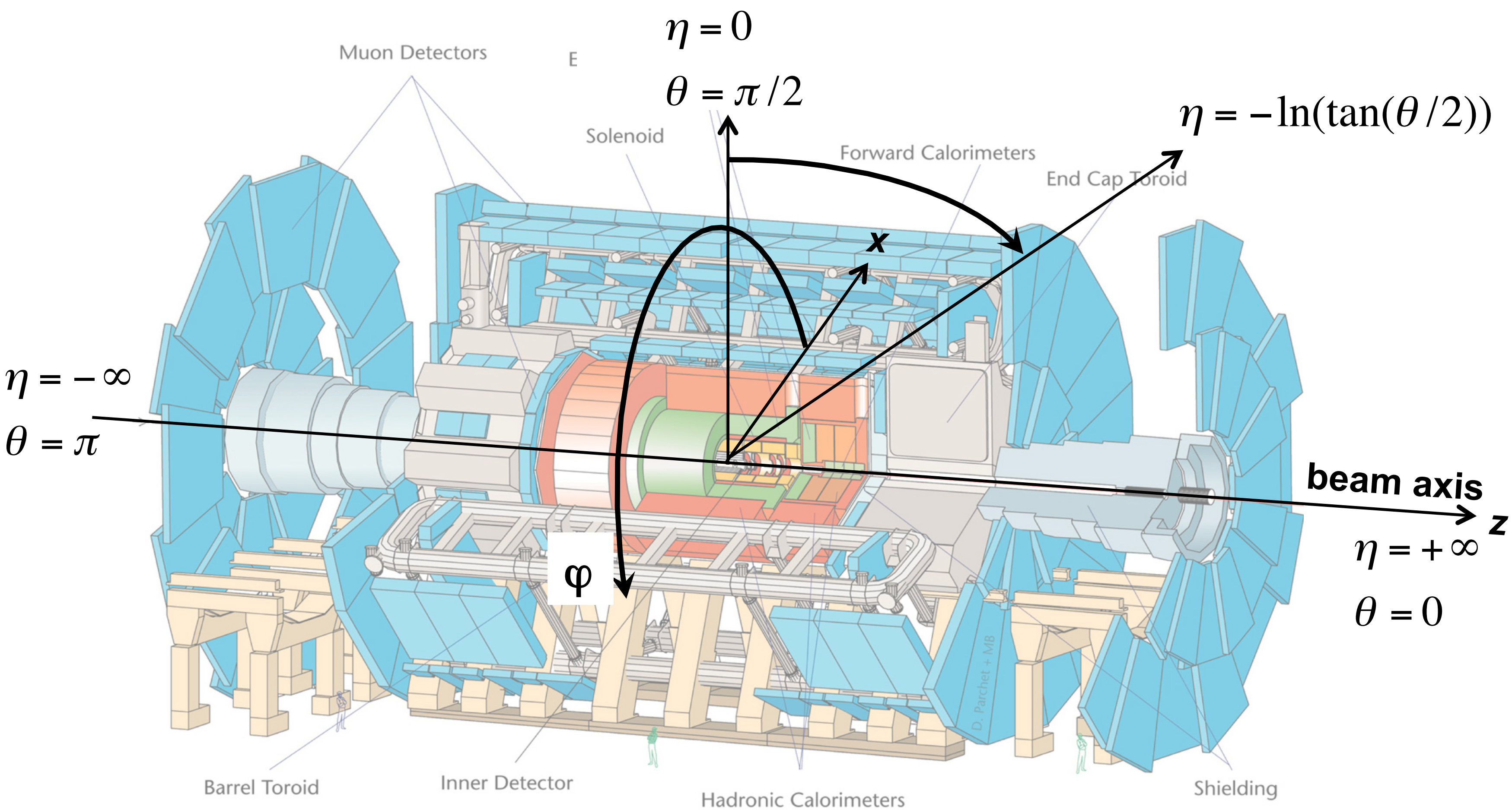
TRT (straw tubes

Hadronic calorimeter (jets, hadrons)

Steel absorber + scintillator

LAr with copper/tungsten absorber

Hadron Collider Kinematics



$$\vec{p}_T = (p_x, p_y) \qquad p_T = p\sin\theta, \quad E_T = E\sin\theta$$

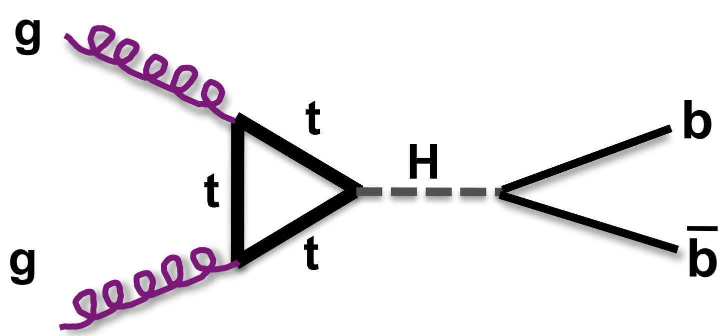
How to Detect a Higgs Boson

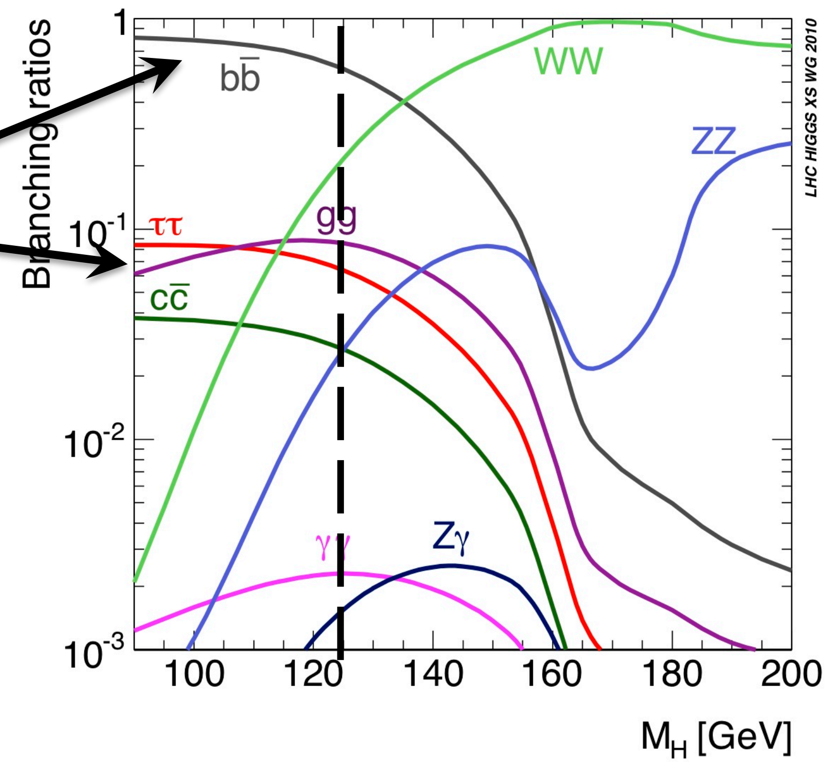
Recall: coupling strength ∝ m^2

→ *Interactions tend to go through the heaviest kinematically available particle*

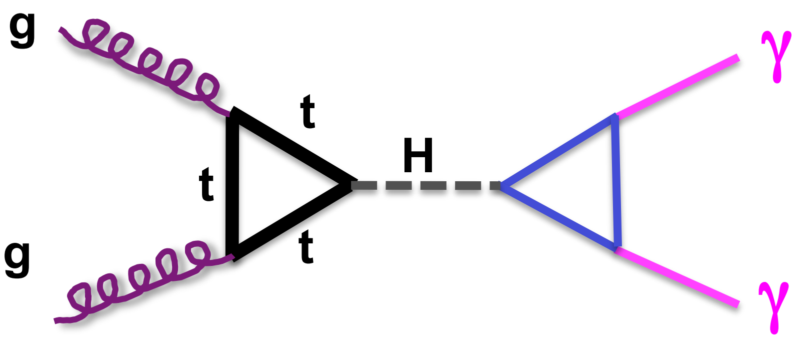
Branching ratio set by m_H:

$b\bar{b}$ and **$\tau\tau$**: largest BRs at **low** m_H, full m_H reconstruction, huge continuum **background**

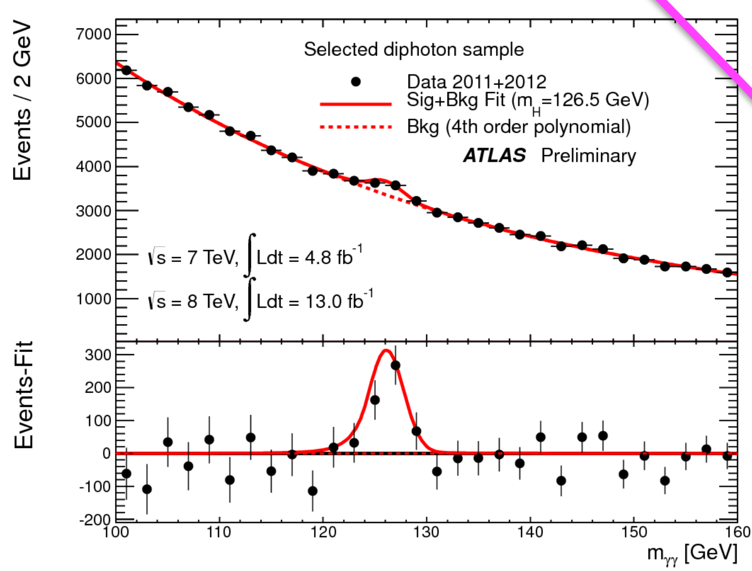




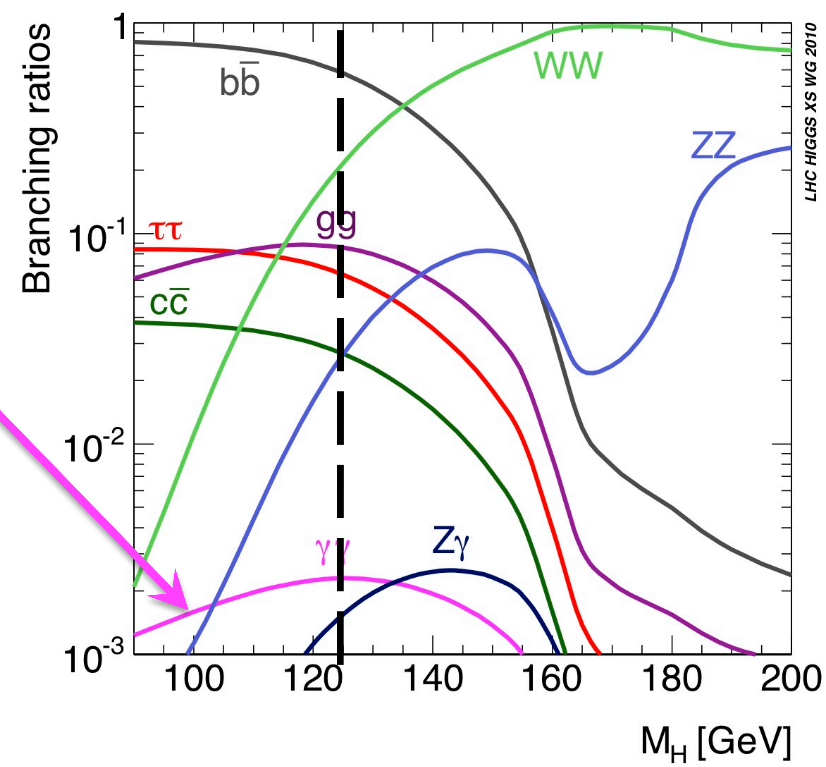
How to Detect a Higgs Boson



γγ: good sensitivity at **low** m_H, full m_H reconstruction from photon 4-vectors



Branching ratio set by m_H:

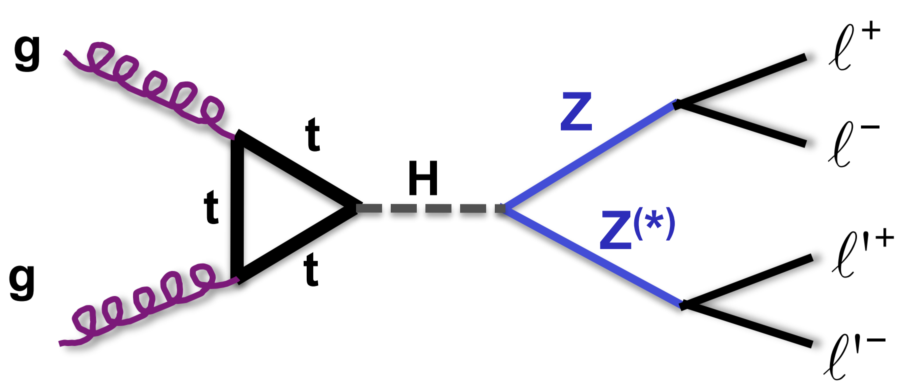


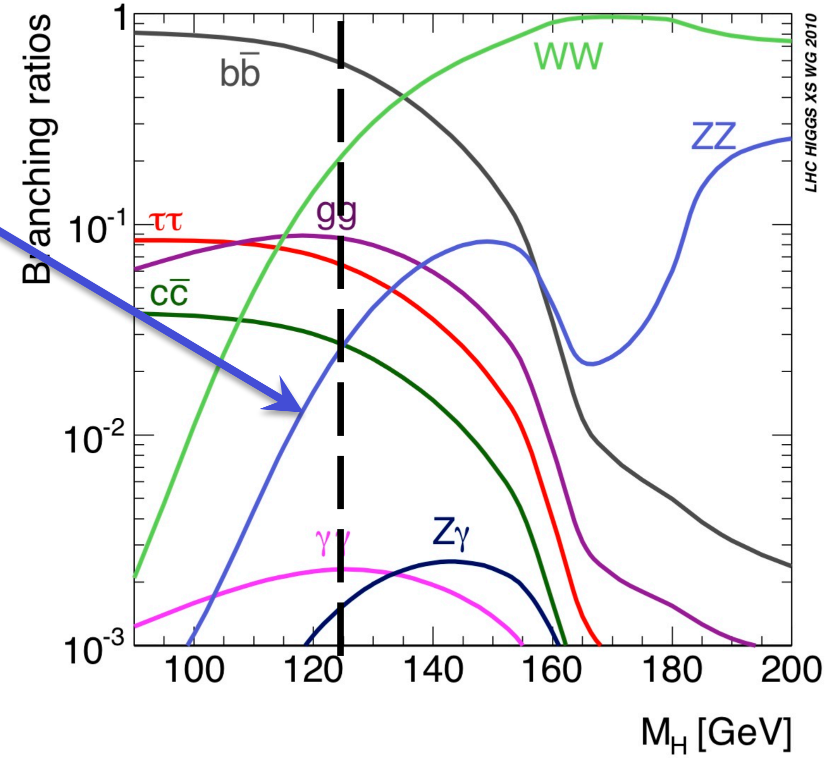
How to Detect a Higgs Boson

ZZ: 4l channel has excellent S/B, and best resolution for m_H reconstruction

Note: $m_H < 2M_Z \Rightarrow$ one Z off-shell

Branching ratio set by m_H:

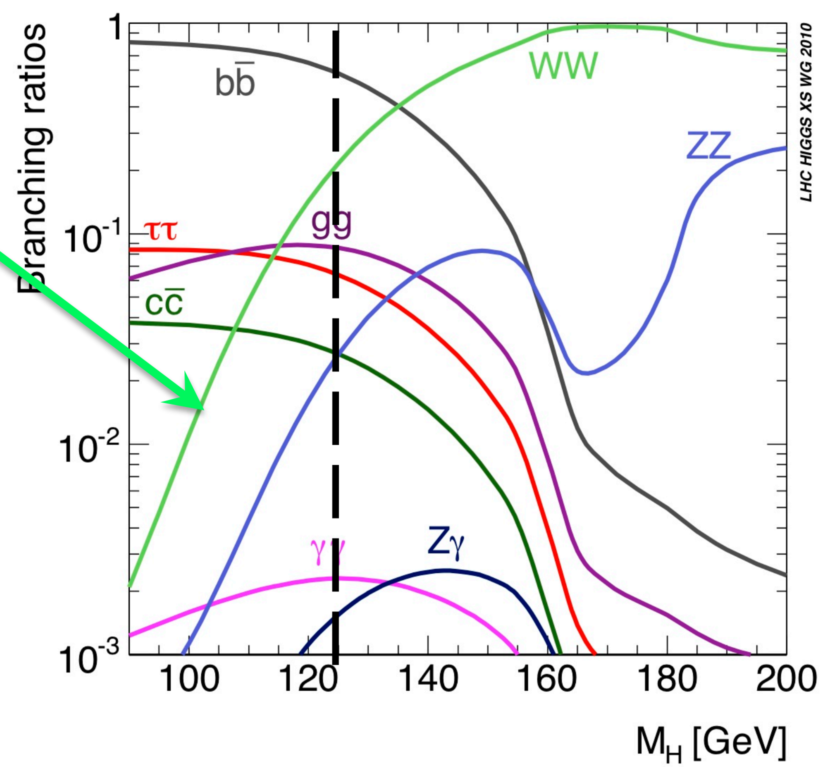


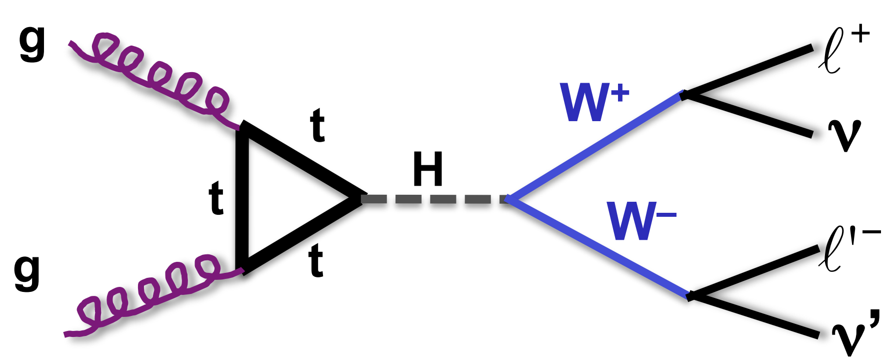


How to Detect a Higgs Boson

WW: good channel for discovery:
sensitivity at **many** m_H, but cannot fully reconstruct m_H in lνlν final state "no mass resolution"

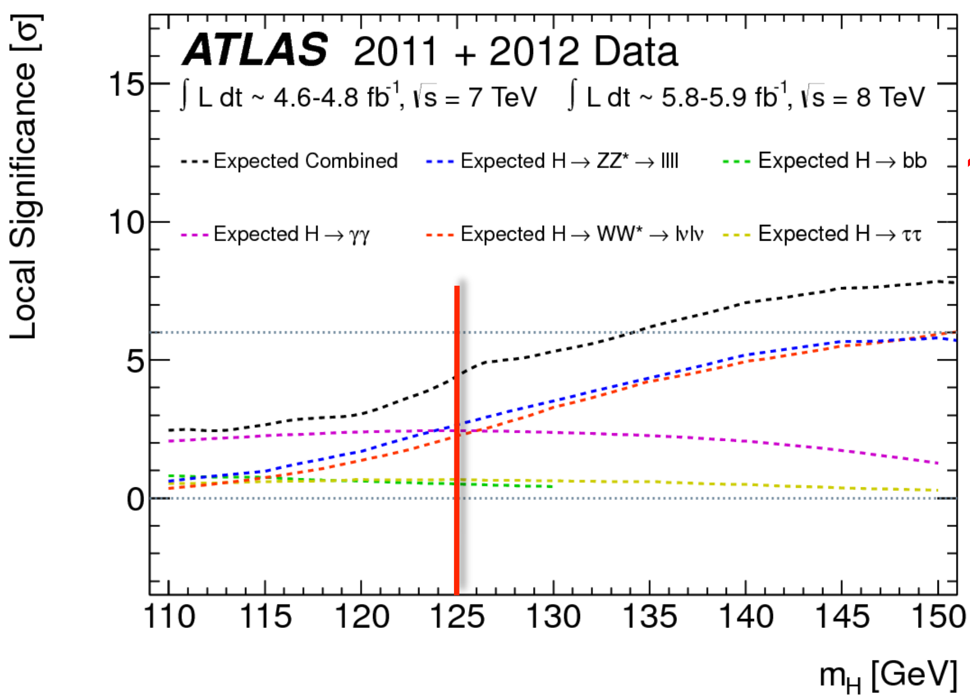
Branching ratio set by m_H:

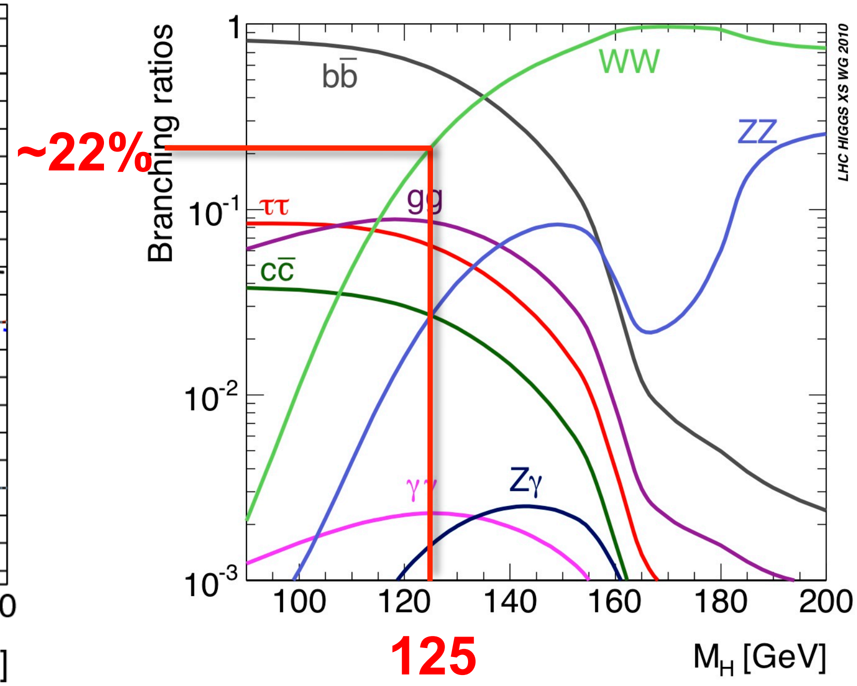




$WW^* \rightarrow l\nu l\nu$

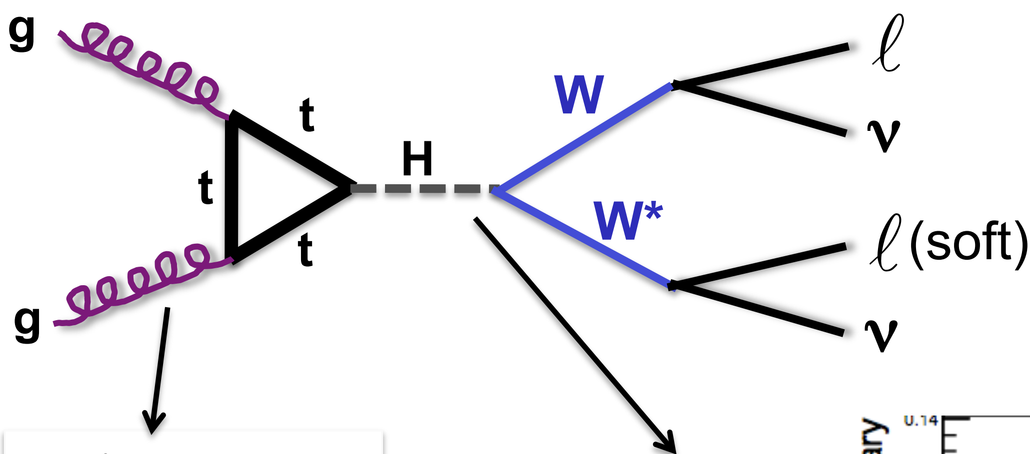
- The price at low m_H: one W off mass shell ⇒ no mass resolution, soft lepton from W* requires increased backgrounds to maintain efficiency
- The payoff: still better signal/background than γγ and more signal yield than ZZ → 4l for m_H ~ 125 GeV ⇒ contribution to discovery
  - → *Post-discovery: key channel for rate ($\mu = \sigma/\sigma_{SM}$) measurement*





The Details

The signal



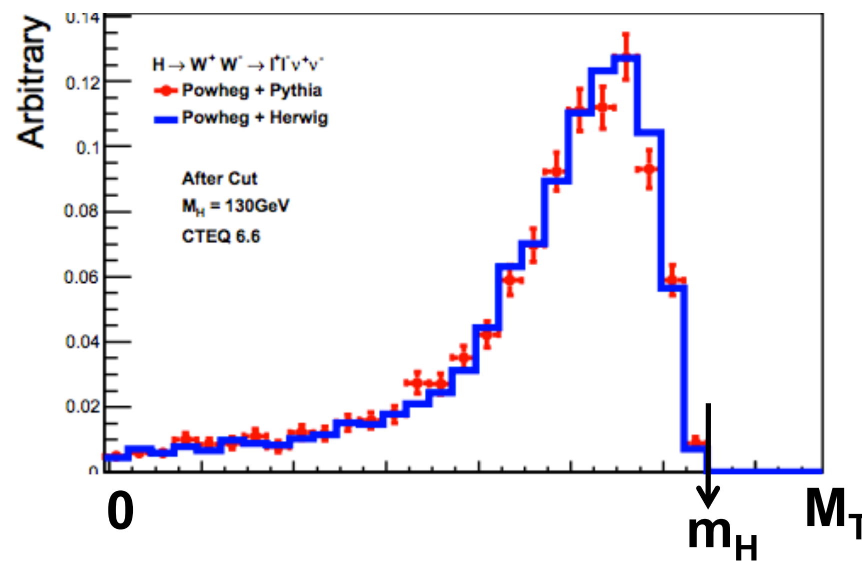
Final-state signature:
2 charged leptons +
2 neutrinos

no jets at
leading order

spin zero
initial state

Transverse mass M_T: Like invariant mass, but drop missing p_z information

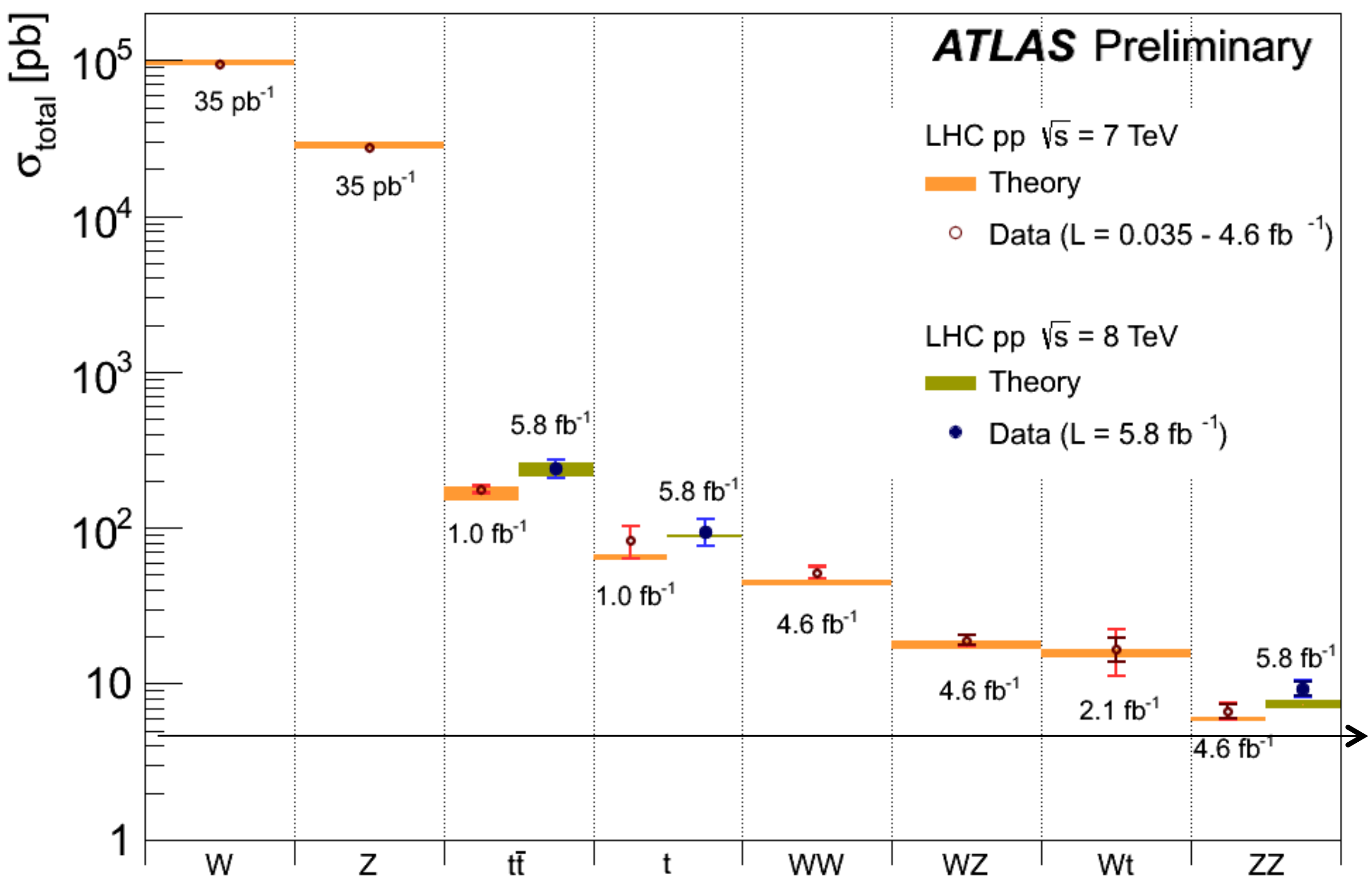
Signal discriminant: fit this distribution for signal extraction



from 1201.3084v1

$$M_T^2 = (E_T^{\ell\ell} + E_T^{\text{miss}})^2 - (\vec{p}_T^{\,\ell\ell} + \vec{E}_T^{\text{miss}})^2 \qquad (E_T^{\ell\ell})^2 = (\vec{p}_T^{\,\ell\ell})^2 + (m_{\ell\ell})^2$$

The scale of the challenge



$\sigma(pp \to H)$ x BR($H \to WW$)
= 20 pb x 0.22
= 4.4 pb
(at 8 TeV)

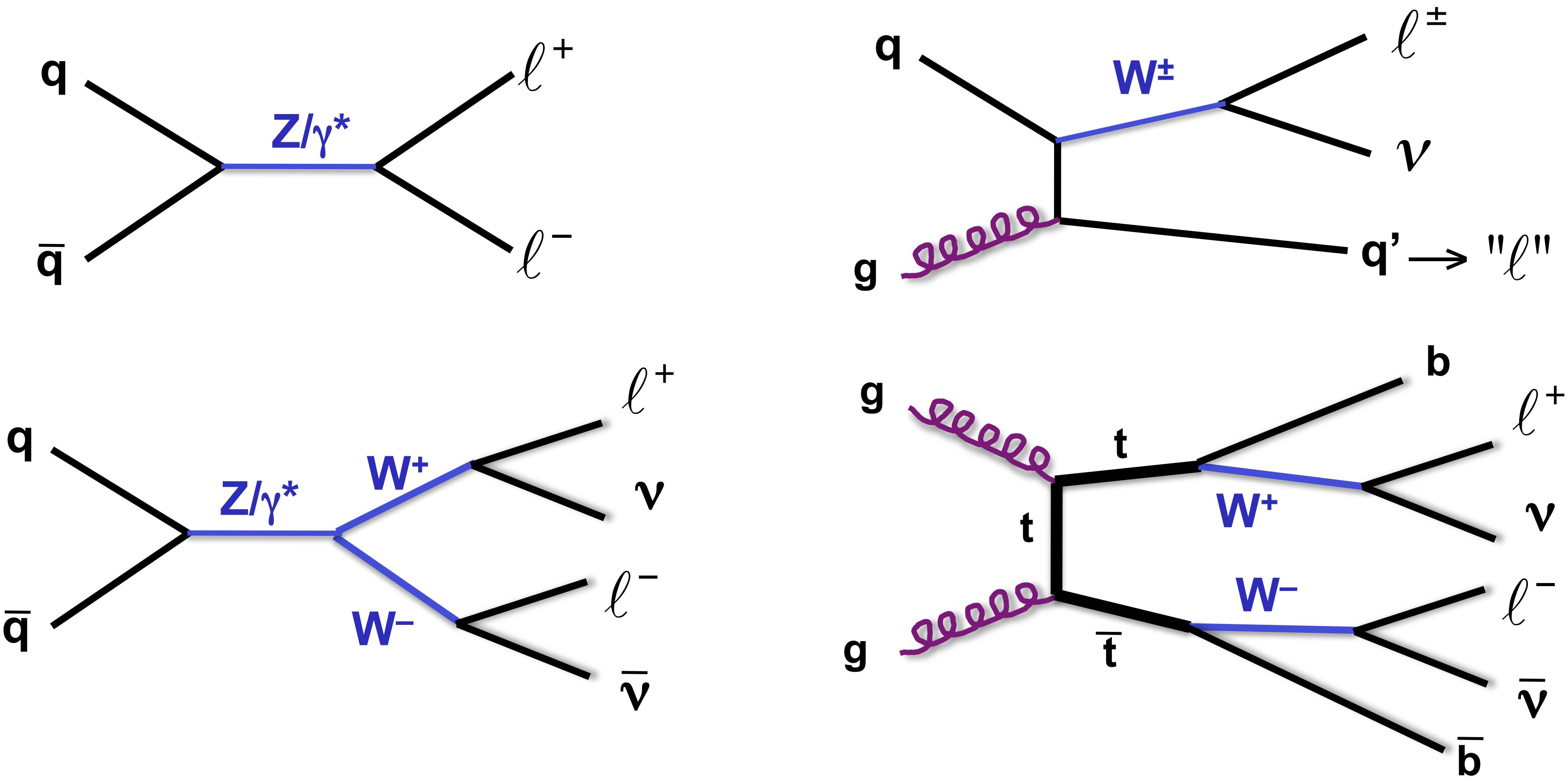
What Matters?

	Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	$Z/\gamma^* +$ jets	$W +$ jets	Total Bkg.
$H+$ 0-jet	45 ± 9	242 ± 32	26 ± 4	16 ± 2	11 ± 2	4 ± 3	34 ± 17	334 ± 28
$H+$ 1-jet	18 ± 6	40 ± 22	10 ± 2	37 ± 13	13 ± 7	2 ± 1	11 ± 6	114 ± 18

- Bottom line: S/B ~ 15%, so BG must be **small** or **well understood**
  - → *Estimate it reliably (small uncertainty) or knock it out*
- Key examples:
  - → ***WW:*** *relatively well-understood but not small*
  - → ***W+jets****: small but large systematic uncertainty*

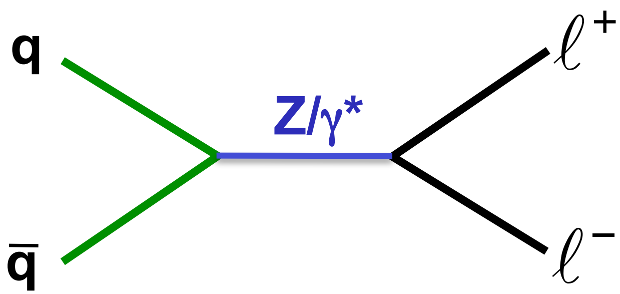
Backgrounds

What do you get when you select dilepton events with E_T^{miss}?

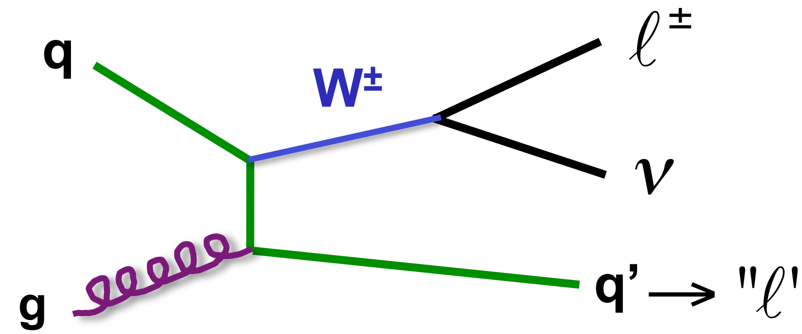


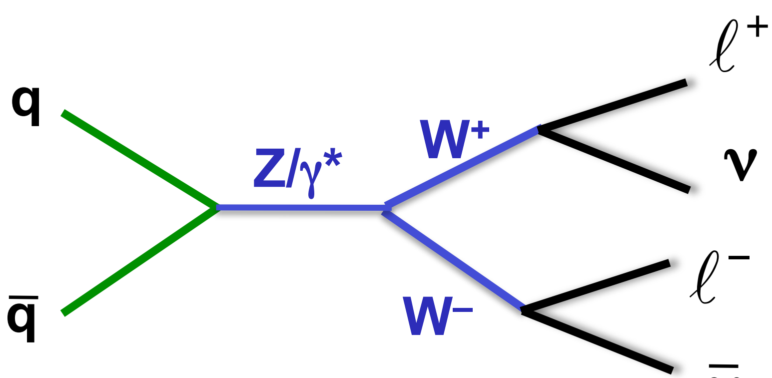
Backgrounds

Z/γ*: no neutrinos

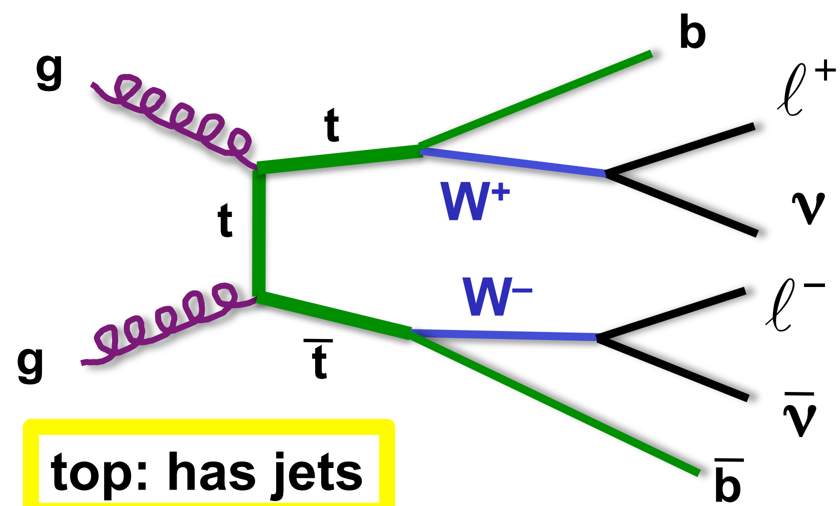


W+jets: fake leptons





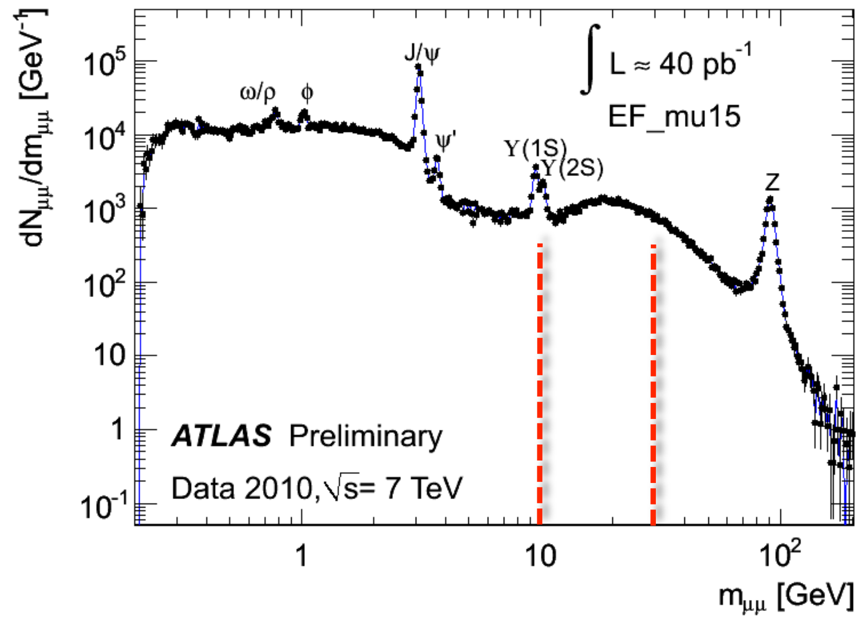
WW: irreducible



top: has jets

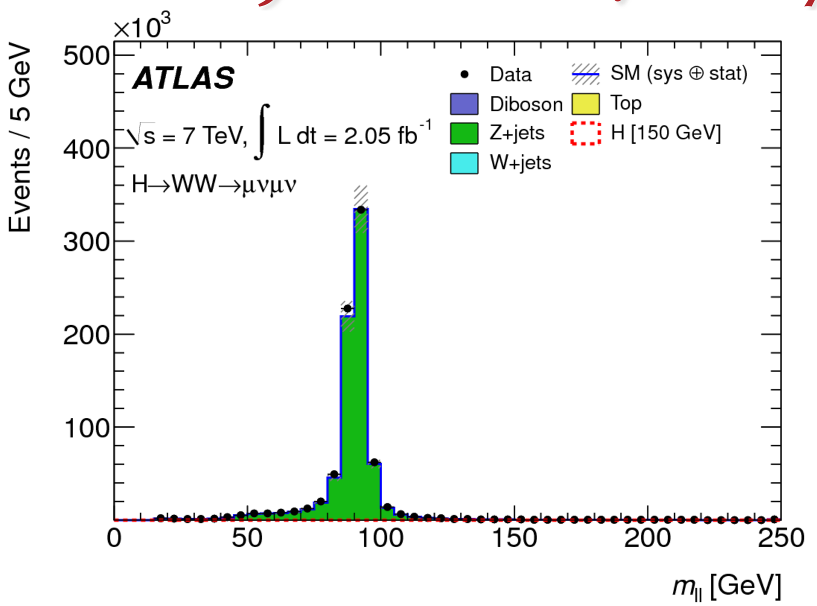
Dilepton selection

- Lepton selection dictated by signal acceptance and W+jets rejection
- **Electrons** selected using most selective ID: calo shower shape, track match, conversion rejection
- **Muons** selected as combined ID, MS track (incl. d_0 significance)
- track- and calorimeter- based **isolation**
- **p_T(lead) > 25 GeV, p_T(sublead) > 15 GeV**
- m(ll) > 10 GeV for eμ+μe (12 for ee+μμ)
- (no) Taus



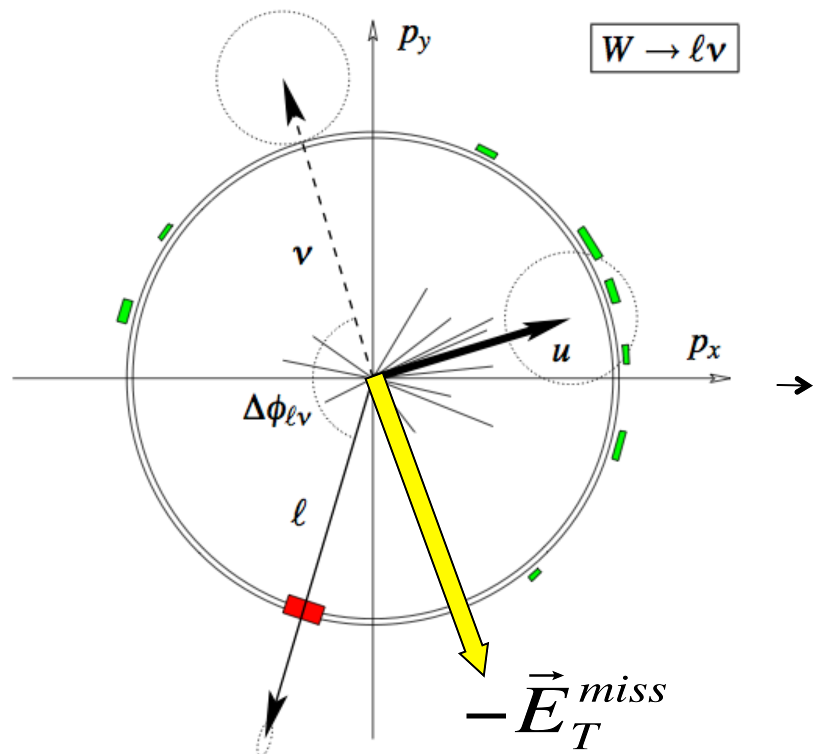
reject low-mass resonances

Reject Z/γ* by selecting MET



dilepton data is all Z/γ* (Drell-Yan)…

… but Drell-Yan has no neutrinos so we can reject most of it

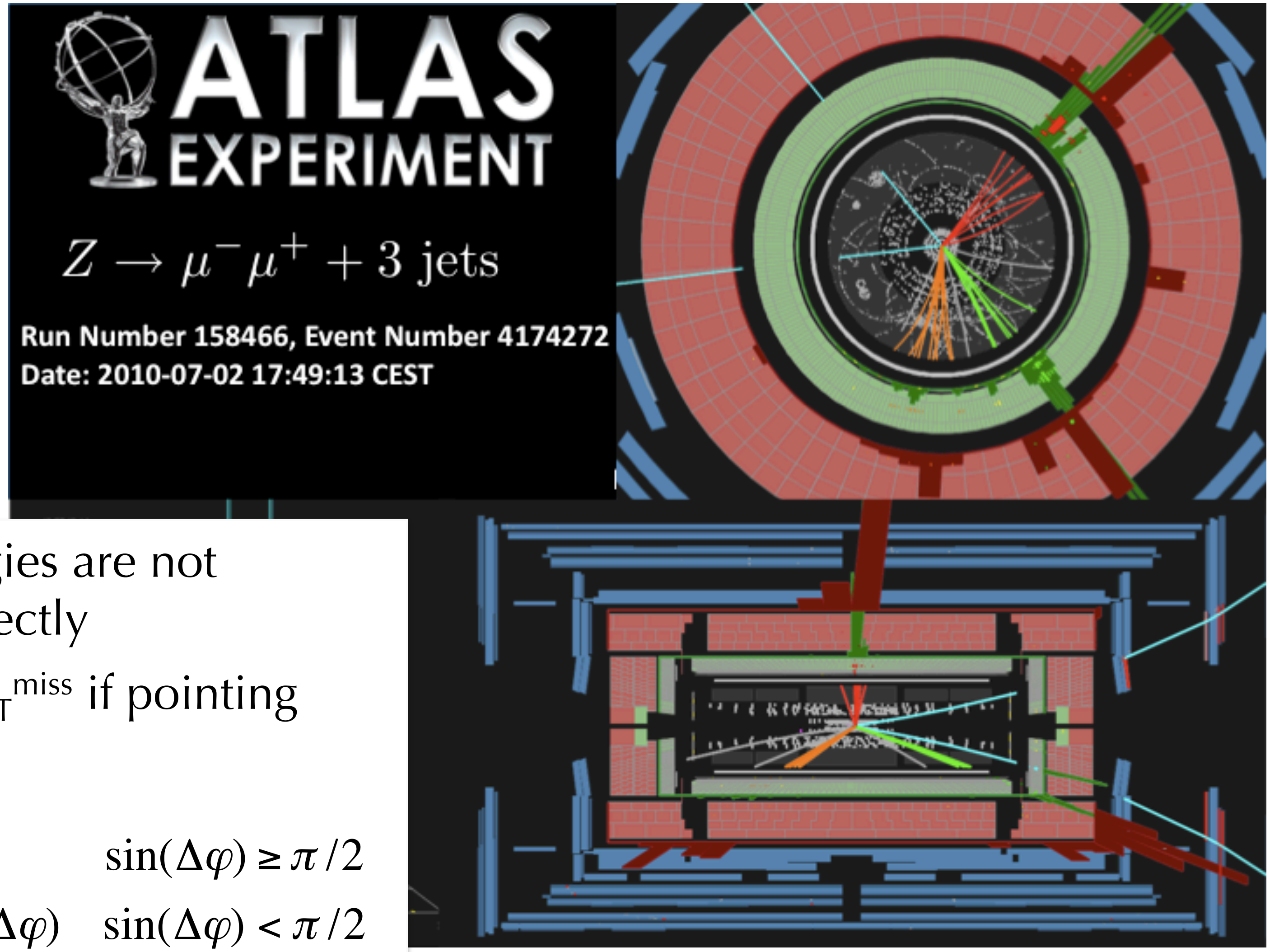


Detect neutrinos by invoking conservation of momentum in the plane transverse to the beam:

$$\vec{E}_T^{miss} = -\sum_{\text{objects}\, i} \vec{p}_T^{\,\text{object}}$$

"Missing Transverse Energy"

MET → METRel



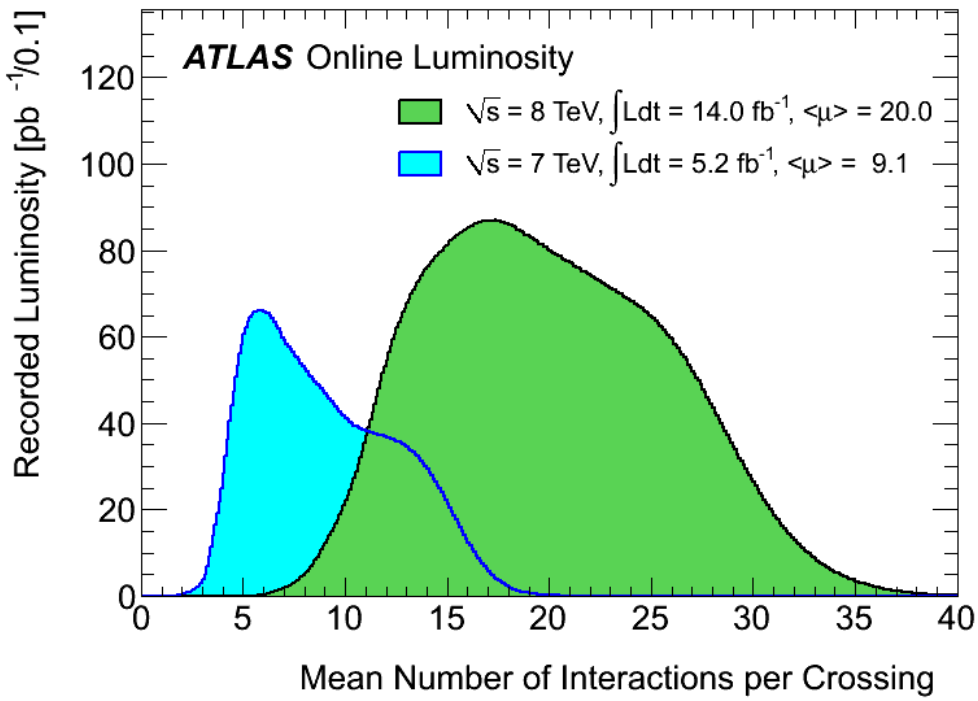
But objects' energies are not measured perfectly

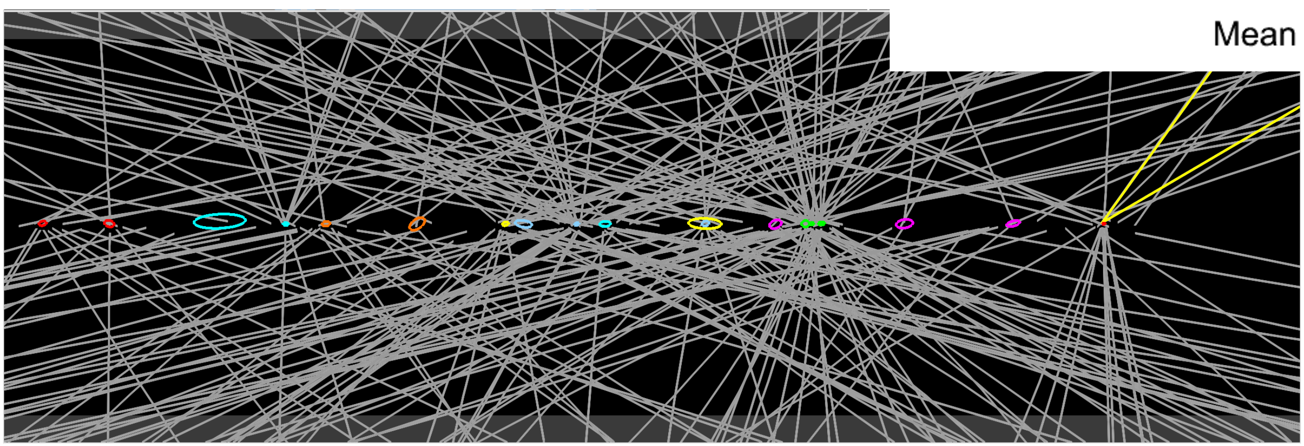
METRel: stricter E_T^{miss} if pointing near an object

$$E_{T,\,\mathrm{rel}}^{\mathrm{miss}} = \begin{cases} E_T^{\mathrm{miss}} & \sin(\Delta\varphi) \geq \pi/2 \\ E_T^{\mathrm{miss}} \sin(\Delta\varphi) & \sin(\Delta\varphi) < \pi/2 \end{cases}$$

Pileup

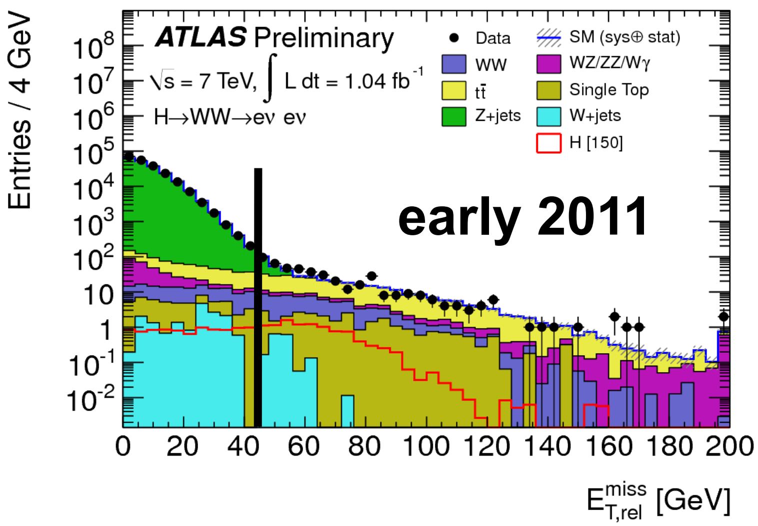
- Price of luminosity: multiple interactions per bunch crossing
- Primary impact on physics: E_T^{miss} resolution scales with sqrt($\Sigma(E_T)$)
- Pileup adds "soft stuff"

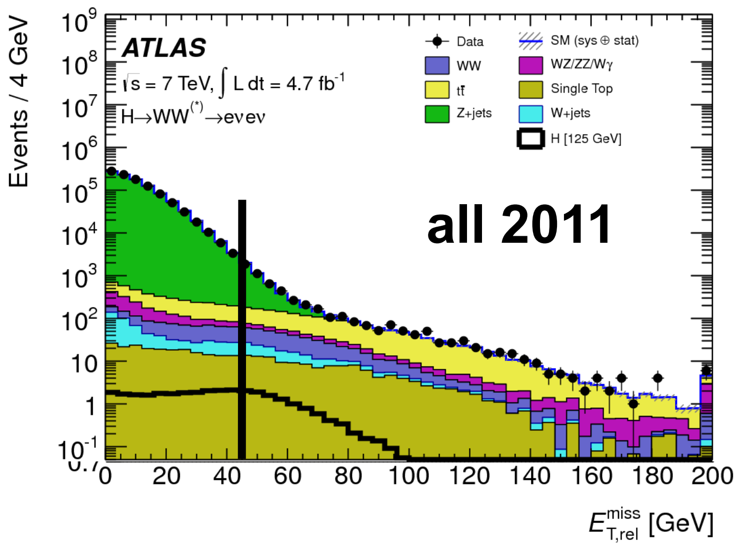


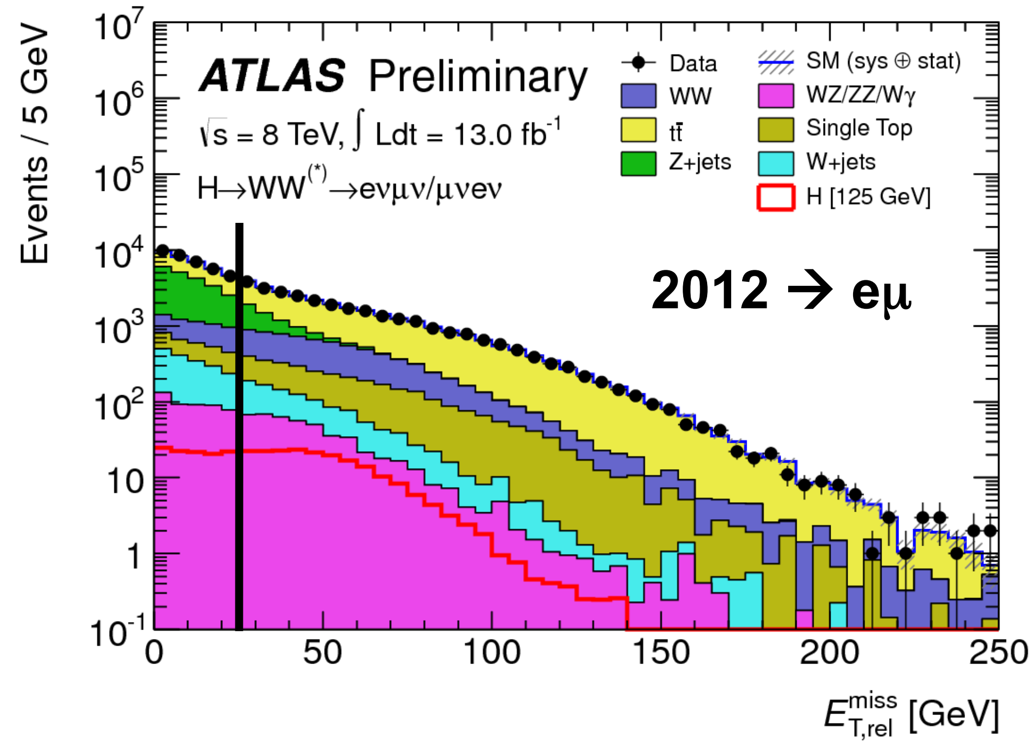


Z → μμ event from 2011 with 20 vertices

Select MET to reject Z/γ*



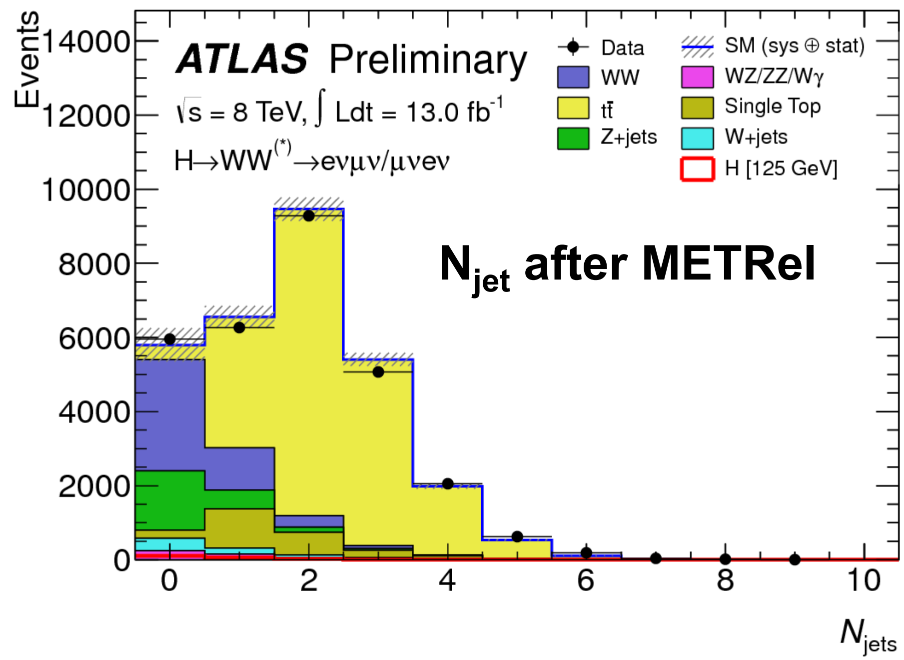




- Omitted ee+μμ in 2012 so far
- Work in progress includes track-based variables for pileup-robust DY rejection

Analysis by Njet

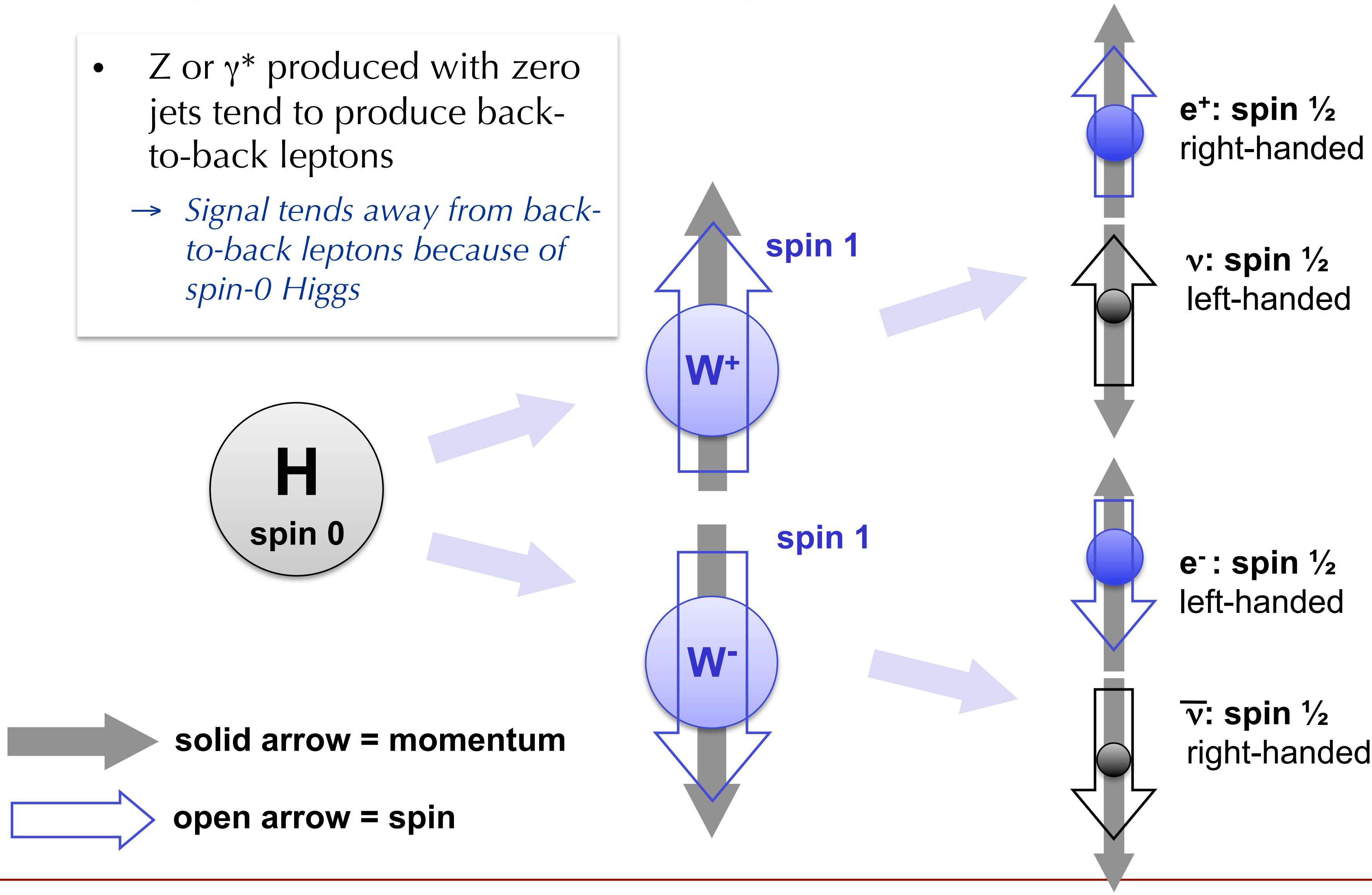
- ggF signal mostly has zero jets ⇒ use data with zero or one jet
- Jets: anti-k_T, cone 0.4
  - → *p_T > 25 GeV (p_T > 30 GeV for $|\eta|$ > 2.5)*
  - → *$|\eta|$ < 4.5 (edge of calorimeter)*



- Control top BG, for a price (systematics)
  - → *experimental: **jet energy scale and resolution** (4% on 0-jet signal yield)*
  - → *theoretical: **QCD scale uncert. of 17% and 30%** on 0-jet and 1-jet signal yield (partially anti-correlated; reduced impact on total signal strength)*

*Signal and Backgrounds – Z/γ**

- Z or γ* produced with zero jets tend to produce back-to-back leptons
  → *Signal tends away from back-to-back leptons because of spin-0 Higgs*



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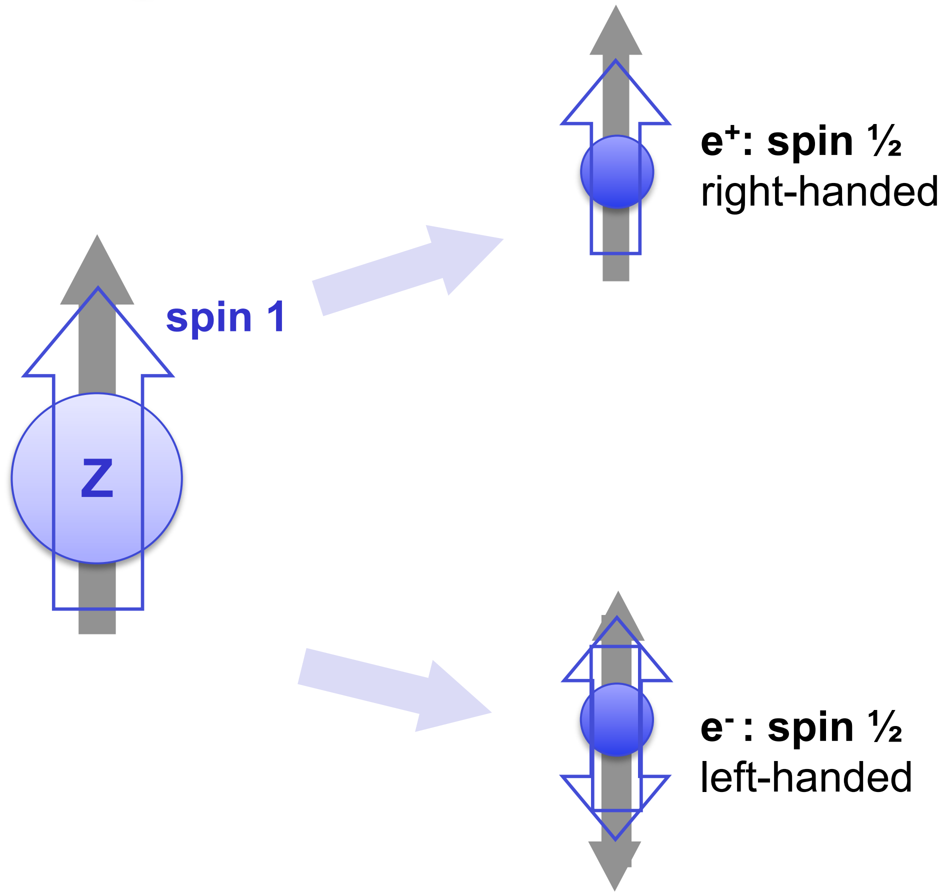
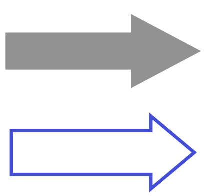


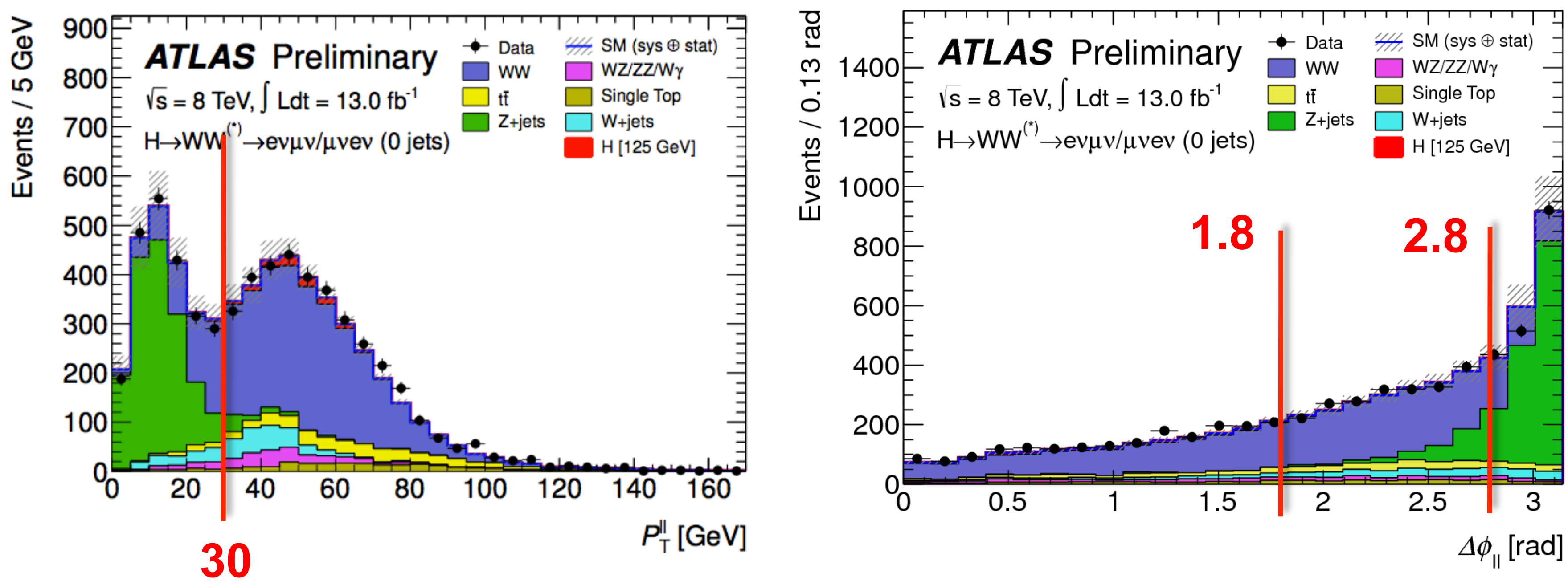


solid arrow = momentum

open arrow = spin

$p_T(ll)$ and $Z \rightarrow \tau\tau$

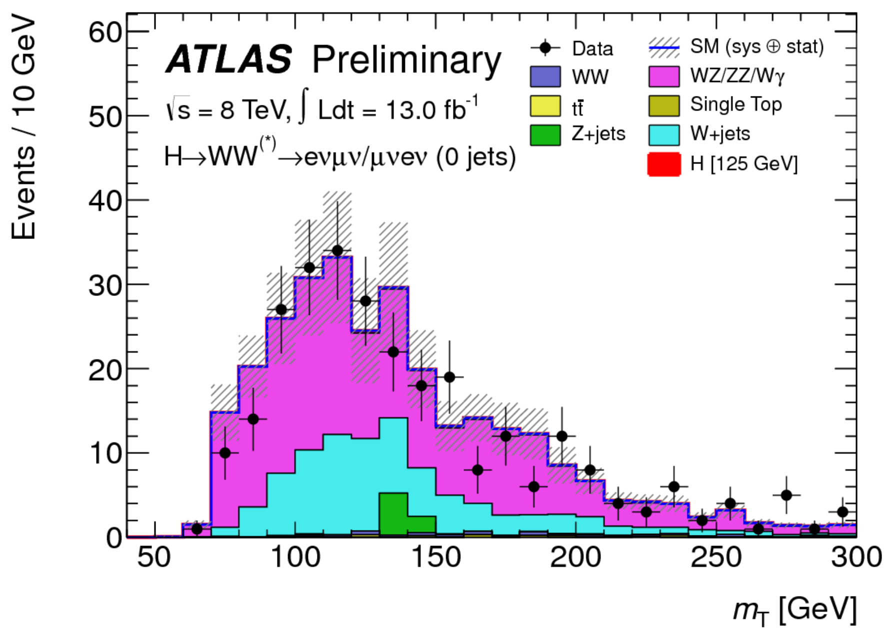
distributions after jet veto



- Most Z/γ^* background in eμ is from ττ
  - → *Spin correlation still holds*
  - → *0 jet: reject by requiring $p_T(ll) > 30$ GeV*
- Normalize remaining BG using data with m(ll) < 80, Δφ(ll) > 2.8

W+X

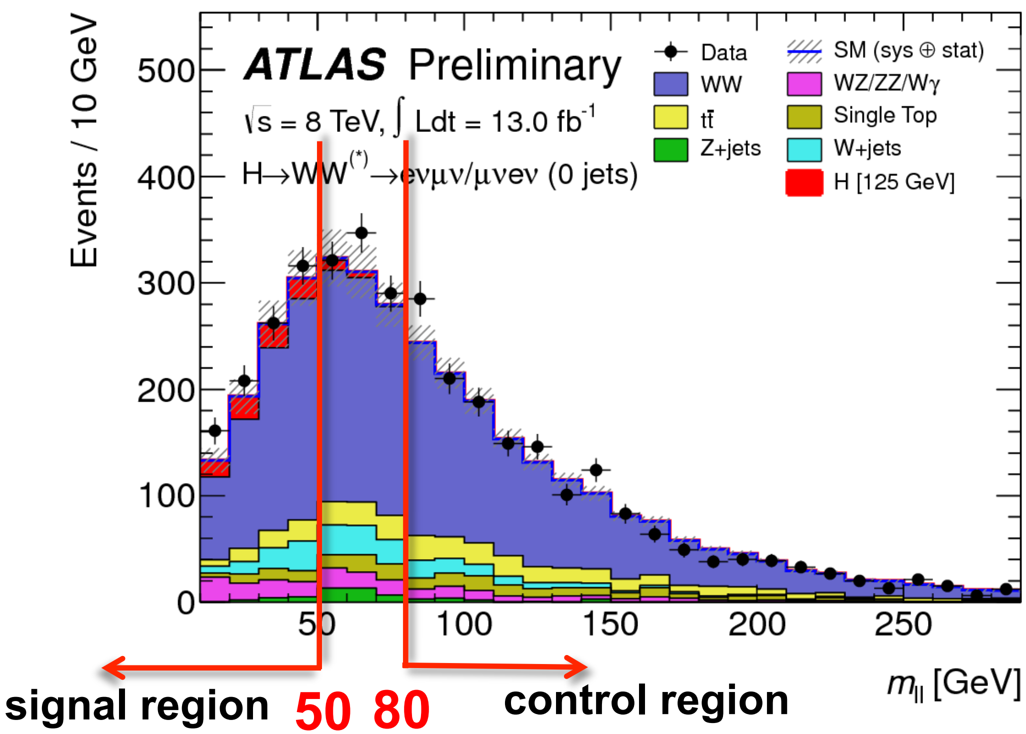
- **W+jets: "fake factor"** (ratio of identified to anti-identified leptons in a QCD-enriched sample) multiplied by W+anti-ID distribution
  - → *50% err. on fake factor (sample dependence, EWK subtraction, pileup, trigger bias)*
  - → *5% uncertainty on total BG yield. 0, 1 jet bin: compare 8%, 16% total!*
- Validate in same-charge events (below: after METRel, jet veto, p_T(ll))



Note:
- peak at m_T~125, like signal
- same sign dominated by non-WW diboson!

m(ll) and WW: control regions

- WW is the dominant background
- Reduce uncertainties by normalizing WW background to data in signal-depleted "control regions" CR
  - → *Extrapolate in m(ll)*



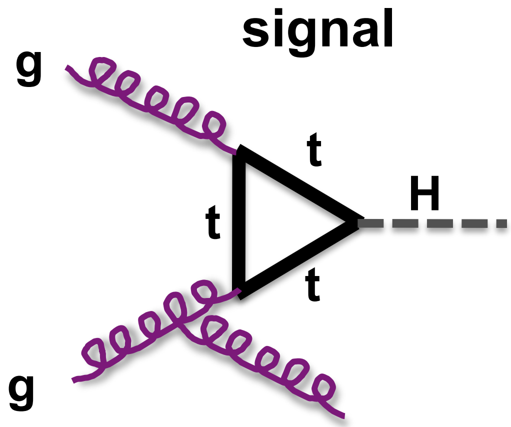
uncertainties: extrapolation [experimental + theoretical]

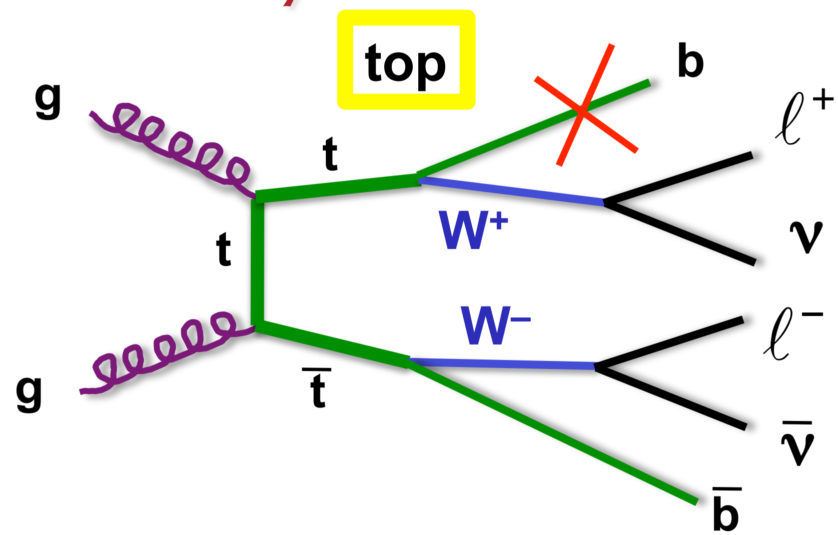
$$N_{SR} = \left(\frac{N_{SR}^{MC}}{N_{CR}^{MC}}\right)\left(N_{CR}^{\text{data}} - N_{CR}^{\text{other}}\right)$$

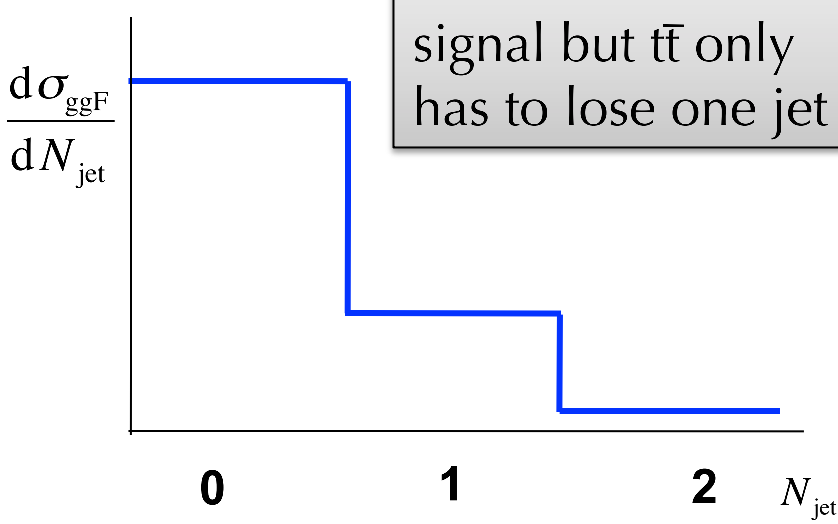
CR statistics

"background subtraction" or "crosstalk"

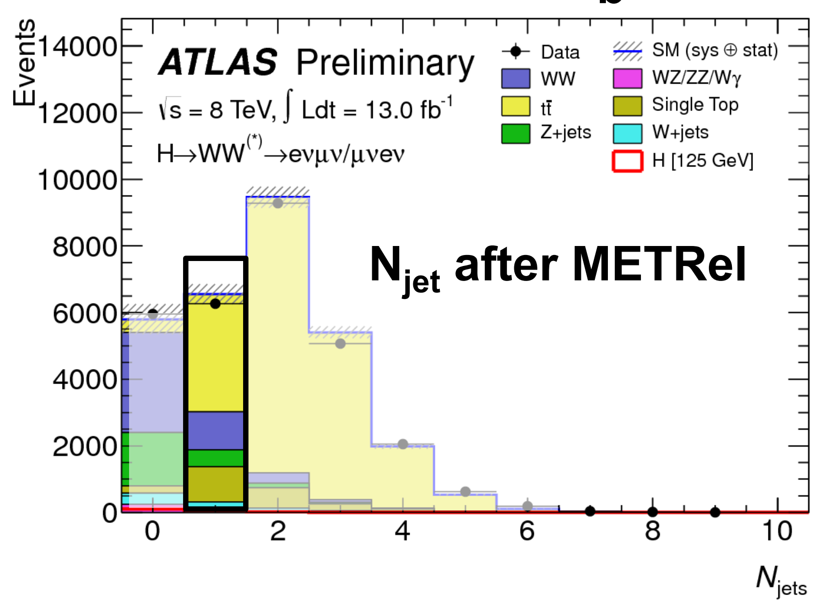
1-jet analysis



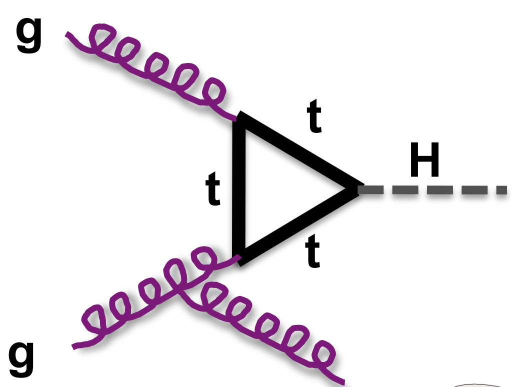


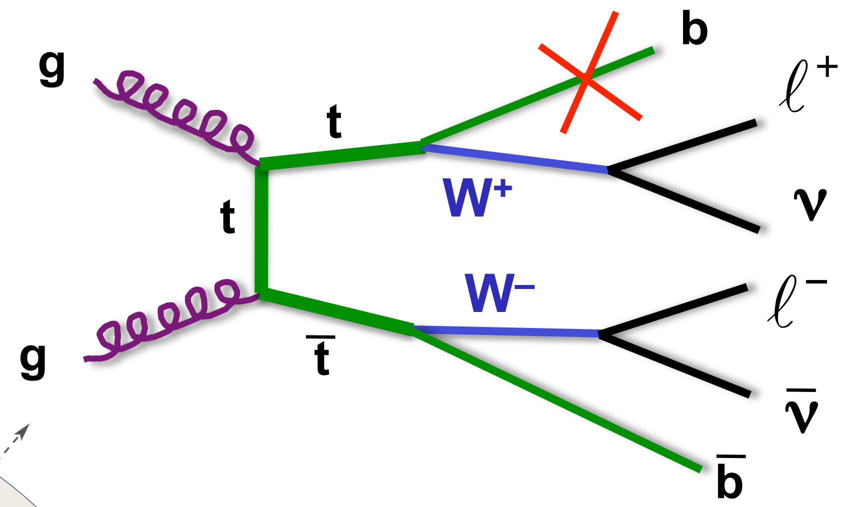


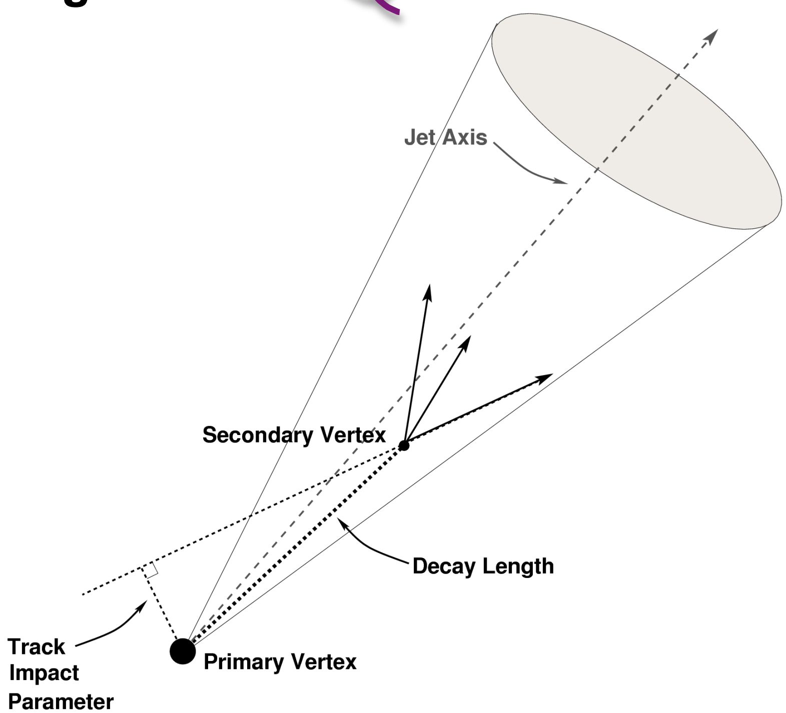
considerable signal but $t\bar{t}$ only has to lose one jet



1-jet analysis: top and the b-veto







But these **jets are not the same**: t → Wb always, and we can tag b-jets using impact parameter + secondary vertex information

Multivariate algorithm
"MV1" is ATLAS benchmark

1-jet analysis: top and the b-veto

Veto b-tagged jets for signal region

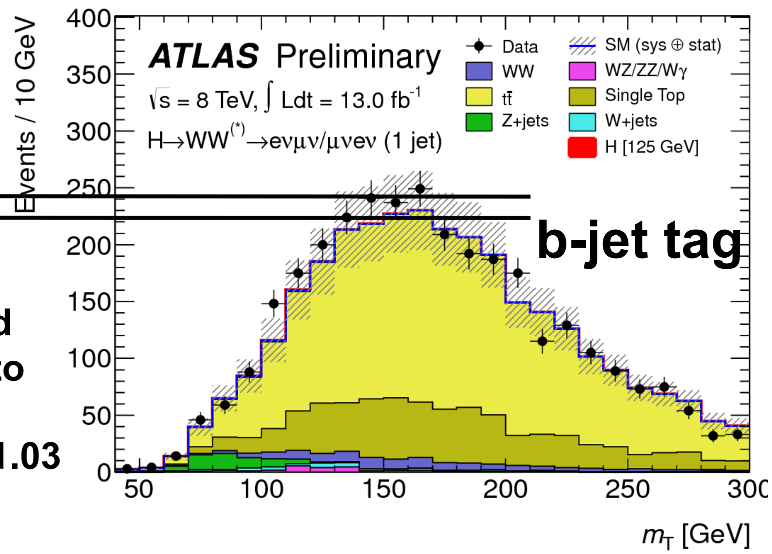
- → *85% b-jet efficiency operating point ⇒ aggressive veto, only 85% efficient for signal but rejects 75% of top background*
- → *Even with veto, largest background in 1-jet SR, 44% of total*

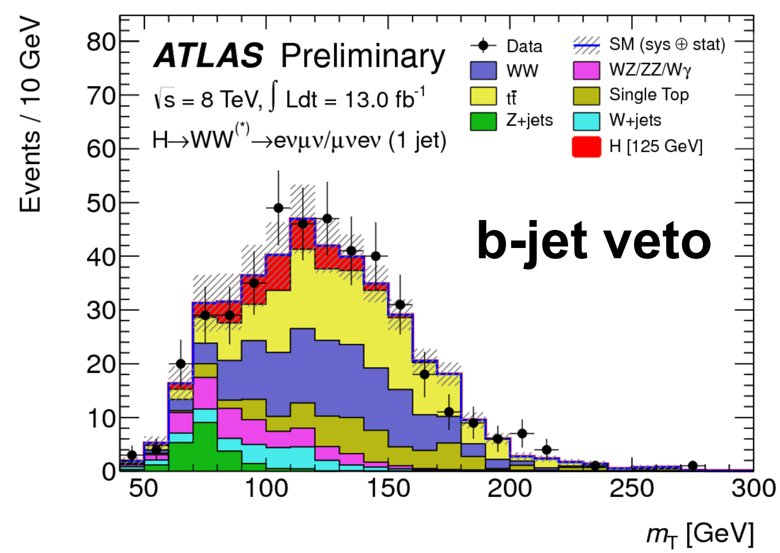
Tagged events form **control region** used to normalize background

Total uncertainty on 1-jet top = 37% (uncertainty on eff. 5-10%)

b-tagging is leading systematic on 1-jet background yield, at 11%

normalize background prediction to CR data, scale by ~ 1.03



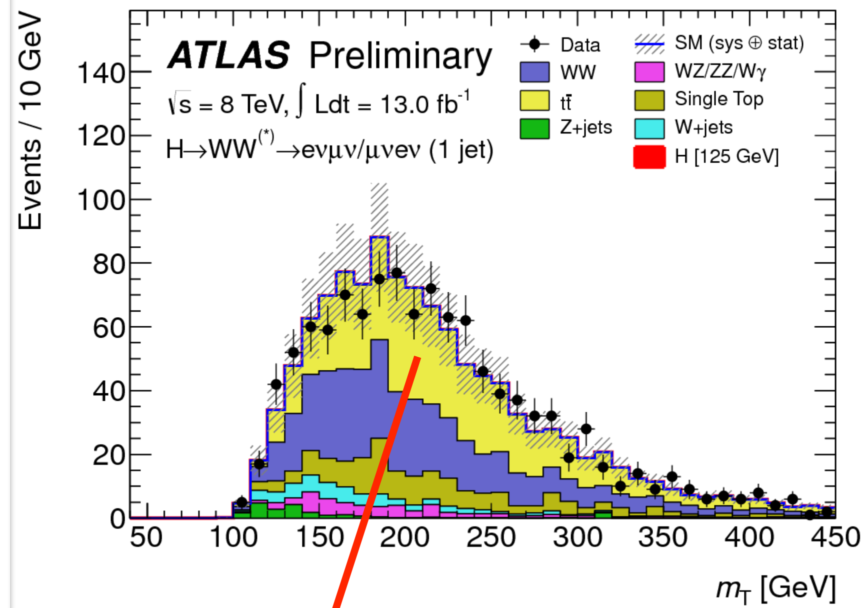


Interplay between systematics

Theoretical uncertainties:

- QCD **scale** and **PDFs**
- **Parton shower and underlying event**: Pythia8 / Pythia6 / Herwig
- **Modelling and shape**: MC@NLO vs. MCFM

WW background extrapolation uncertainties				
	Scale	PDFs	PS/UE	Modelling
α^{0j}_{WW}	2.5%	3.7%	4.5%	3.5%
α^{1j}_{WW}	4%	2.9%	4.5%	3.5%



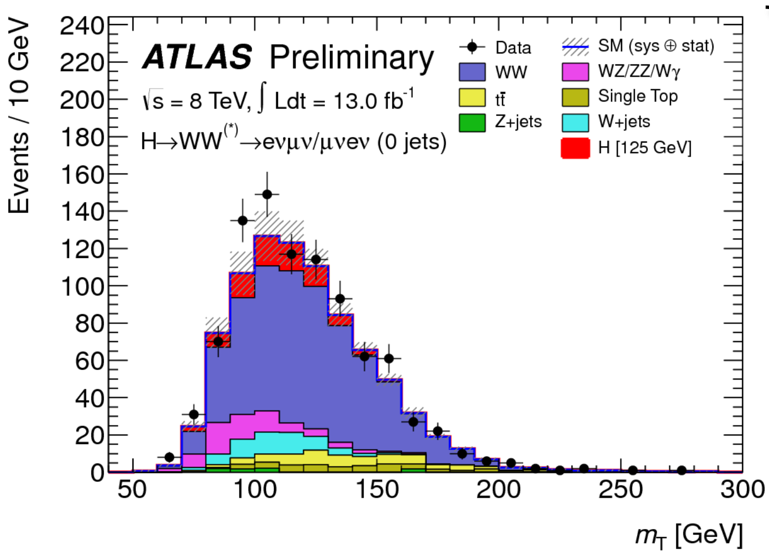
summary of uncertainties:

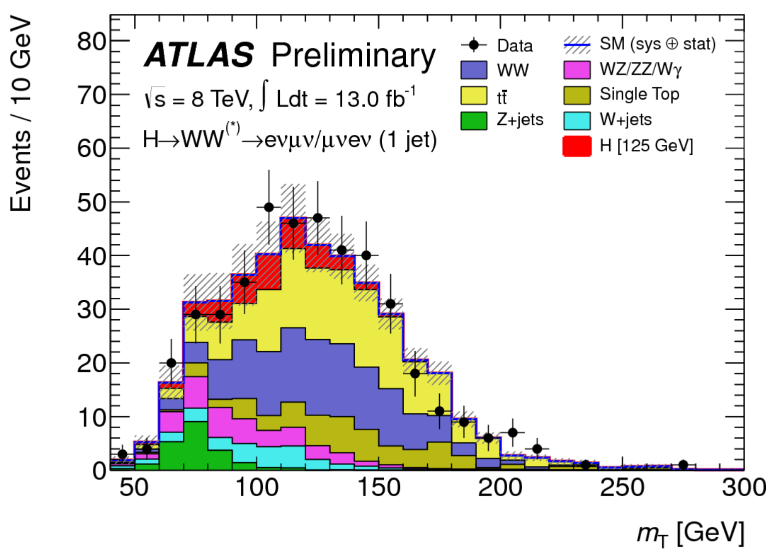
Background	Stat. (%)	Theory (%)	Expt. (%)	Crosstalk (%)	Total (%)
WW, $H+$0-jet	3.3	7.2	1.5	6.2	13
WW, $H+$1-jet	9	8	12	34	54
top, $H+$1-jet	2	8	29	1	37

correlations correctly treated in fit: total 1-jet BG uncertainty is 16%

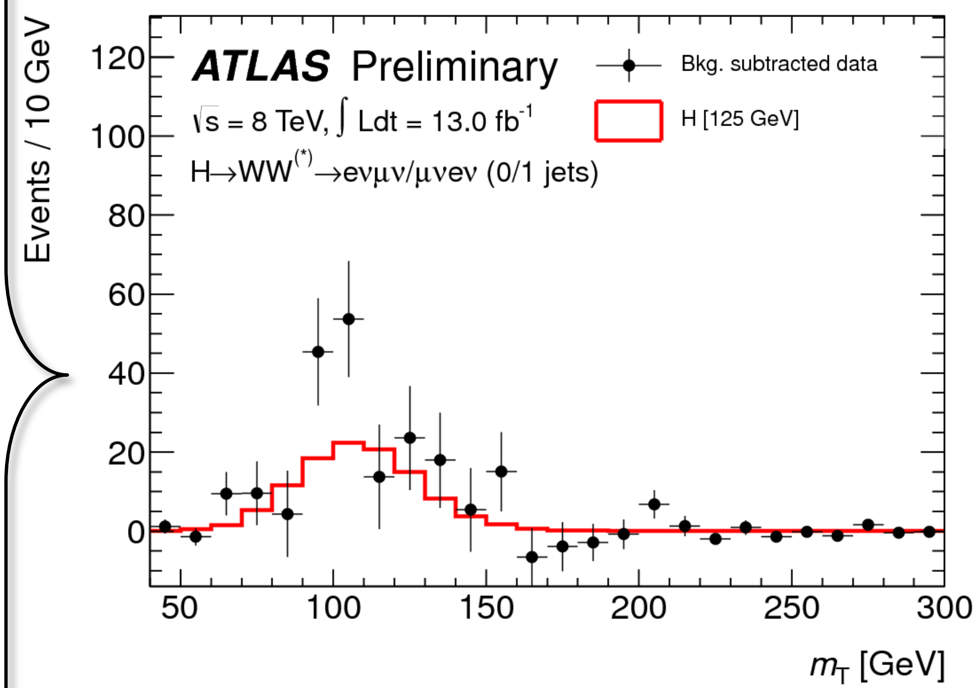
The Results

Observed m_T Distribution





summed 0+1 jet background-subtracted data

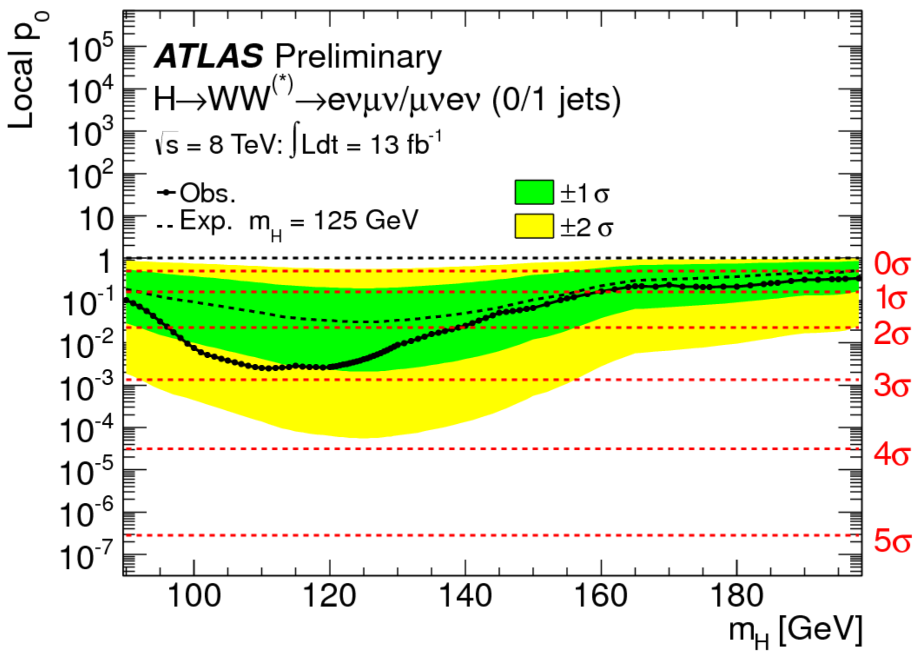


Statistical Interpretation

- Profile log likelihood $\mathcal{L}(\mu,\theta)$ is our model of the data
  - → *Product of Poisson distributions describing number of events in data and Gaussian distributions describing systematic constraints*
  - → *Fit for free parameter* **signal strength μ** = *ratio of observed signal yield to SM Higgs prediction*
  - → *Systematic uncertainties represented by* ***nuisance parameters θ***
- Key quantities:
  - → *95% confidence level (CL) excluded cross section (or mass; more on the next slide)* → ***exclusion***
  - → *Significance* p_0 = *probability that the observed data generated by background alone* → ***discovery***
    - uses test statistic $$q_\mu = -2\ln\left(\mathcal{L}(\mu,\hat{\theta}_\mu)/\mathcal{L}(\hat{\mu},\hat{\theta})\right)$$
  - → *Best-fit signal strength* μ → ***consistency with Standard Model***

The Bottom Line: p_0

	Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	$Z/\gamma^* +$ jets	$W +$ jets	Total Bkg.	Obs.
$H+$ 0-jet	45 ± 9	242 ± 32	26 ± 4	16 ± 2	11 ± 2	4 ± 3	34 ± 17	334 ± 28	423
$H+$ 1-jet	18 ± 6	40 ± 22	10 ± 2	37 ± 13	13 ± 7	2 ± 1	11 ± 6	114 ± 18	141

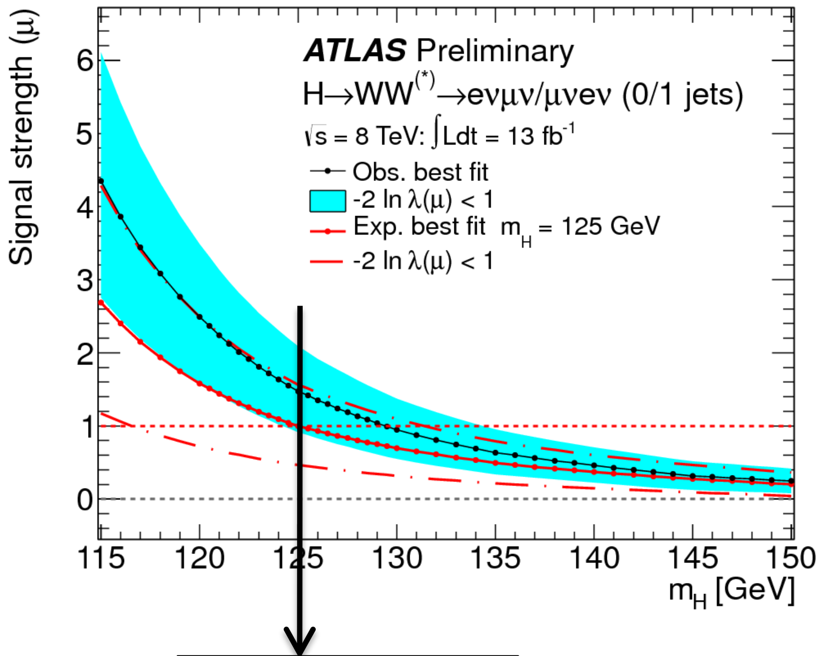


for m_H = 125 GeV:

- **observed p_0 = 4 x 10^{-3} (2.6σ)**
- expected p_0 = 3 x 10^{-2} (1.9σ)

(ICHEP values, 2012 only):
3.1σ observed, 1.6σ expected

Signal Strength and Systematics



$$\boxed{\mu = 1.5 \pm 0.6}$$

- or, in more detail -

uncertainty on signal and background yields by source:

Source (0-jet)	Signal (%)	Bkg. (%)
Inclusive ggF signal ren./fact. scale	13	-
1-jet incl. ggF signal ren./fact. scale	10	-
PDF model (signal only)	8	-
QCD scale (acceptance)	4	-
Jet energy scale and resolution	4	2
W+jets fake factor	-	5
WW theoretical model	-	5
Source (1-jet)	**Signal (%)**	**Bkg. (%)**
1-jet incl. ggF signal ren./fact. scale	26	-
2-jet incl. ggF signal ren./fact. scale	15	-
Parton shower/ U.E. model (signal only)	10	-
b-tagging efficiency	-	11
PDF model (signal only)	7	-
QCD scale (acceptance)	4	2
Jet energy scale and resolution	1	3
W+jets fake factor	-	5
WW theoretical model	-	3

$$\boxed{\mu = 1.48^{+0.35}_{-0.33}\,(\text{stat})^{+0.41}_{-0.36}\,(\text{sys theor})\,^{+0.28}_{-0.27}\,(\text{sys exp}) \pm 0.05\,(\text{lumi})}$$

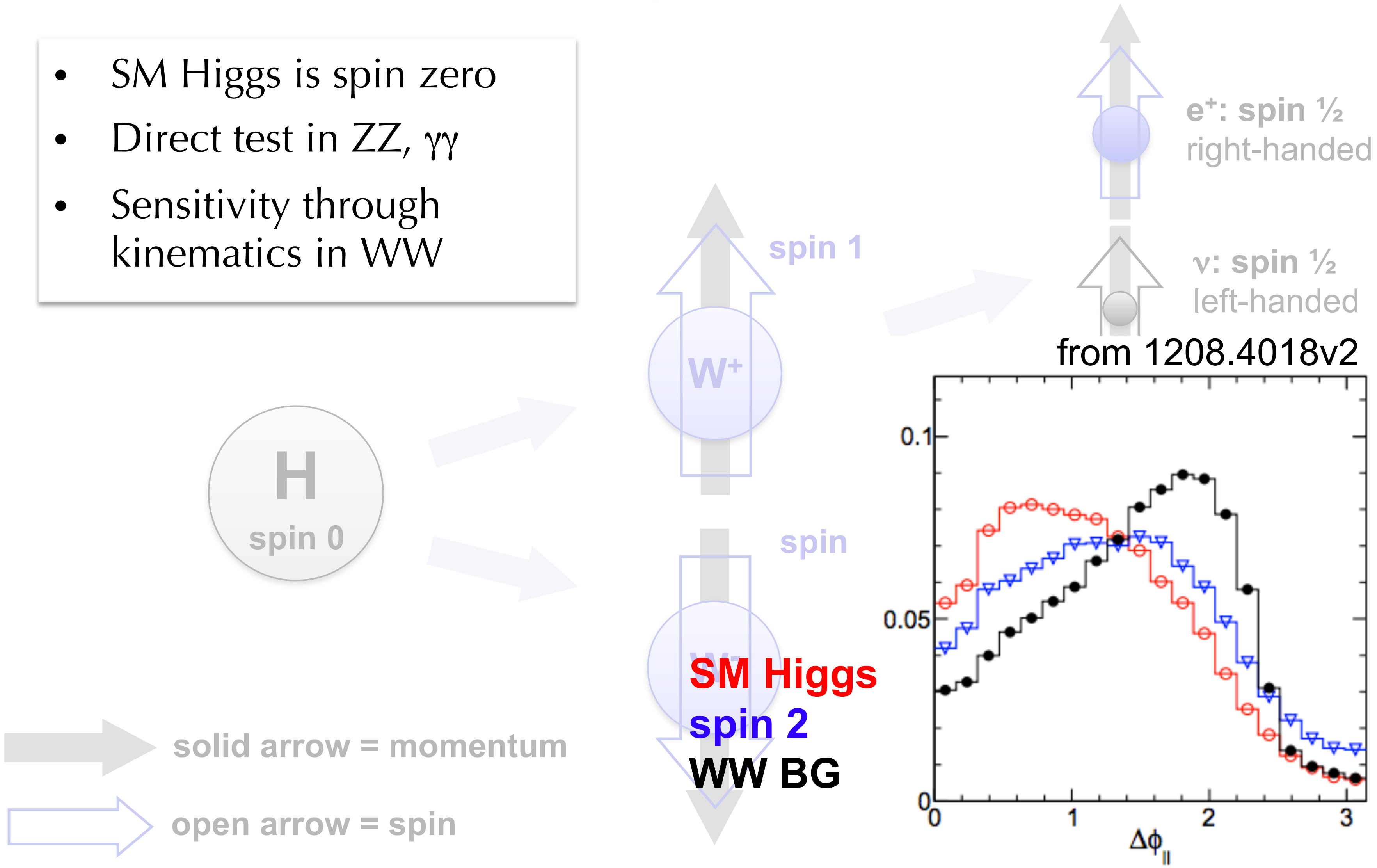
The Question

The next steps

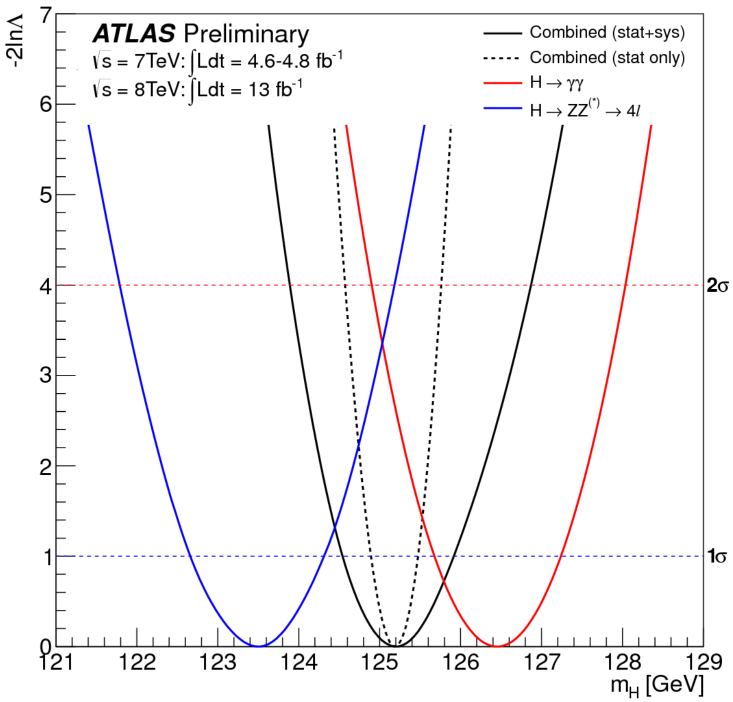
- Standard Model-like Higgs can't be the whole story
  - → *What about dark matter?*
  - → *If this is a fundamental particle and a scalar, what stabilizes the quantum corrections to its mass?*
- But is this a Standard Model Higgs boson? *We don't know*
- Precise Higgs measurements may show the way forward
  - → *Mass and global signal strength*
  - → *Spin and parity: Can we firmly establish 0^+?*
  - → *Test interactions with existing particles: new particles in the loop?*

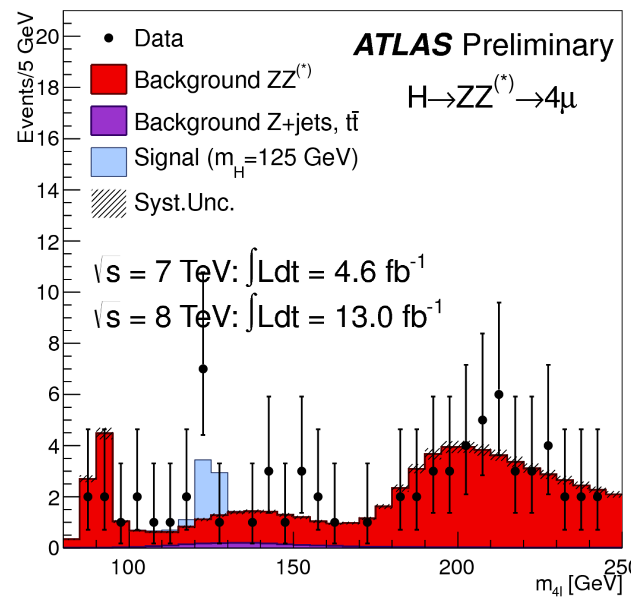
Testing the spin

- SM Higgs is spin zero
- Direct test in ZZ, $\gamma\gamma$
- Sensitivity through kinematics in WW



Determining m_H





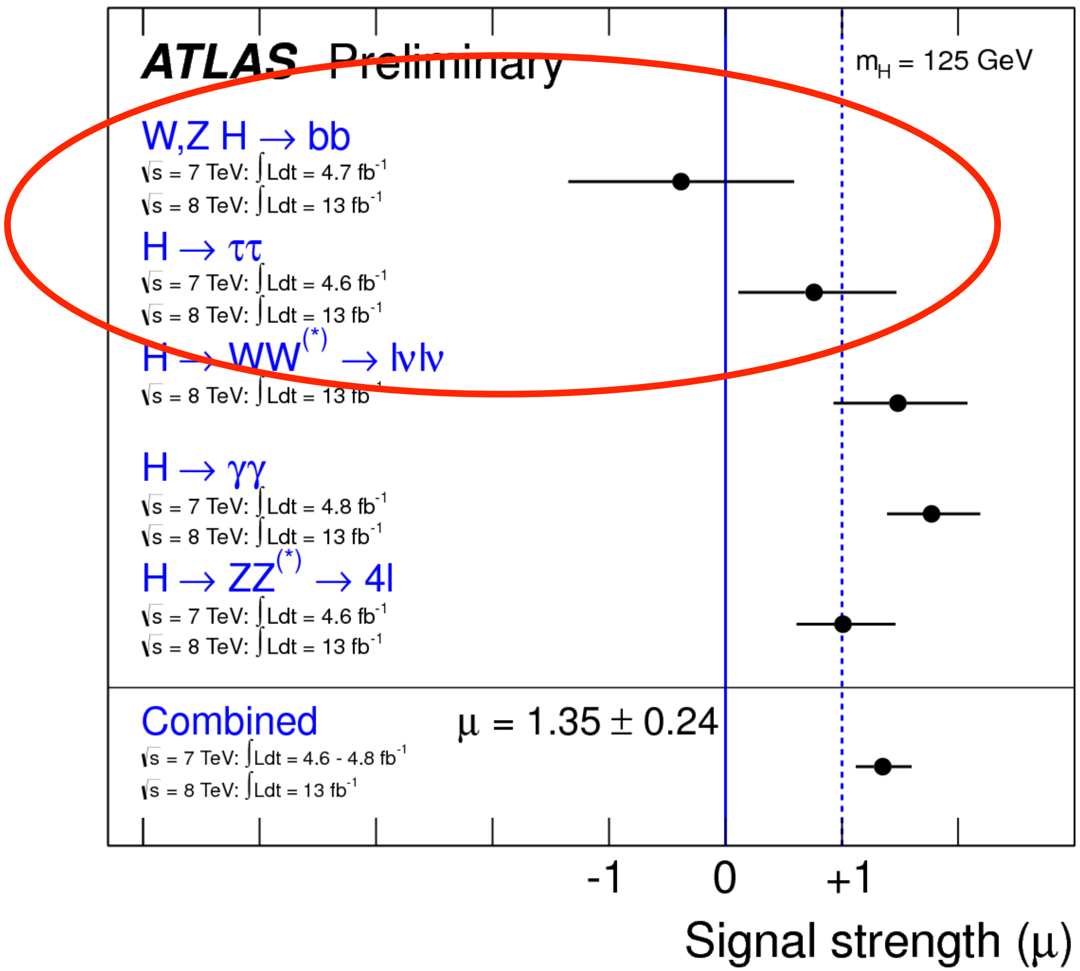
$$m_H(\gamma\gamma) = 126.6 \pm 0.3(\text{stat}) \pm 0.7(\text{sys})\ \text{GeV}$$

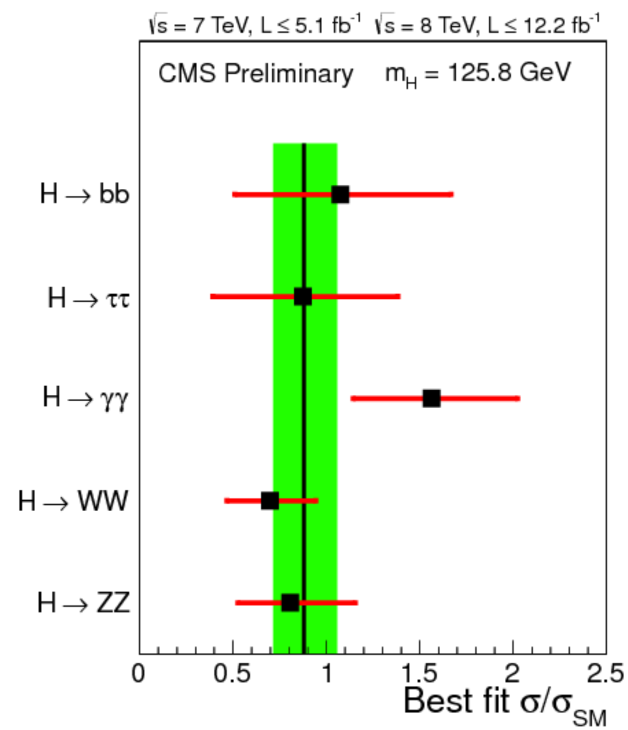
$$m_H(4\ell) = 123.5 \pm 0.8(\text{stat}) \pm 0.3(\text{sys})\ \text{GeV}$$

$$m_H(\text{comb.}) = 125.2 \pm 0.3(\text{stat}) \pm 0.6(\text{sys})\ \text{GeV}$$

Mass measurement from γγ and ZZ → 4l (best resolution for 4μ, above)

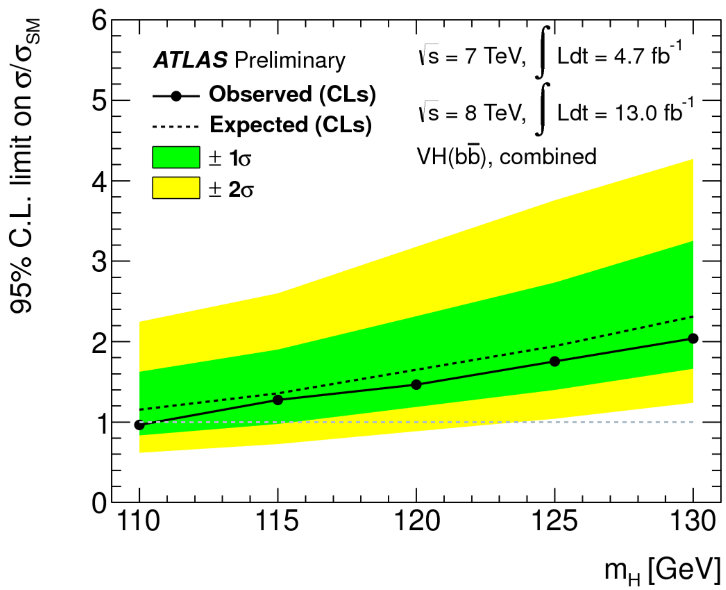
Latest combined results (Dec. '12)

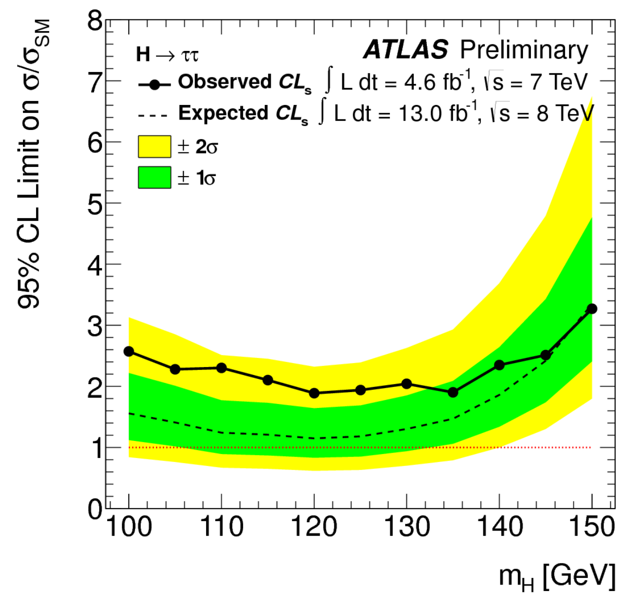




Interactions: fermions

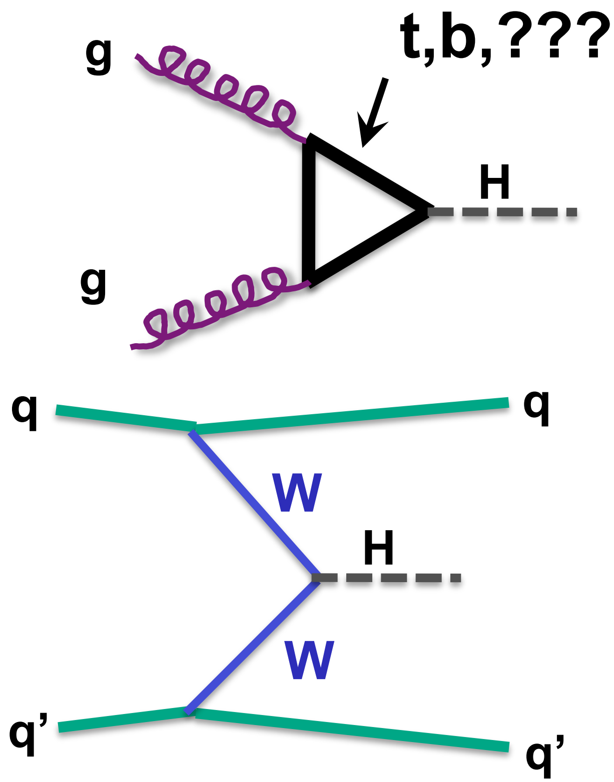
- Recall: EWSB does not *require* the same particle to provide fermion mass
- bbar and ττ have highest branching ratios in SM for m_H=125 GeV
- just reaching SM sensitivity



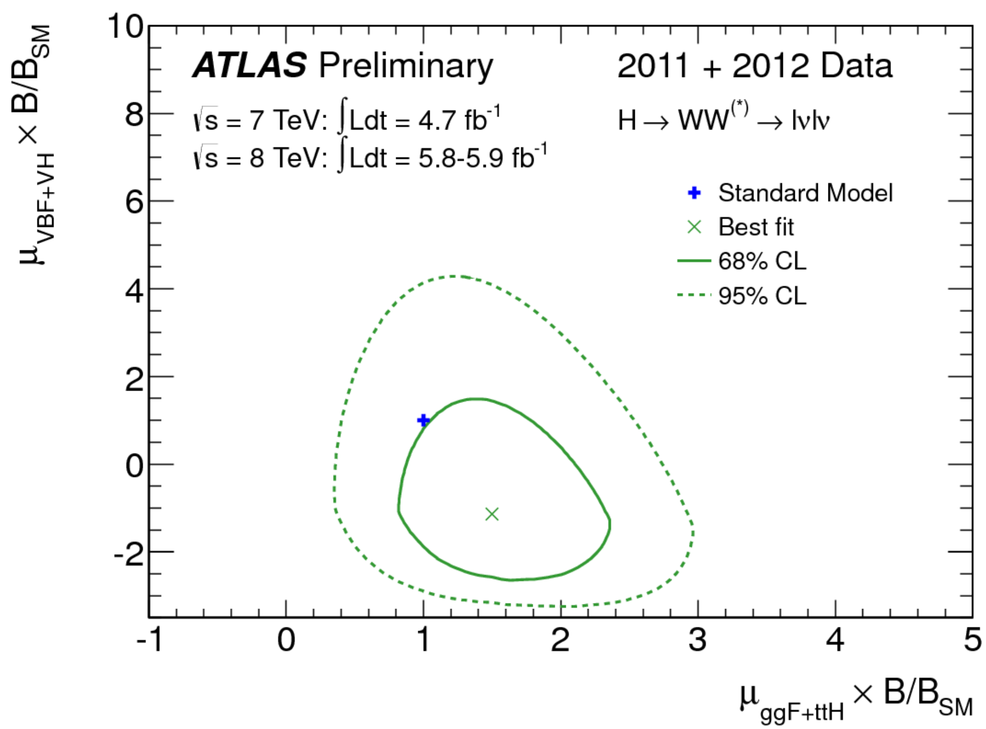


Indirect search for new physics

VBF vs. ggF: different production mechanisms with different potential virtual contributions

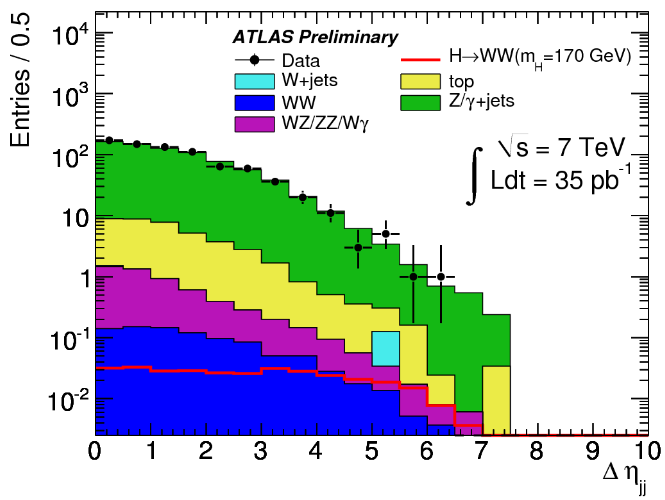


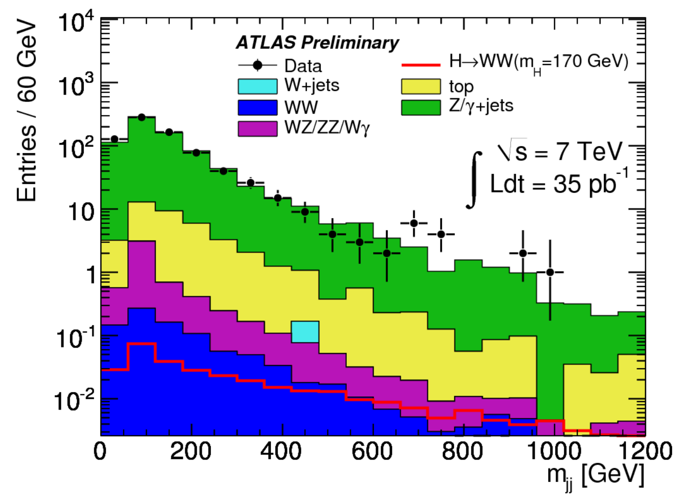
from our summer results



Next up: VBF H → WW

- Soon: updated H → WW 2-jet analysis, optimized for VBF production of SM Higgs boson at m_H=125 GeV





old plots, but illustrate unique VBF signature: **energetic well-separated jets**

Next run: 13-14 TeV

~10x more int. luminosity

cross sections for signal, top background

σ (pb)	√s = 8 TeV	√s = 14 TeV
ggF	20	50 (x 2.5)
VBF	1.6	4.2 (x 2.6)
ttbar	238	920 (x 3.9)

Summary

- Update of July 2012 analysis consolidates evidence for a new Higgs-like particle in the WW → lνlν channel
  - → *2012 observed min. p_0 = 3 x 10^{-3} or 2.8σ*
  - → *Broad minimum in p_0 centered at m_H = 125*
  - → *Signal strength in agreement with Standard Model*

$$\boxed{\mu = 1.48^{+0.35}_{-0.33}\,(\mathrm{stat})^{+0.41}_{-0.36}\,(\mathrm{sys\ theor})\,^{+0.28}_{-0.27}\,(\mathrm{sys\ exp}) \pm 0.05\,(\mathrm{lumi})}$$

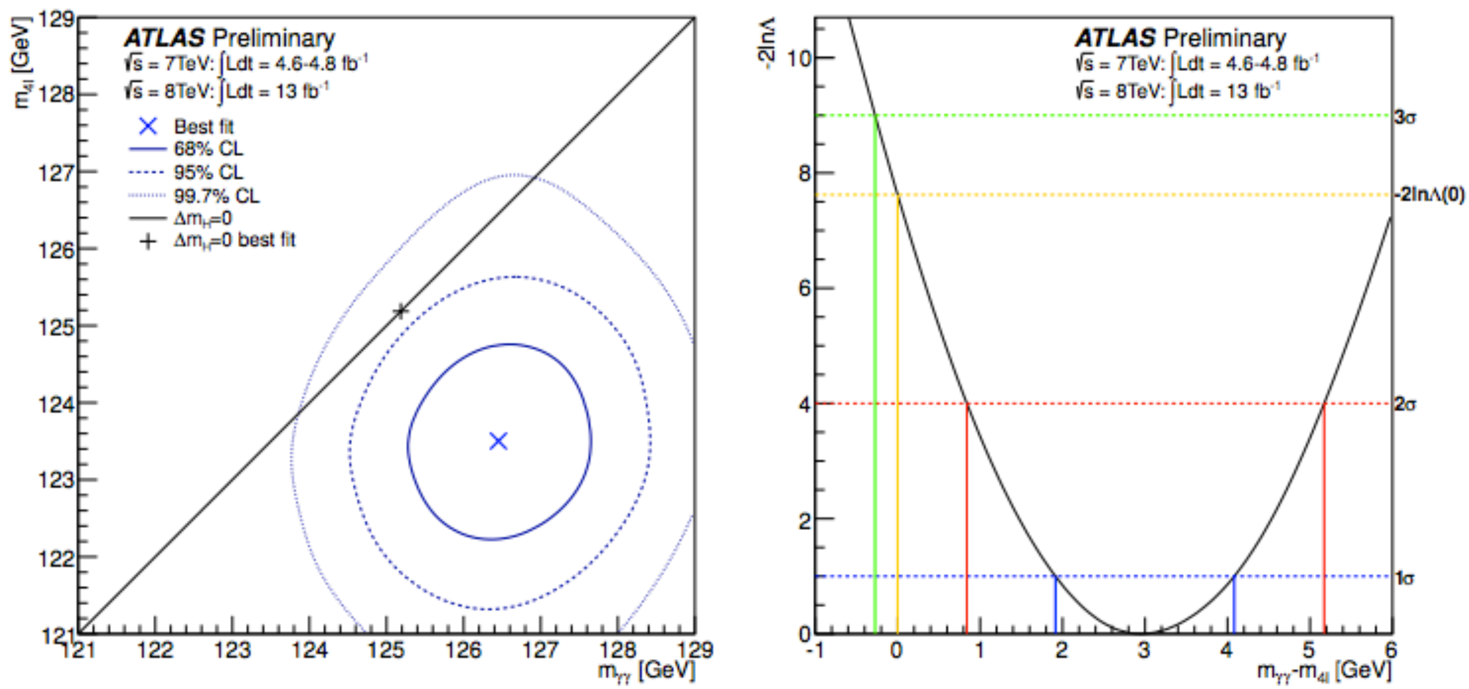
- Analysis of full 2011+2012 dataset maturing rapidly
  - → *Interactions with SM particles*
    - fermionic decays and VBF measurements
  - → *Spin and parity measurements*
  - → *Improved mass and signal strength measurements*

Backup

$\gamma\gamma$ – 4l measured m_H difference

- After extensive study, significance of difference estimated to be just less than three sigma (2.3-2.8 depending on assumptions made)

$$\Delta\hat{m}_H = \hat{m}_H^{\gamma\gamma} - \hat{m}_H^{4\ell} = 3.0^{+1.1}_{-1.0}\ \text{GeV} = 3.0 \pm 0.8\,(\text{stat})\,^{+0.7}_{-0.6}\,(\text{sys})\ \text{GeV}$$

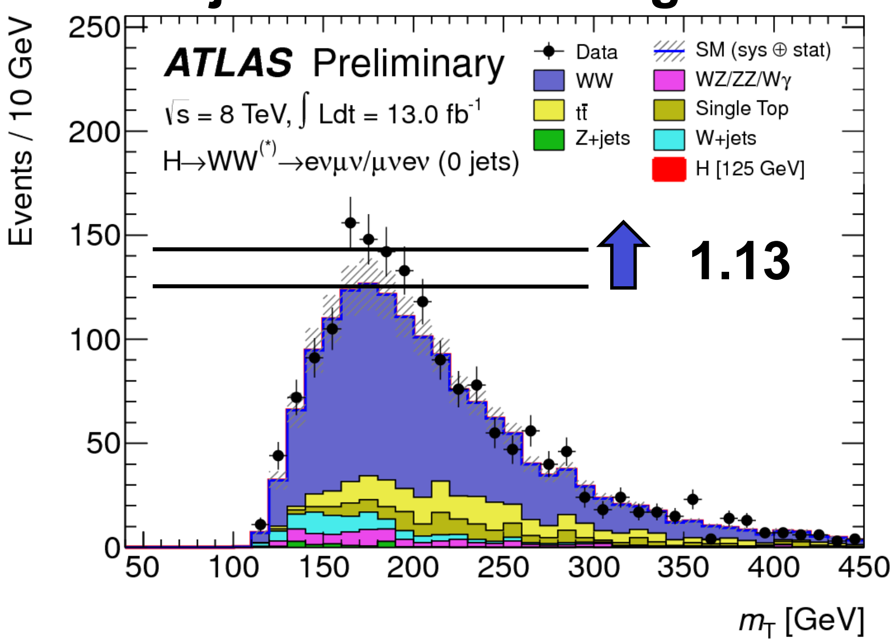


(a) (b)

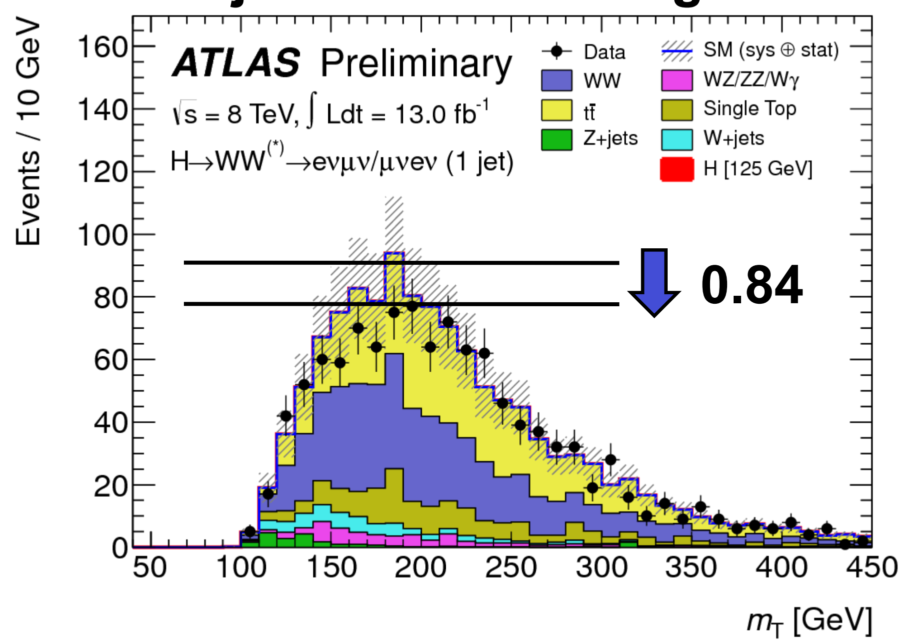
m(ll) and WW

- POWHEG+PYTHIA8 model for WW
  - → *better model of lepton kinematics than MC@NLO (ICHEP model)*
- Worse model of jet multiplicity, but correct for this by design

0-jet WW control region



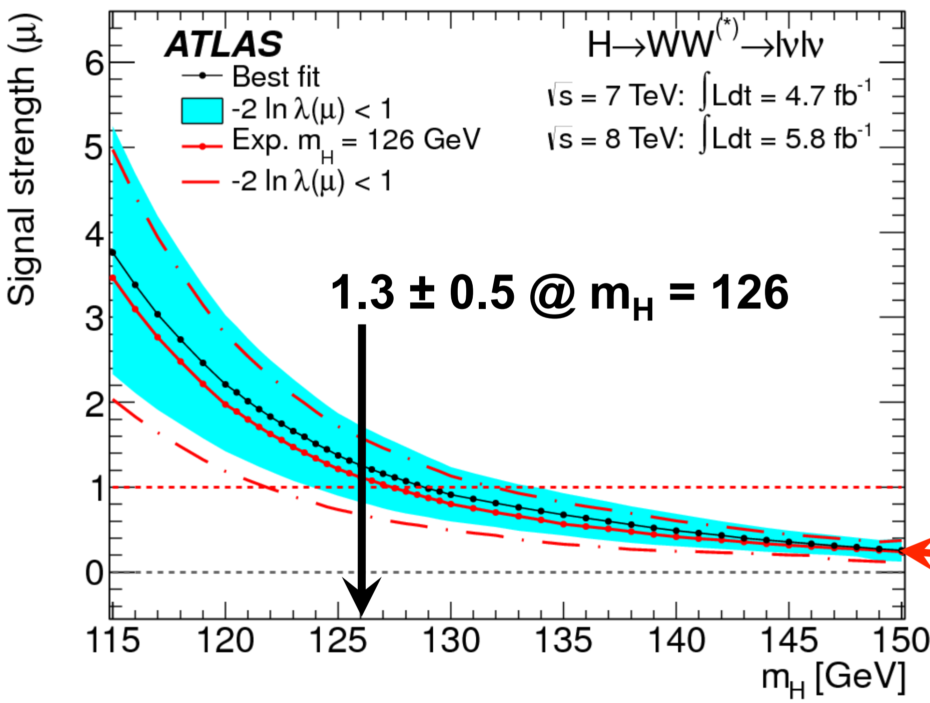
1-jet WW control region

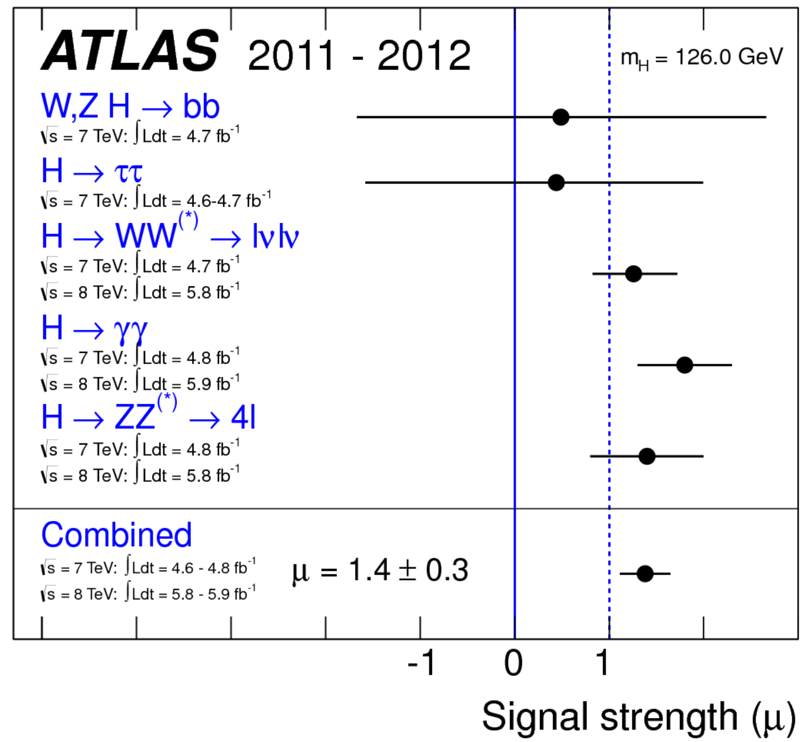


July 2012 Results

Signal Strength μ for 2011 + 2012 combined

- → *comparable to other channels,*
- → ***best individual measurement of μ!***





Expected curve for m_H = 126: behavior consistent with expectation

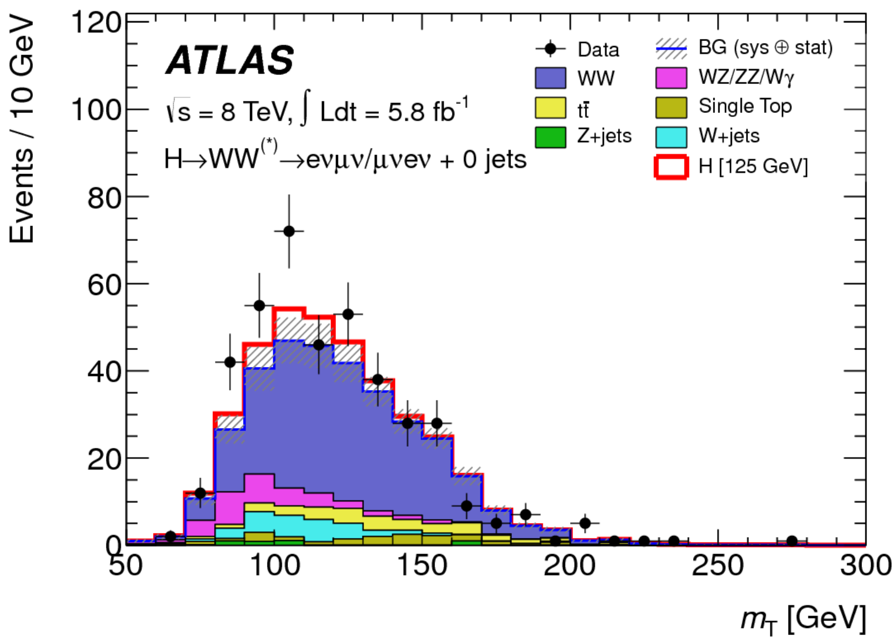
July 2012 Results

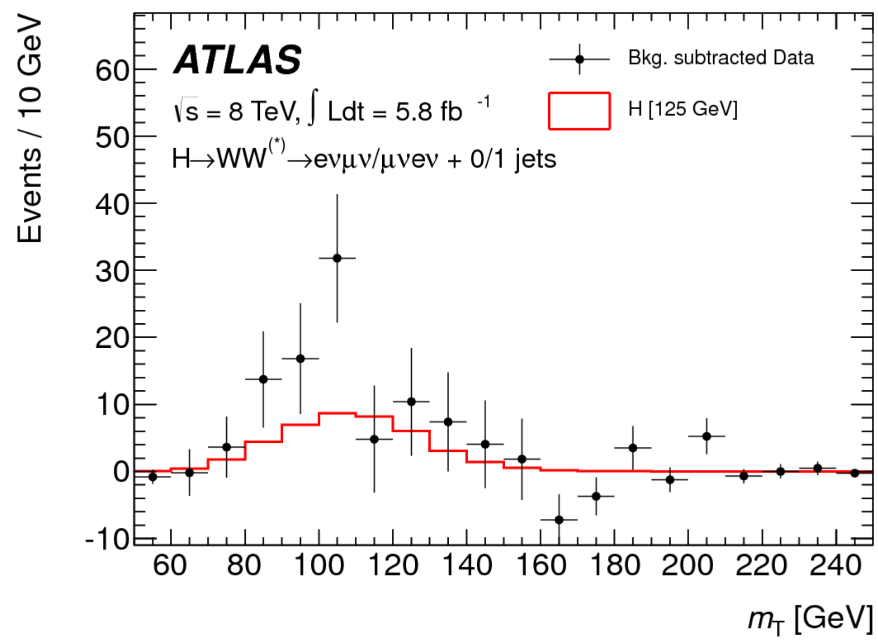
Signal and BG with systematics for different jet bins

m_T cut applied to be "indicative of analysis sensitivity"

Note different treatment of WW, top systematics compared to Nov. note

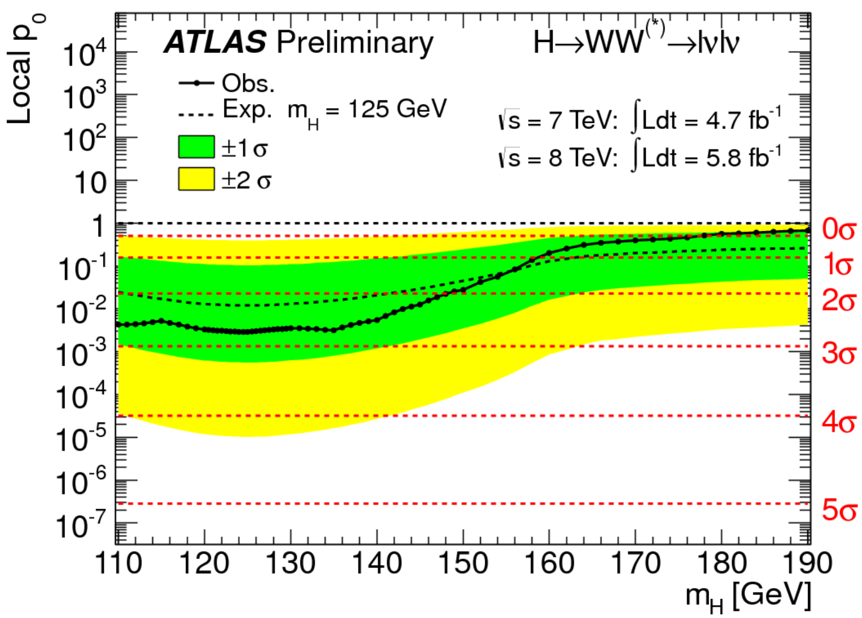
	Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	$Z/\gamma^* + \text{jets}$	$W + \text{jets}$	Total Bkg.	Obs.
$H+$ 0-jet	20 ± 4	101 ± 13	12 ± 3	8 ± 2	3.4 ± 1.5	1.9 ± 1.3	15 ± 7	142 ± 16	185
$H+$ 1-jet	5 ± 2	12 ± 5	1.9 ± 1.1	6 ± 2	3.7 ± 1.6	0.1 ± 0.1	2 ± 1	26 ± 6	38
$H+$ 2-jet	0.34 ± 0.07	0.10 ± 0.14	0.10 ± 0.10	0.15 ± 0.10	-	-	-	0.35 ± 0.18	0

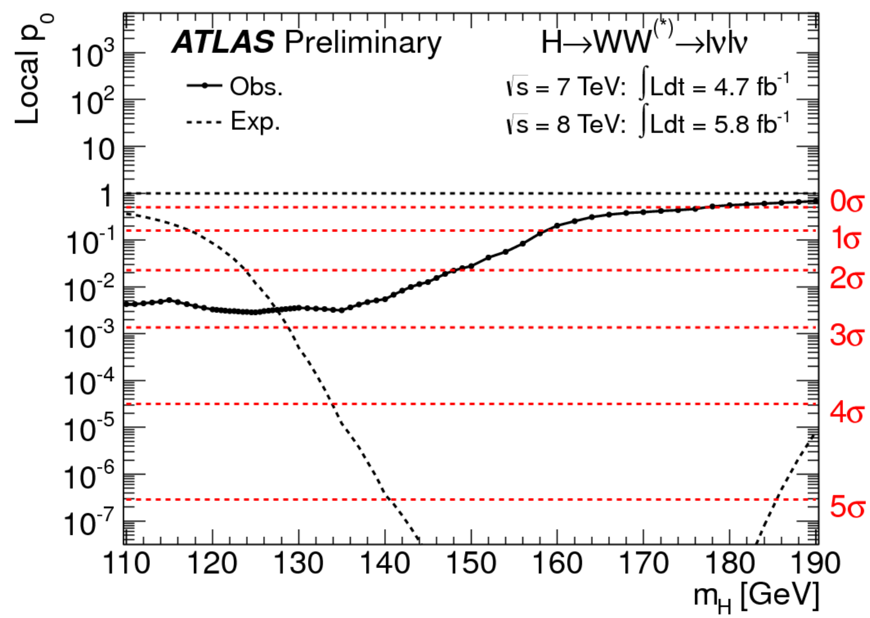




July 2012 results

- Combined 2011+2012 p_0: **3 x 10^{-3} (2.8σ) observed**, 1 x 10^{-2} (2.3σ) expected





Event Selection Summary

0 jet analysis

- → ***$\Delta\varphi(ll,MET) > \pi/2$ to clean up events with fake MET (rejects few events)***
- → *$p_T(ll) > 30$ GeV*

1 jet analysis

- → *b-jet veto*
- → *$Z \rightarrow \tau\tau$ veto ($|m_{\tau\tau}-m_Z| > 25$GeV)*
- → ***p_T(tot) cut removed***

Common "topological" selection

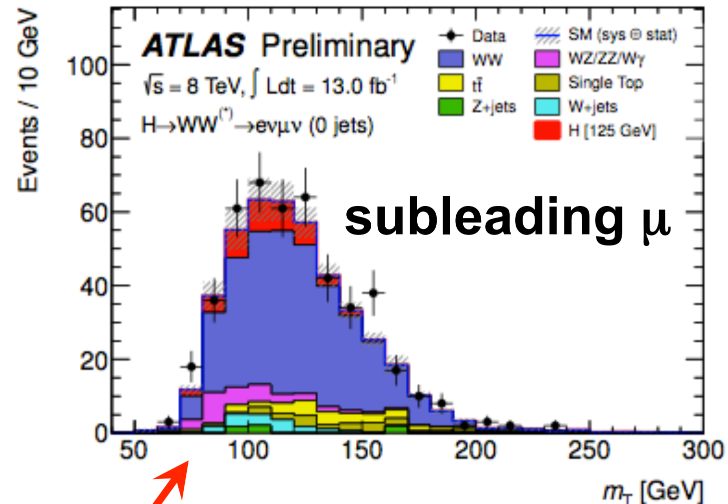
- → *$m(ll) < 50$ GeV*
- → *$\Delta\varphi(ll) < 1.8$*

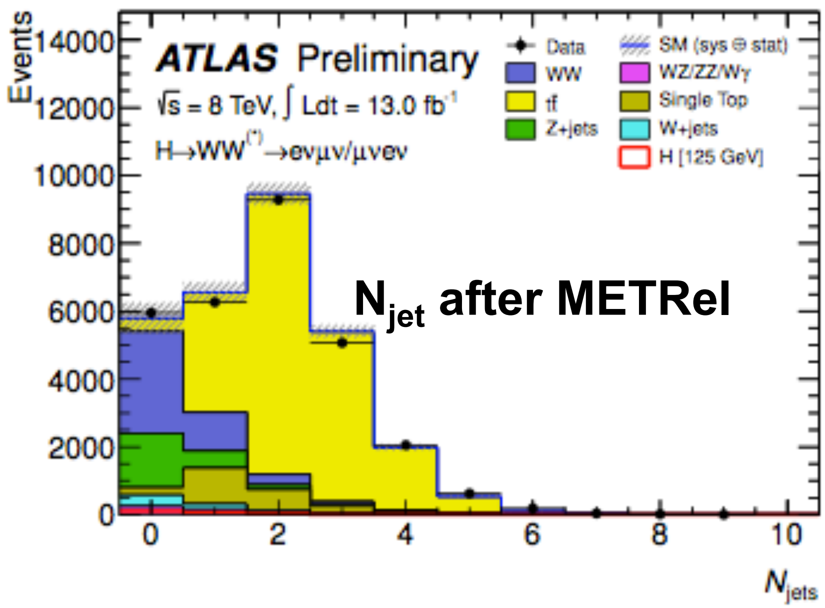
Candidate event **blinding** to remove phase space with significant m_H ~ 125 GeV signal

- → *pass preselection*
- → *zero jets or no b-tagged jet*
- → *$m(ll) < 50$ GeV*
- → *$\Delta\varphi(ll) < 1.8$*
- → *$82.5 < m_T < 140$ GeV*

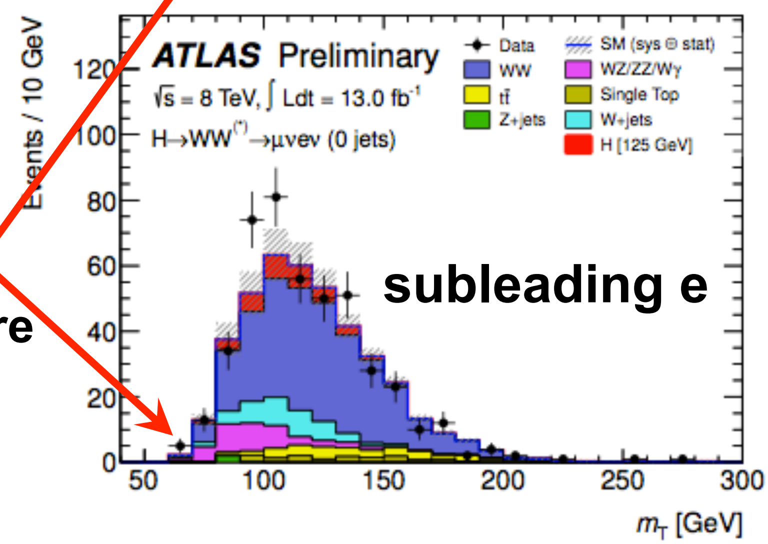
Signal region, in four parts

- Subdivide analysis to benefit from different S/B and background composition in different final states
  - → *By number of jets: 0 or 1*
  - → *Into (eμ, μe) sub-channels where second lepton is subleading*





compare W+jets (cyan)



Signal region, in four parts

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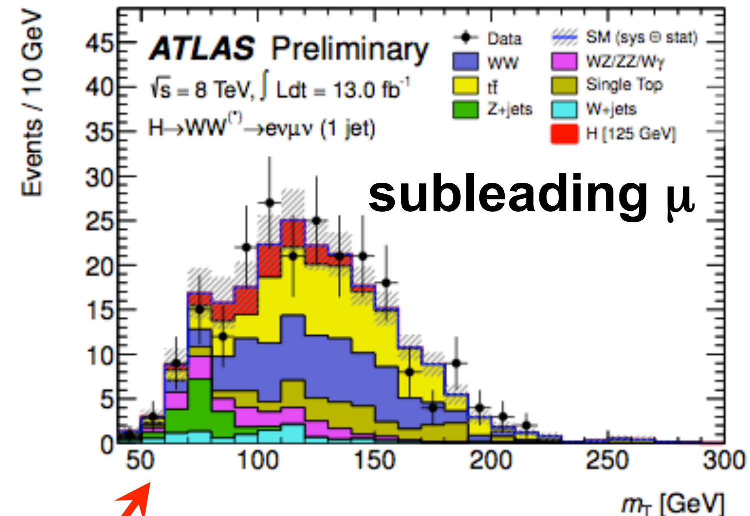
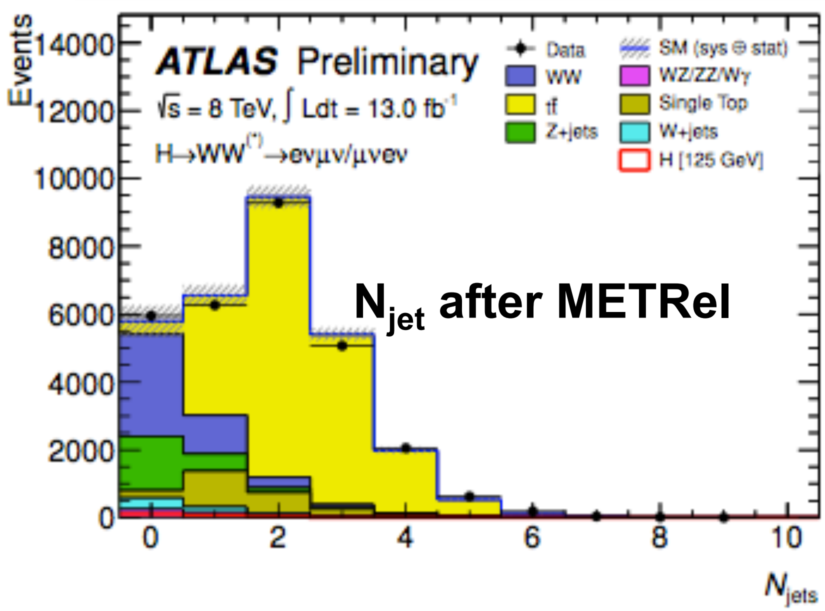
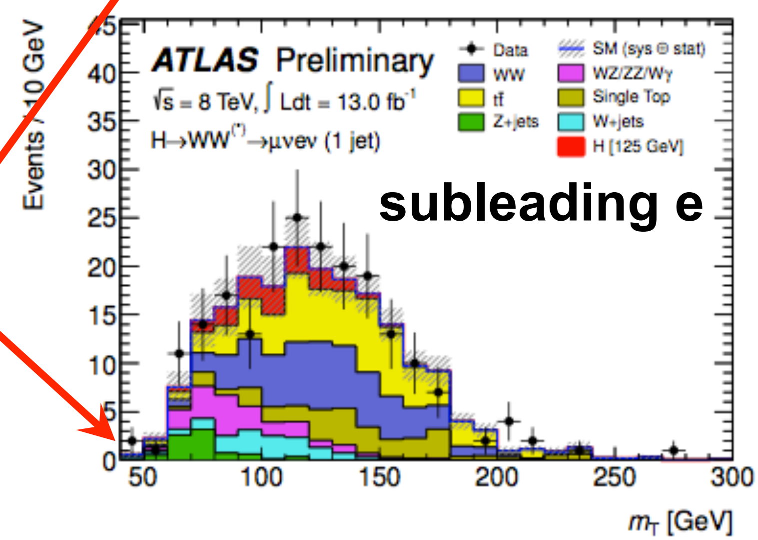


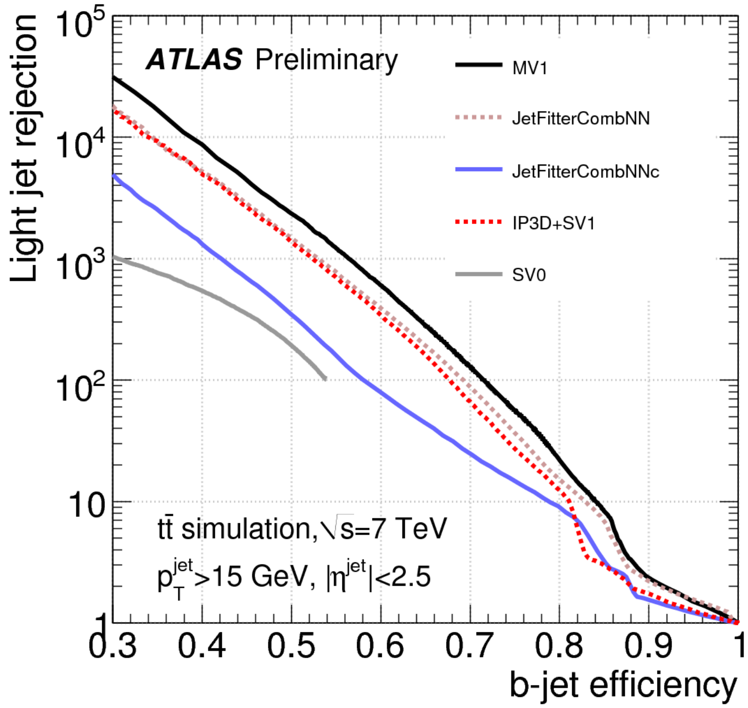


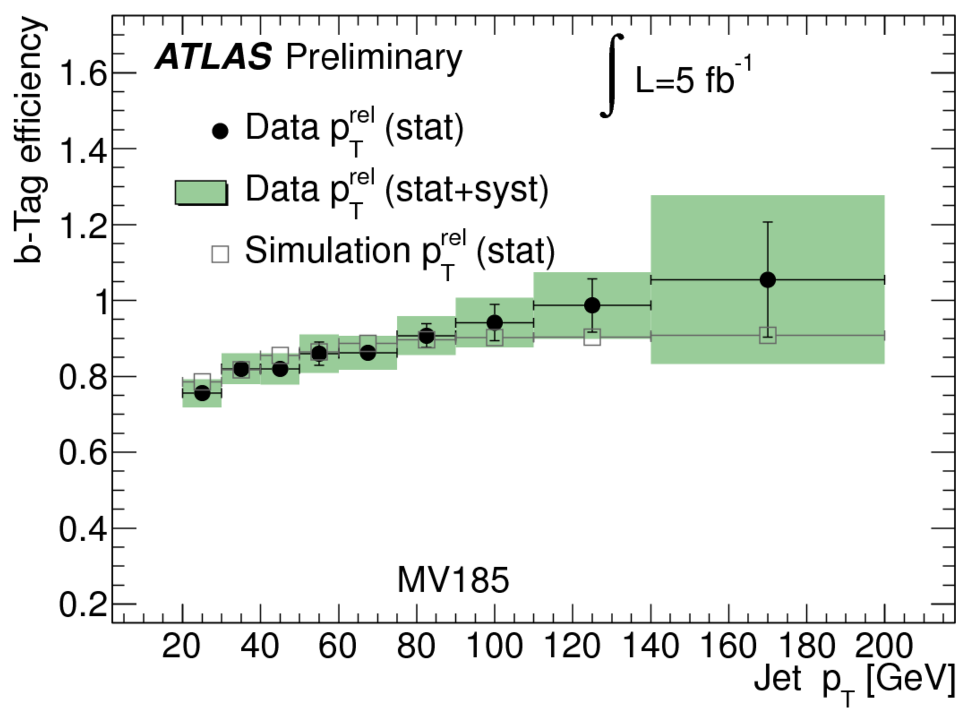
compare W+jets (cyan)



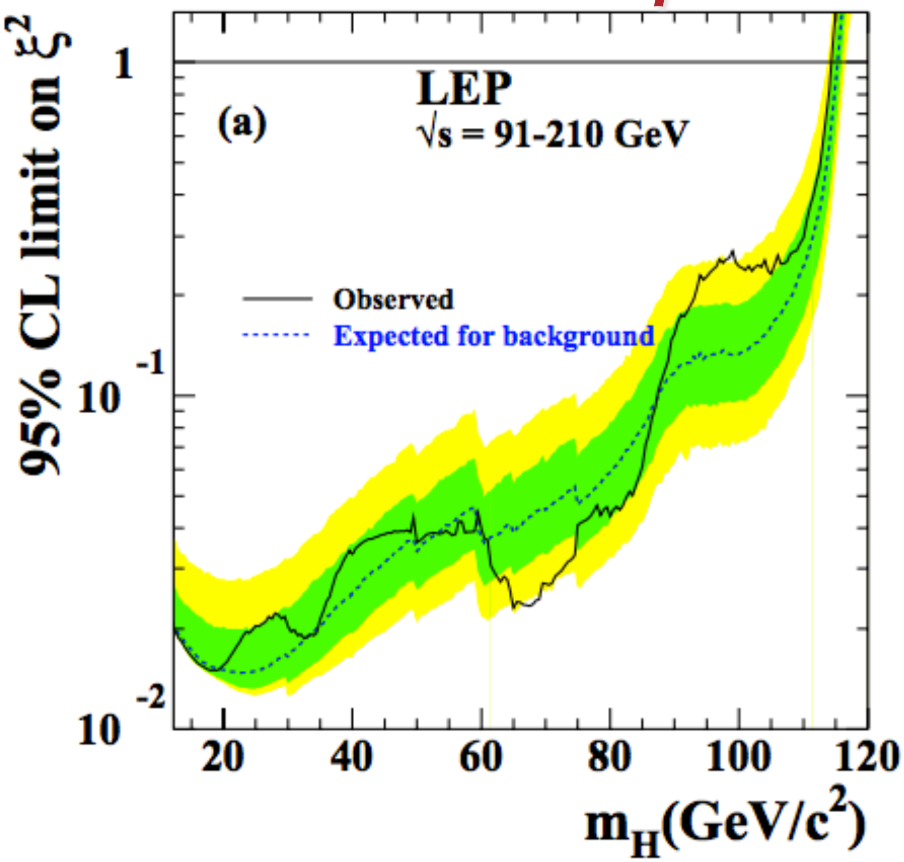
MV1 b-tagging at ATLAS

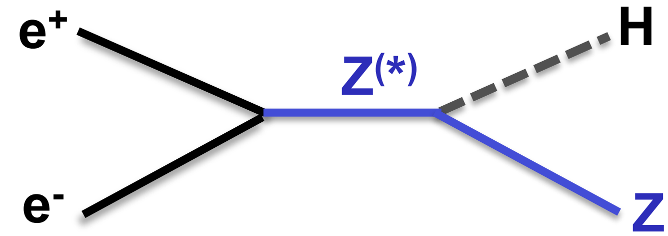
- NN to combine input from SV0 (secondary vertex), IP3D+SV1 (3d impact parameter via likelihood ratio, secondary vertex), and CombNN (neural net) algorithms for best performance
- ~0.1 light-jet mistag rate at our 85% efficient operating point





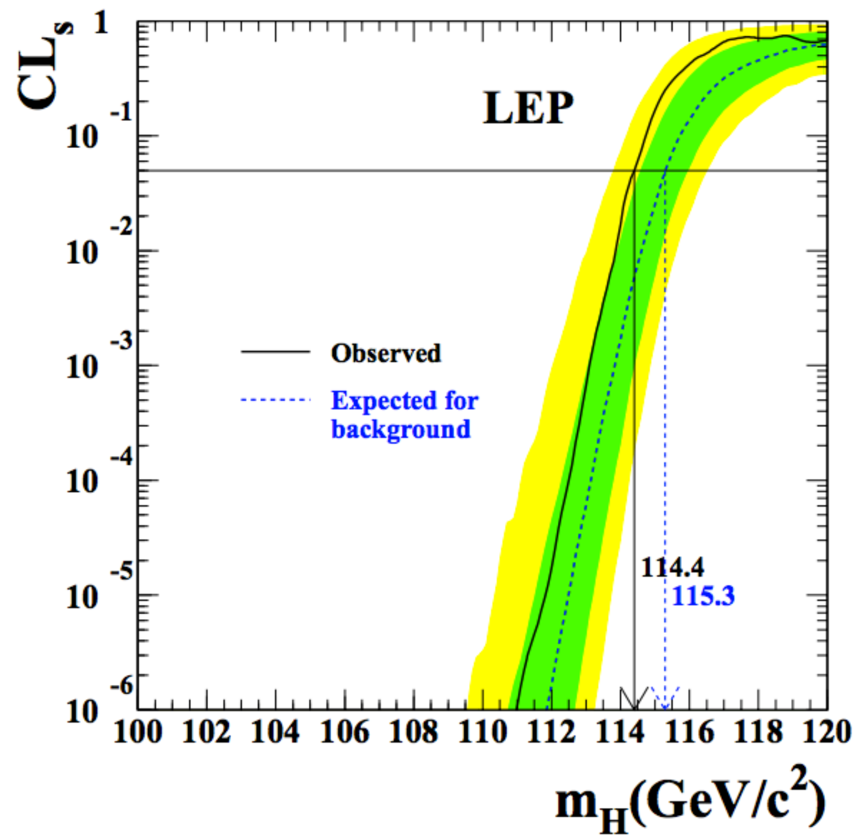
LEP: not quite enough energy





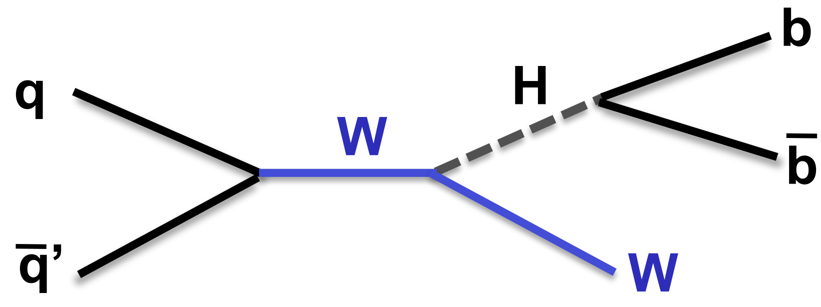
- **Direct bound at low mass from LEP: 114.4 GeV**

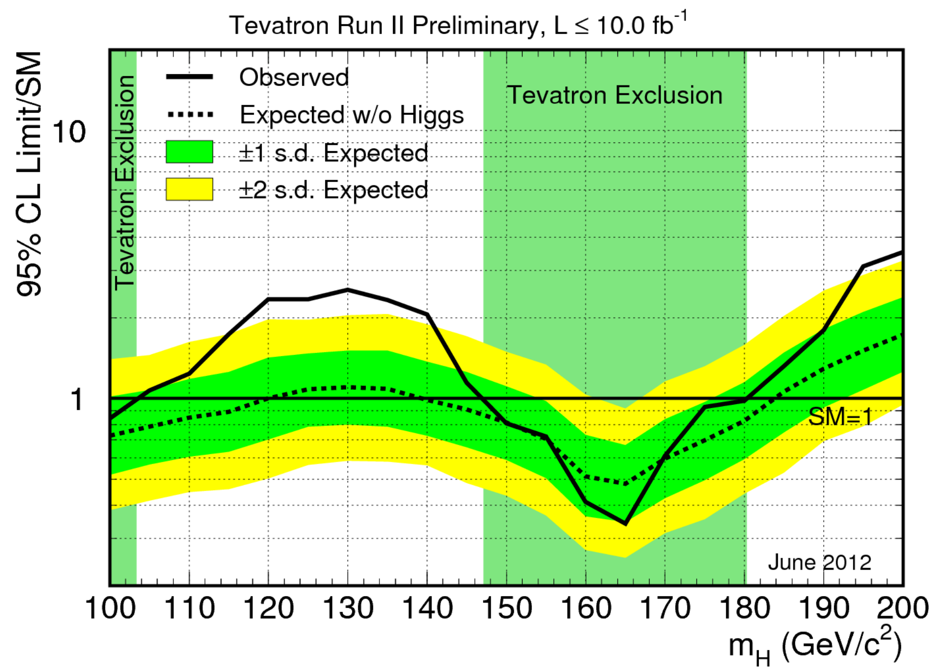
  → *electron-positron collisions $\sqrt{s}$ = 189-209 GeV*



Tevatron: almost…

- Cross section for ggH @ 125 = 0.95 pb
  - → *compare 20 pb at LHC*
- Most sensitivity at low mass from associated production searches (sigma_WH = 0.13 pb)





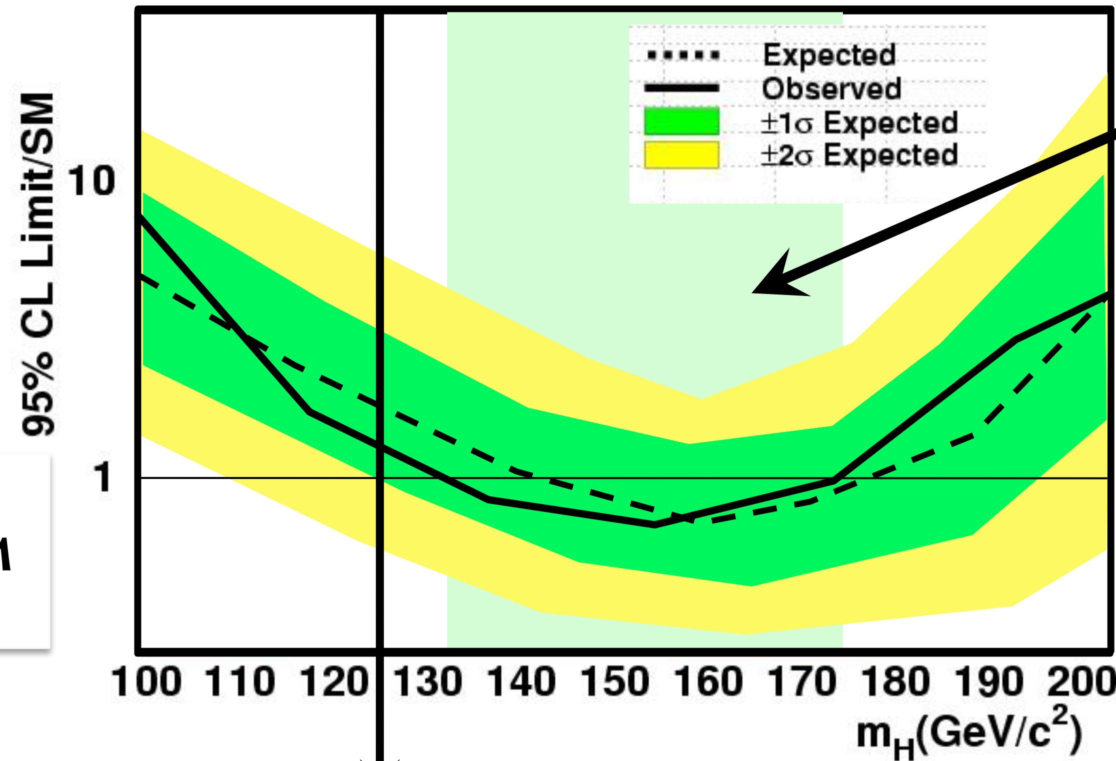
Full 13 fb^{-1} Cutflow

Cutflow evolution in the different signal regions

$H+$ 0-jet	Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	Z/γ^{*} + jets	W + jets	Total Bkg.	Obs.
Jet veto	110 ± 1	3004 ± 12	242 ± 8	387 ± 8	215 ± 8	1575 ± 20	340 ± 5	5762 ± 28	5960
$\Delta\phi_{\ell\ell,E_{\mathrm{T}}^{\mathrm{miss}}} > \pi/2$	108 ± 1	2941 ± 12	232 ± 8	361 ± 8	206 ± 8	1201 ± 21	305 ± 5	5246 ± 28	5230
$p_{\mathrm{T},\ell\ell} > 30$ GeV	99 ± 1	2442 ± 11	188 ± 7	330 ± 7	193 ± 8	57 ± 8	222 ± 3	3433 ± 19	3630
$m_{\ell\ell} < 50$ GeV	78.6 ± 0.8	579 ± 5	69 ± 4	55 ± 3	34 ± 3	11 ± 4	65 ± 2	814 ± 9	947
$\Delta\phi_{\ell\ell} < 1.8$	75.6 ± 0.8	555 ± 5	68 ± 4	54 ± 3	34 ± 3	8 ± 4	56 ± 2	774 ± 9	917
$H+$ 1-jet	Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	Z/γ^{*} + jets	W + jets	Total Bkg.	Obs.
One jet	59.5 ± 0.8	850 ± 5	158 ± 7	3451 ± 24	1037 ± 17	505 ± 9	155 ± 5	6155 ± 33	6264
b-jet veto	50.4 ± 0.7	728 ± 5	128 ± 5	862 ± 13	283 ± 10	429 ± 8	126 ± 4	2555 ± 20	2655
$Z \to \tau\tau$ veto	50.1 ± 0.7	708 ± 5	122 ± 5	823 ± 12	268 ± 9	368 ± 8	122 ± 4	2411 ± 19	2511
$m_{\ell\ell} < 50$ GeV	37.7 ± 0.6	130 ± 2	39 ± 2	142 ± 5	55 ± 4	99 ± 3	30 ± 2	495 ± 8	548
$\Delta\phi_{\ell\ell} < 1.8$	34.9 ± 0.6	118 ± 2	35 ± 2	134 ± 5	52 ± 4	22 ± 2	24 ± 1	386 ± 8	433

above: stat. uncertainties only
below: add m_T cut and systematics

Those Green and Yellow Plots



excluded region

lower line = stronger exclusion

normalize to predicted SM cross section

For every mass
Theoretical cro
Predicted num
Observed num

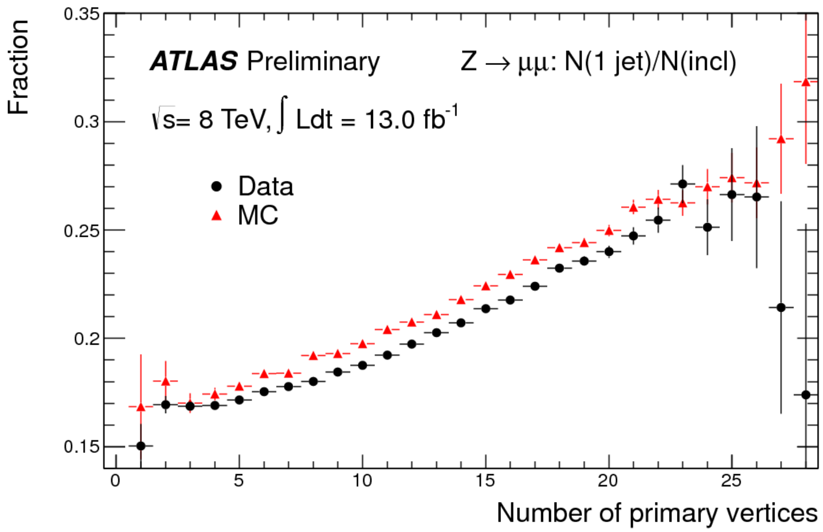
Expected exclusion
Generated using Monte Carlo "pseudodata" to model outcome of experiments under no-signal hypothesis
(Distribution of these gives you uncertainty bands)

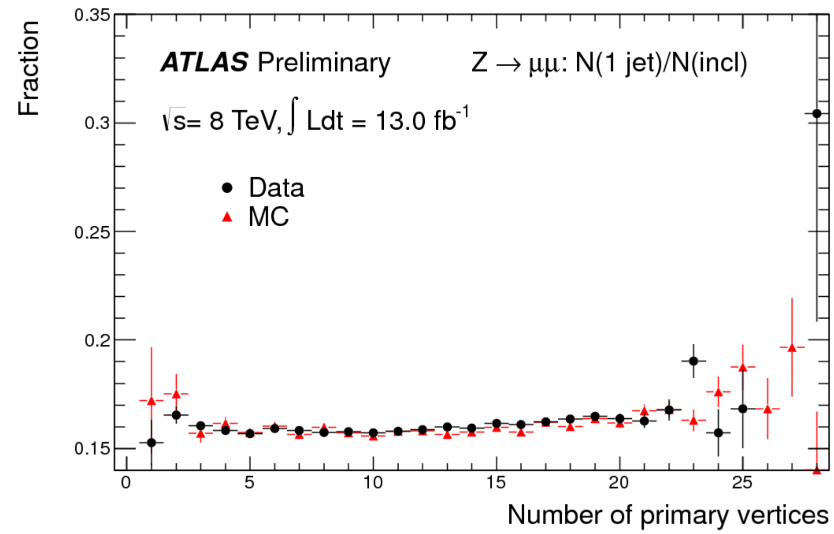
to maximum signal cross

s method

Pileup vs. Jets

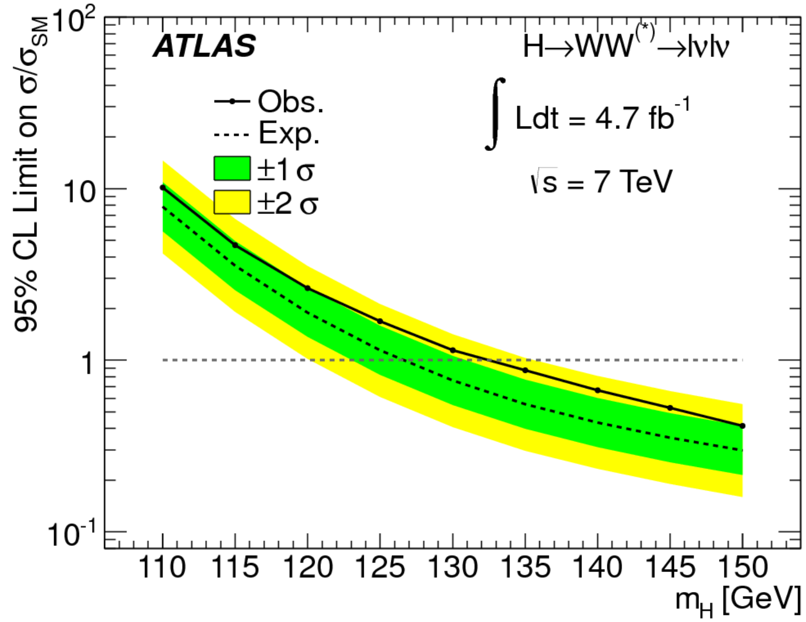
- Pileup adds jets: stability of analysis in jet bins
- Take care with what you define as a “jet”
  - → *associate to primary vertex using tracks*

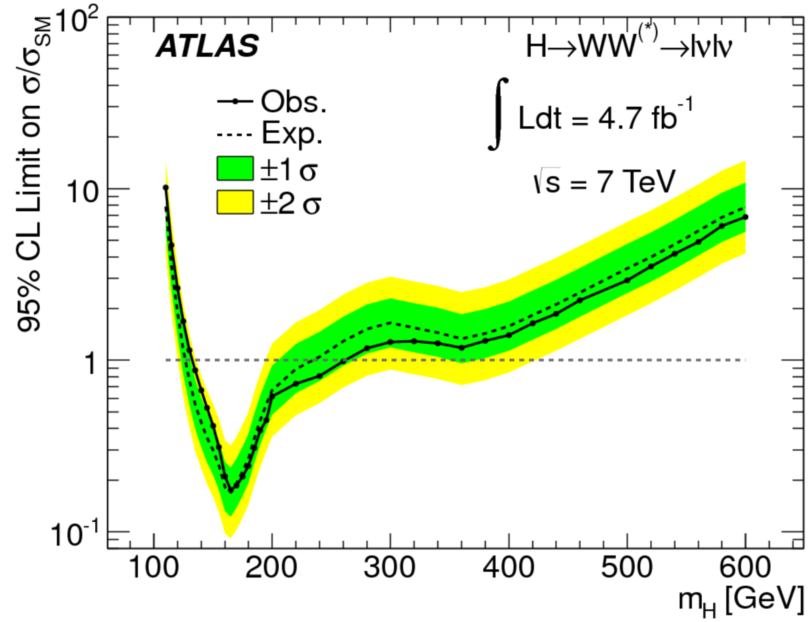




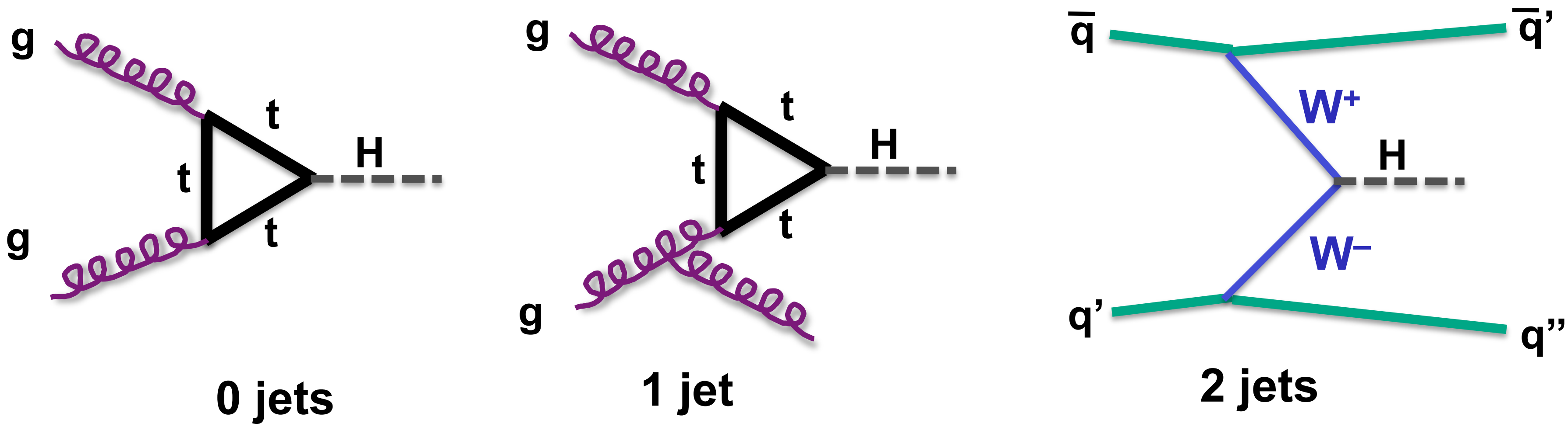
2011 Analysis

- Possible signal at m_H ~ 125 in γγ, ZZ → 4l channels
- Ambiguous results from WW → lνlν





How to Make a Higgs Boson



- Gluon-gluon fusion is dominant production mode at the LHC
- Analysis done for zero, one, two jet events separately
  - → *In this talk, I will focus on the zero jet analysis, which contributes the most sensitivity for low Higgs masses*
- Theoretical uncertainty on inclusive cross section now well under control (~ 15-20%) in spite of large corrections LO → NLO and NLO → NNLO
  - → *Still a leading uncertainty in the combined limits*

The Atlas Detector, in Numbers

- Tracker: precision tracking to $|\eta| = 2.5$
  - → *3d spacepoints from semiconductor tracking: 3 pixel layers, SCT is 4 double-layers (SAS)*
  - → *TRT is 4 mm diameter straw tubes (Xenon), providing 36 additional R-φ (or z-φ) points*
- Calorimetry
  - → *LAr barrel from $1.5 < R < 2$m, 22 X_0 deep*
  - → *10 λ (interaction lengths) active, >11 total*
  - → *HCAL from $2.3 < R < 4.3$ m, 7.4λ by itself*
  - → *total coverage to almost $|\eta| = 5$*
- Magnets
  - → *Solenoid field 2T*
  - → *Toroid field bending power $1 < \int B \cdot dl < 7.5$ T· m*
- Muons
  - → *Three MDT planes measure R-z using 3mm diameter tubes (Ar/CO_2)*
    - Nominal single-hit precision 80 μm
  - → *Forward precision by CSC (MWPC strip-wire-strip) $2 < |\eta| < 2.7$*
    - Designed to be functional at expected rates of > 150 Hz/cm^2
  - → *RPC and TGC: fast 2d spacepoints for triggering and second (phi) coordinate*