H→ττ Searches at the LHC

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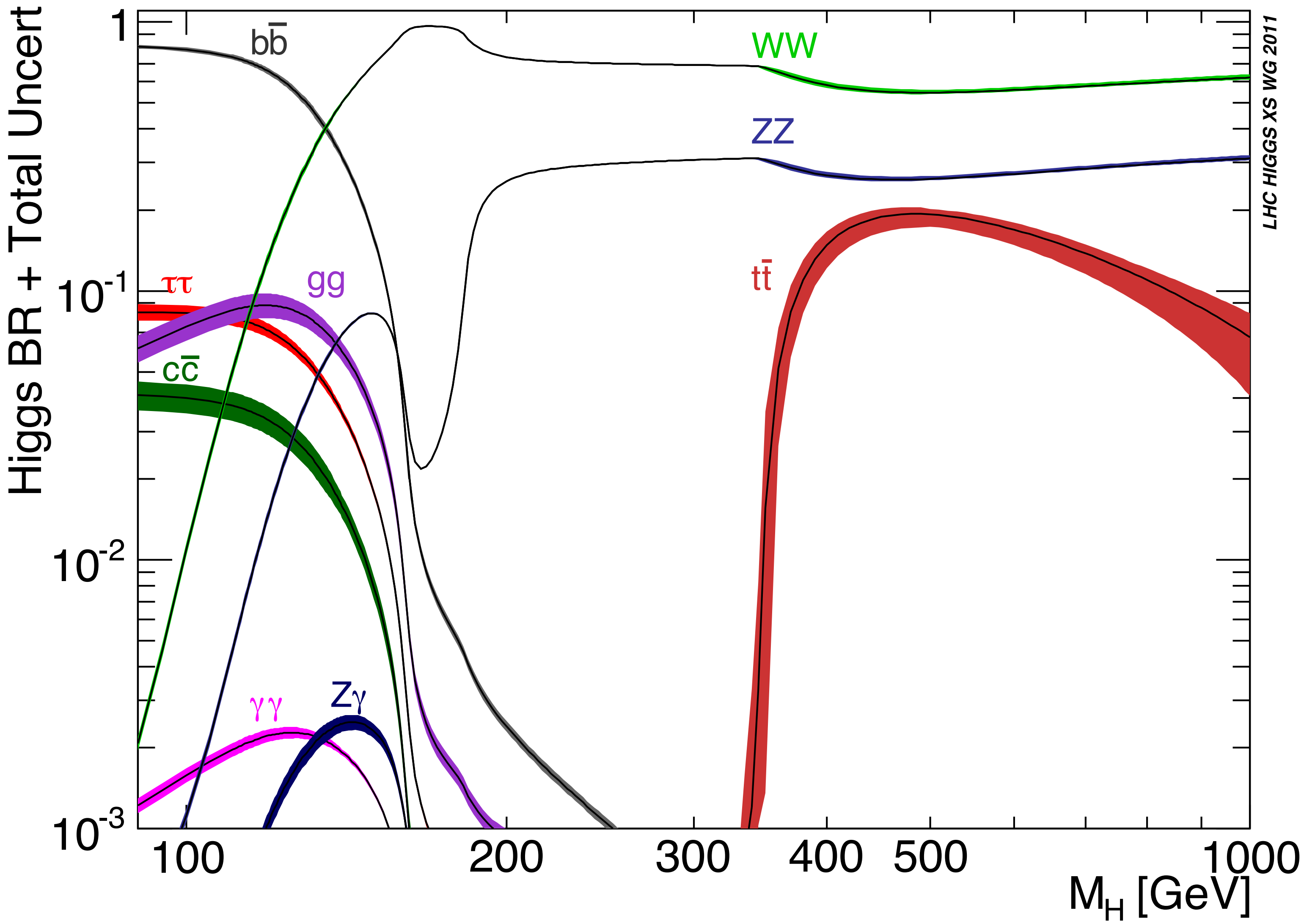
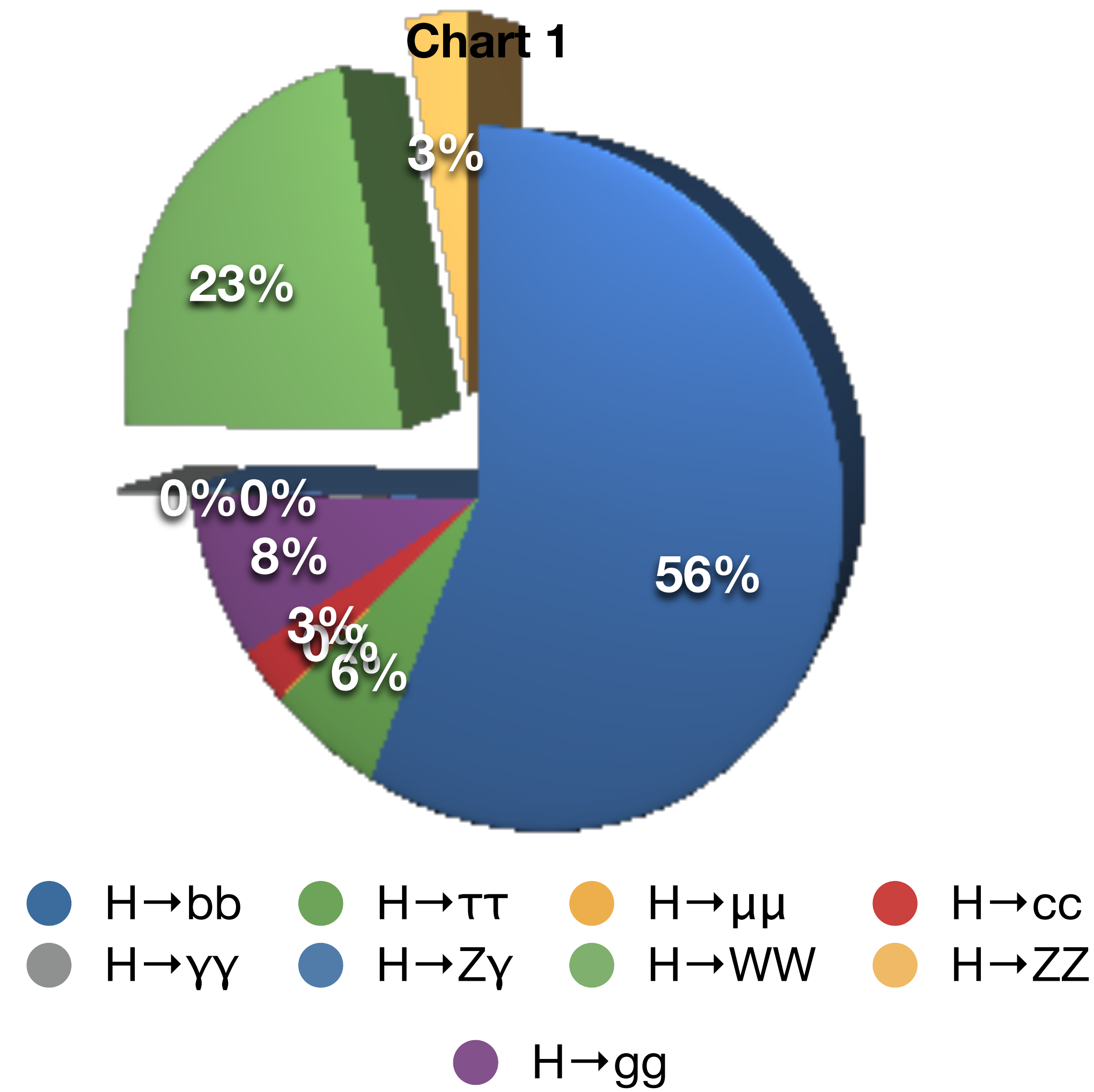
Higgs-Maxwell Workshop
13.02.2013

LANCASTER
UNIVERSITY

Higgs Decays



arXiv.org > hep-ph > arXiv:1107.5909

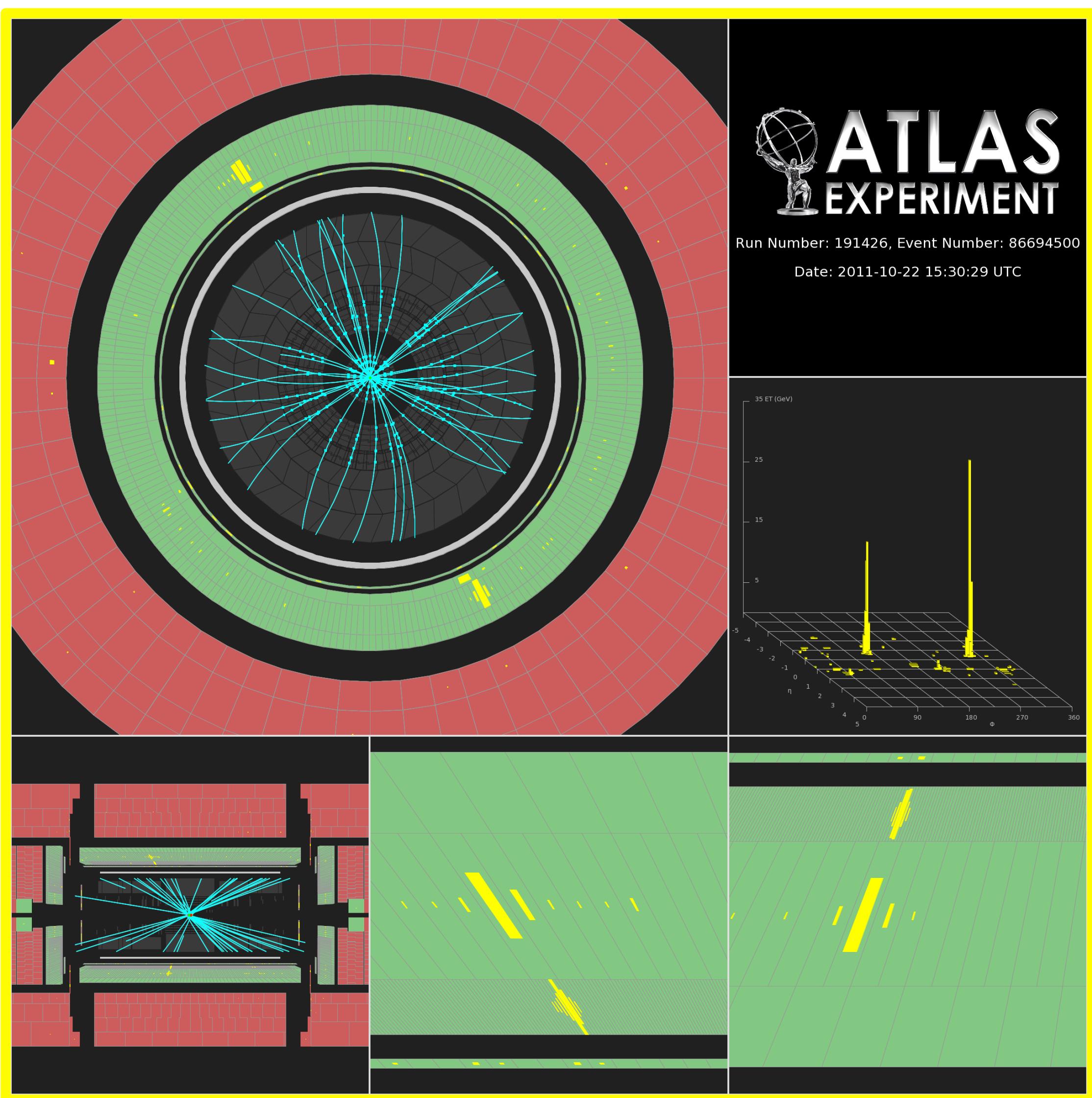


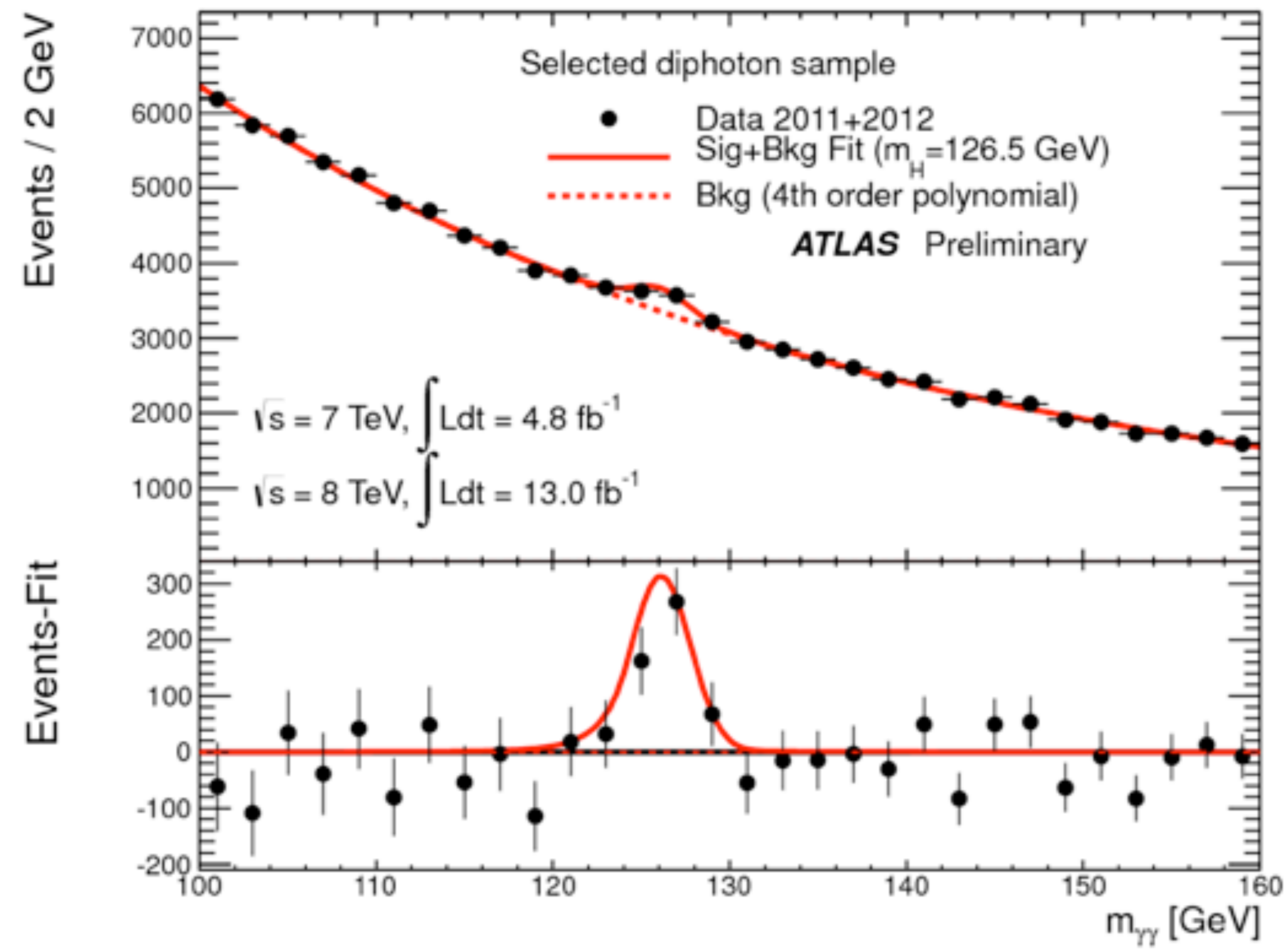
The true Higgs boson is a spin-0^+ particle

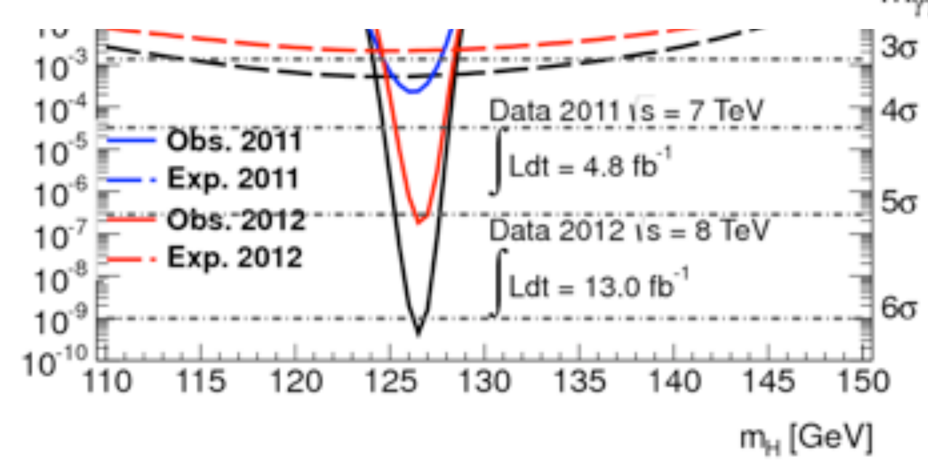
H→γγ

Measure 2 photons in the calorimeter (no track) and their opening angle α

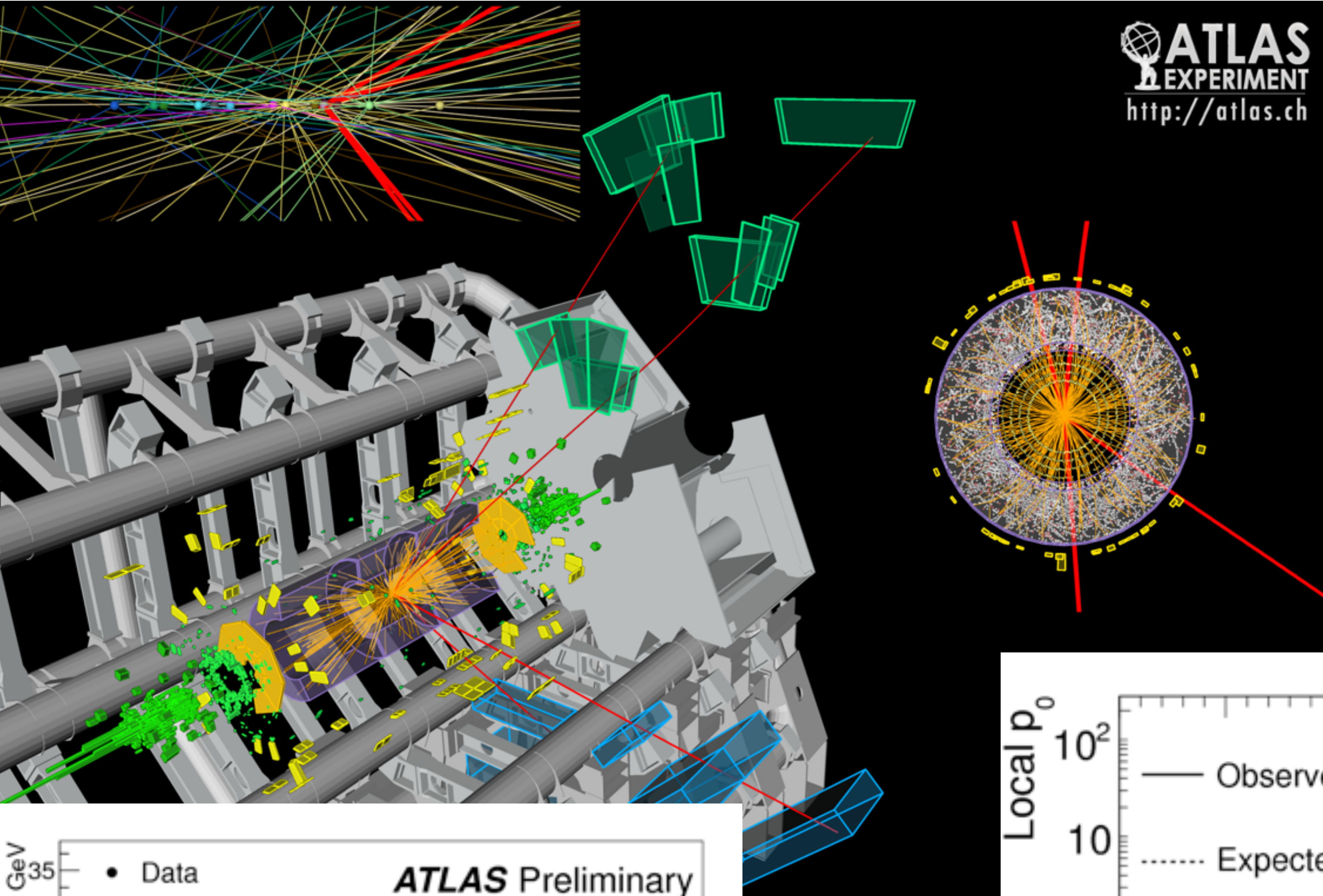
$$m_{\gamma\gamma}^2 = 2E_1E_2(1-\cos\alpha)$$





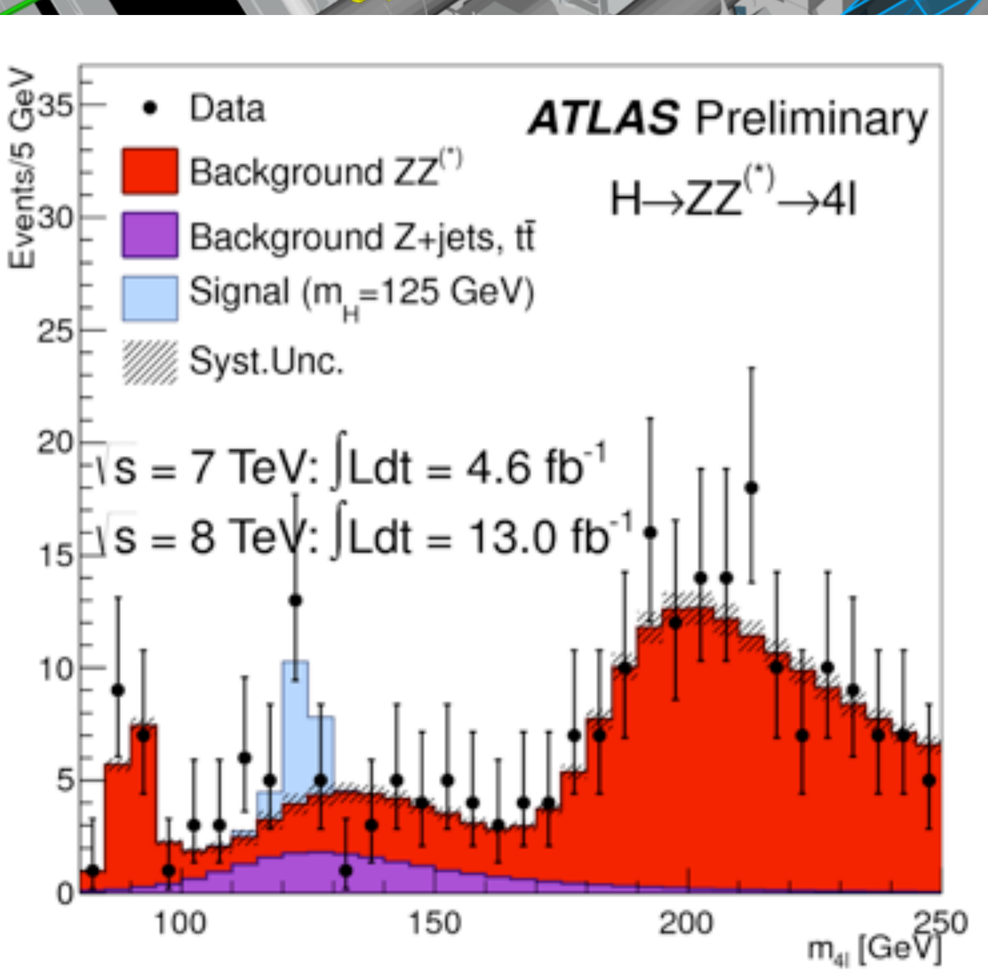


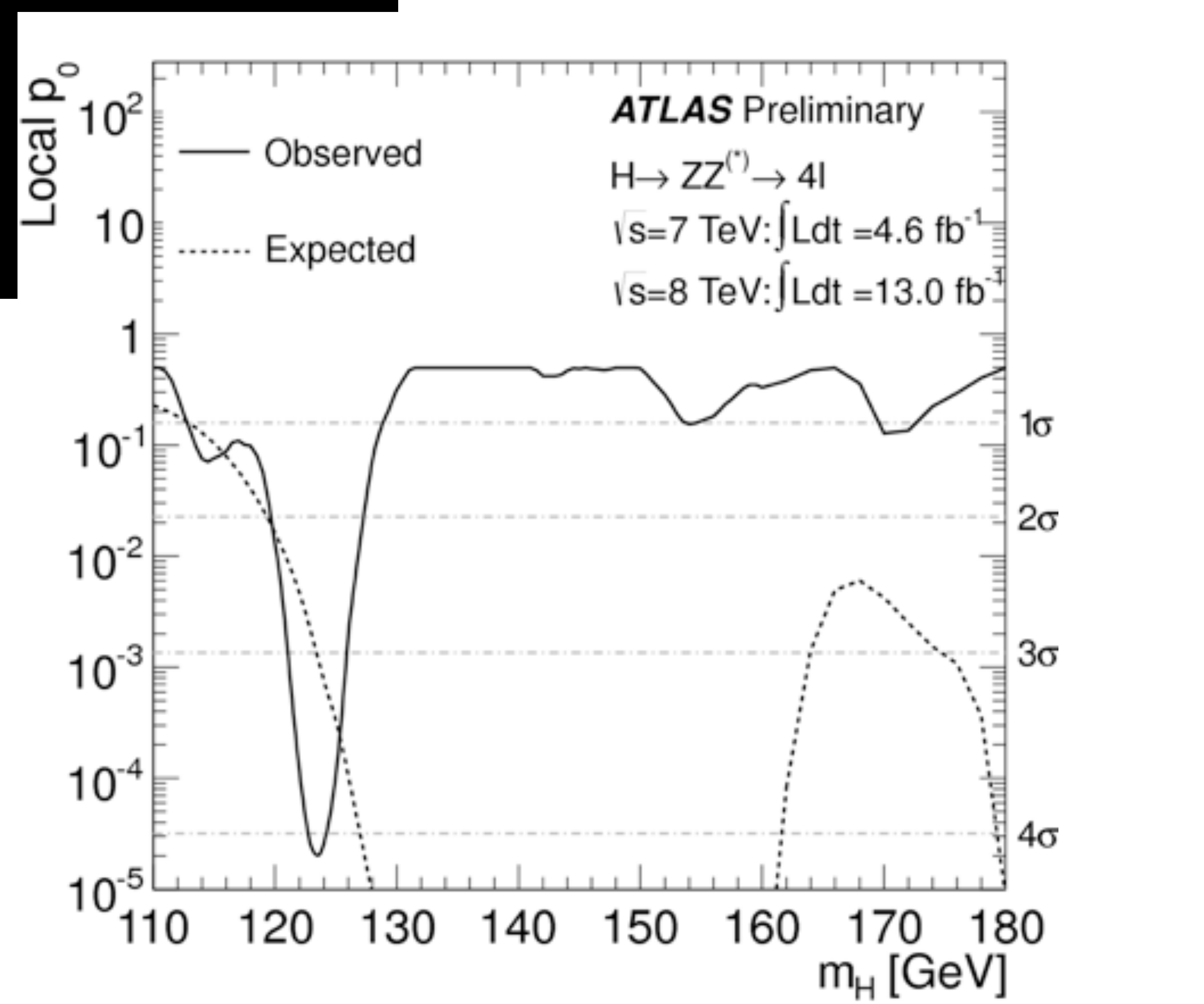
H→ZZ



±5 GeV around 125 GeV

Expected background	8.3 ± 0.6
Expected signal	9.9 ± 1.3
Observed	18





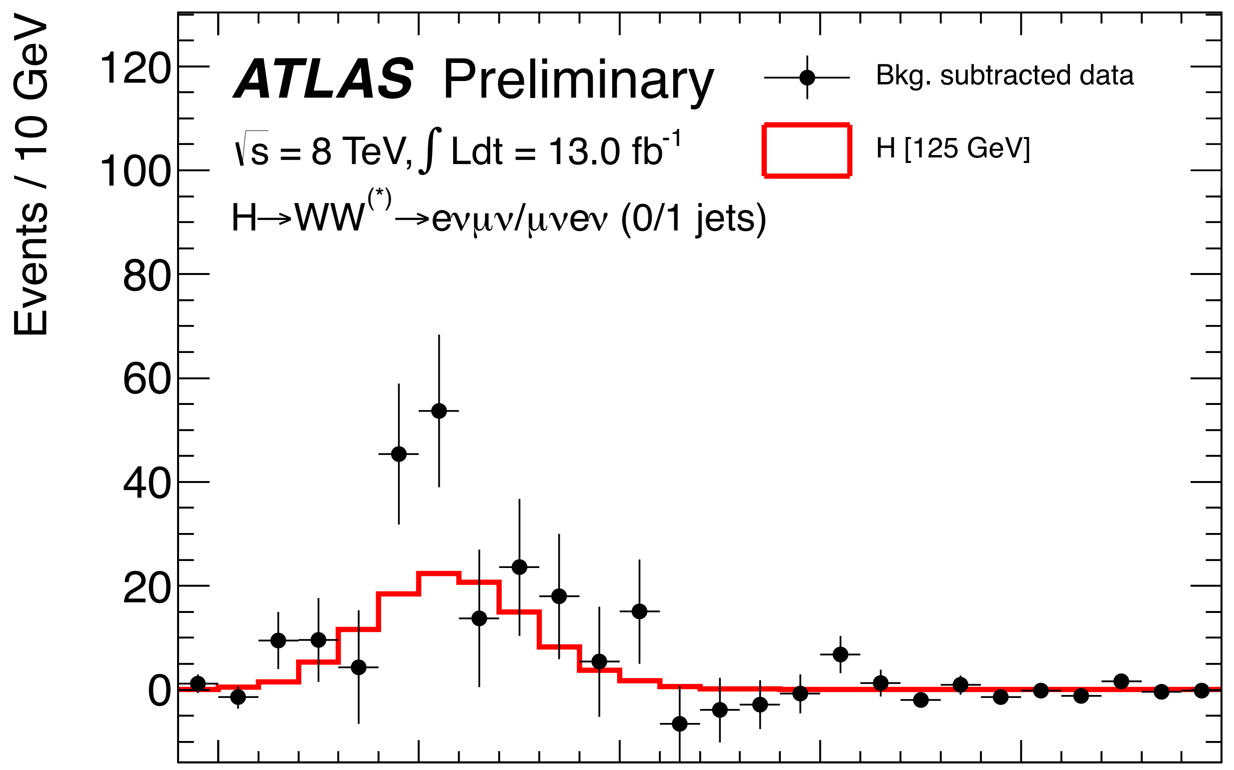
H → WW

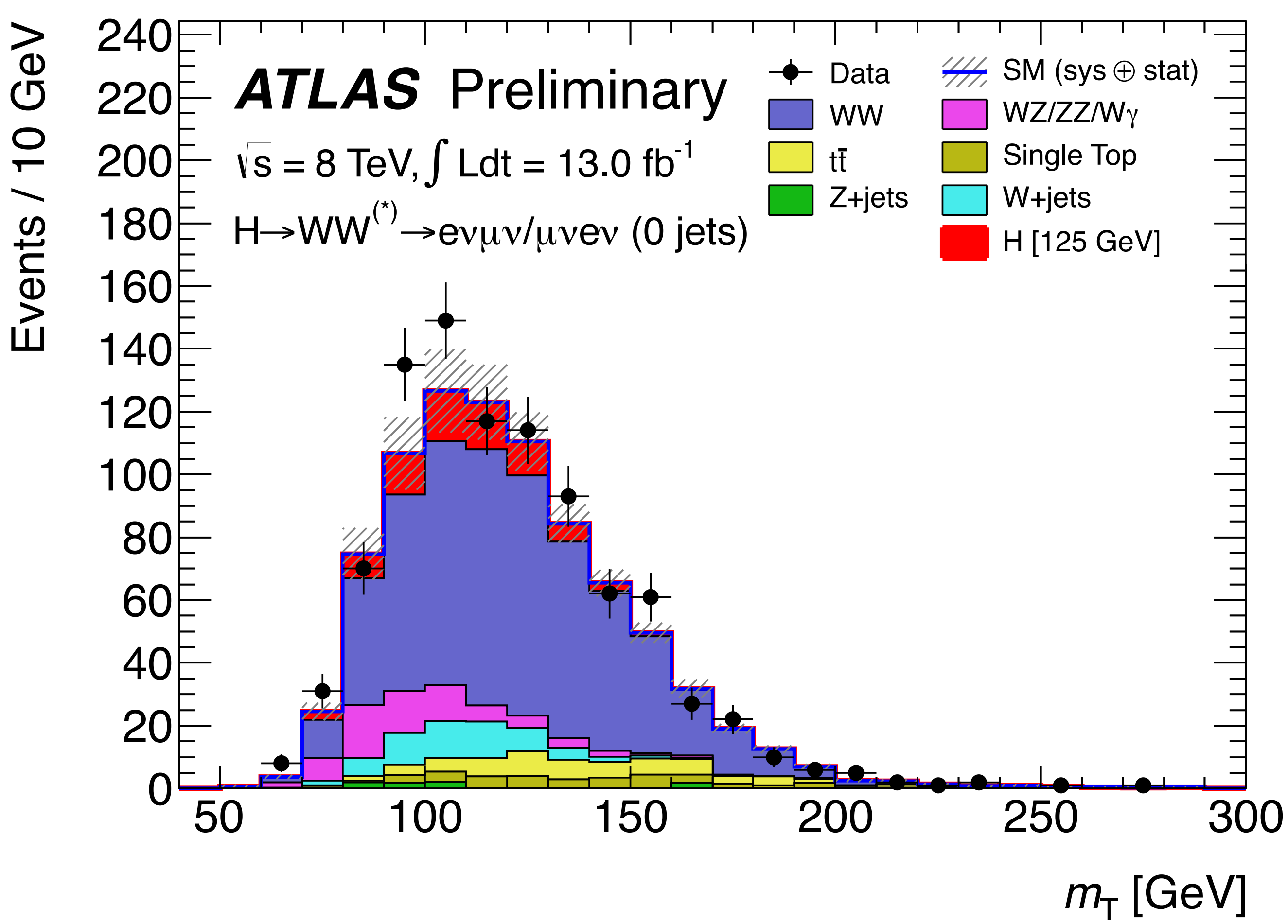
2 neturinos → m_T

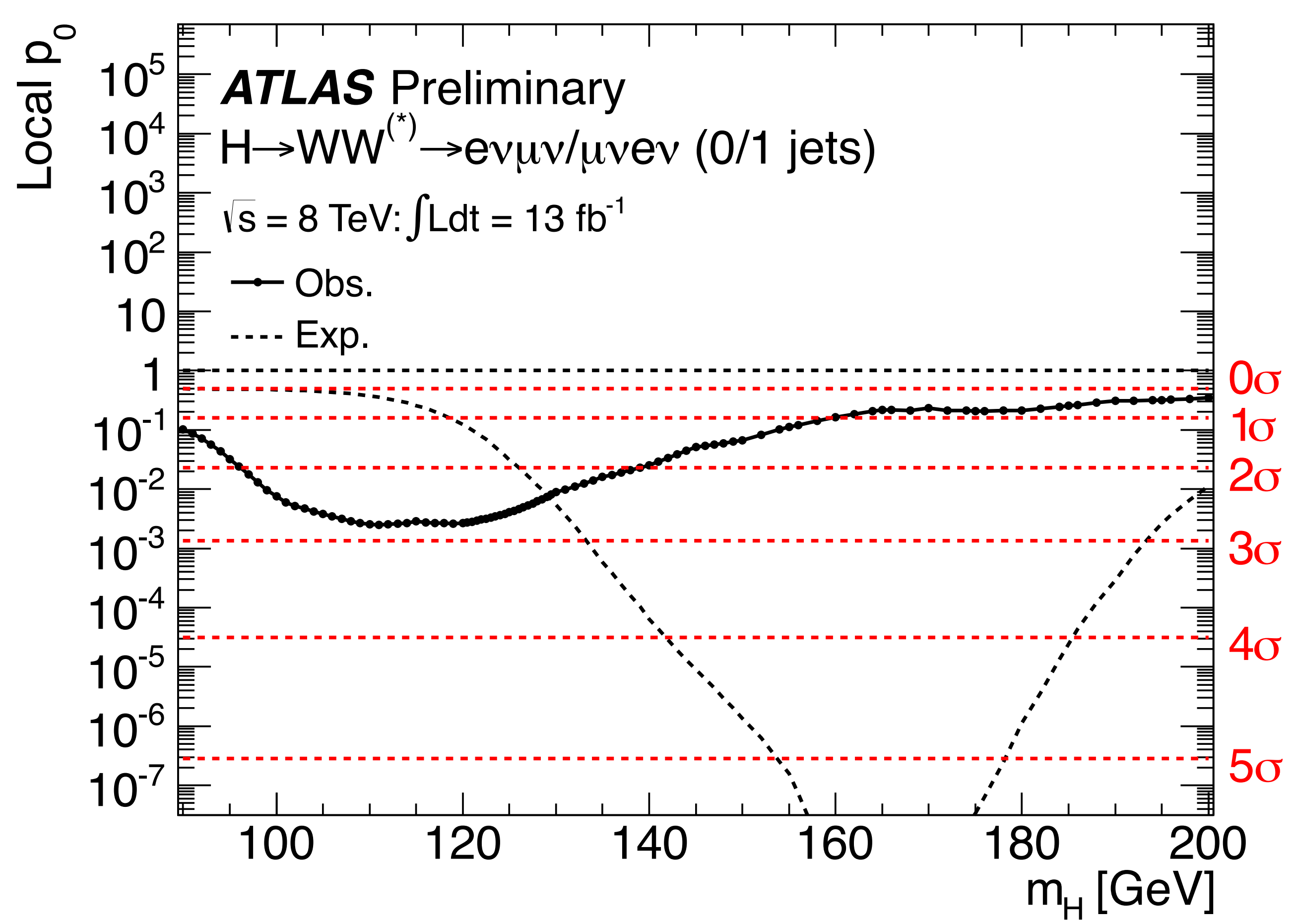
large MET

jet bins

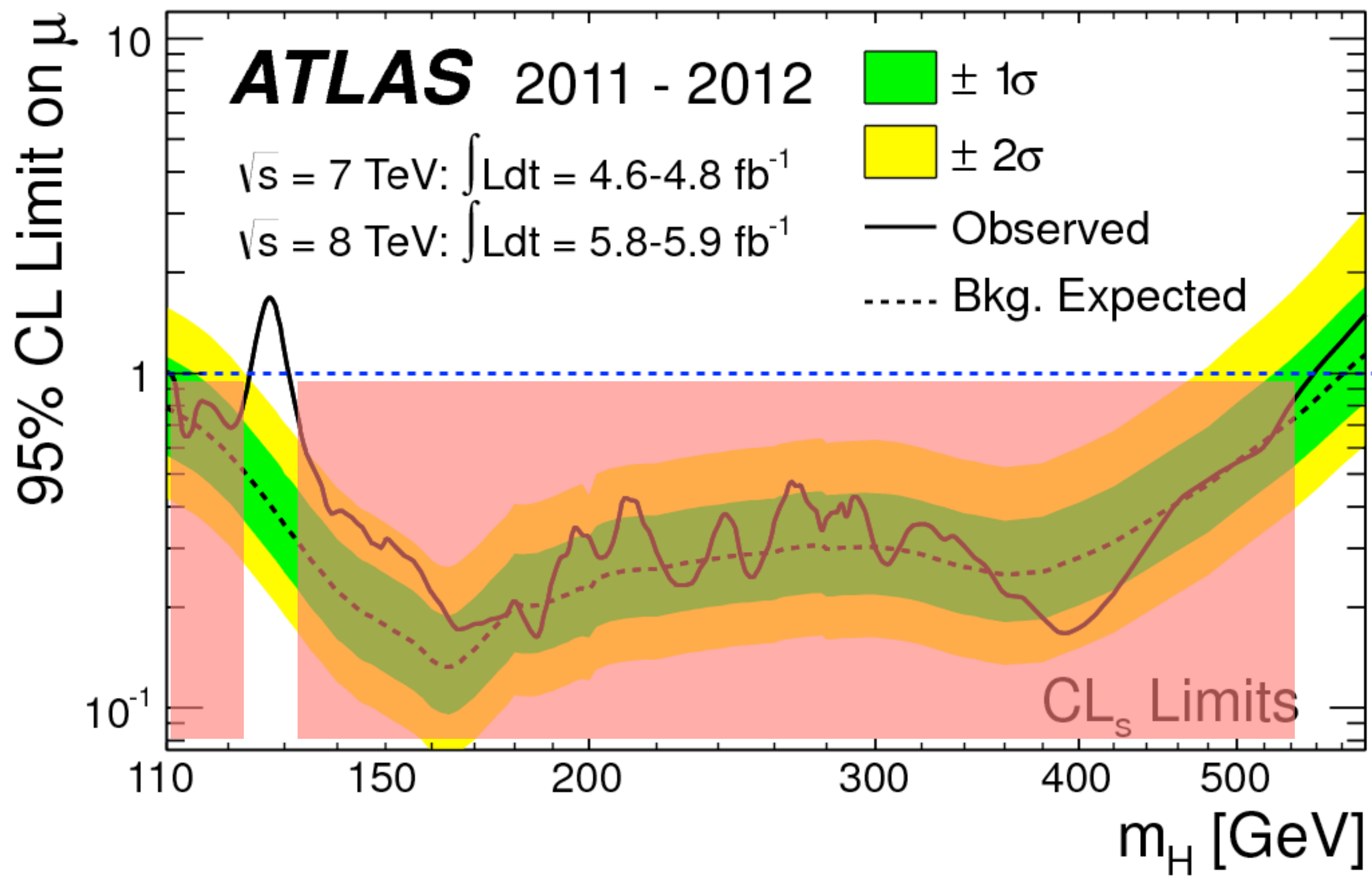
Exp Bg	448 +/- 45
Exp Signal	63+/- 13
Obs 0.75mH < mT < mH	546





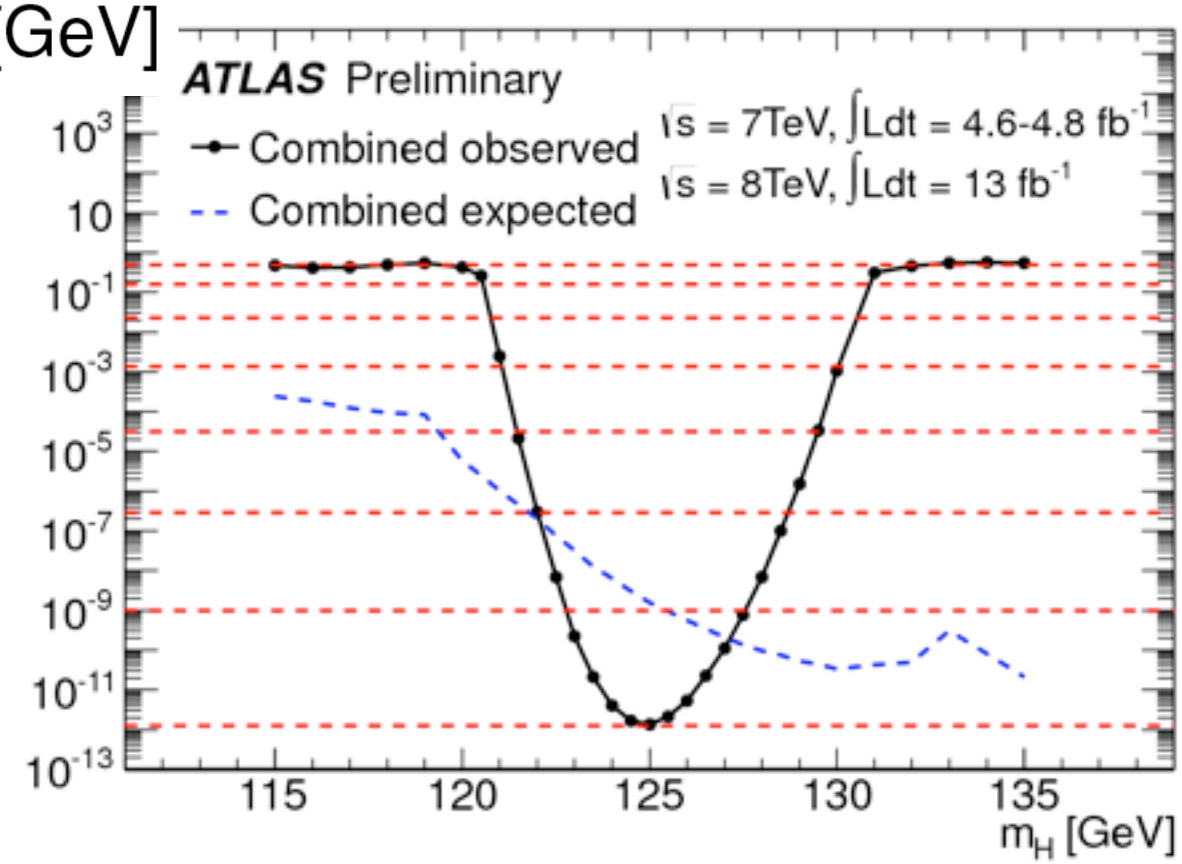


ATLAS Combination

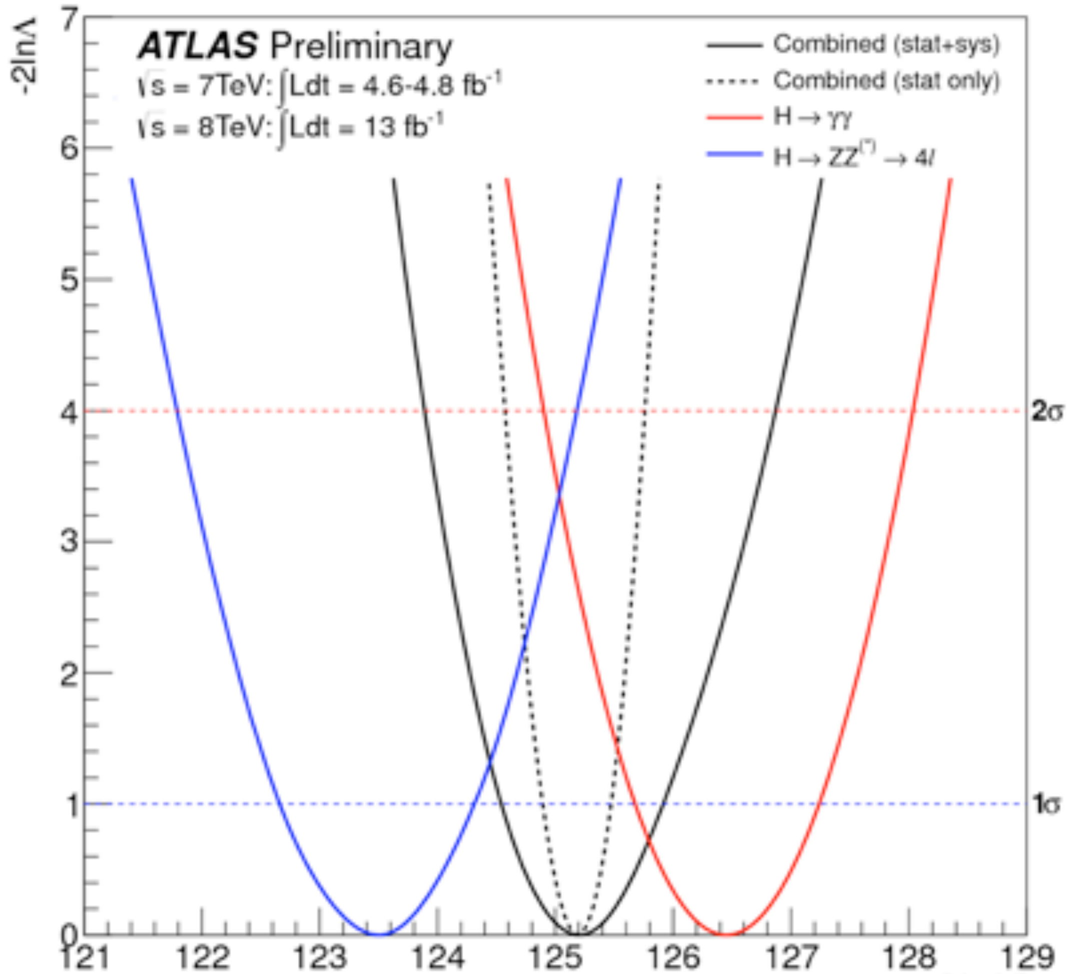


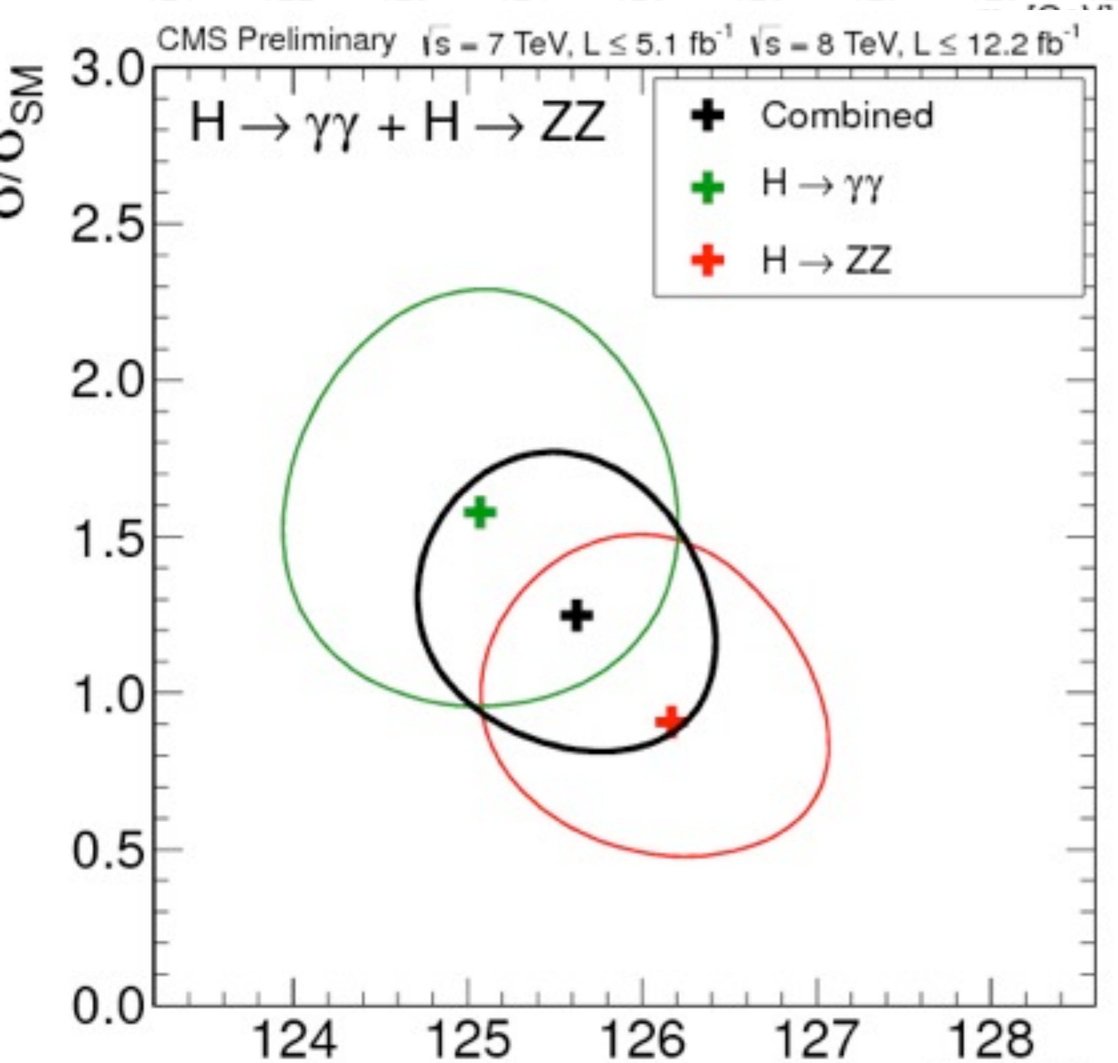
Excluded region

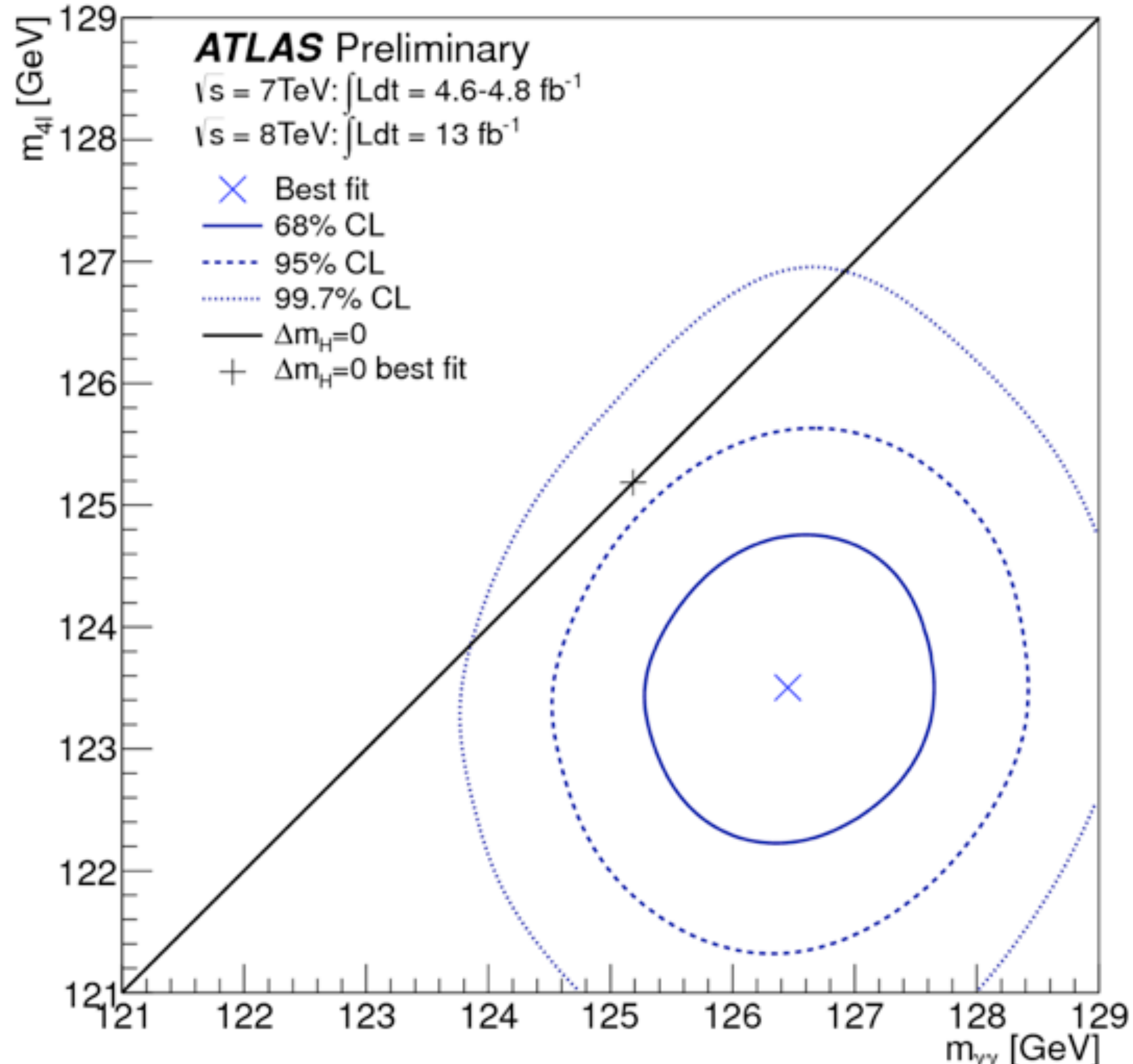
The significance of the signal at 125.0 GeV is 7.0 standard deviations for ATLAS alone!



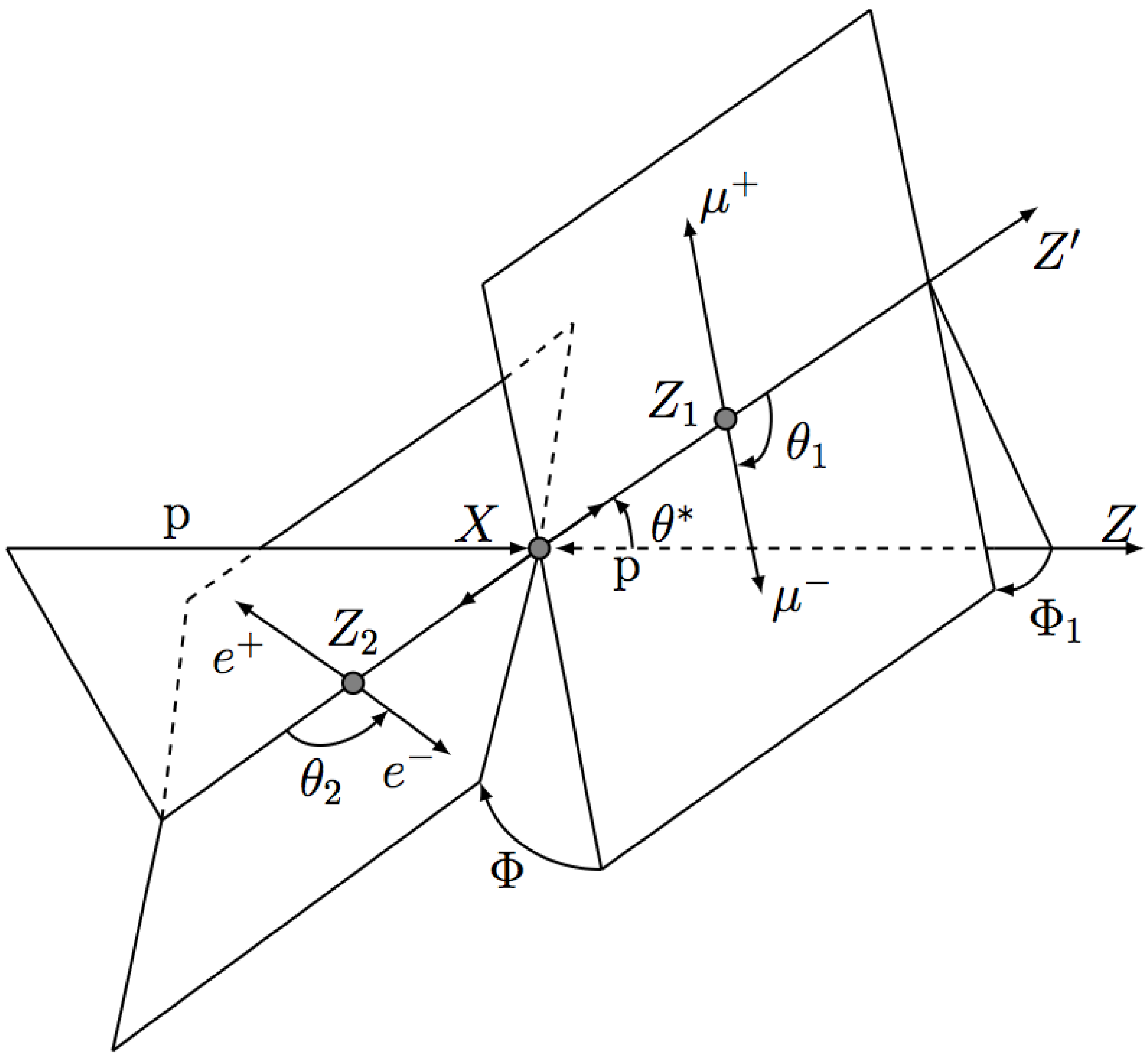
Mass Combinations







H→ZZ J^P Measurement



Observables:

The 2 Z masses

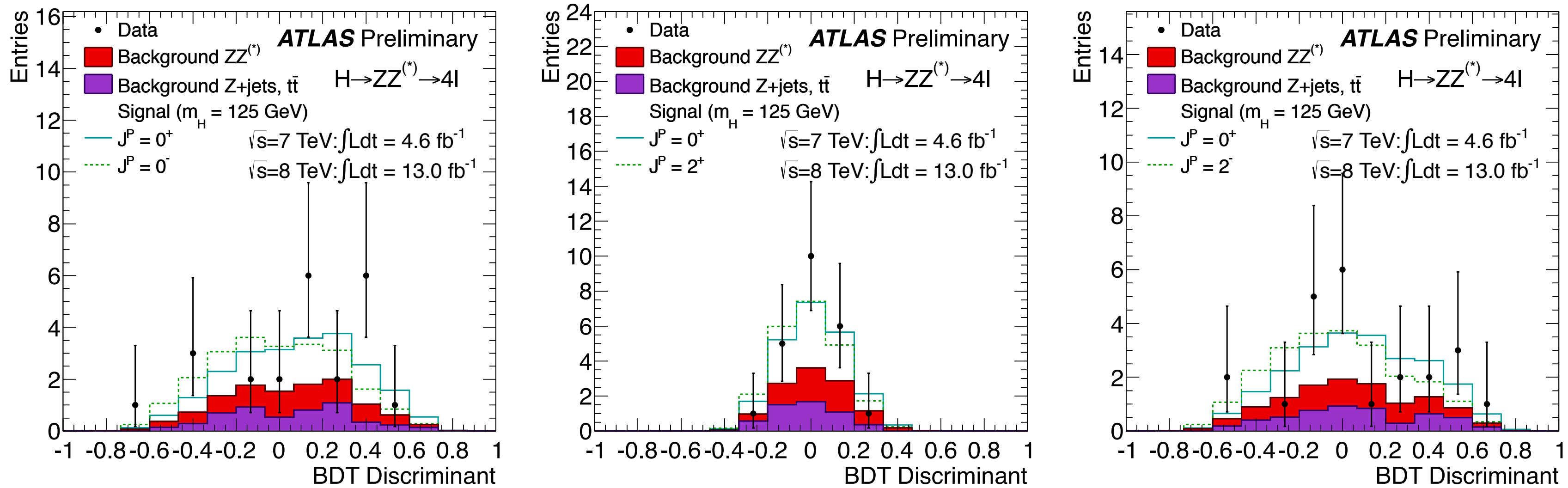
Production angle Θ*

Decay angles ϕ_1, ϕ, Θ_1, Θ_2

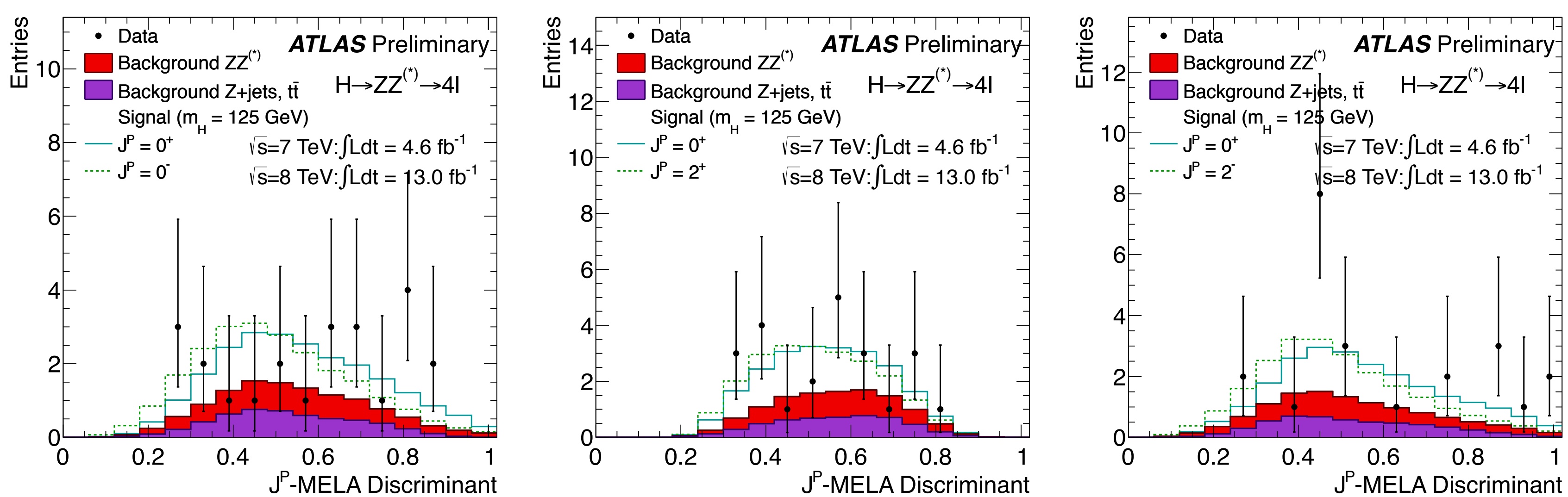
Spin 0: no dependence on Θ^* and ϕ_1

Two different methods are employed: a Boosted Decision Tree (BDT) and a weighted Matrix Element approach (MELA)

J^P 0^+ vs 0^-, 0^+ vs 2^+, 0^+ vs 2^-



(a) (b) (c)



(d) (e) (f)

0^+ is preferred over 0^- and 2^- at almost 2σ

0^+ vs $2m^+$ has an expected separation of $<1\sigma$

0^- is the least likely hypothesis

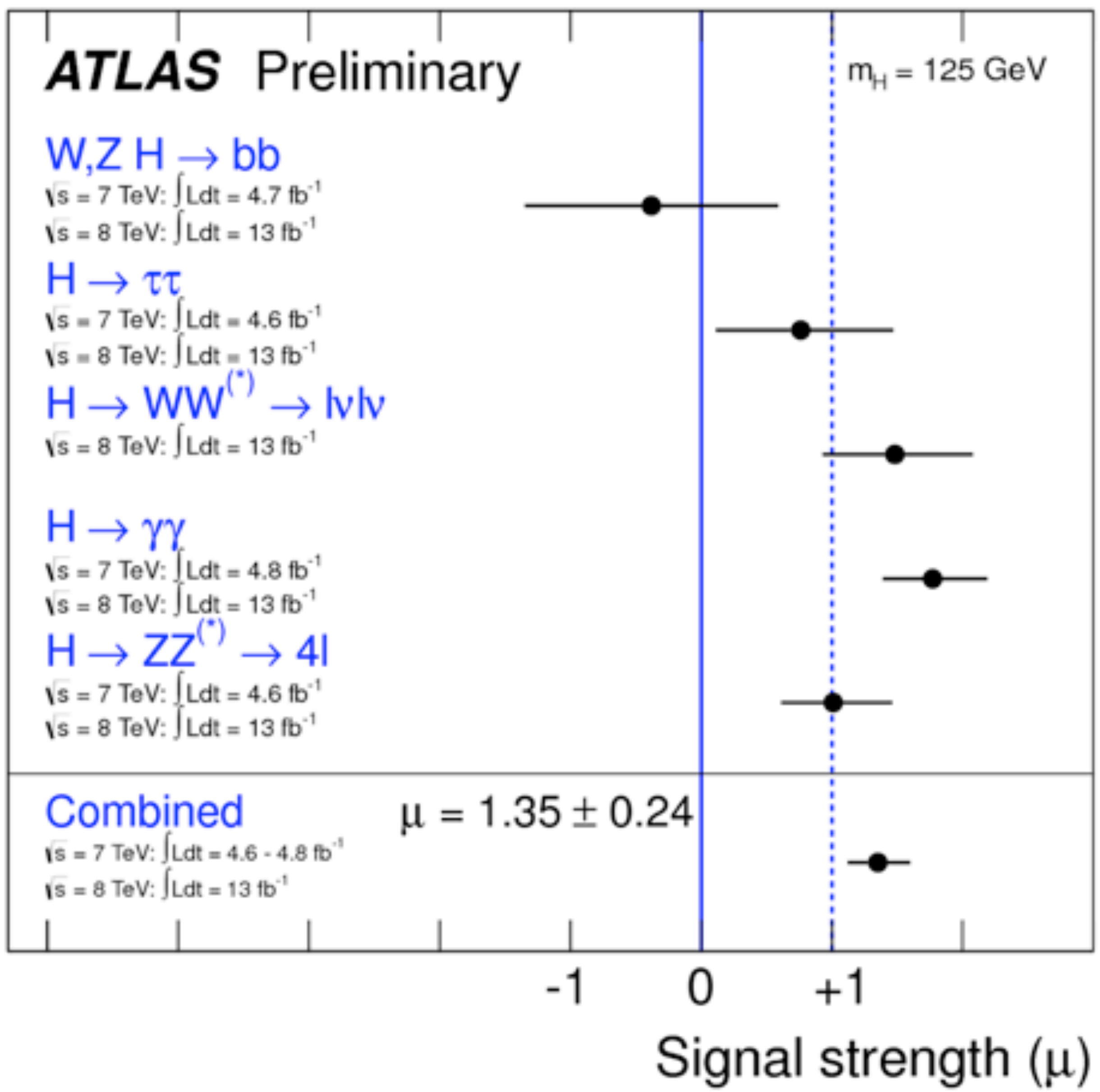
SM 0^+ is clearly preferred

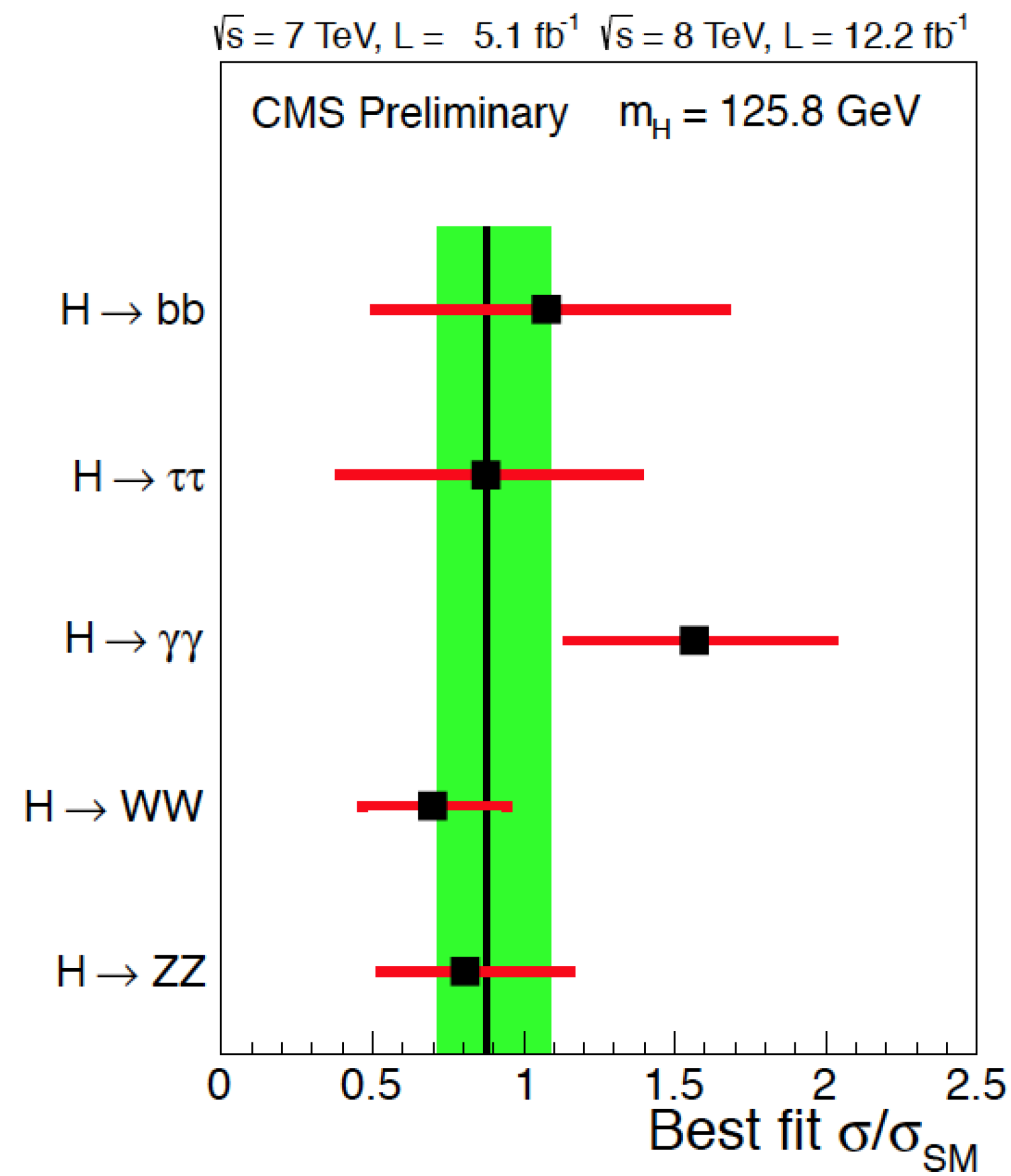
exclusion:

BDT (JP-MELA) analysis: 98.9% (99.7%) for 0^-, 84% (83%) for 2^+m and 97.1% (97.5%) for 2^-

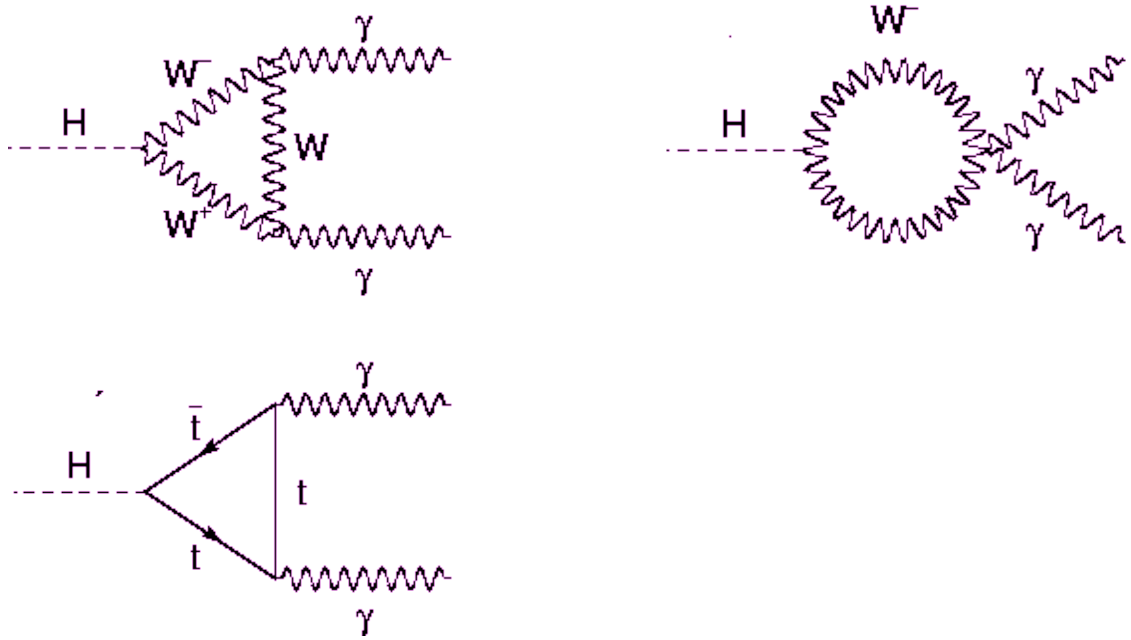
CMS: 0^- disfavoured at CL_s of 2.4%

Higgs Signal Strength

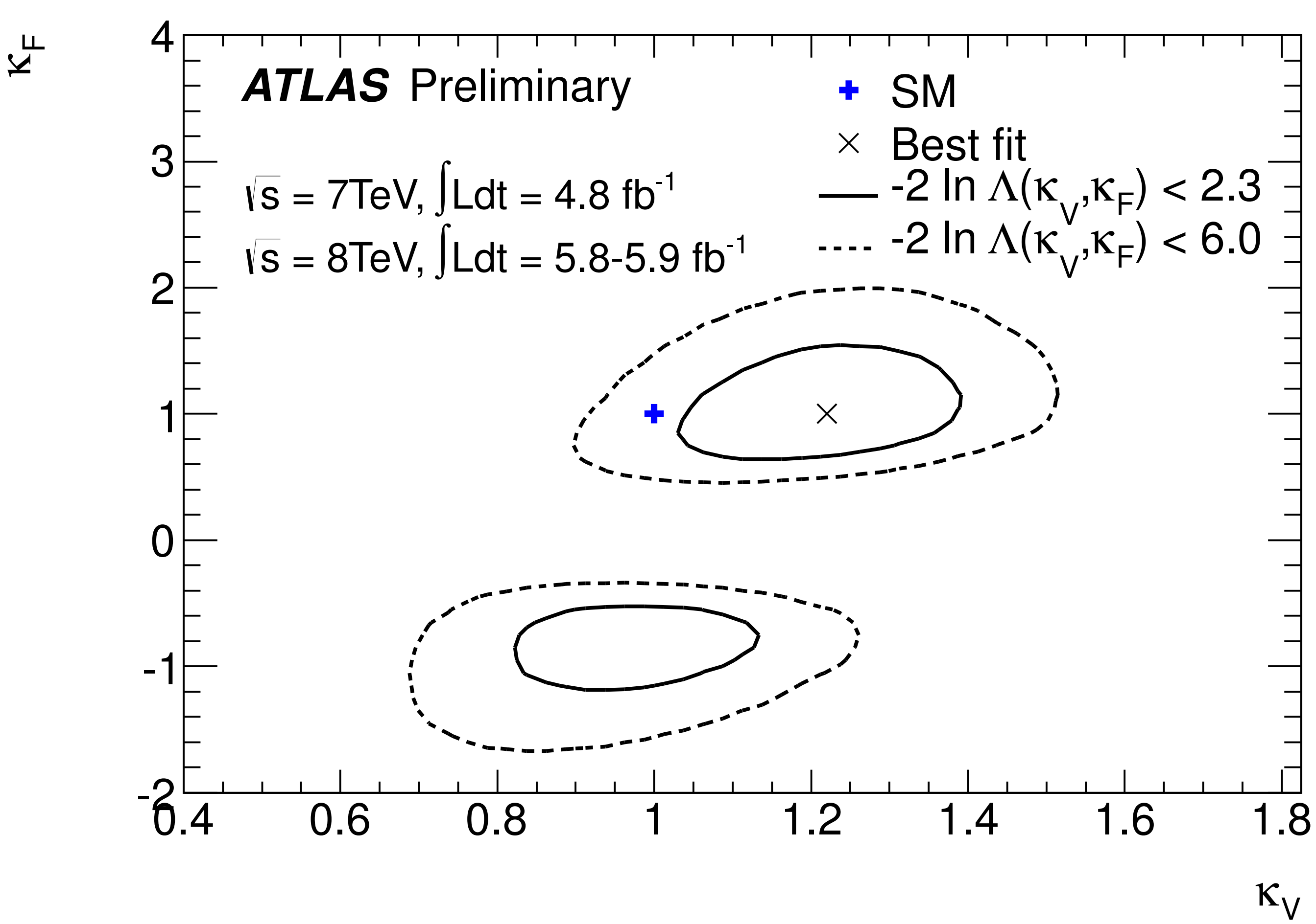


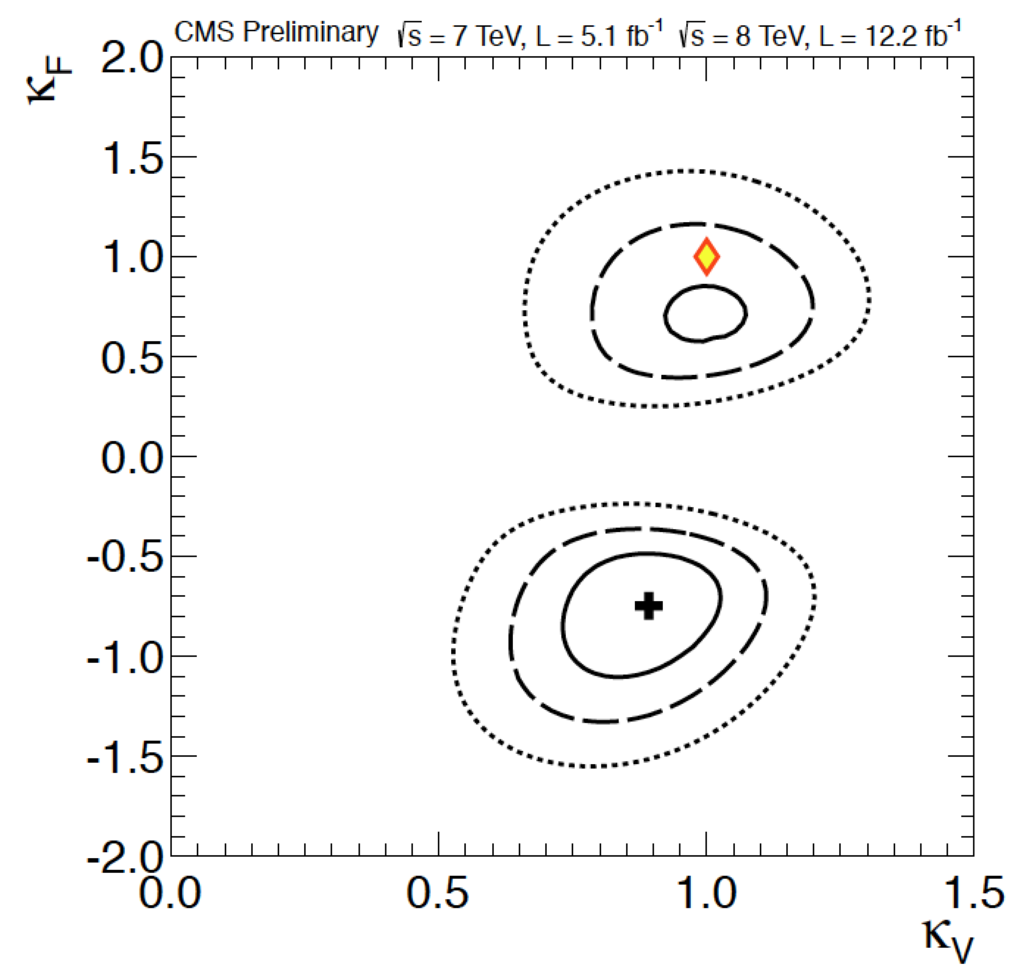


Vector-Boson and Fermion Coupling

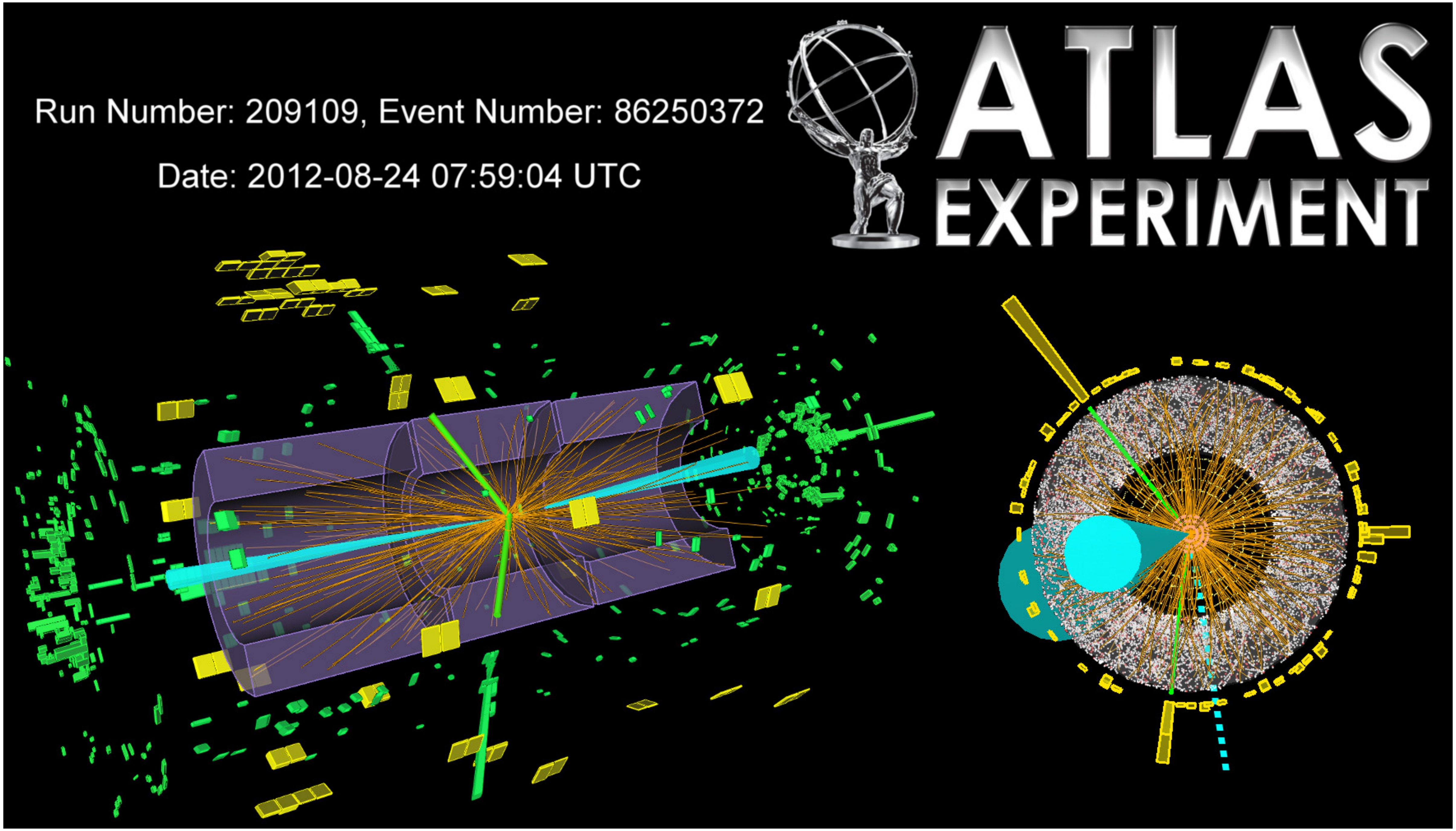


Interference between three different diagrams involving vector bosons (W) and fermions (t):
One can measure the sign of the coupling and constructive or destructive (SM) interference.





$H \rightarrow \tau_{had} \tau_{had}$ (VBF) Candidate



H→ττ

Like many other analyses this is in reality a complicated mix:

τ lep τ lep; τ lep τ had; τ had τ had

each of these is split into 7TeV (~4.6fb-1) and 8TeV (~13fb-1)

each of these has

2-4 sub-categories:

- VBF (2-jet)
- boosted (1-jet)
- VH production
- gluon fusion

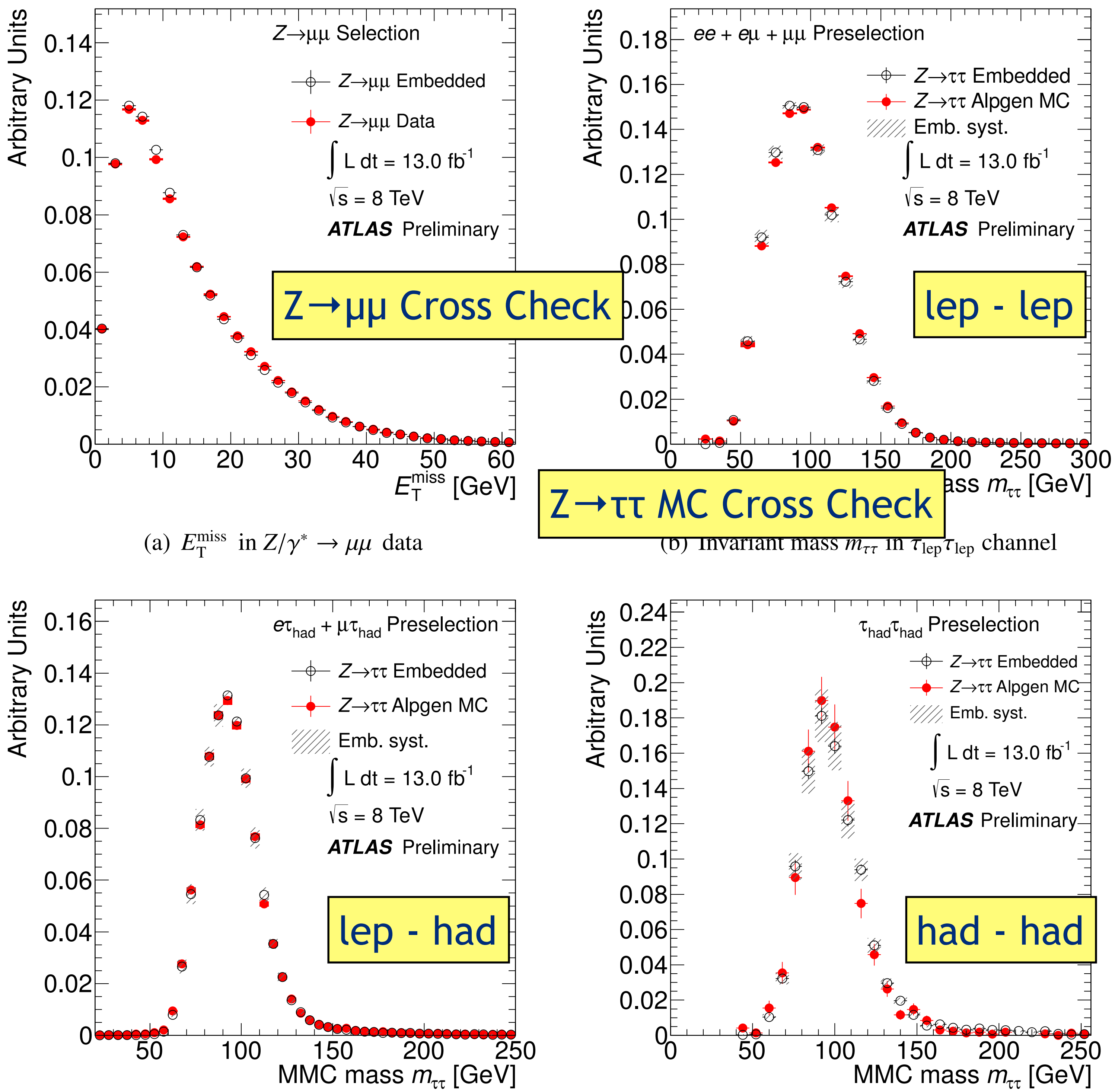
Trigger conditions

changed during the run

Table 2: The categorization of the $H \to \tau_{\text{lep}}\tau_{\text{lep}}$ analysis. The JVF cut is $|JVF| > 0.75$ for 7 TeV data, the lepton centrality is not applied for 7 TeV analysis, and the 0-jet category is not used for 8 TeV data analysis.

2-jet VBF	Boosted	2-jet VH	1-jet
Pre-selection: exactly two leptons with opposite charges			
30 GeV $< m_{\ell\ell} <$ 75 GeV (30 GeV $< m_{\ell\ell} <$ 100 GeV) for same-flavor (different-flavor) leptons, and $p_{T,\ell 1} + p_{T,\ell 2} >$ 35 GeV			
At least one jet with $p_T >$ 40 GeV ($\lvert JVF_{\text{jet}}\rvert > 0.5$ if $\lvert\eta_{\text{jet}}\rvert < 2.4$)			
$E_{\text{T}}^{\text{miss}} >$ 40 GeV ($E_{\text{T}}^{\text{miss}} >$ 20 GeV) for same-flavor (different-flavor) leptons			
$H_{\text{T}}^{\text{miss}} >$ 40 GeV for same-flavor leptons			
$0.1 < x_{1,2} < 1$			
$0.5 < \Delta\phi_{\ell\ell} < 2.5$			
$p_{T,j2} >$ 25 GeV (JVF)	excluding 2-jet VBF	$p_{T,j2} >$ 25 GeV (JVF)	excluding 2-jet VBF, Boosted and 2-jet VH
$\Delta\eta_{jj} > 3.0$	$p_{T,\tau\tau} >$ 100 GeV	excluding Boosted	$m_{\tau\tau j} >$ 225 GeV
$m_{jj} >$ 400 GeV	b-tagged jet veto	$\Delta\eta_{jj} < 2.0$	b-tagged jet veto
b-tagged jet veto	–	30 GeV $< m_{jj} <$ 160 GeV	–
Lepton centrality and CJV		b-tagged jet veto	
0-jet (7 TeV only)			
Pre-selection: exactly two leptons with opposite charges			
Different-flavor leptons with 30 GeV $< m_{\ell\ell} <$ 100 GeV and $p_{T,\ell 1} + p_{T,\ell 2} >$ 35 GeV			
$\Delta\phi_{\ell\ell} > 2.5$			
b-tagged jet veto			

μ → τ Embedding



(a) E_T^{miss} in $Z/\gamma^* \to \mu\mu$ data

(b) Invariant mass $m_{\tau\tau}$ in $\tau_{lep}\tau_{lep}$ channel

(c) Invariant mass $m_{\tau\tau}$ in $\tau_{lep}\tau_{had}$ channel

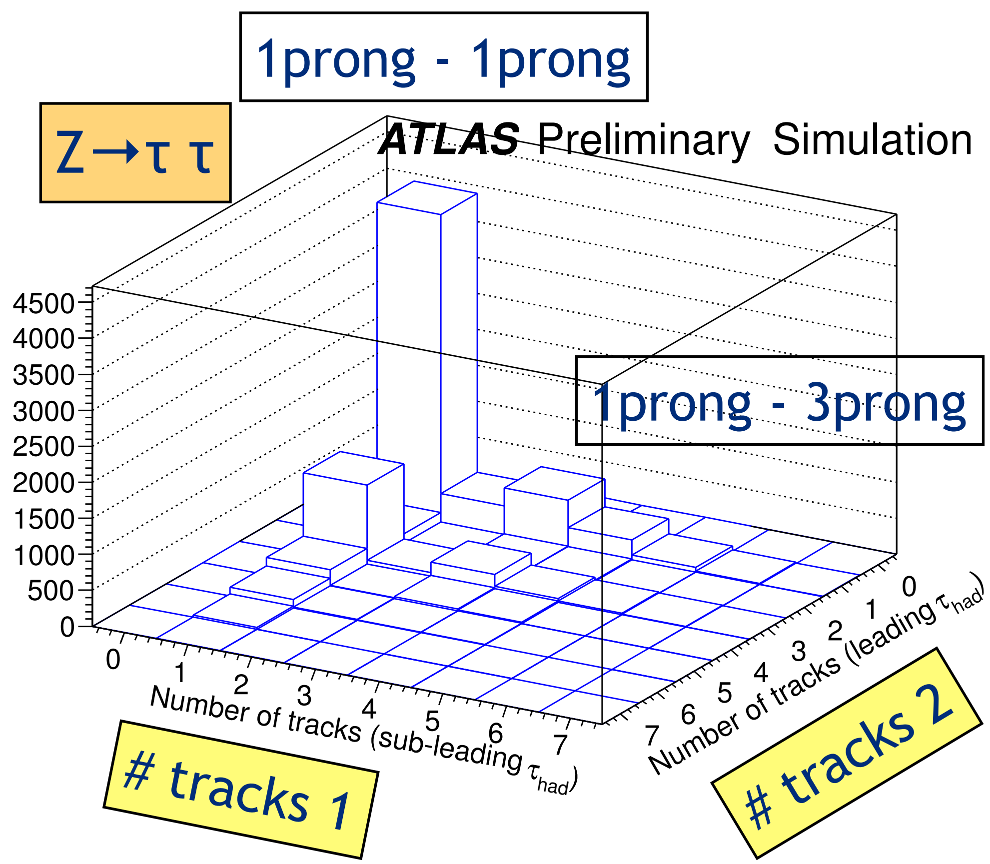
(d) Invariant mass $m_{\tau\tau}$ in $\tau_{had}\tau_{had}$ channel

Take $Z/\gamma^* \to \mu\mu$ data and replace the muon with τ track(s) and calorimeter information from $Z/\gamma^* \to \tau\tau$ simulation

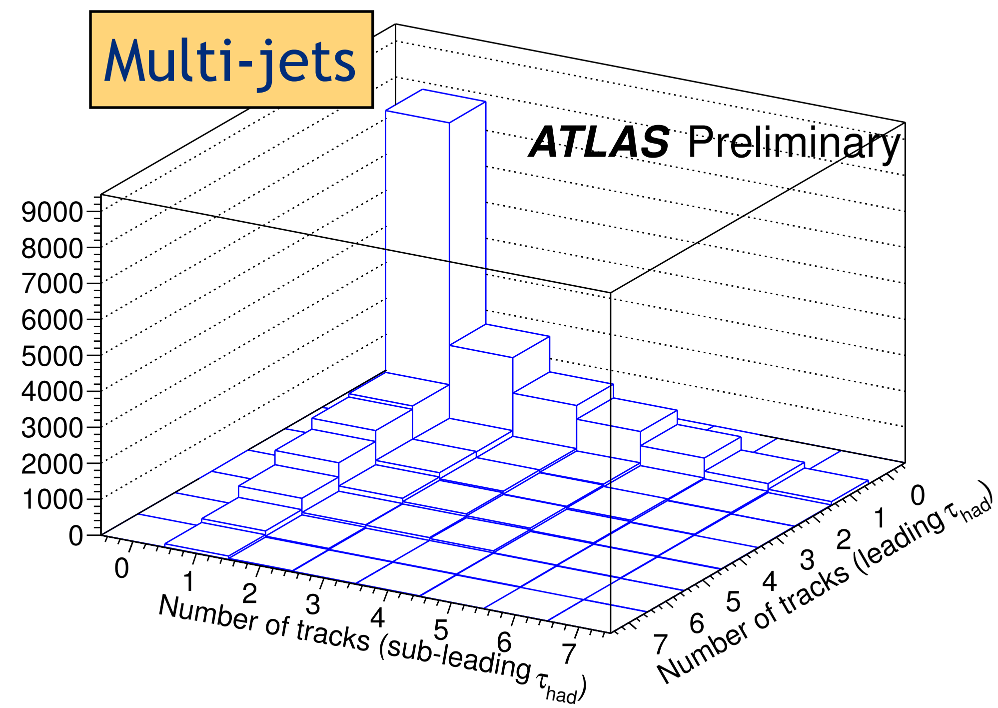
No signal contamination
Jets, underlying event, pile-up etc from data
Correct kinematics
Lower systematics

$\tau_{had}\ \tau_{had}$ Normalisation

Background templates in track multiplicity are derived from MC for $Z\to\tau\tau$ and from same sign data for multi jet events.



(a) $Z \to \tau\tau$ events



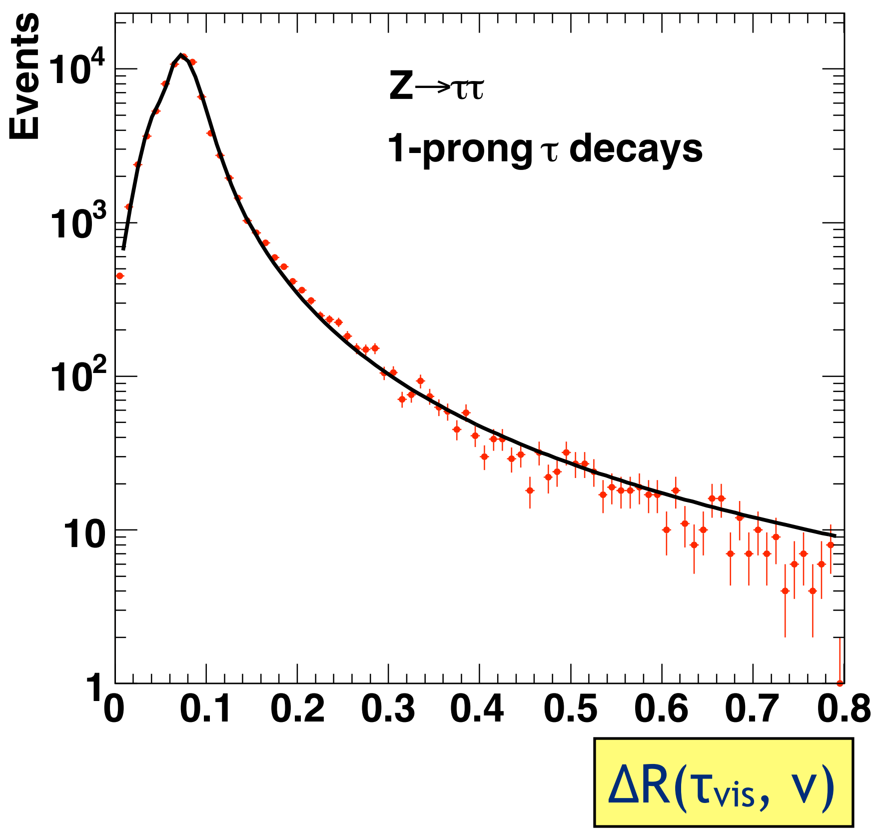
(b) Multi-jet events

A 2D fit in the low mass region at pre-selection level is performed.

Mass Reconstruction

There are 2 (had-had) to 4 (lep-lep) neutrinos in the event

⇒ an exact mass reconstruction is impossible.



Visible Mass

invariant mass using only the visible quantities

Transverse Mass

visible quantities + MET

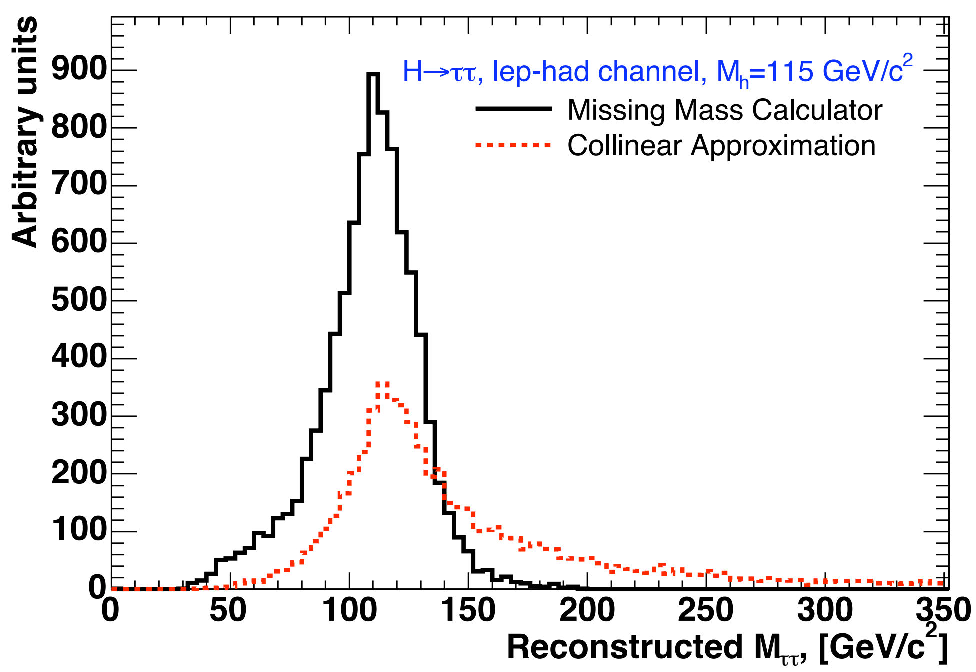
Collinear Mass

neutrinos are collinear with visible decay products

MET constrains the transverse neutrino direction

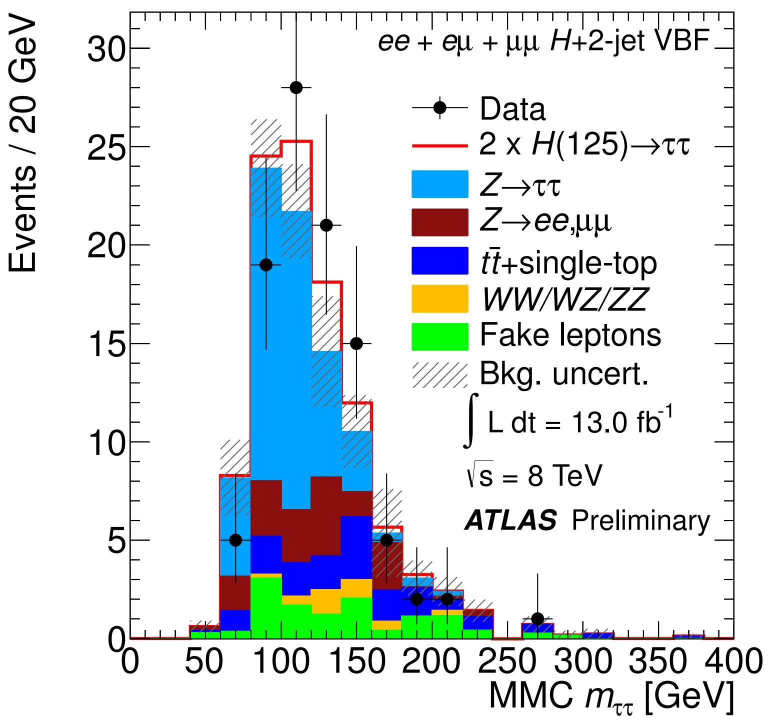
Missing Mass Calculator

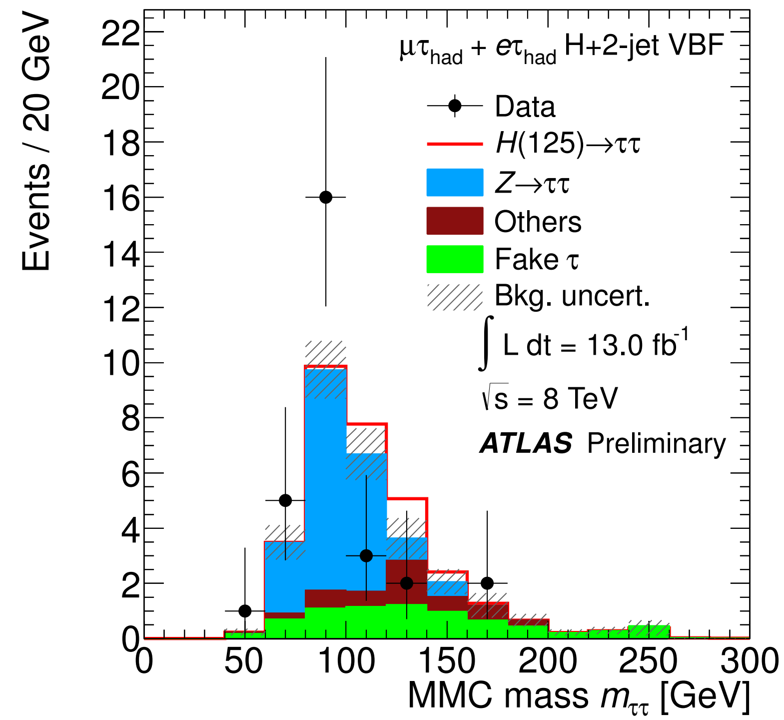
A likelihood function is constructed for the neutrino direction w.r.t. the visible decay products

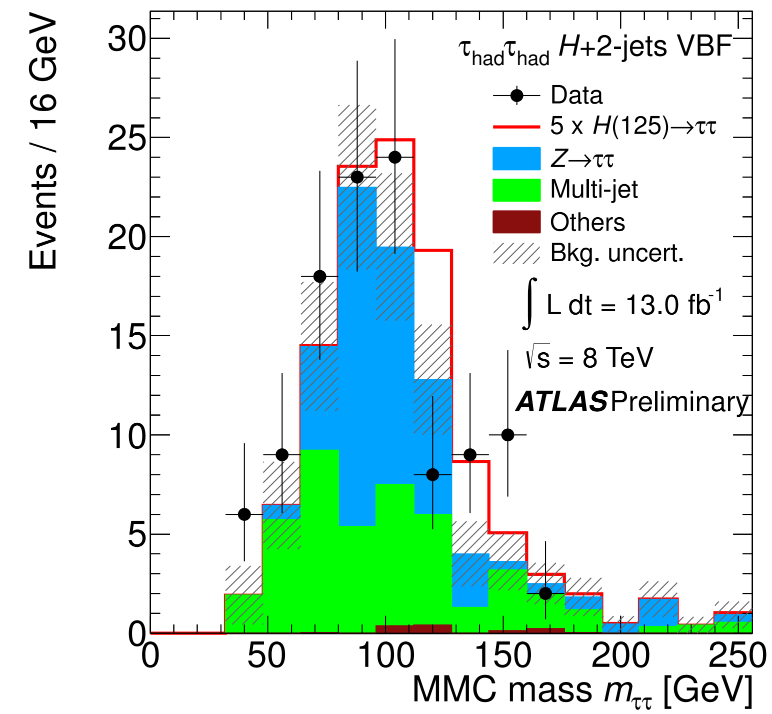


A.Elagin, P.Murat, A.Pranko, A.Safonov
Nucl.Instrum.Meth. A654 (2011) 481-489

Event Numbers VBF







VBF Analysis	lep-lep 7	lep-lep 8	lep-had 7	lep-had 8	had-had 7	had-had 8	combined
gg	0.2	1.3	0.17	0.5	0.36	1.0	3.53
VBF	1.05	3.63	0.87	2.5	1.12	3.01	12.18
VH	0	0.01	0	0	0	0	0.01
Sum Signal	1.25	4.94	1.04	3	1.48	4.01	15.72
Background	29	91	9.5	29	32.5	96	287
Observed	28	98	10	29	38	110	313

Systematics

Uncertainty	$H \to \tau_{lep}\tau_{lep}$	$H \to \tau_{lep}\tau_{had}$	$H \to \tau_{had}\tau_{had}$
$Z \to \tau^+\tau^-$			
Embedding	1–4% (S)	2–4% (S)	1–4% (S)
Tau Energy Scale	–	4–15% (S)	3–8% (S)
Tau Identification	–	4–5%	1–2%
Trigger Efficiency	2–4%	2–5%	2–4%
Normalisation	5%	4% (non-VBF), 16% (VBF)	9–10%
Signal			
Jet Energy Scale	1–5% (S)	3–9% (S)	2–4% (S)
Tau Energy Scale	–	2–9% (S)	4–6% (S)
Tau Identification	–	4–5%	10%
Theory	8–28%	18–23%	3–20%
Trigger Efficiency	small	small	5%

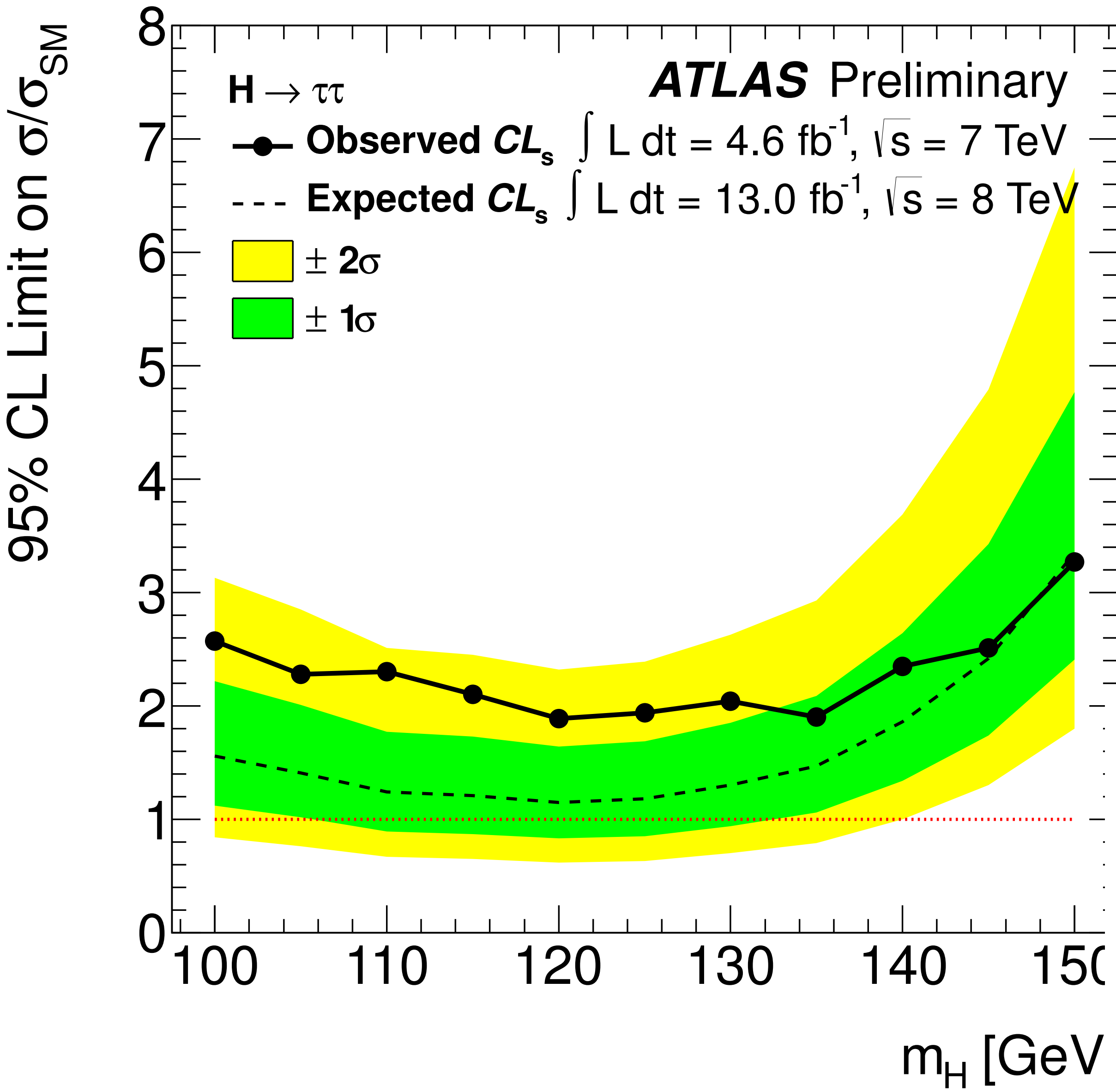
misrec.

σ for jets, QCD scale

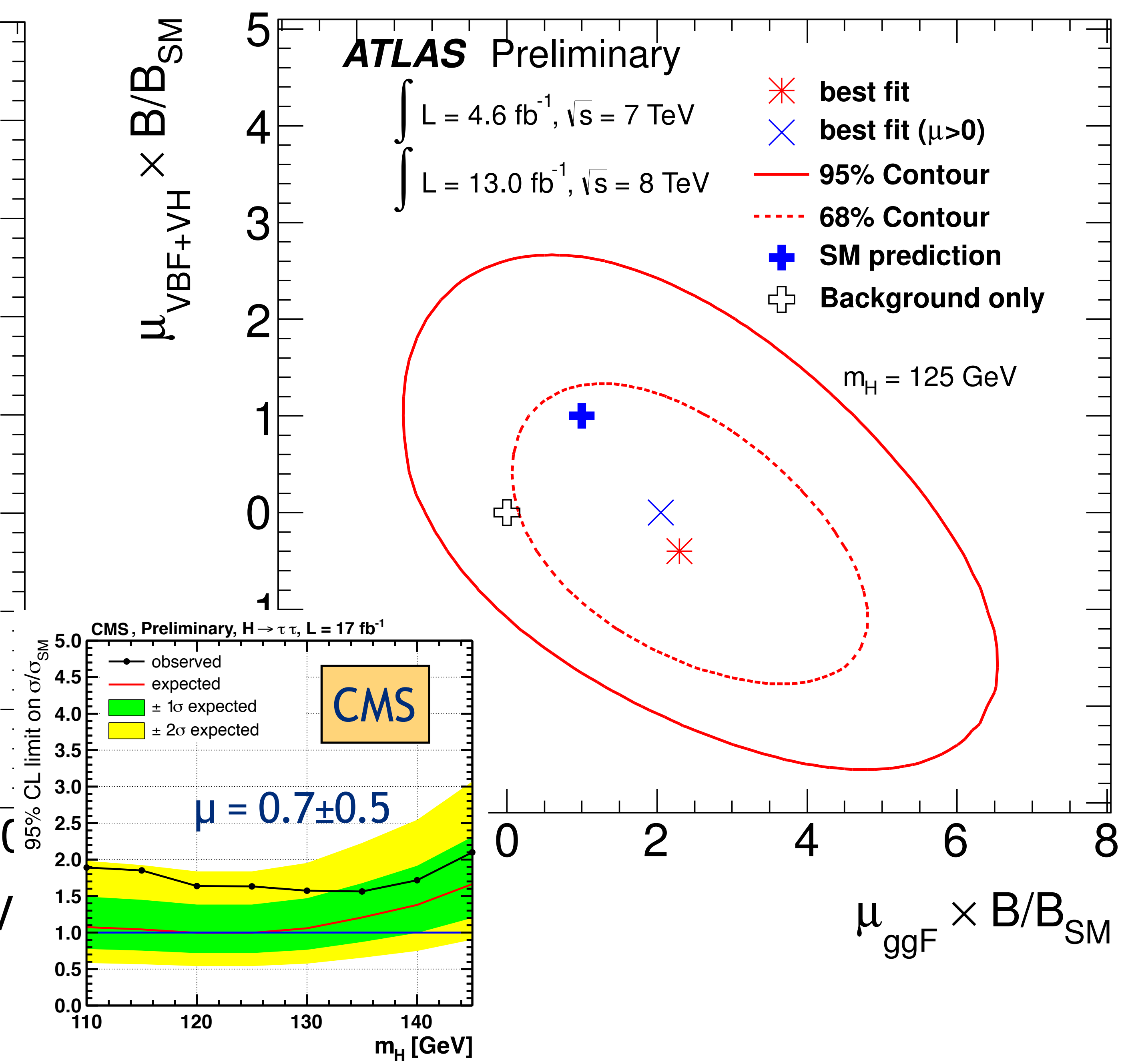
H → τ τ Results

The observed (expected) limit on the SM σ × BR is 1.9 (1.2)

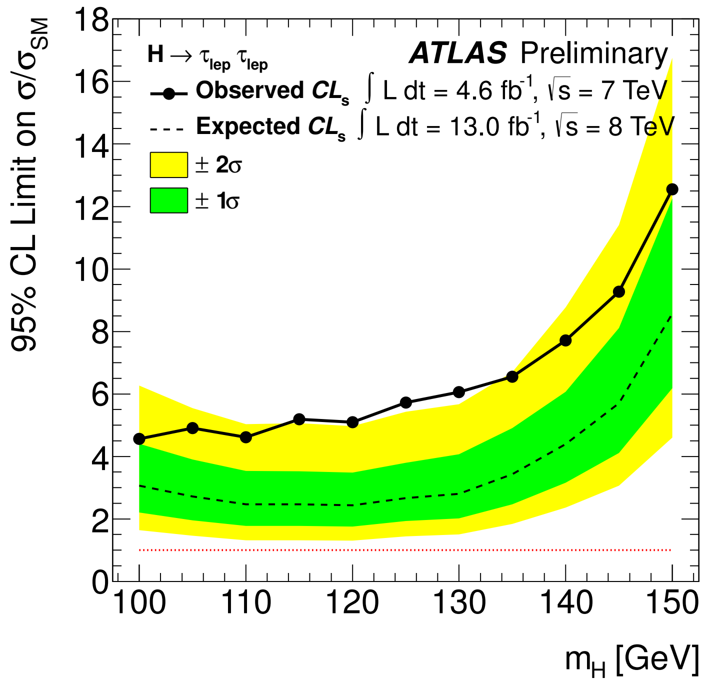
For mH=125 GeV a signal of 1.1σ is observed whereas 1.7σ is expected



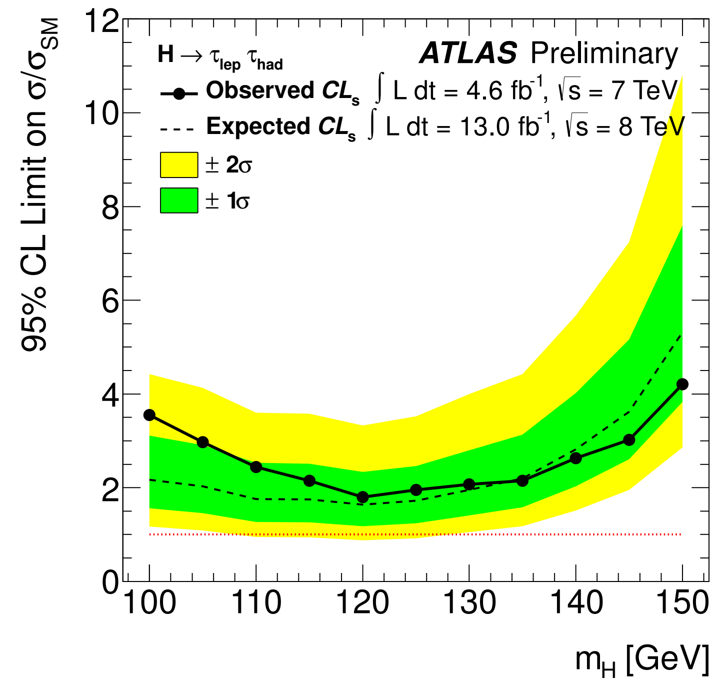
(c) Combined 2011 plus 2012



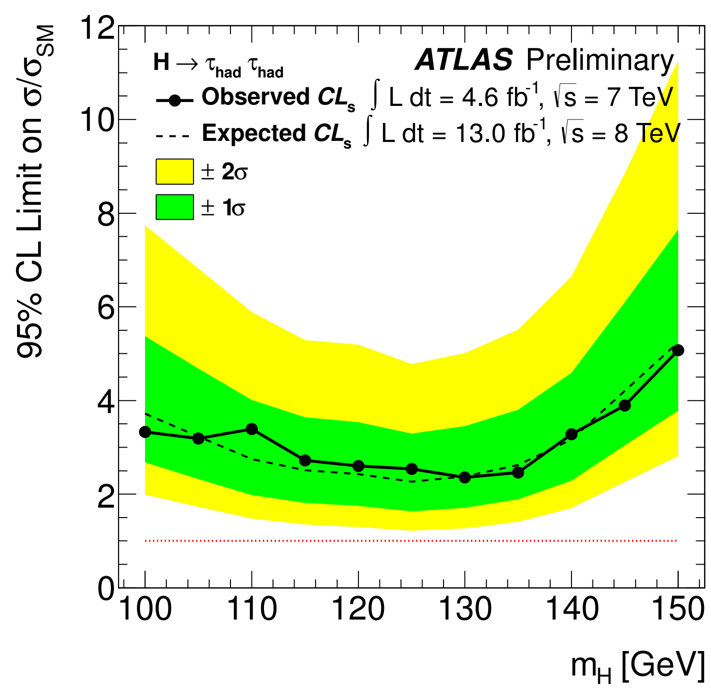
Limits by Channel



(a) Combined $H \to \tau_{\rm lep}\tau_{\rm lep}$



(b) Combined $H \to \tau_{\rm lep}\tau_{\rm had}$



(c) Combined $H \to \tau_{\rm had}\tau_{\rm had}$

Conclusions

The existence of a new boson is firmly established.

The mass is m_X=125.2 ± 0.3 (stat) ± 0.6 (sys) GeV

The CP quantum numbers 0^+ are somewhat preferred

The signal strength/SM is 1.35 ± 0.19 (stat) ± 0.15 (sys)

The couplings (V/F and ggV/VBF) are consistent with a SM Higgs

Direct observation of the fermion coupling is still missing

$H \rightarrow \tau\tau$ may be important for CP-violation measurement