Higgs results in the $WW(*) \rightarrow l\nu l\nu$ decay channel at ATLAS

M.Testa (LNF-INFN)

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DELLE ALTE ENERGIE
2013

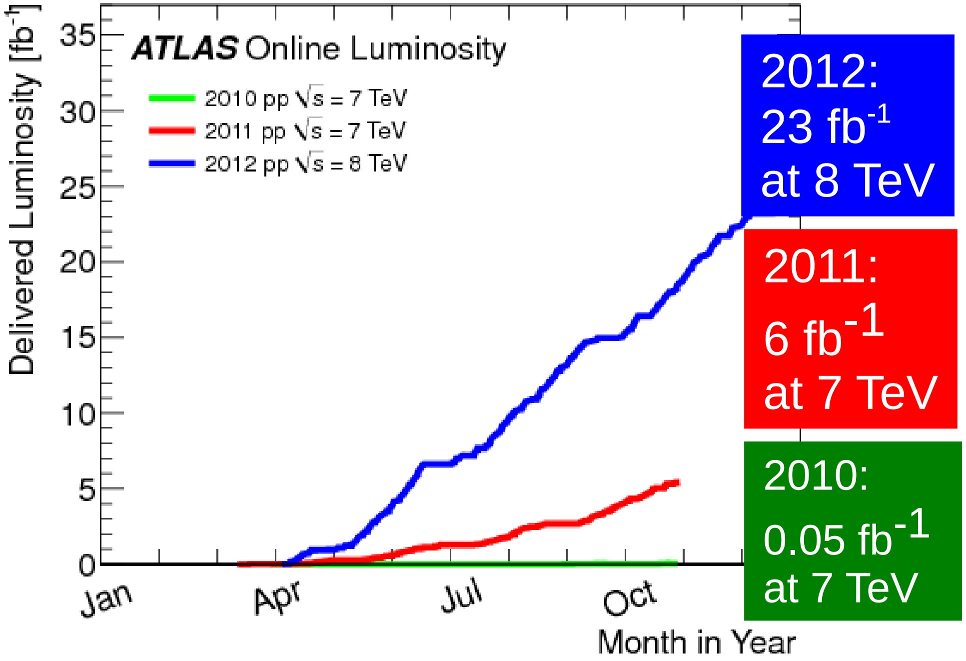
INFN
Istituto Nazionale
di Fisica Nucleare

Outline

- **LHC operations in 2012**
- **Higgs production and decay**
- **The H → WW(*) → lνlν analysis in ATLAS**
- **Experimental signature**
- **Backgrounds**
- **ggF/VBF categorization**
- **Results**

See http://cds.cern.ch/record/1527126/files/ATLAS-CONF-2013-030.pdf

LHC & ATLAS performances



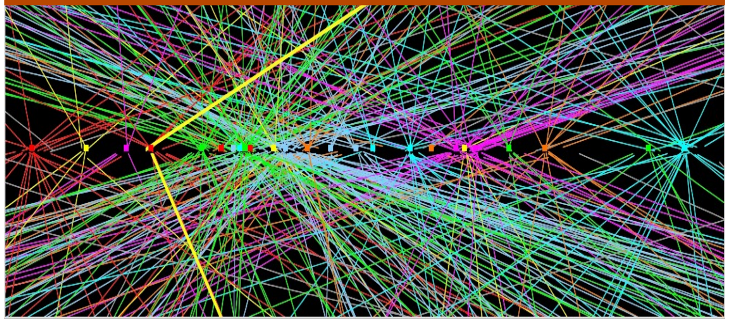
2012: 23 fb^{-1} at 8 TeV

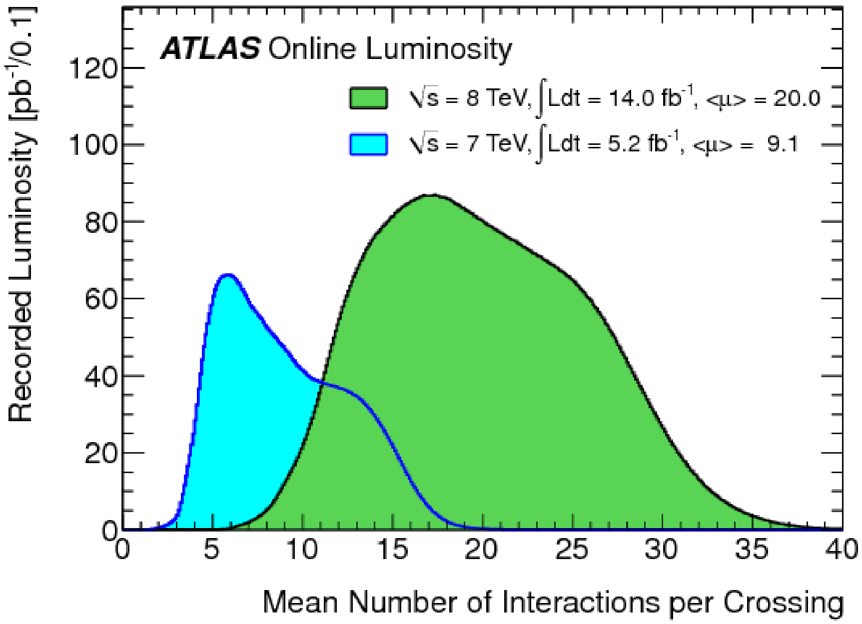
2011: 6 fb^{-1} at 7 TeV

2010: 0.05 fb^{-1} at 7 TeV

- L$_{peak}$ up to 7.7•10^{33} cm^{-2}s^{-1} in 2012 at 8 TeV
- L$_{delivered}$ ~23 fb^{-1} (8 TeV) + 6 fb^{-1} (7 TeV)
- ~90% of delivered collisions are used in ATLAS physics analyses

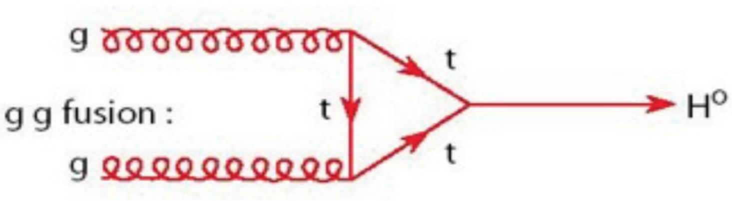
Zμμ with 25 vertices

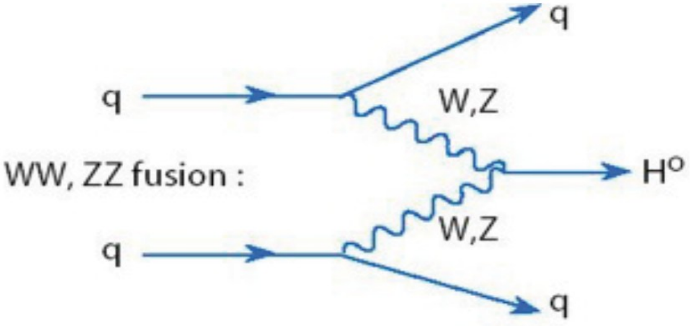


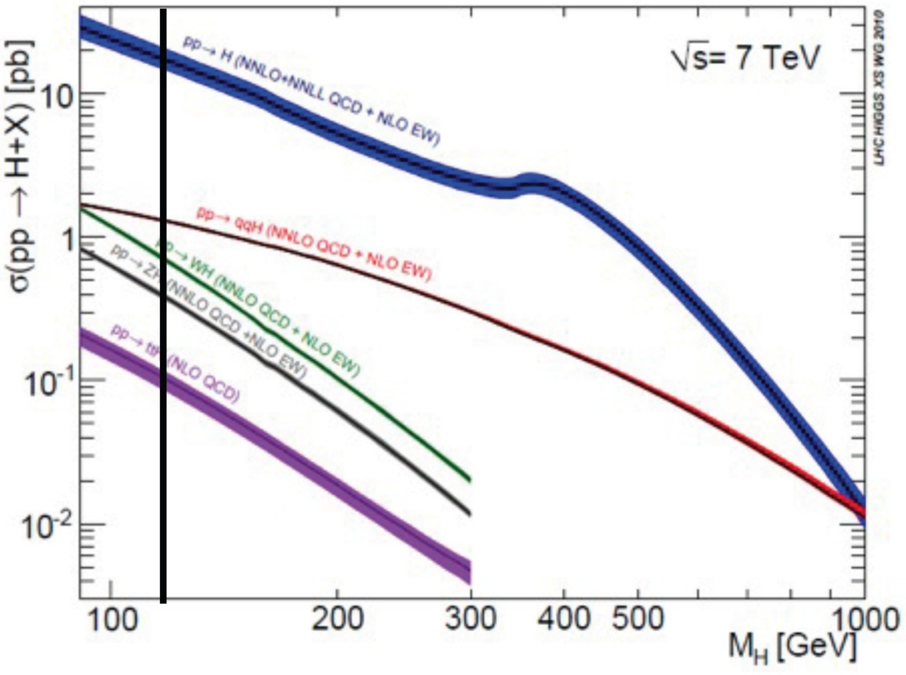


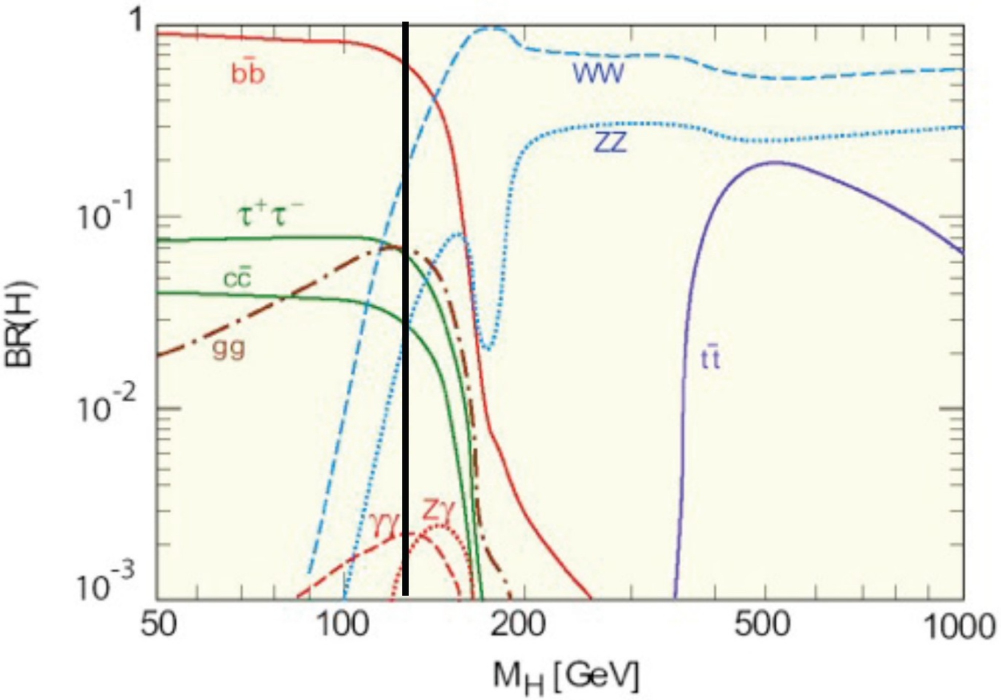
- Pile-up level above design value (50 ns bunch crossing)
- Many challenges to mitigate its impact at all levels: trigger, computing, reco/identification of physics objects

Higgs at LHC









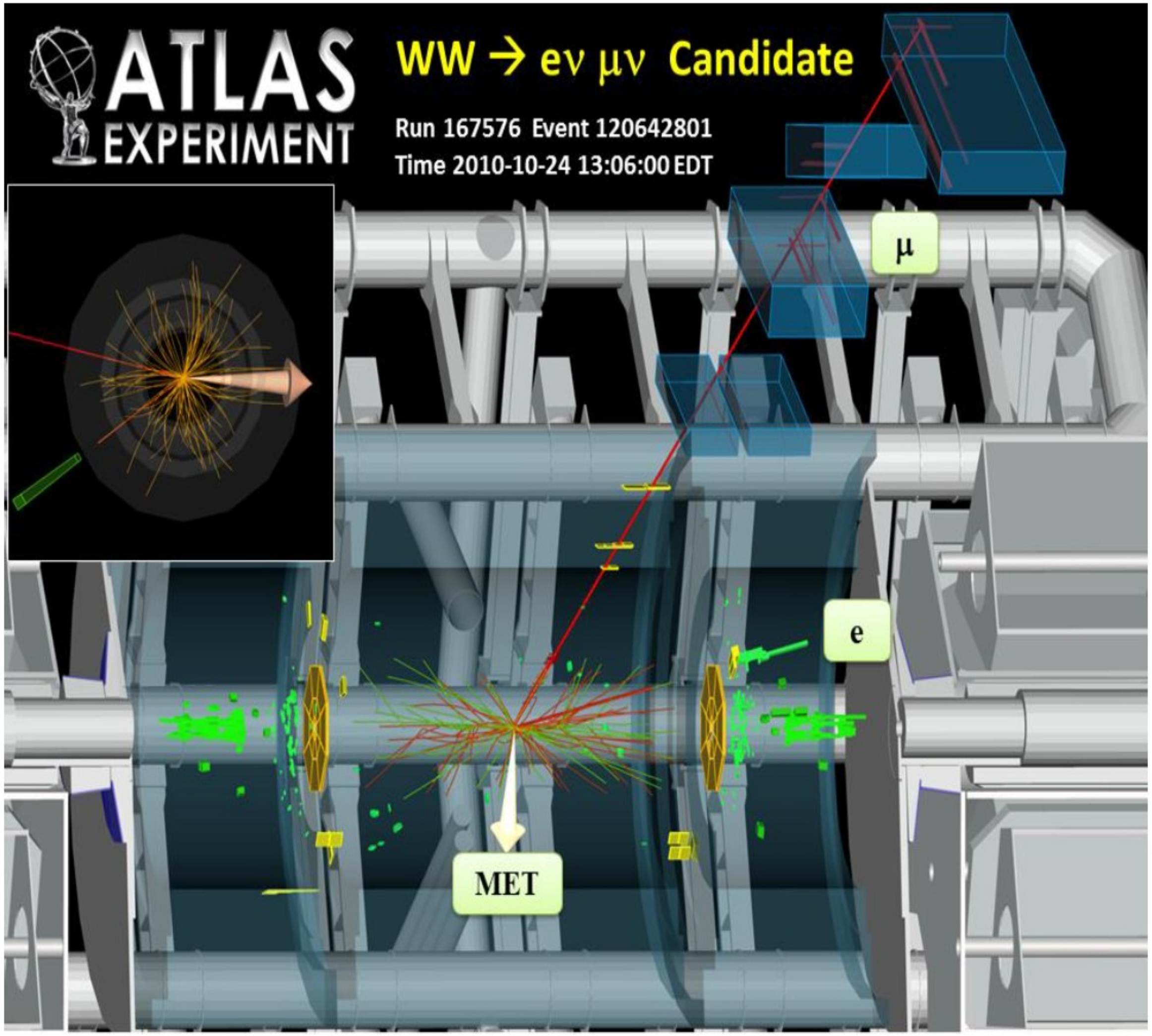
- **NNLO prediction for SM Higgs production cross section in most cases**
  - theory uncertainties reduced to < 20%
- **H → WW → lνlν one of the most sensitive channel**

Analysis Strategy

Experimental signature:
- **Two high pT leptons**
  - **- ee, μμ same flavour (SF)**
  - **- eμ, μe opposite flavour (OF)**
- **Two neutrinos**
  - **- Large E_T^{miss}**
  - **- No mass peak (~20% mass resolution)**
- **counting experiment**

Binned in jet multiplicity
- **Njet =0, 1 optimized for ggF**
- **Njet = 2 optimized for VBF**

Use full data sample:
data 2011 ($\sqrt{s}$ = 7 TeV, Lint ~4.9 fb^{-1}) +
data 2012 ($\sqrt{s}$ = 8 TeV, Lint ~20.6 fb^{-1})



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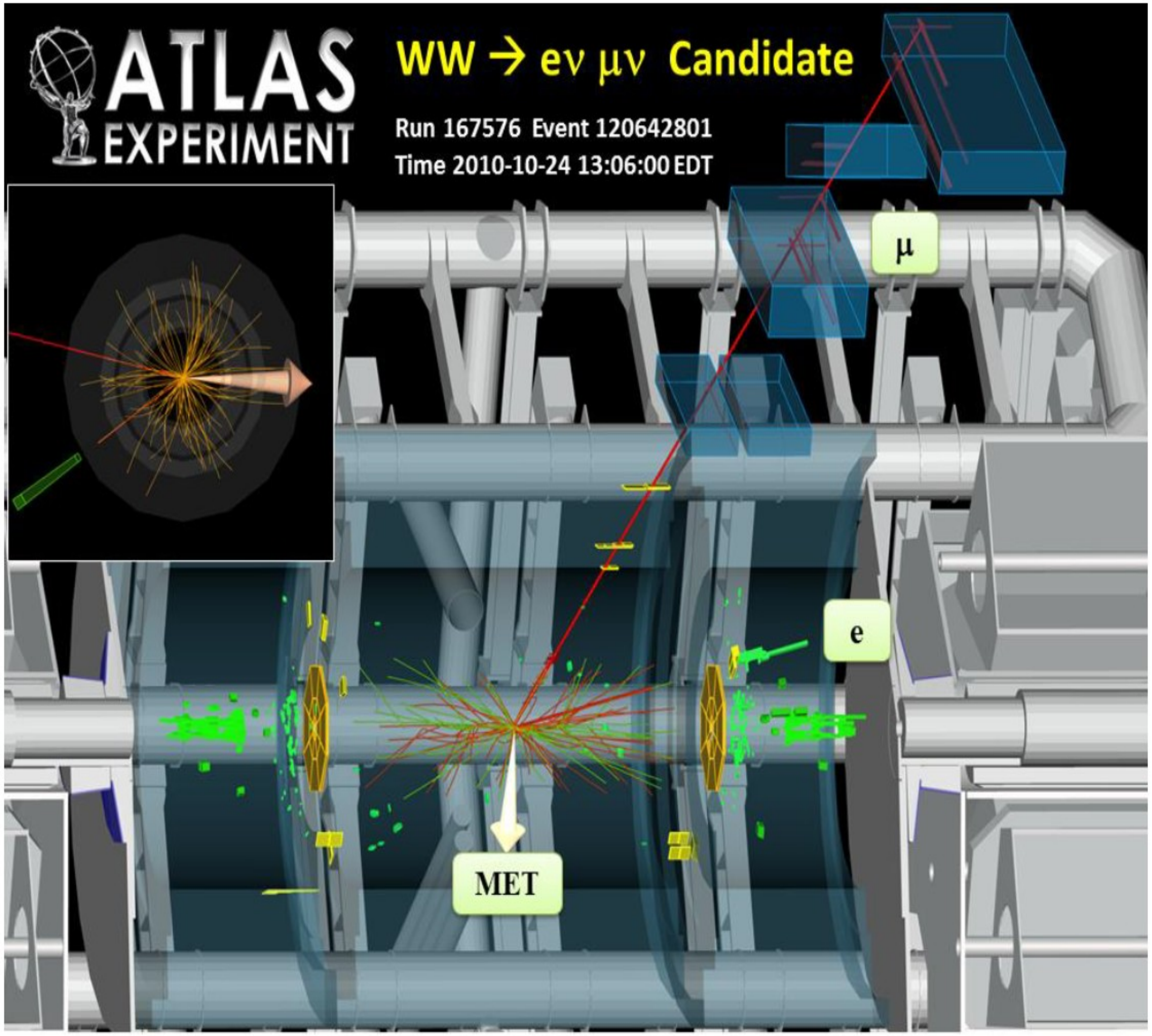
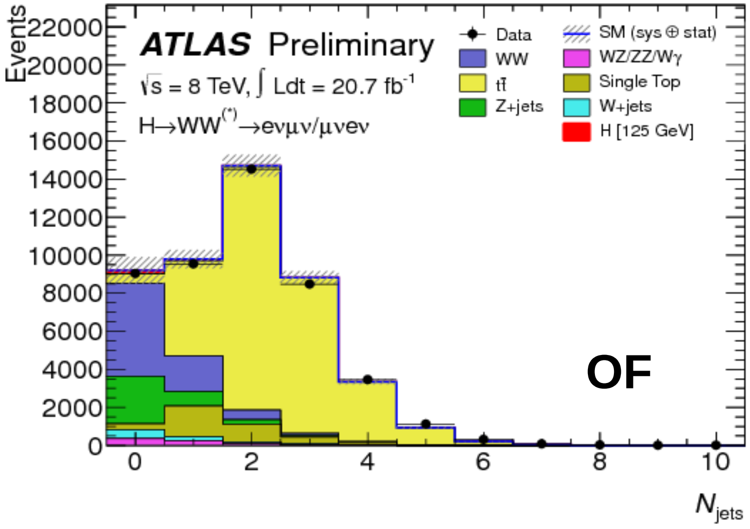
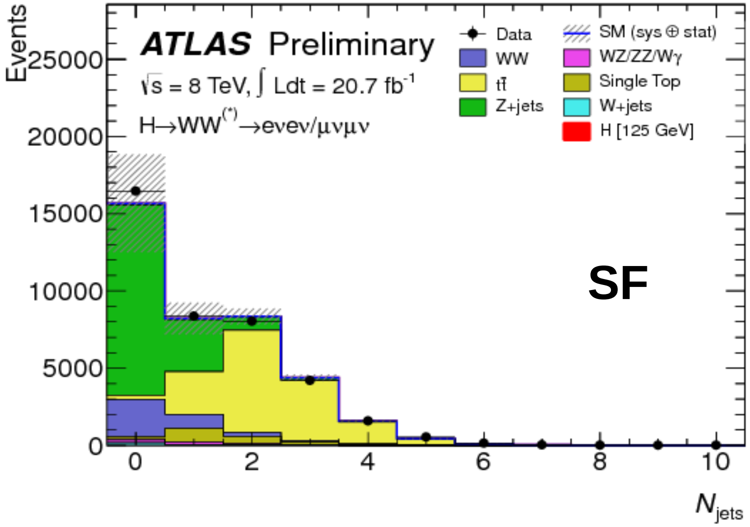


New wrt to July discovery paper

Background





- **Drell-Yan**
  - **large, reducible, require large E_T^{miss}**
  - **Z veto $|m_{ll}-M_Z|$ <15 GeV**
  - **data-driven estimation**
- **Top (1+2j bins)**
  - **Large, reducible with cuts, modeled by MC**
  - **B-jets veto**
  - **Normalization from CR**
- **WW**
  - **Reducible by topological cuts**
  - **Normalization from CR**
- **W +jets**
  - **small**
  - **isolation, ID lepton**
  - **data-driven estimation**
- **di-boson (WZ,ZZ,Wγ)**

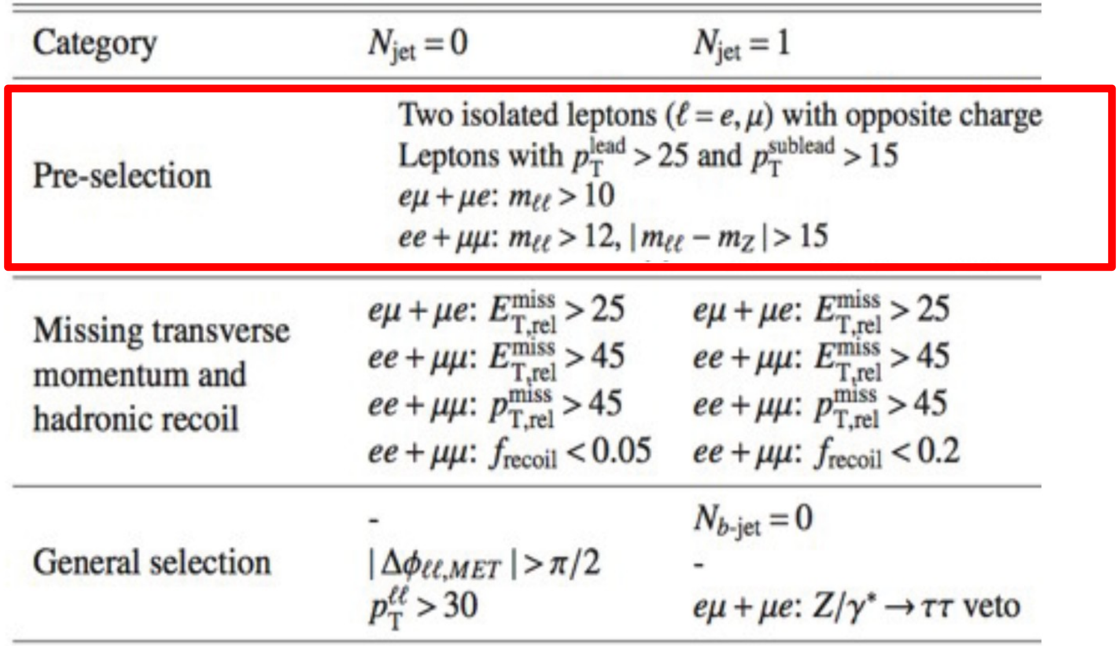
  Small, reducible and modeled by MC

Key of the analysis: understand background and normalize to control regions

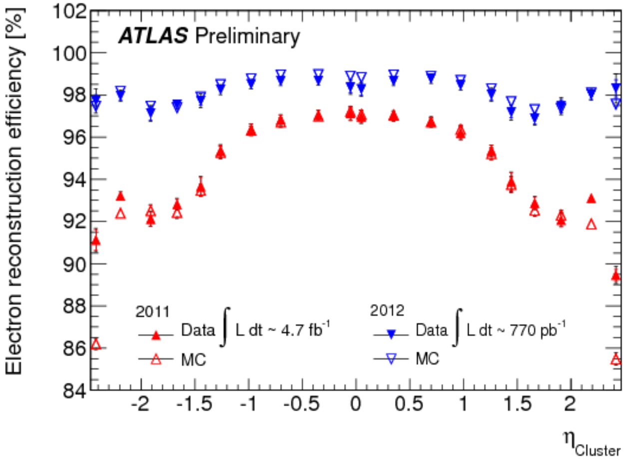
- **Different background composition depending on the number of jets**
  - **0 jet : WW(DY) dominate in OF (SF)**
  - **1 jet : Top,WW and DY in SF**
  - **2 jet: Top dominate, VBF topology**

Event selection

Pre-selection:Good leptons



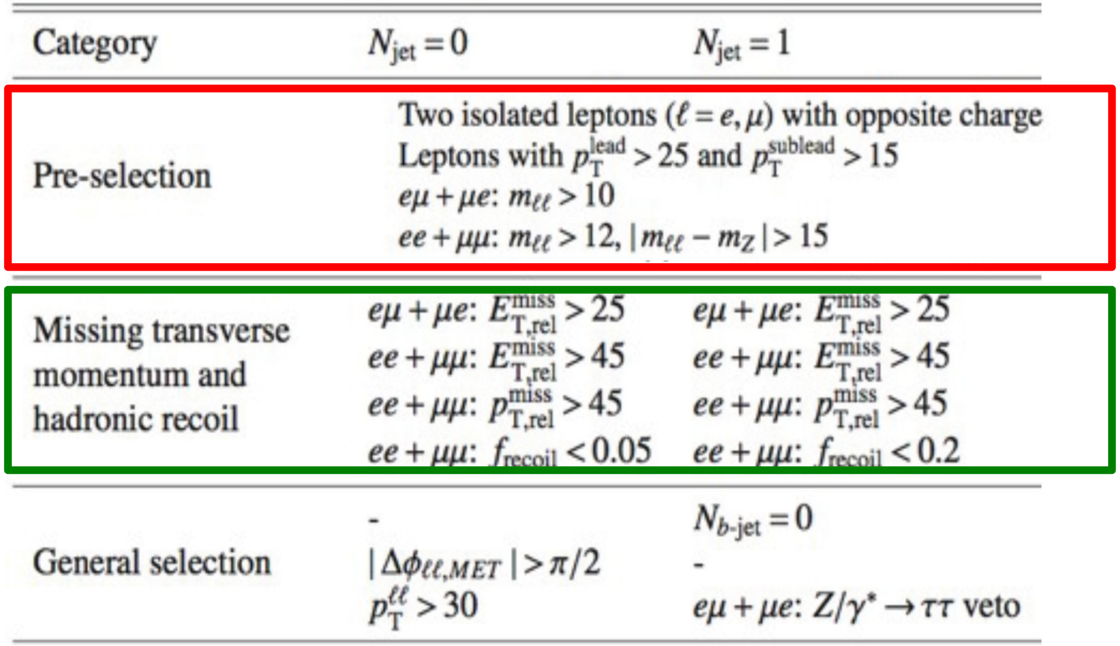
Category	$N_{\text{jet}} = 0$	$N_{\text{jet}} = 1$
Pre-selection	Two isolated leptons ($\ell = e, \mu$) with opposite charge Leptons with $p_{\text{T}}^{\text{lead}} > 25$ and $p_{\text{T}}^{\text{sublead}} > 15$ $e\mu + \mu e$: $m_{\ell\ell} > 10$ $ee + \mu\mu$: $m_{\ell\ell} > 12$, $\lvert m_{\ell\ell} - m_Z \rvert > 15$	
Missing transverse momentum and hadronic recoil	$e\mu + \mu e$: $E_{\text{T,rel}}^{\text{miss}} > 25$ $ee + \mu\mu$: $E_{\text{T,rel}}^{\text{miss}} > 45$ $ee + \mu\mu$: $p_{\text{T,rel}}^{\text{miss}} > 45$ $ee + \mu\mu$: $f_{\text{recoil}} < 0.05$	$e\mu + \mu e$: $E_{\text{T,rel}}^{\text{miss}} > 25$ $ee + \mu\mu$: $E_{\text{T,rel}}^{\text{miss}} > 45$ $ee + \mu\mu$: $p_{\text{T,rel}}^{\text{miss}} > 45$ $ee + \mu\mu$: $f_{\text{recoil}} < 0.2$
General selection	- $\lvert \Delta\phi_{\ell\ell,MET} \rvert > \pi/2$ $p_{\text{T}}^{\ell\ell} > 30$	$N_{b\text{-jet}} = 0$ - $e\mu + \mu e$: $Z/\gamma^* \to \tau\tau$ veto



Event selection

Pre-selection:Good leptons

DY suppression: E_T^{miss}



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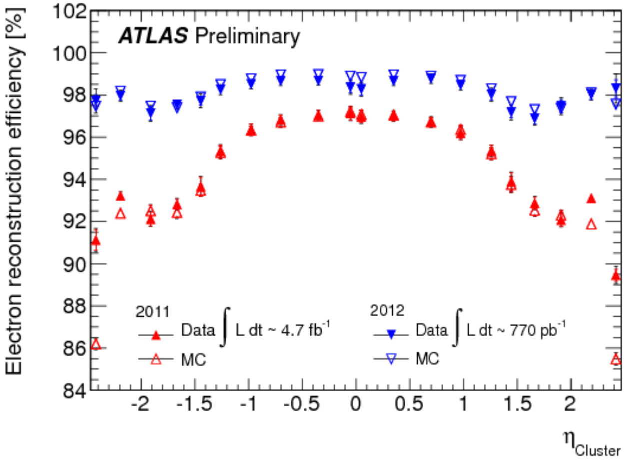
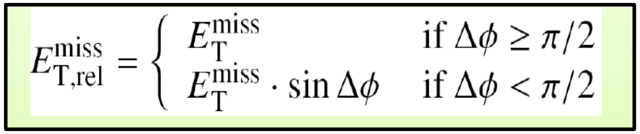
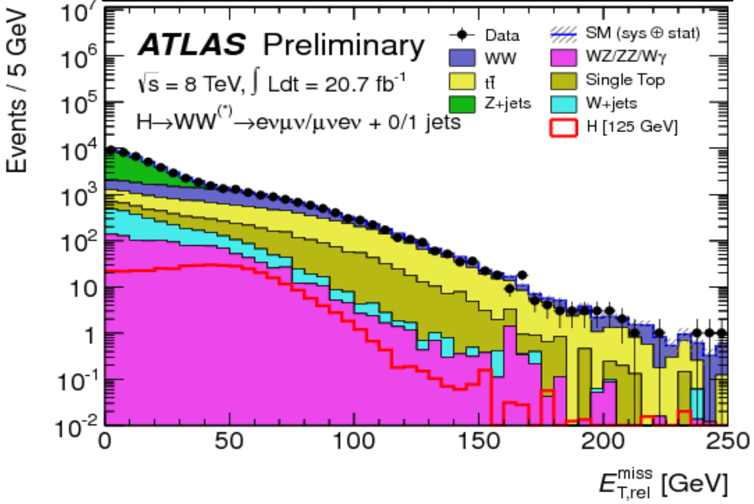




$$E_{T,rel}^{miss} = \begin{cases} E_T^{miss} & \text{if } \Delta\phi \geq \pi/2 \\ E_T^{miss} \cdot \sin\Delta\phi & \text{if } \Delta\phi < \pi/2 \end{cases}$$

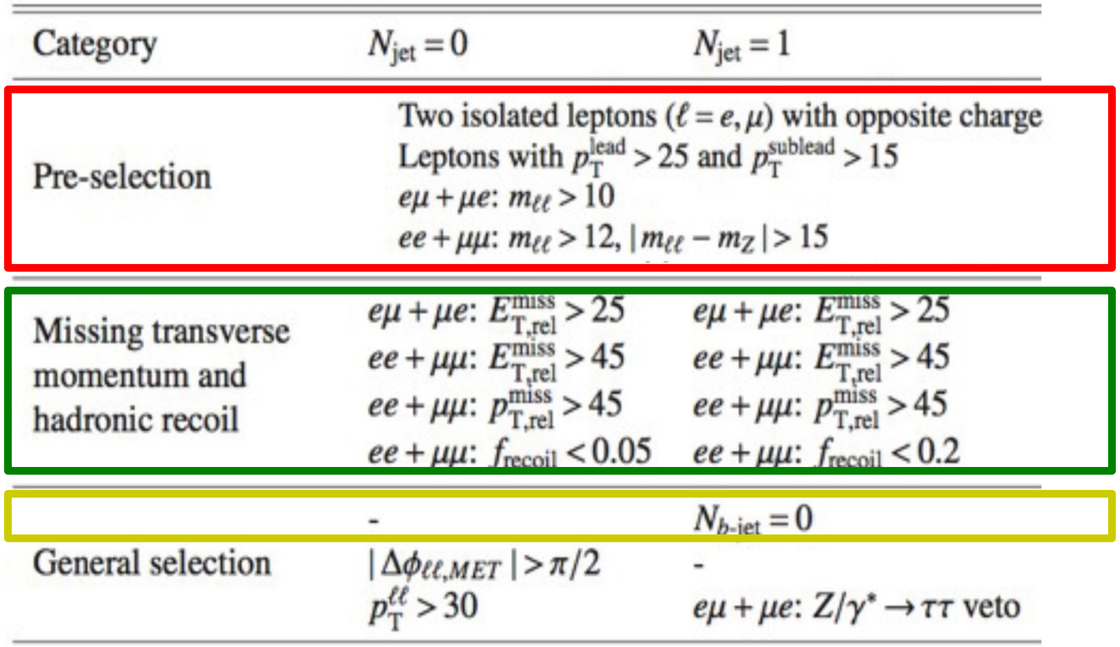


Event selection

Pre-selection:Good leptons

DY suppression: E_T^{miss}

Top suppression: Veto b-jet



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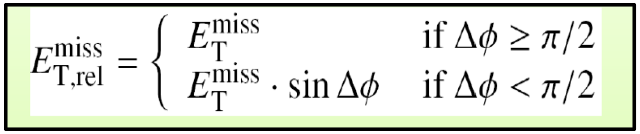

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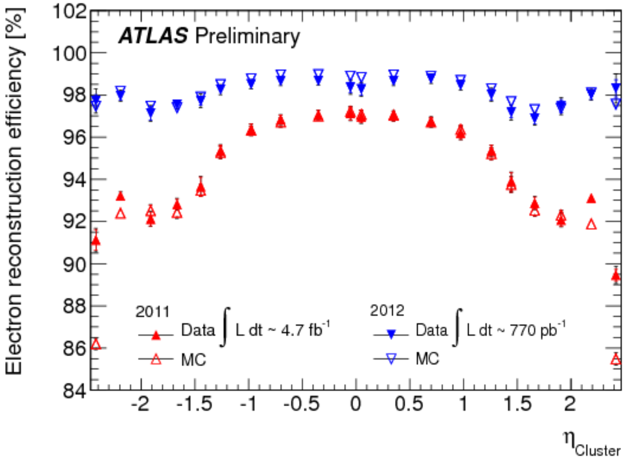

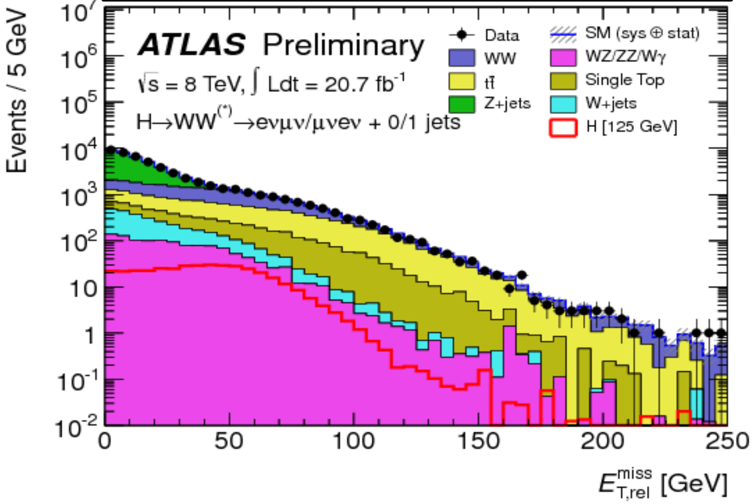

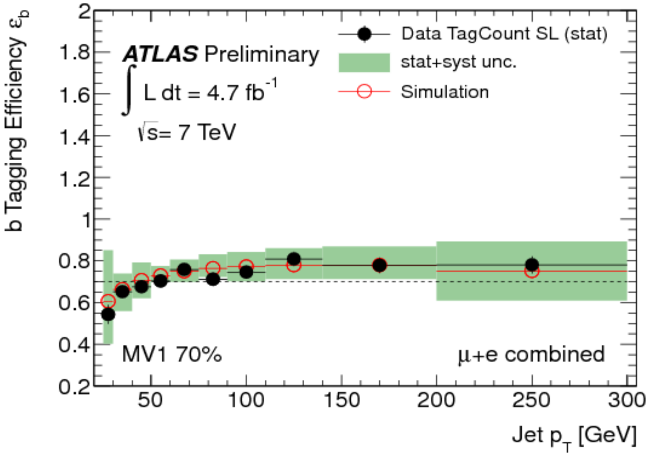

Event selection

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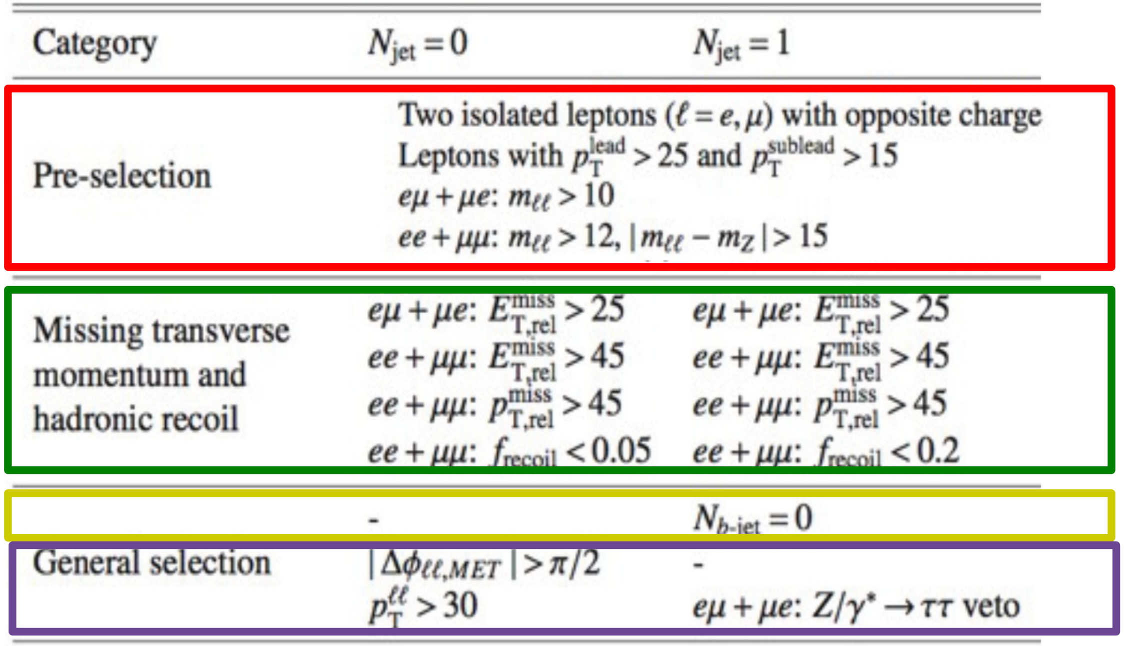
DY suppression: E_T^{miss}

Top suppression: Veto b-jet

WW suppression based on topology



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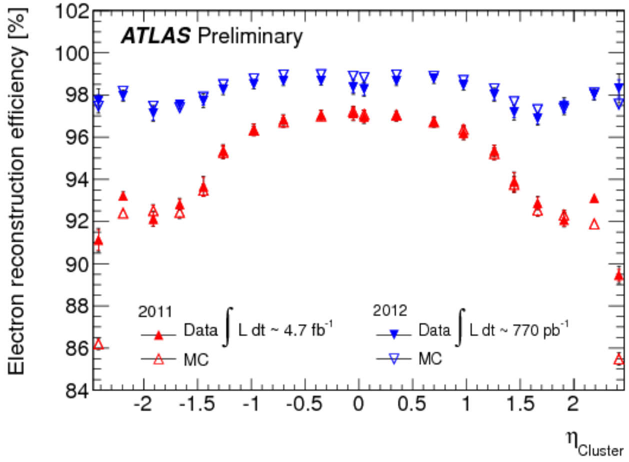
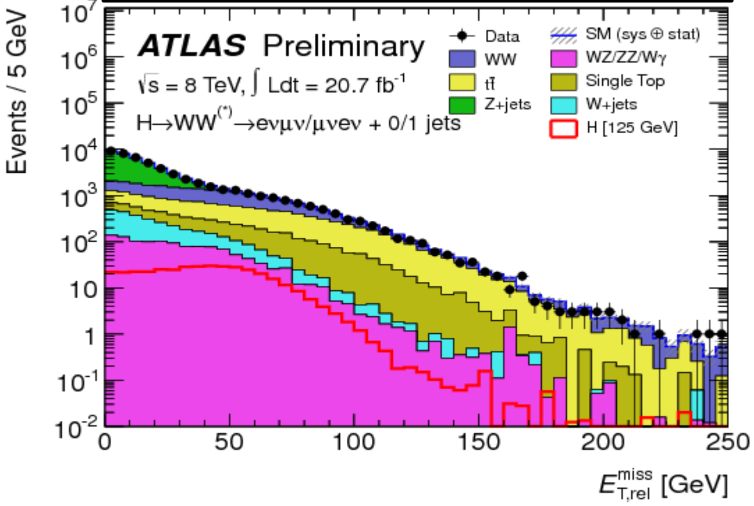
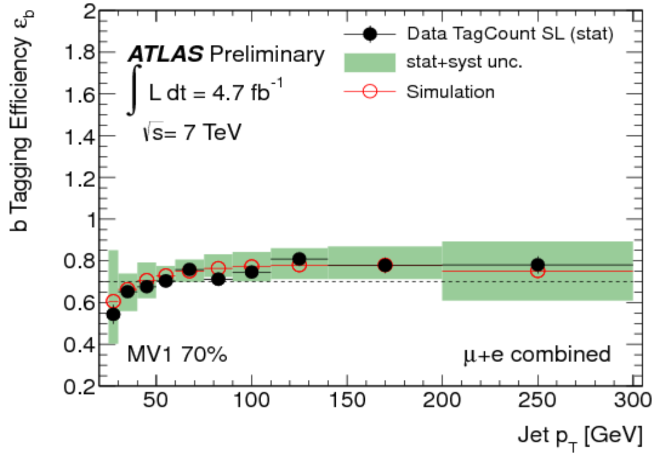
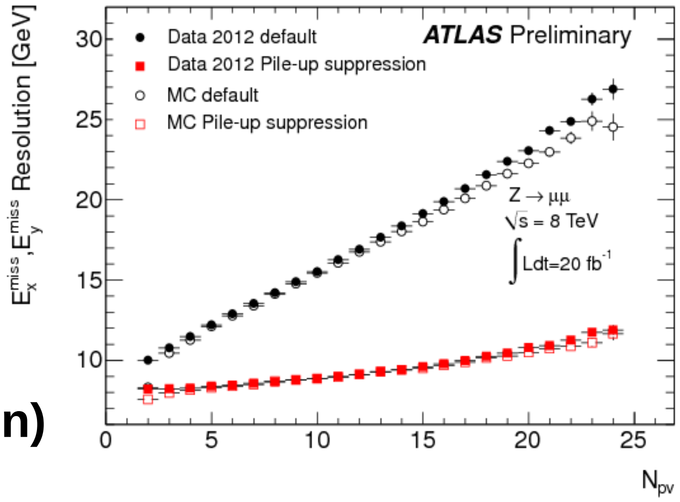






SM DY background

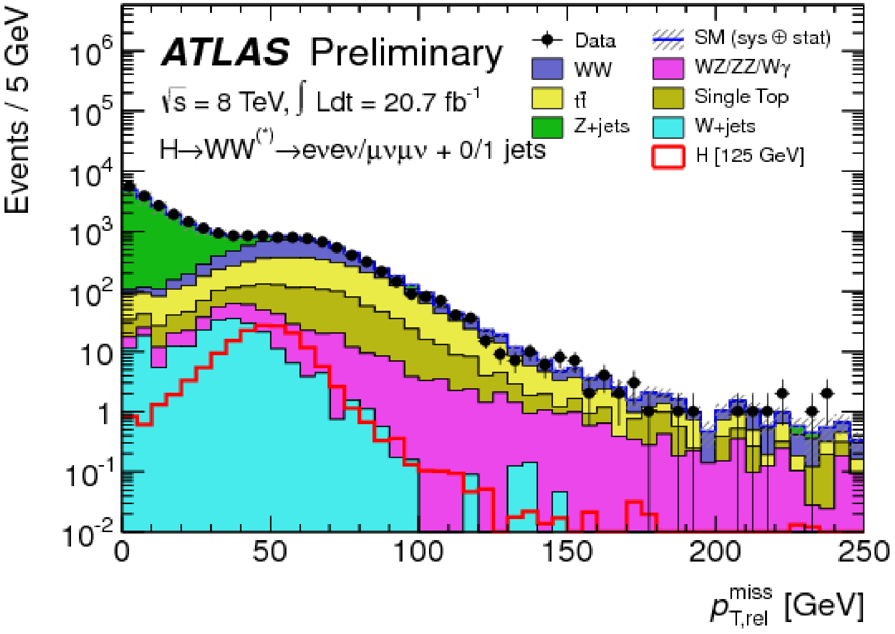


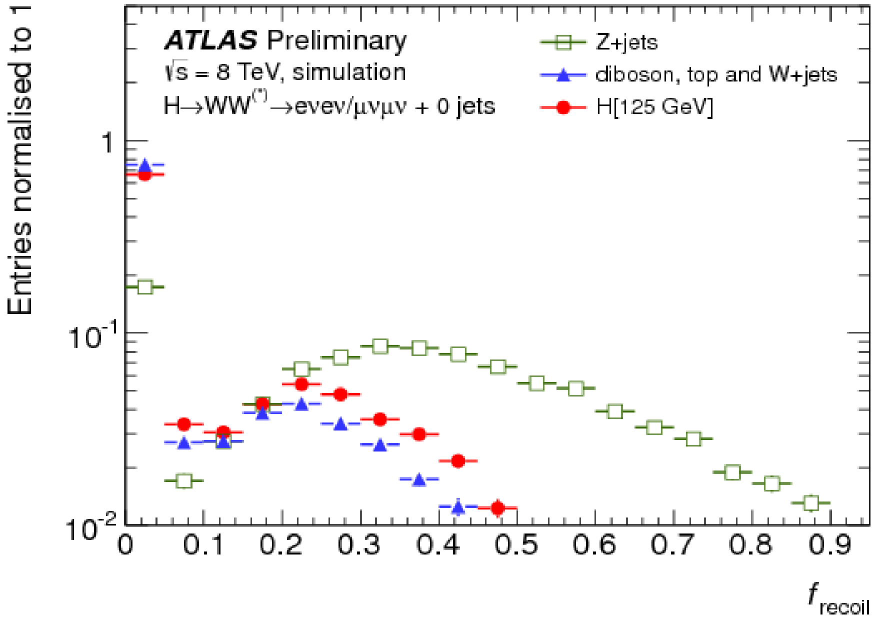
Large background due to fake E_T^{miss}
→increase of resolution with PileUp

DY Reduction crucial for SF finale state (high Z cross section)
Use combination of

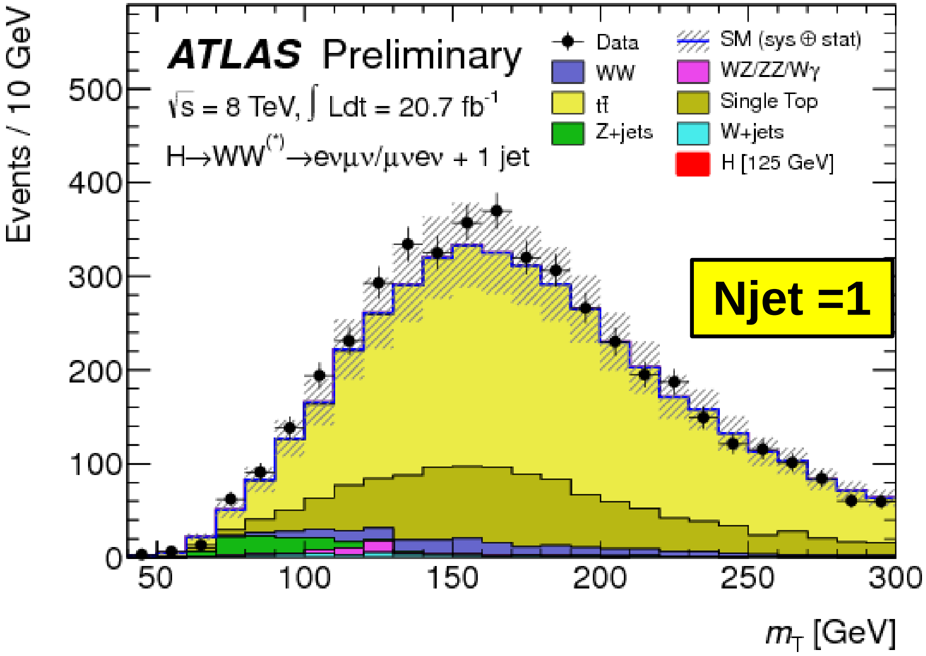
- **$E_{T,rel}^{miss}$ calorimeter based, degradation with increasing of PileUp**
- **$p_{T,rel}^{miss}$ use only track at the PV information, ~ independent on PileUp**
- **frecoil: ratio between vectorial sum pT of low-pT jets, opposite to pTllj and pTll**

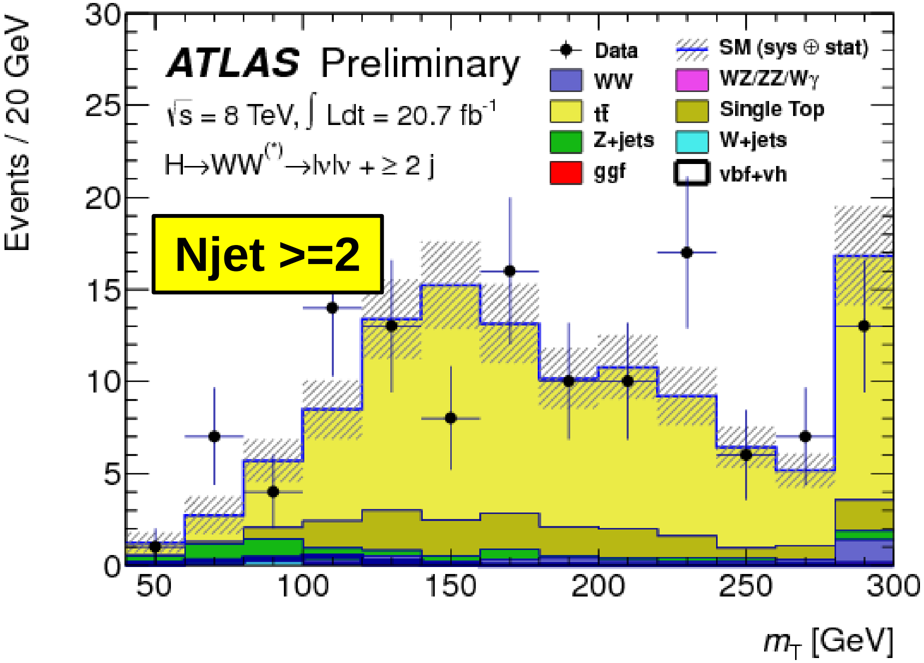
Uncertainty of 60%, 80%, 15% for Njet =0,1, >= 2





SM Top background



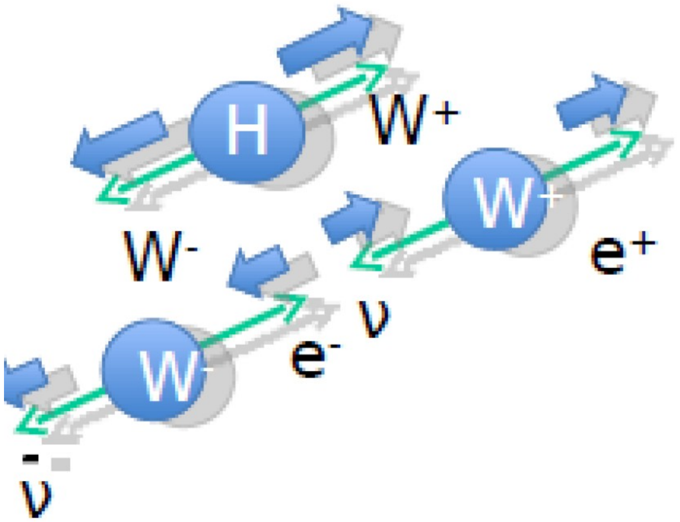


Definition of data control sample to normalize MC prediction

- **reversing the b-jet veto**
- **Remove the requirements on Δφll and mll.**

Uncertainty: 28% for N_{jet} = 1 , 39% for N_{jet} >=2j

SM WW background



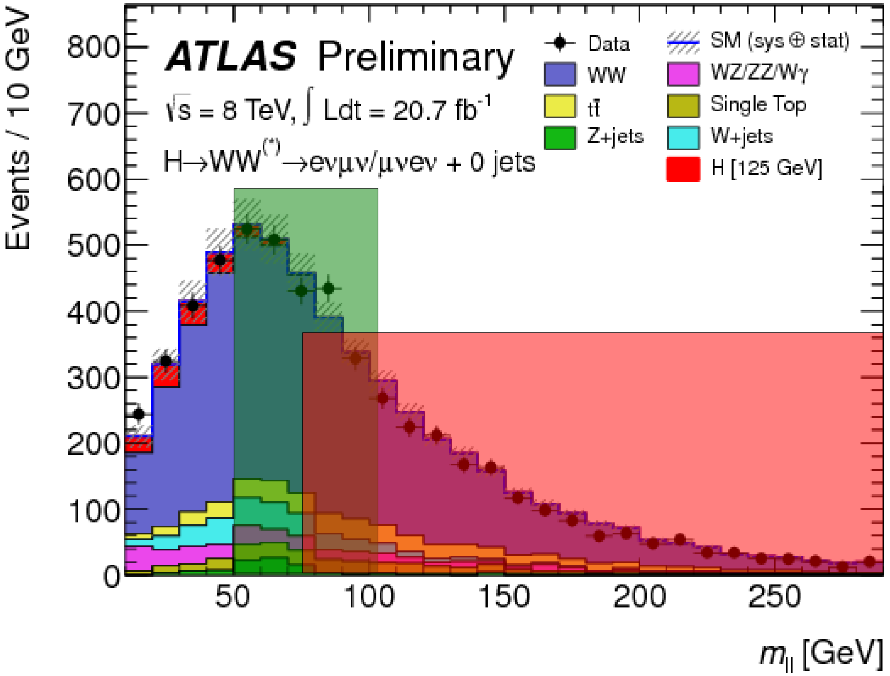
WW background dominates, crucial to understand
Same final state of H → WW

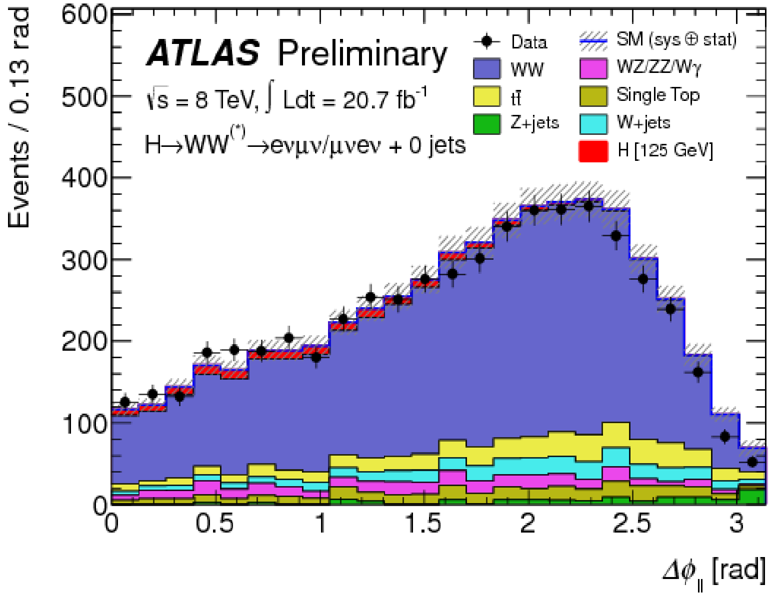
- **exploit spin correlation: small opening angle, low mll**

$$m_{ll} = \sqrt{2E_1E_2(1-\cos\Delta\varphi_{12})}$$

Control region definition:
$|\Delta\phi_{ll}|$ cut remove
$50 < m_{ll} < 100$ GeV for Njet = 0
$m_{ll} > 80$ GeV for Njet = 1

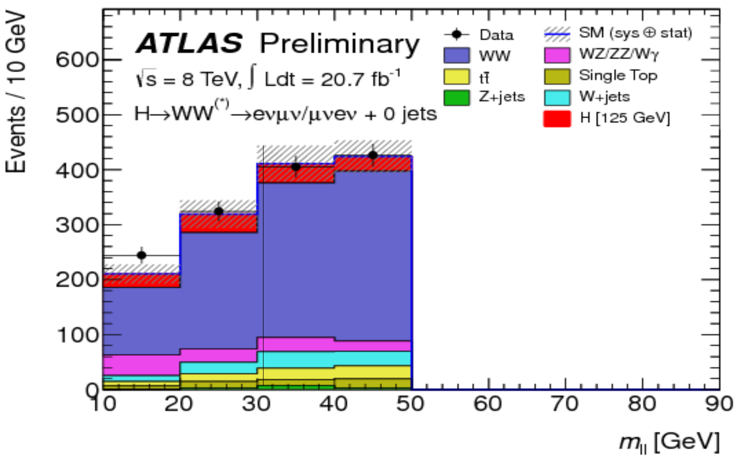
Uncertainty:
7.4 % for N_{jet} =0
37 % for N_{jet} =1
37 % for N_{jet} >=2 (from MC)



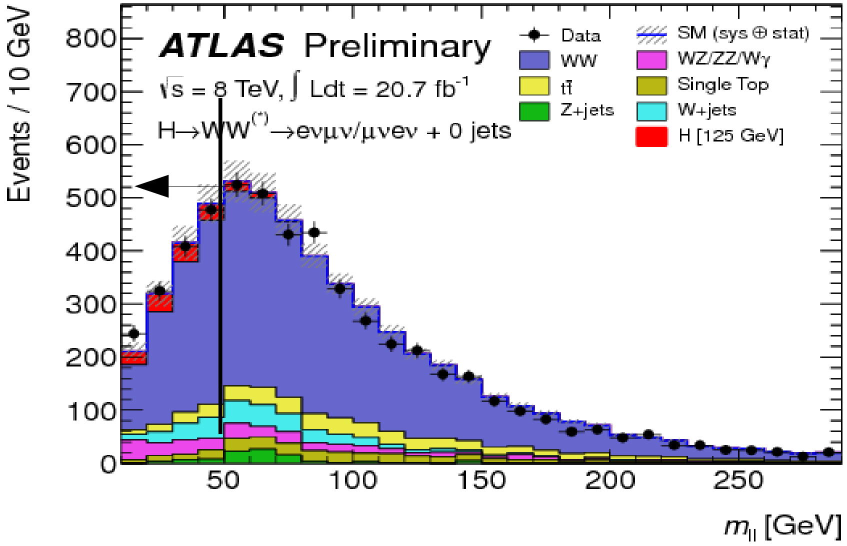


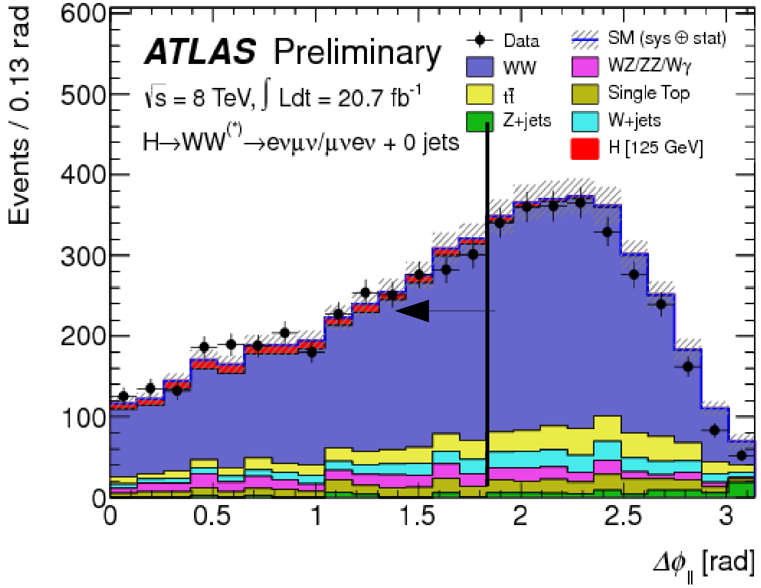
Signal extraction

- **Split signal region in 2 mll bins**
  - improves the sensitivity (different S/B ratio and background composition)
- **Cut based analysis**
- **Final fit on MT**



Category	$N_{\text{jet}} = 0$	$N_{\text{jet}} = 1$
$H \to WW^{(*)} \to \ell\nu\ell\nu$ topology	$m_{\ell\ell} < 50$ $\lvert\Delta\phi_{\ell\ell}\rvert < 1.8$ $e\mu + \mu e$: split $m_{\ell\ell}$ Fit m_{T}	$m_{\ell\ell} < 50$ $\lvert\Delta\phi_{\ell\ell}\rvert < 1.8$ $e\mu + \mu e$: split $m_{\ell\ell}$ Fit m_{T}

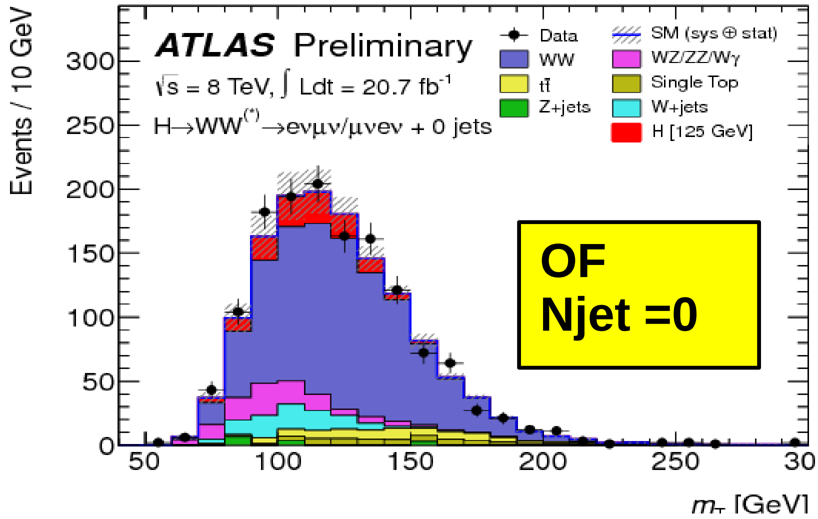




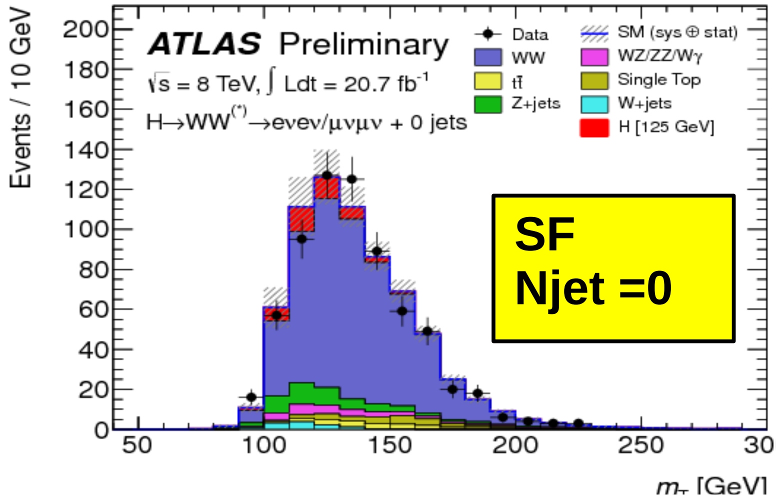
Signal extraction

Fit Transverse mass distribution

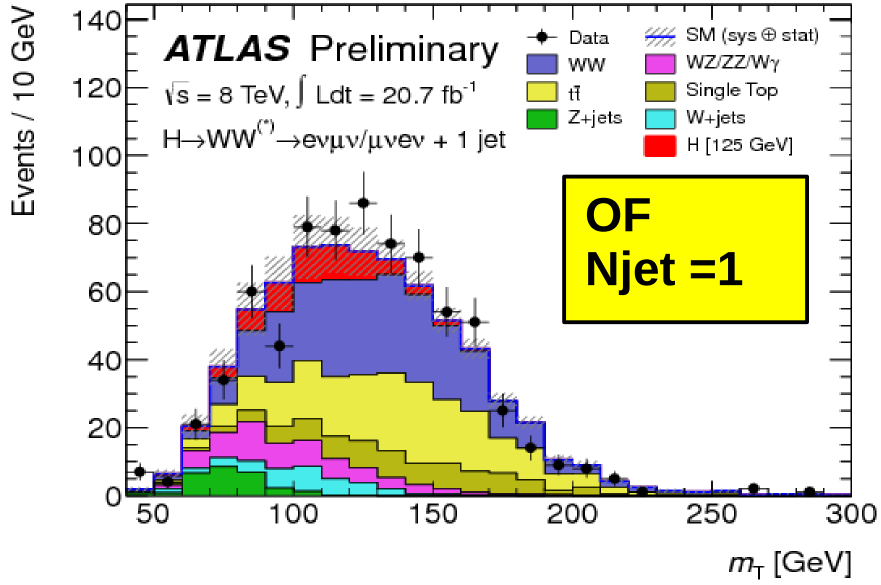
$$m_T^2 = \left(\sqrt{m_{ll}^2 + |\vec{p}_{T_{ll}}|^2} + E_T^{\mathrm{miss}}\right)^2 - \left(\vec{p}_{T_{ll}} + \vec{E}_T^{\mathrm{miss}}\right)^2$$



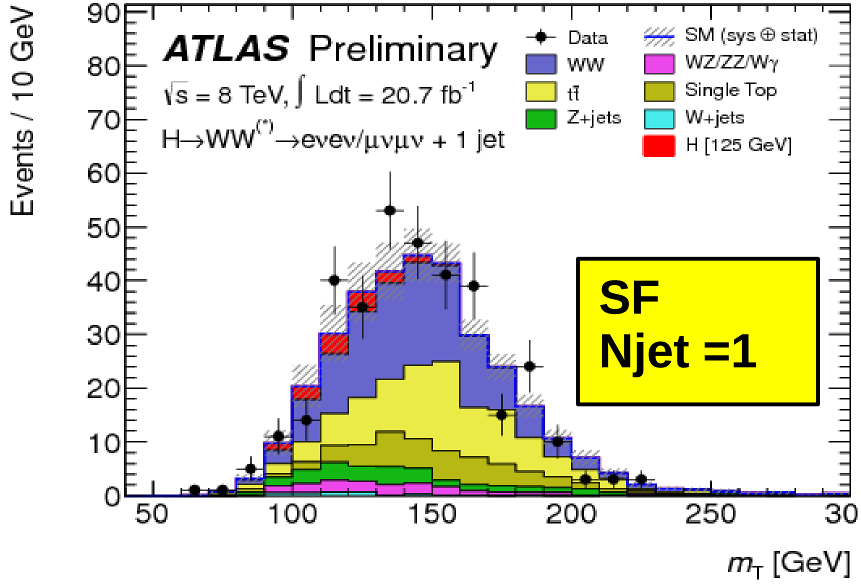
OF
Njet =0



SF
Njet =0

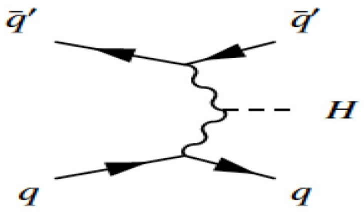


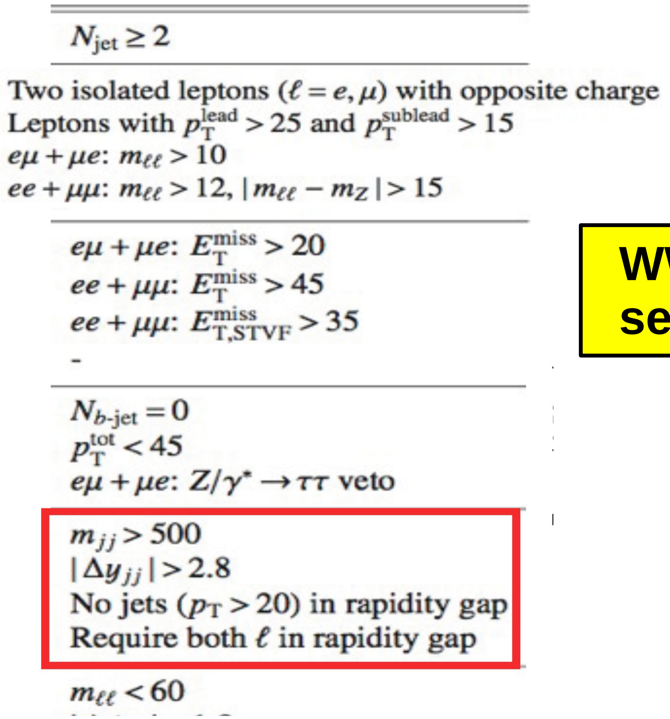
OF
Njet =1



SF
Njet =1

VBF





$N_{\text{jet}} \geq 2$

Two isolated leptons ($\ell = e, \mu$) with opposite charge
Leptons with $p_{\text{T}}^{\text{lead}} > 25$ and $p_{\text{T}}^{\text{sublead}} > 15$
$e\mu + \mu e$: $m_{\ell\ell} > 10$
$ee + \mu\mu$: $m_{\ell\ell} > 12$, $|m_{\ell\ell} - m_Z| > 15$

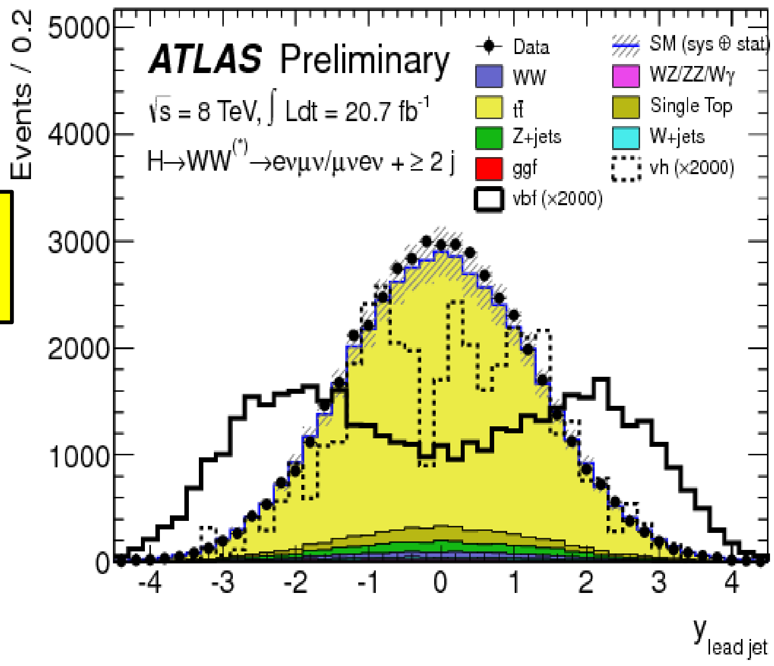
$e\mu + \mu e$: $E_{\text{T}}^{\text{miss}} > 20$
$ee + \mu\mu$: $E_{\text{T}}^{\text{miss}} > 45$
$ee + \mu\mu$: $E_{\text{T,STVF}}^{\text{miss}} > 35$
-

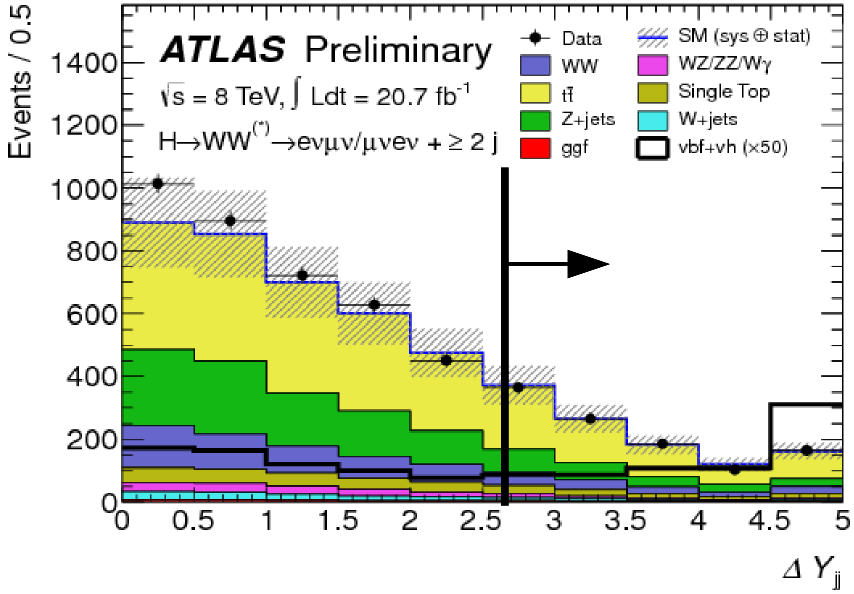
$N_{b\text{-jet}} = 0$
$p_{\text{T}}^{\text{tot}} < 45$
$e\mu + \mu e$: $Z/\gamma^* \to \tau\tau$ veto

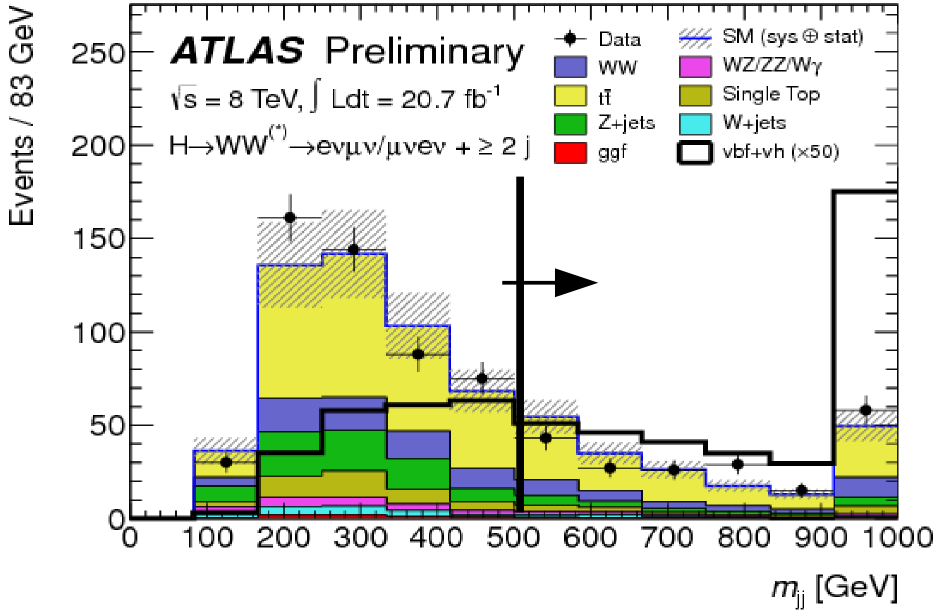
$m_{jj} > 500$
$|\Delta y_{jj}| > 2.8$
No jets ($p_{\text{T}} > 20$) in rapidity gap
Require both ℓ in rapidity gap

$m_{\ell\ell} < 60$

WW + 2 jets
separated in rapidity



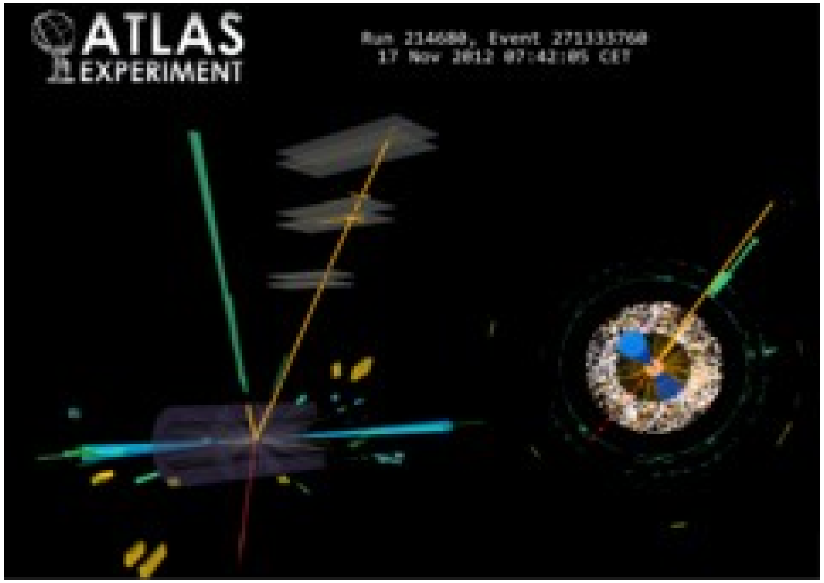


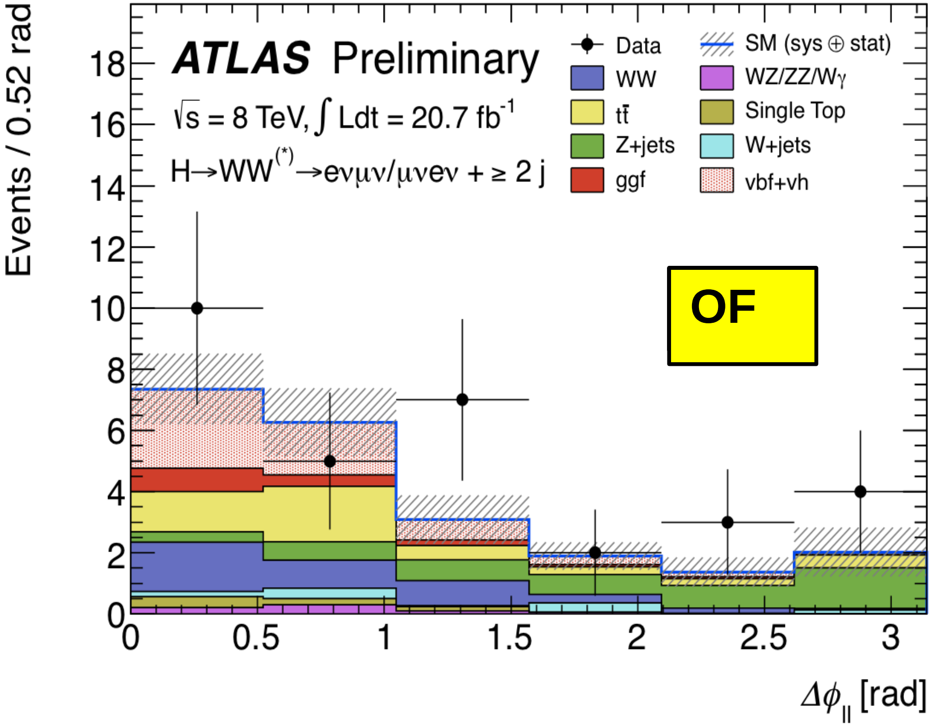


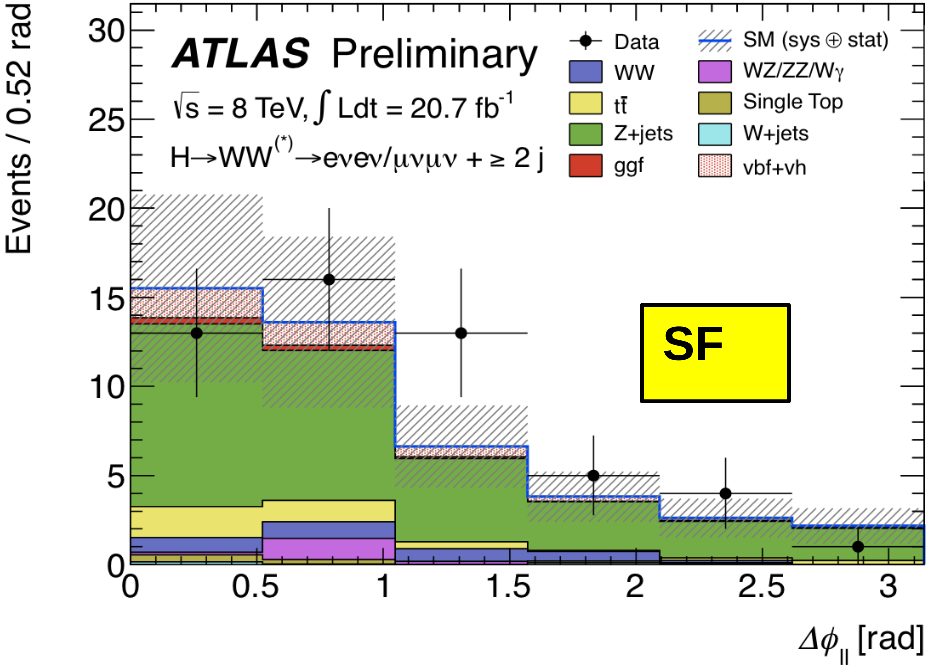
VBF

Backgrounds:

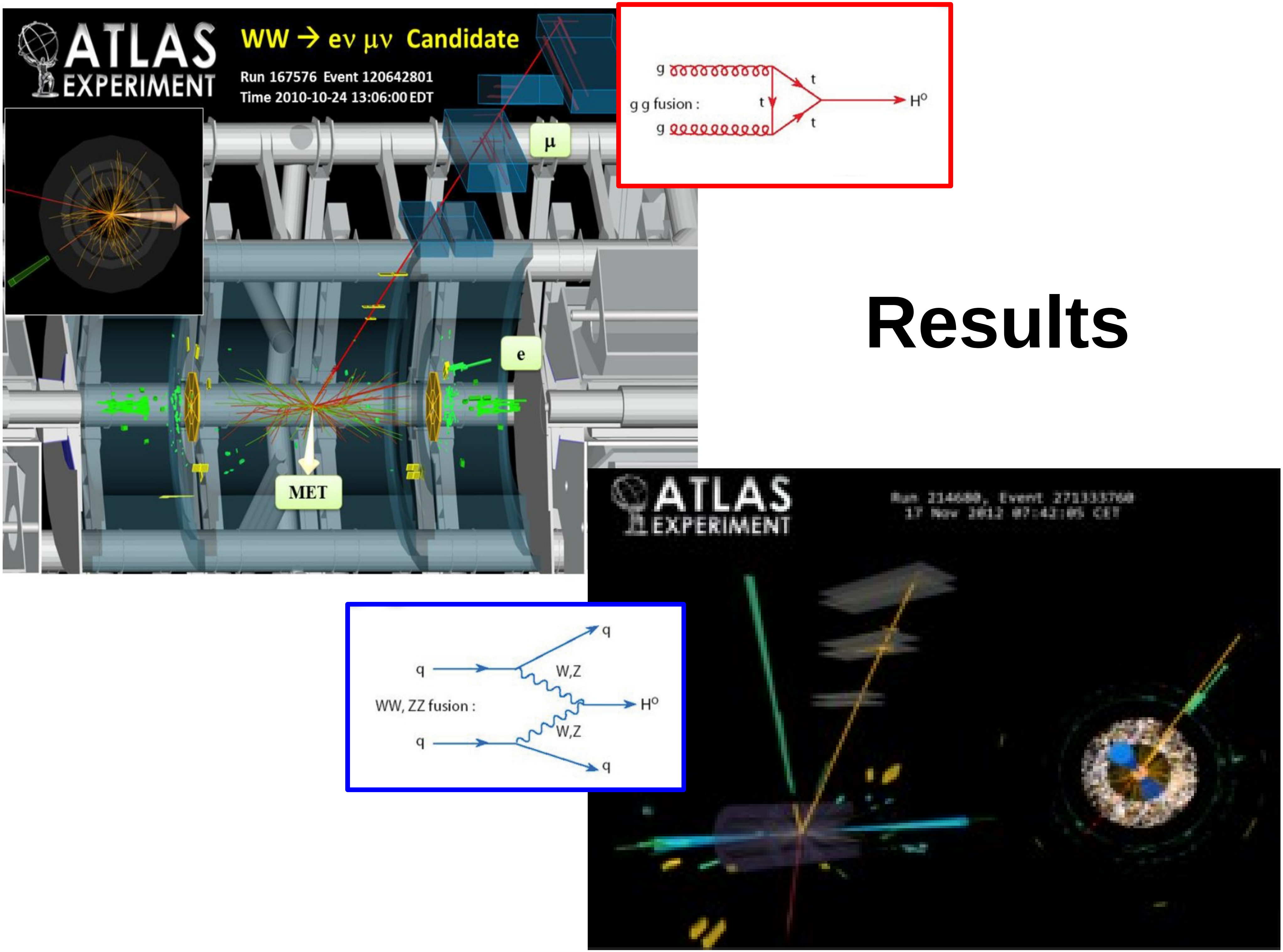
- **Top dominate, constrained by CR**
- **WW from theory (37% uncertainty)**
- **DY from CR**
- **ggF signal considered as background**



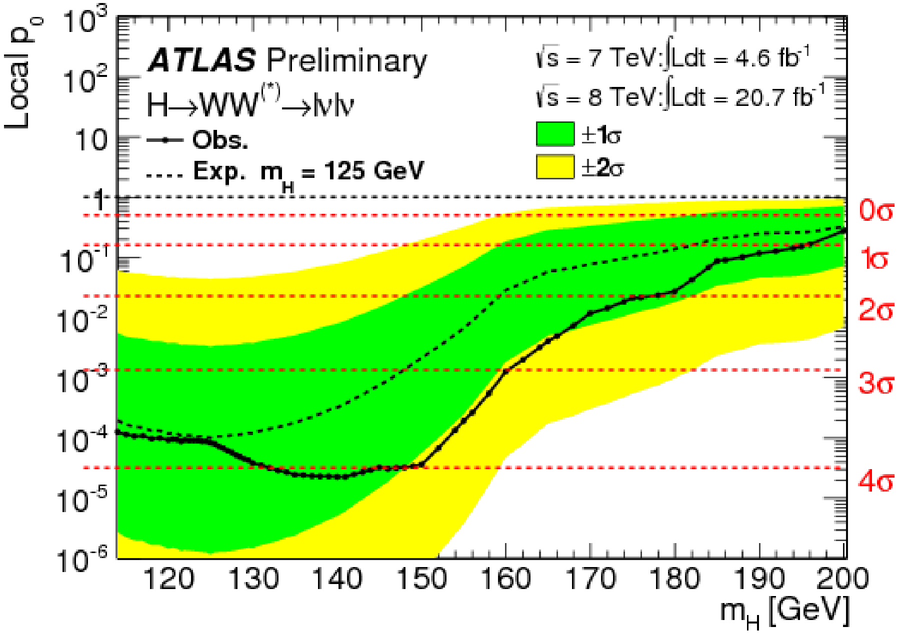


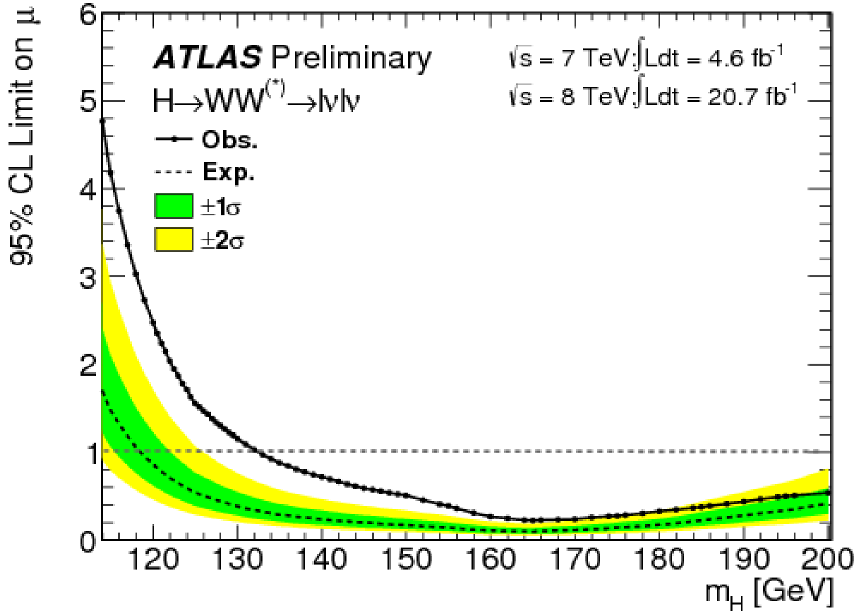


Results


ATLAS EXPERIMENT
WW → eν μν Candidate
Run 167576 Event 120642801
Time 2010-10-24 13:06:00 EDT
μ
e
MET
g
g g fusion :
t
t
t
g
H°
q
W,Z
WW, ZZ fusion :
H°
W,Z
q
q
q
ATLAS EXPERIMENT

Significance p_0 and signal strength μ



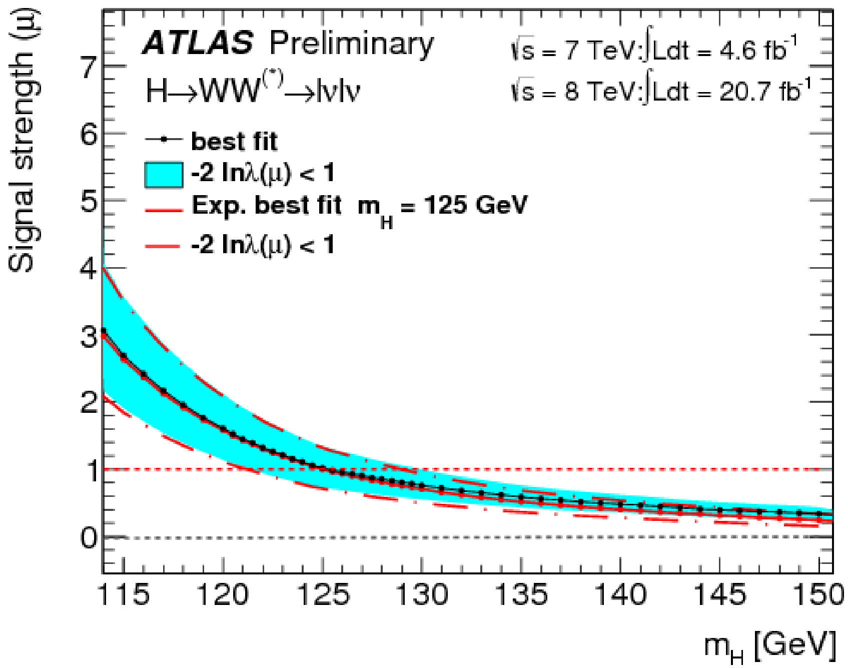


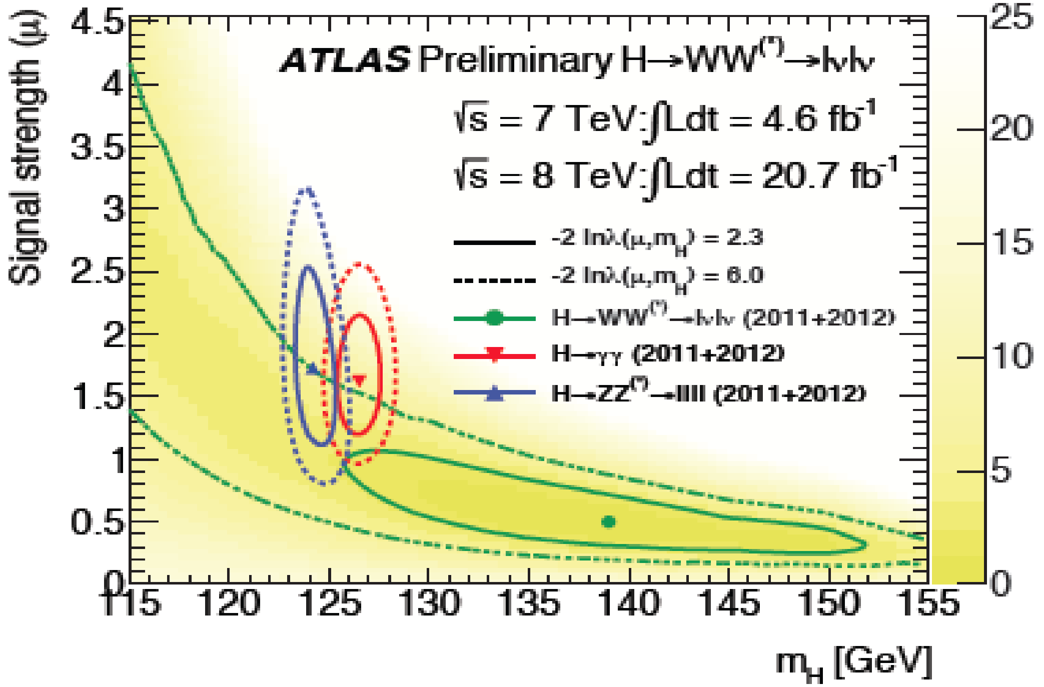
Significance at mH 125 GeV: exp = 3.7σ, Obs = 3.8σ
Largest significance at mH = 140 GeV, 4.1σ

Exclusion limit at 95% CL:
Expected: mH >119
Observed: mH> 133 GeV

Good consistency with SM

Signal strength and best mass fit





$\mu_{obs}(m_H=125\ \text{GeV})$= 1.01 ±0.12(stat)± 0.19(theo.syst.) ±0.12(exp.syst.)± 0.04 (lumi)= 1.01 ±0.31

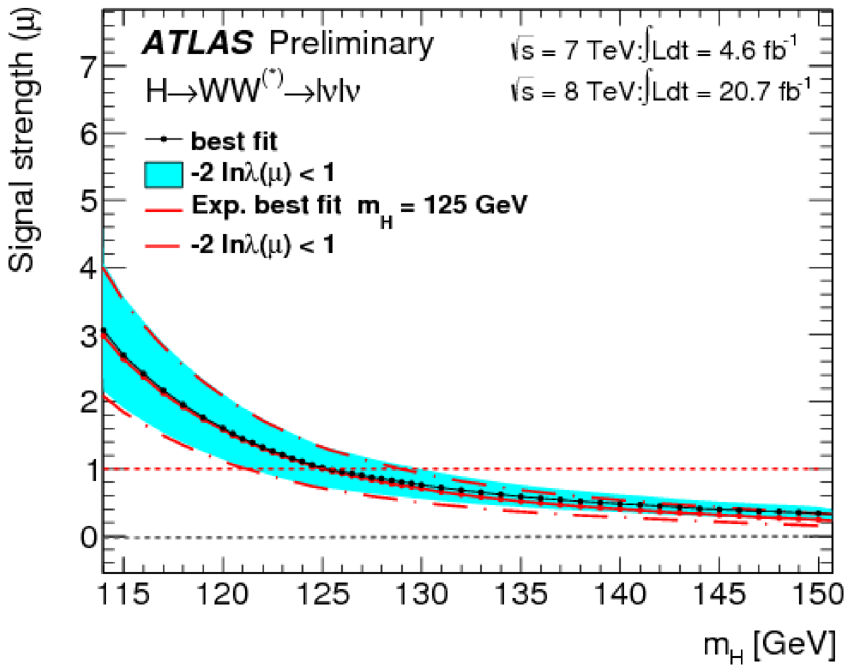
Best Mass fit consistent with other channels within 2σ.

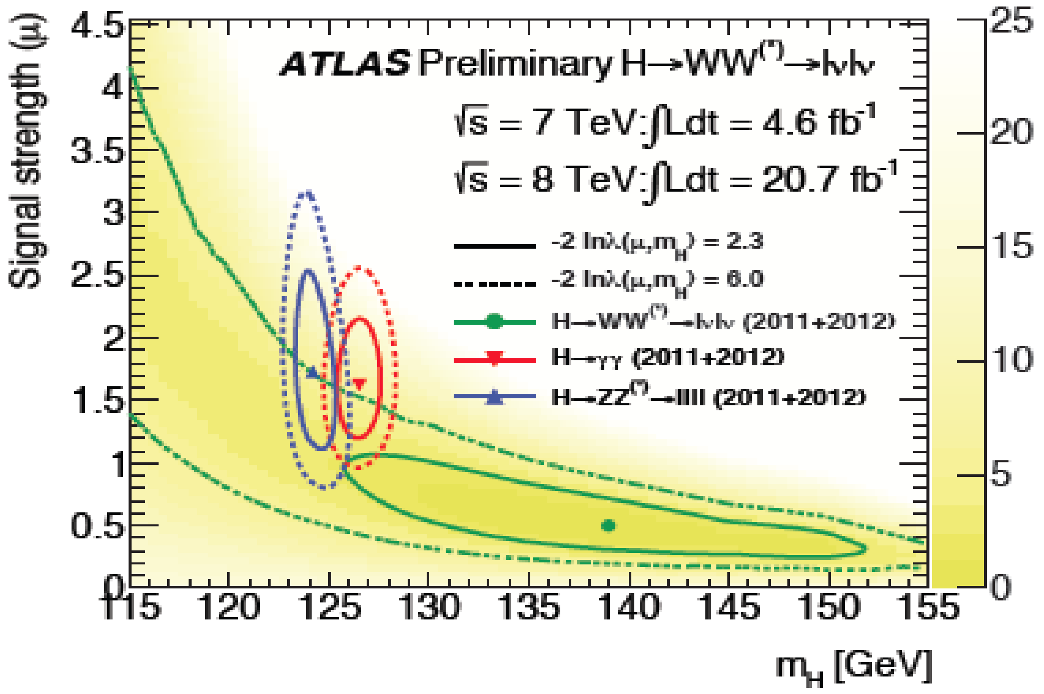
Category	Source	Uncertainty, up (%)	Uncertainty, down (%)
Statistical	Observed data	+21	−21
Theoretical	Signal yield ($\sigma \cdot \mathcal{B}$)	+12	−9
Theoretical	*WW* normalisation	+12	−12
Experimental	Objects and DY estimation	+9	−8
Theoretical	Signal acceptance	+9	−7
Experimental	MC statistics	+7	−7
Experimental	*W*+jets fake factor	+5	−5
Theoretical	Backgrounds, excluding *WW*	+5	−4
Luminosity	Integrated luminosity	+4	−4
Total		+32	−29

**(σ• B)exp, 8 TeV =
4.8 ± 0.6 (cross section)
± 0.2 (branching ratio)pb=
4.8 ± 0.7 pb**

**(σ• B)obs, 8 TeV =
6.0 ± 1.1 (stat) ± 0.2 (theo.syst)
± 0.7 (exp.syst) ± 0.3 (lumi) pb=
6.0 ± 1.6 pb**

Signal strength and best mass fit





$\mu_{obs}(m_H=125\text{ GeV})= 1.01 \pm 0.12(\text{stat}) \pm 0.19(\text{theo.syst.}) \pm 0.12(\text{exp.syst.}) \pm 0.04\ (\text{lumi}) = 1.01 \pm 0.31$

Best Mass fit consistent with other channels within 2σ.

Good consistency with SM

(σ• B)exp, 8 TeV =
4.8 ± 0.6 (cross section)
± 0.2 (branching ratio)pb=
4.8 ± 0.7 pb

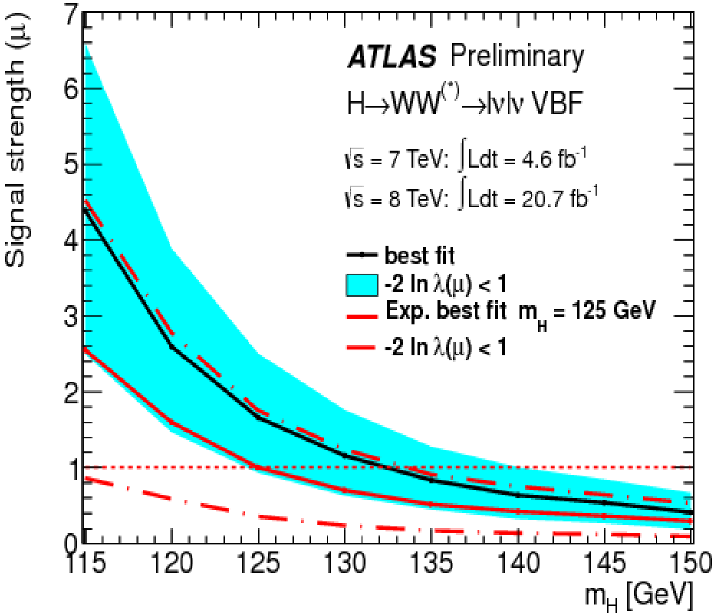
(σ• B)obs, 8 TeV =
6.0 ± 1.1 (stat) ± 0.2 (theo.syst)
± 0.7 (exp.syst) ± 0.3 (lumi) pb=
6.0 ± 1.6 pb

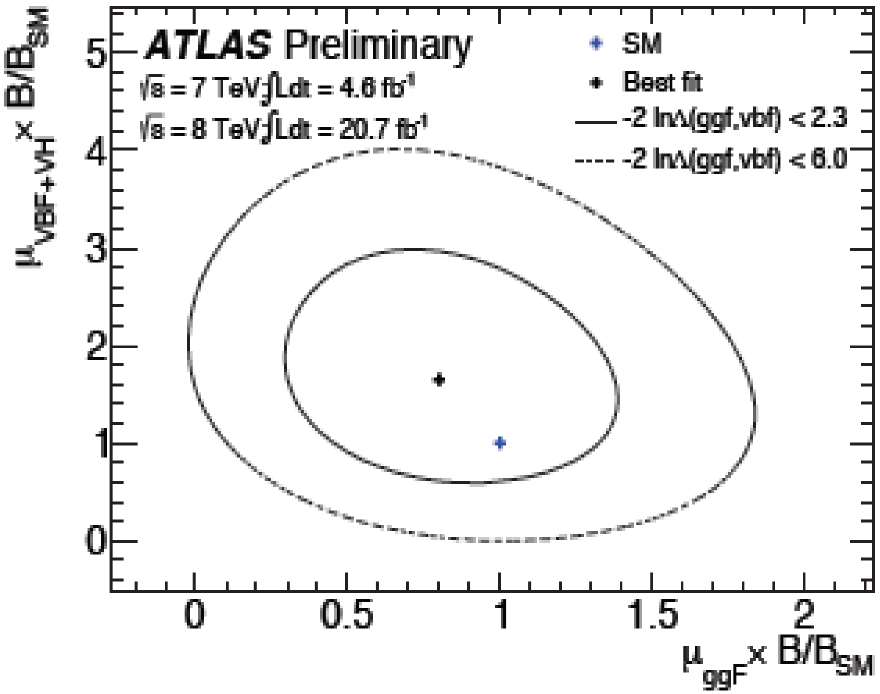
VBF Result

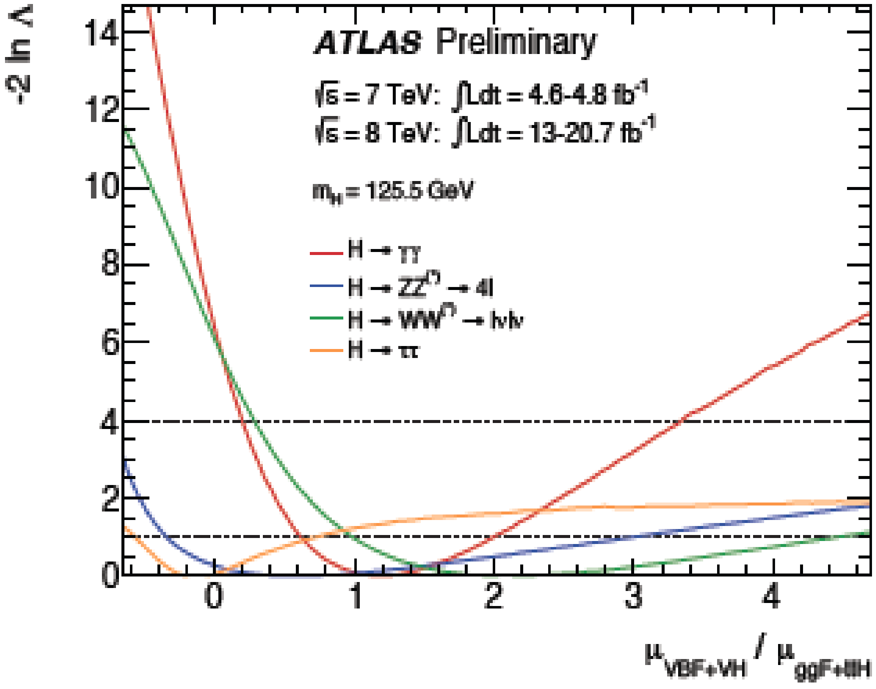
Significance at mH=125 GeV: exp = 1.6σ, Obs = 2.5σ

2D simultaneous ggF vs VBF fit

- **μ_{ggF} (m_H=125 GeV)= 0.82 ± 0.24(stat) ± 0.28(syst) = 0.82 ± 0.36**
- **μ_{VBF} (m_H=125 GeV)= 1.66 ± 0.67(stat) ± 0.42(syst) = 1.66 ± 0.79**







Good consistency with SM

Summary

Excess in H → WW → lνlν already in the July discovery with 4.7fb^{-1} + 5.8 fb^{-1}

Recently H → WW → lνlν analyzed on full ~25 fb^{-1} LHC Run1 dataset

ggF (0+1j)

- **Significance at mH 125 GeV: exp = 3.7σ, Obs = 3.8σ**
- **μ_{ggF} (mH=125 GeV)(0+1j) = 1.01± 0.31**

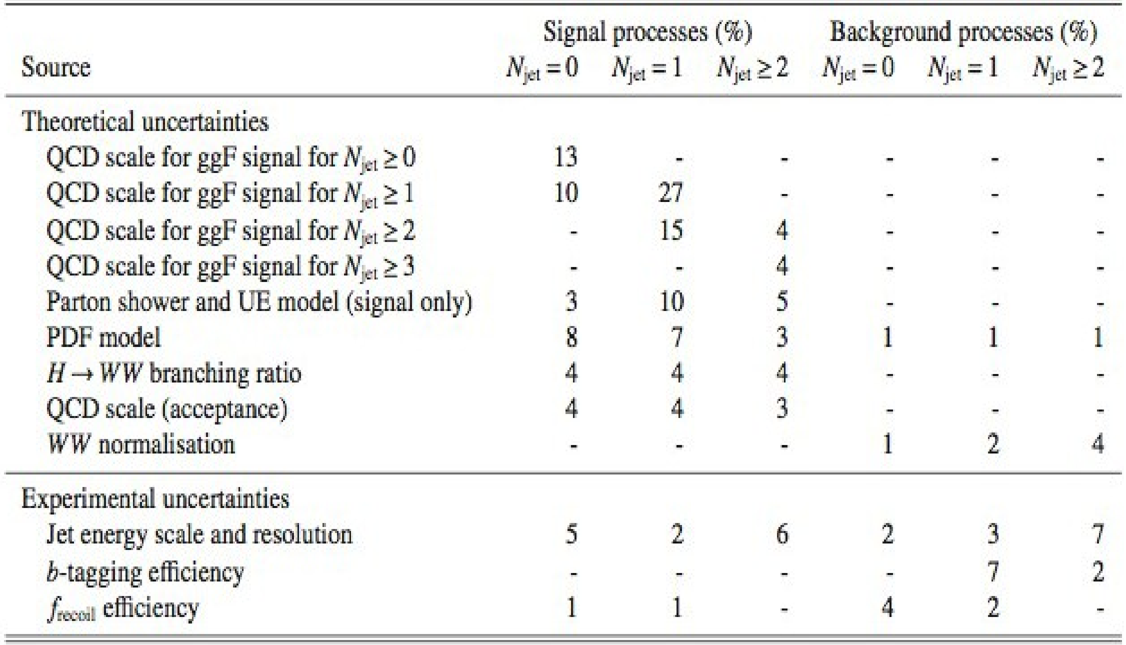
VBF

- **Significance at mH 125 GeV: exp = 1.6σ, Obs = 2.5σ**
- **μ_{ggF}(mH=125 GeV)(0+1+2j) = 0.82 ± 0.36, μ_{VBF}(0+1+2j) = 1.66 ± 0.79**

Measurements are consistent with SM expectations

Backup

Systematics



Source	Signal processes (%) $N_{\mathrm{jet}}=0$	$N_{\mathrm{jet}}=1$	$N_{\mathrm{jet}}\geq 2$	Background processes (%) $N_{\mathrm{jet}}=0$	$N_{\mathrm{jet}}=1$	$N_{\mathrm{jet}}\geq 2$
Theoretical uncertainties						
QCD scale for ggF signal for $N_{\mathrm{jet}}\geq 0$	13	-	-	-	-	-
QCD scale for ggF signal for $N_{\mathrm{jet}}\geq 1$	10	27	-	-	-	-
QCD scale for ggF signal for $N_{\mathrm{jet}}\geq 2$	-	15	4	-	-	-
QCD scale for ggF signal for $N_{\mathrm{jet}}\geq 3$	-	-	4	-	-	-
Parton shower and UE model (signal only)	3	10	5	-	-	-
PDF model	8	7	3	1	1	1
$H\to WW$ branching ratio	4	4	4	-	-	-
QCD scale (acceptance)	4	4	3	-	-	-
WW normalisation	-	-	-	1	2	4
Experimental uncertainties						
Jet energy scale and resolution	5	2	6	2	3	7
b-tagging efficiency	-	-	-	-	7	2
f_{recoil} efficiency	1	1	-	4	2	-

Channel	Δtot(%)
0j signal	20
0j background	4.7
1j signal	33.8
1j background	8.2
2j signal	11.3
2j background	8.3

Signal yield

Data 2011
$\sqrt{s}$ = 7 TeV, Lint ~4.9 fb^{-1}
eμ + μe + μμ + ee

Njet	Signal	Tot Bkg	Data
0	25±5	161±11	154
1	7±2	47±6	62
>=2	1.4±0.2	4.6±0.8	2

Data 2012

$\sqrt{s}$ = 8 TeV, Lint ~20.6 fb^{-1}
eμ + μe + μμ + ee

Njet	Signal	Tot Bkg	Data
0	92±20	739±39	831
1	40±13	261±28	309
>=2	10.6±1.4	36±4	55