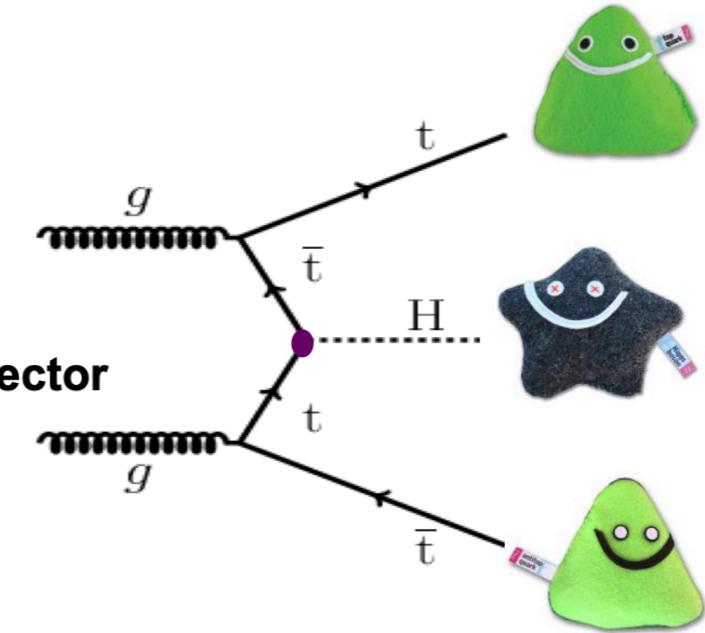




# $t\bar{t}H$ multilepton channels in ATLAS

*Merve Nazlim Agaras*  
*Laboratoire de Physique de Clermont*

*IRN Terascale@Bruxelles*



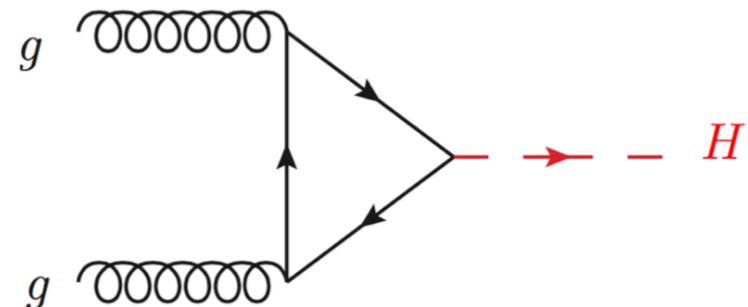
16 Oct, 2019

# The Higgs boson production

## 4 main production modes

At the LHC, the Higgs boson is dominantly produced via gluon fusion

### gluon fusion (ggF)



$\sigma_{H,ggF} \sim 49$  pb at 13 TeV

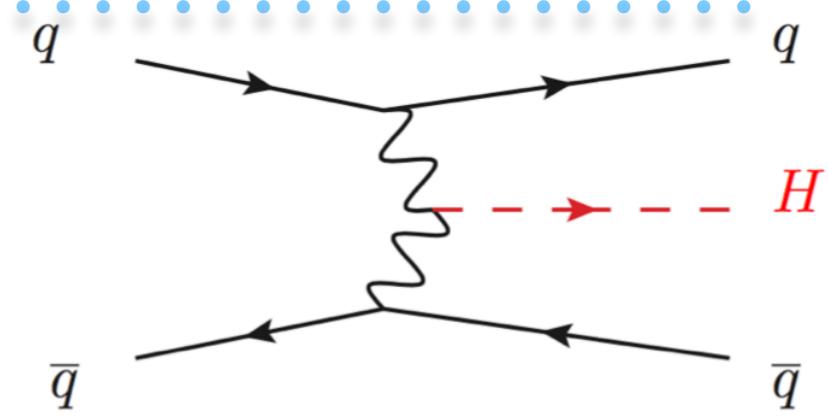
6.9M events in Run-2

Cross sections for  $m_H = 125$  GeV,  $\sqrt{s} = 13$  TeV

### vector boson fusion (VBF)

$\sigma_{VBF} \sim 3.8$  pb

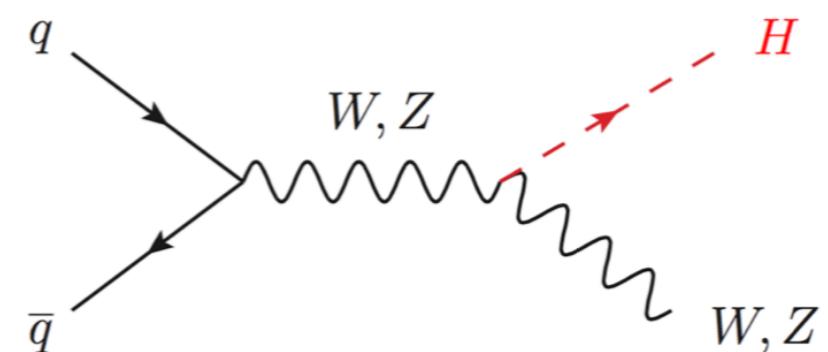
0.5M events in Run-2



### W, Z associated production (VH)

$\sigma_{W/ZH} \sim 1.4-0.9$  pb

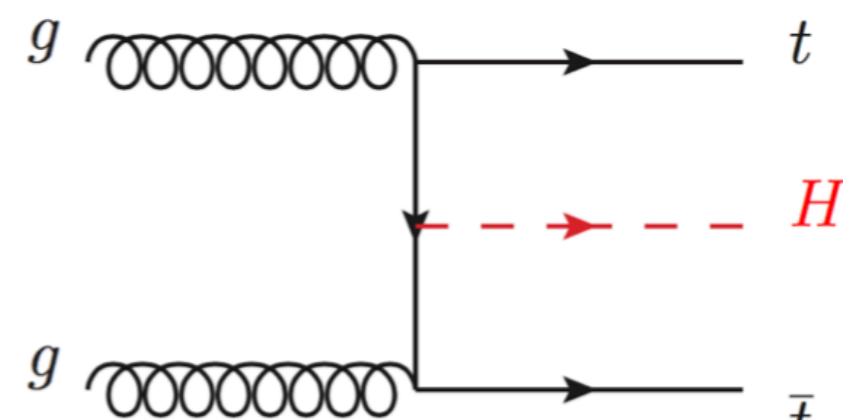
200-130k events in Run-2



### top associated production ( $t\bar{t}H$ )

$\sigma_{ttH} \sim 0.5$  pb

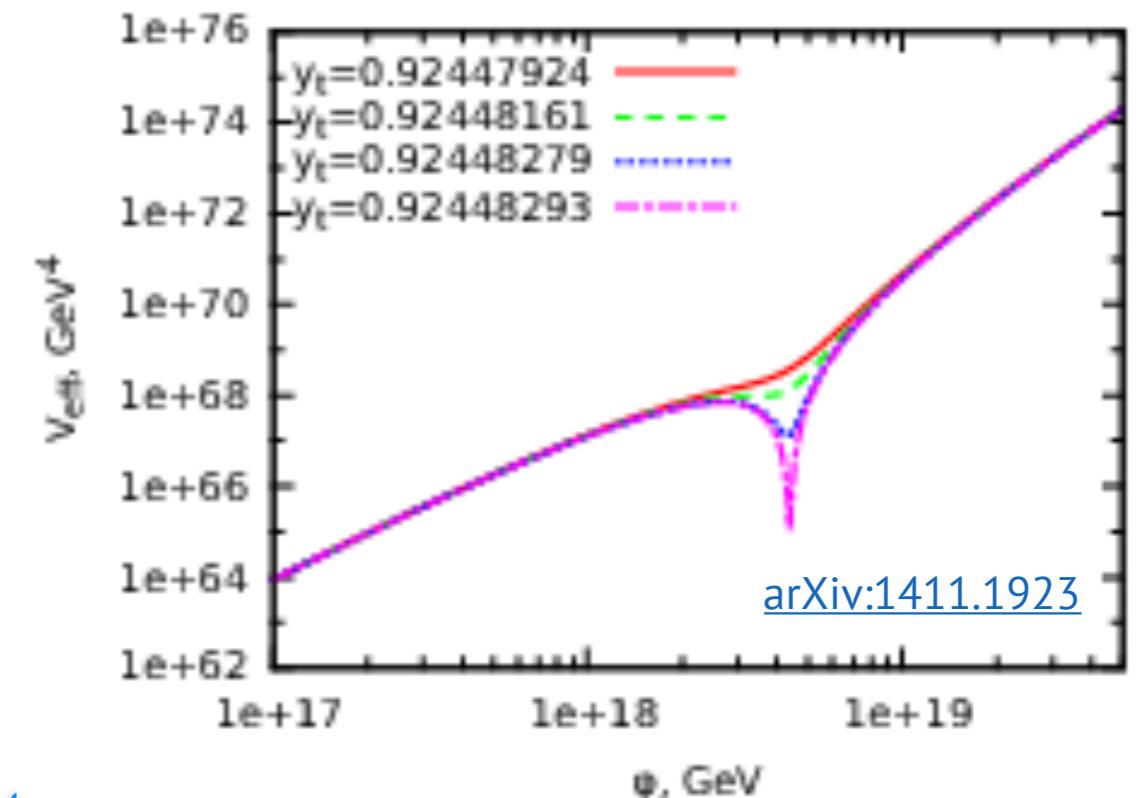
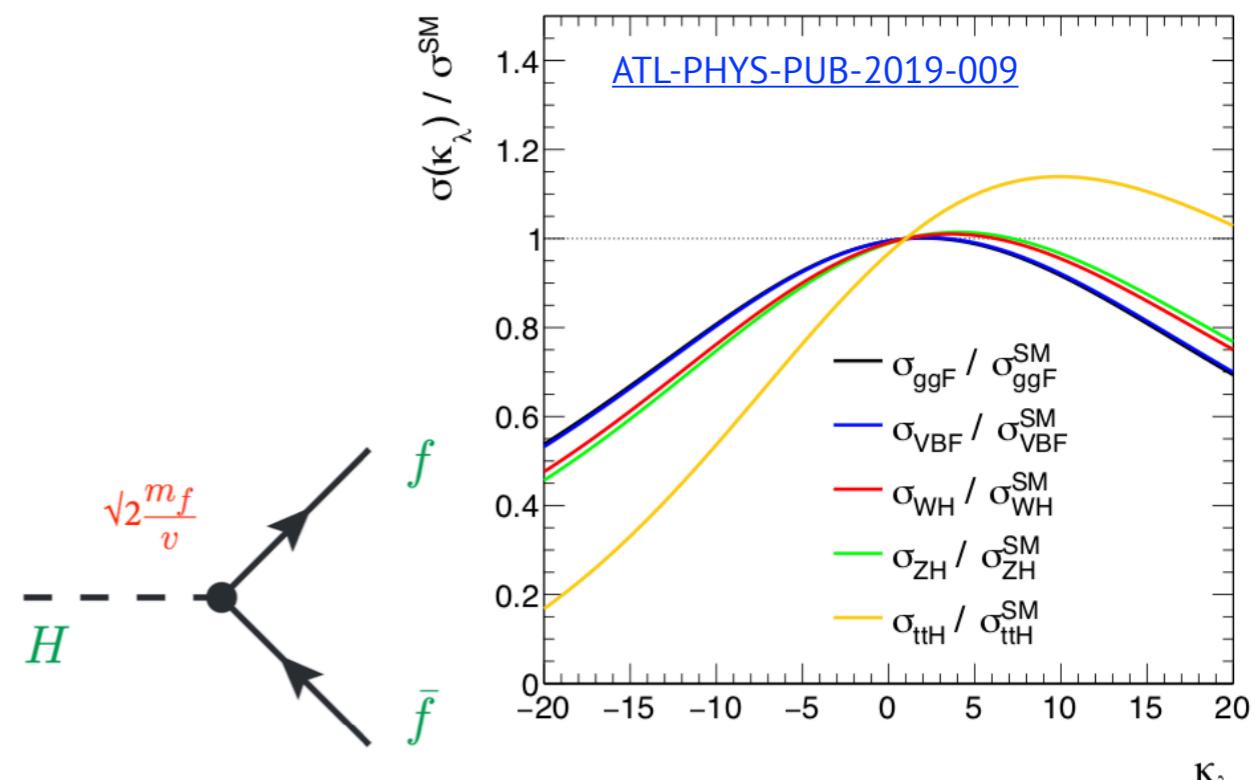
70k events in Run-2



PLB 784 173 (2018)  
Run 1 + up to  $80\text{ fb}^{-1}$   
 $6.3\sigma$  ( $5.1\sigma$  exp)

# Top Yukawa Coupling

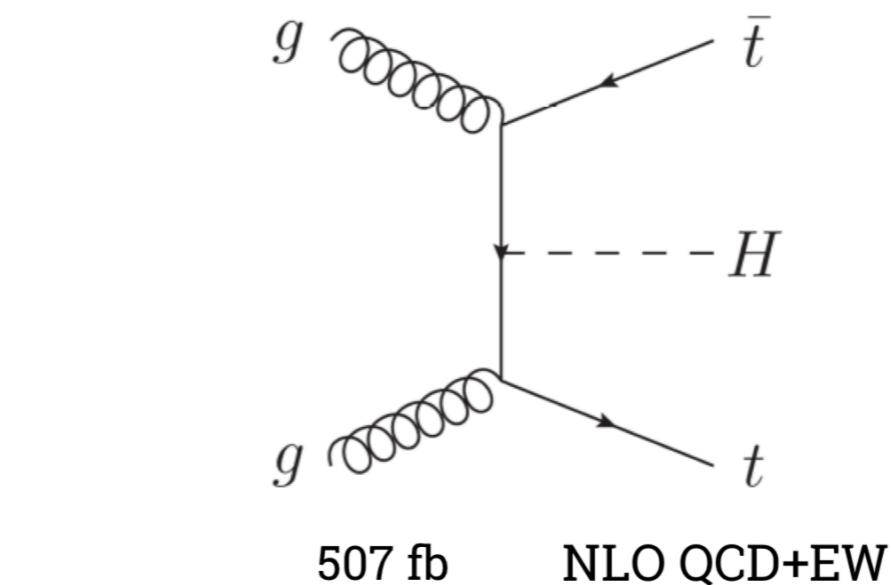
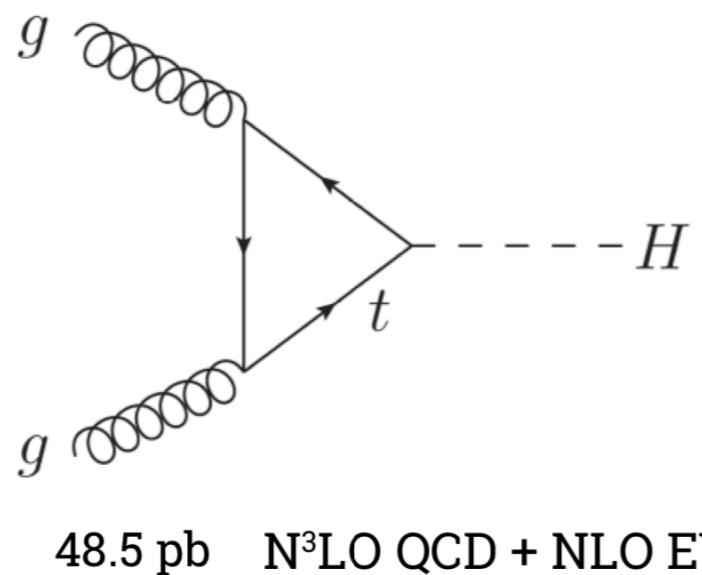
- ~ Yukawa interactions are the non-gauge and not quantised —> can be arbitrary!
- ~ Coupling const. are proportional to fermions masses
- ~ In the SM is the only quark with almost “natural mass”
- ~ Strong impact of the **top Yukawa Coupling** on
  - ▶ Destabilises the weak scale, aka the hierarchy problem ( $m_H^2$  corrections)
  - ▶ Destabilises the vacuum ( $\lambda$  corrections)
  - ▶ Controls the birth ( $gg \rightarrow h$ ) and the death ( $h \rightarrow \gamma\gamma$ ) of the Higgs
  - ▶ Destructive interference between HH production diagrams —> constraint in  $\kappa_\lambda$
- ~ Sensitive to BSM physics
  - ▶ The measured values of  $m_H$  and  $m_t$  place the SM vacuum at the border between stability and metastability.



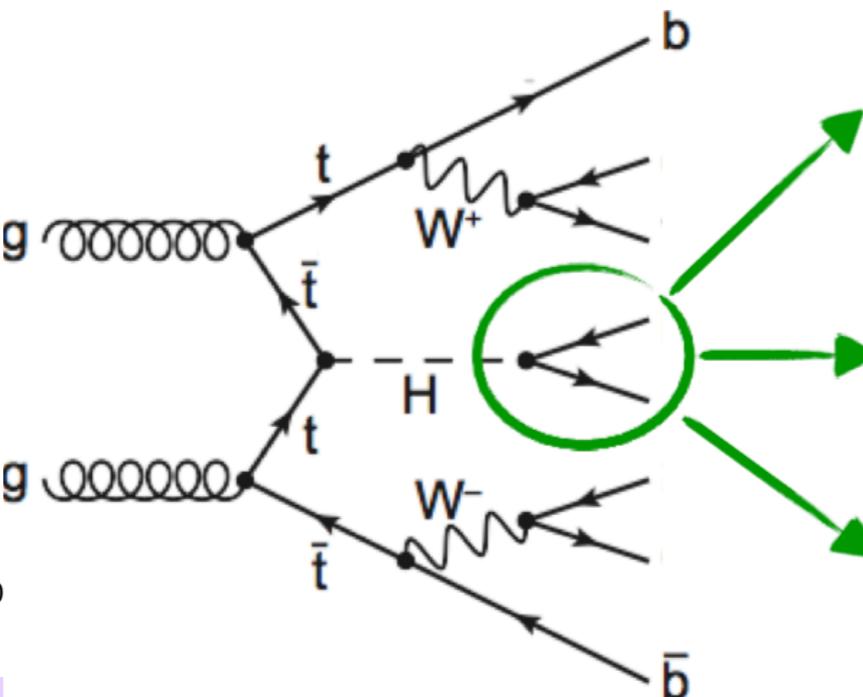
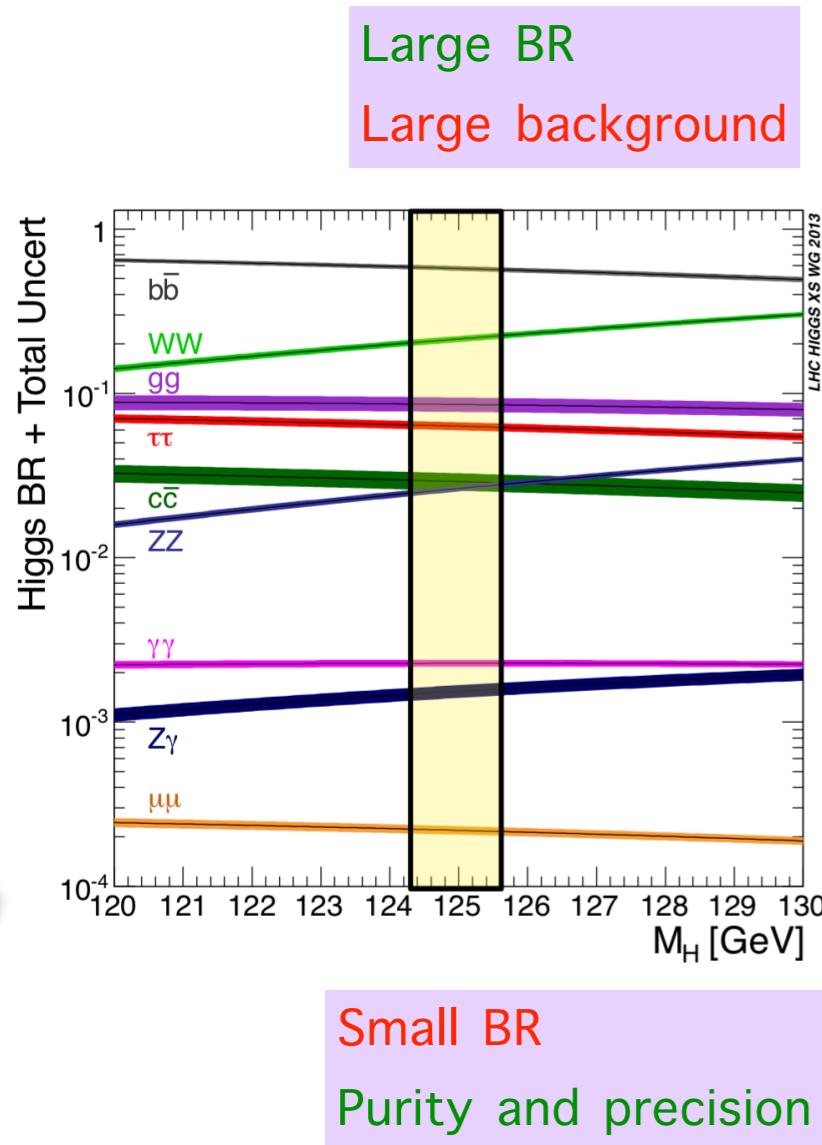
# Top & Higgs at LHC

---

- ~ All LHC Higgs property measurements consistent with SM so far...
- ~ GOAL: Probing the top-Higgs Yukawa coupling  $y_t$ 
  - ▶ Indirectly obtained through measurement of top quark mass
  - ▶ Indirectly observed through SM Higgs decaying in two photons and production of Higgs by gluon-gluon fusion
    - ▶ But sensitive to New Physics contributions
  - ▶ Direct measurement possible through ttH production (lowest level perturbation tree-level)



# ttH production in LHC



Search channel	benefits/ challenges
H->bb	Large rate/ large combinatorics
Multilep (H->WW,ZZ,tt)	Lower rate/ challenging backgrounds
H->gamma-gamma	Very clean/ small rate

# ttH - Multileptons

~ Analysis with integrated luminosity of  $80 \text{ fb}^{-1}$  dataset

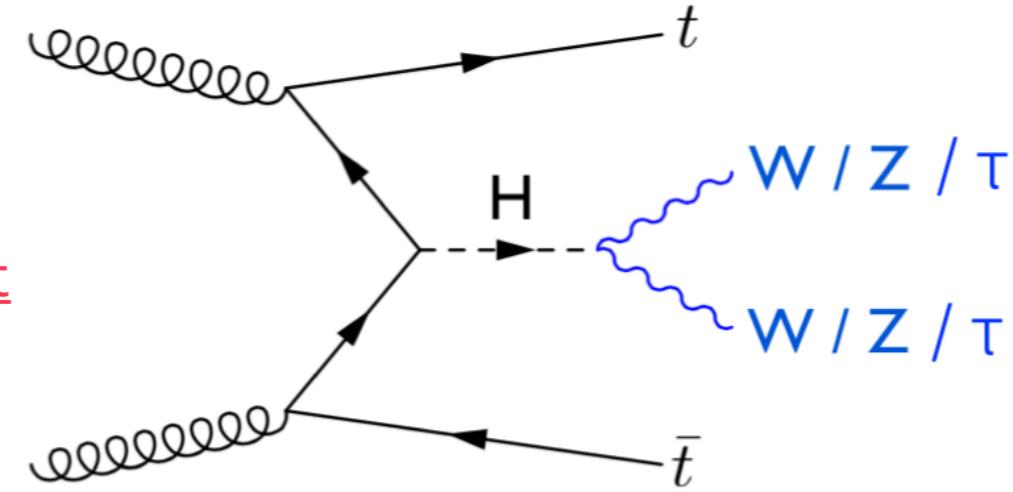
~ Targets

~  $H \rightarrow WW/ZZ/\tau\tau \rightarrow \geq 1 \ell$

~  $t\bar{t} \rightarrow (\ell + \text{jets}, \text{dilepton})$

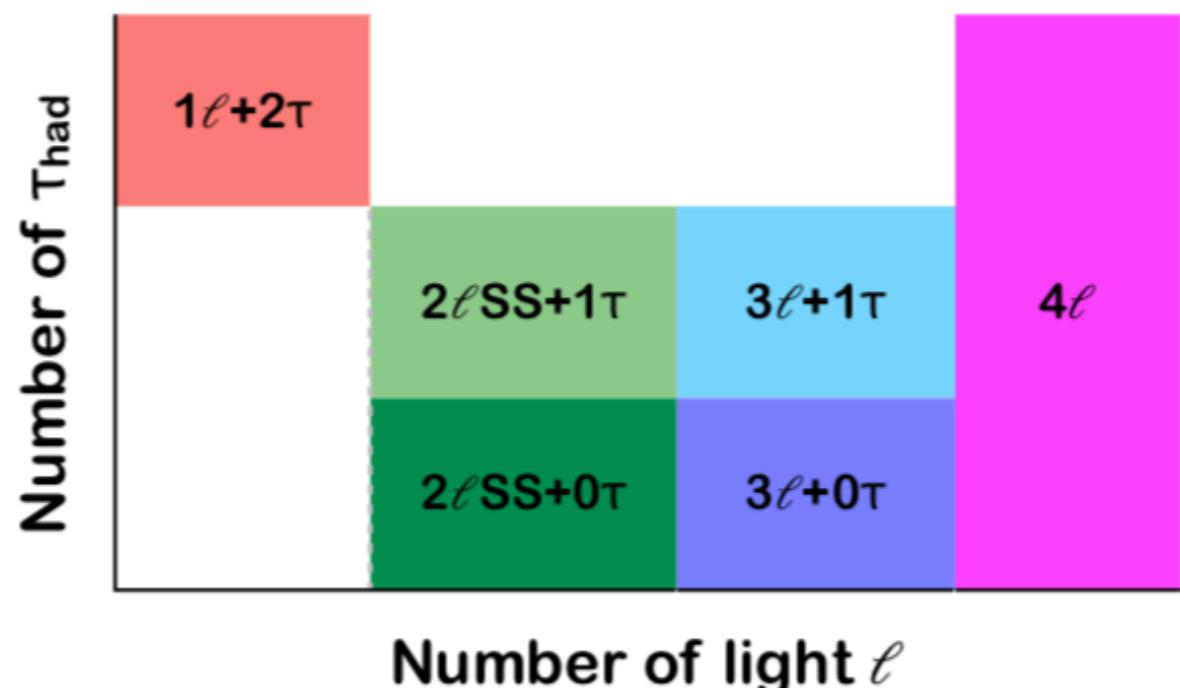
~ Analysis channels are defined wrt light leptons ( $e/\mu$ ) and hadronic taus ( $\tau_{\text{had}}$ ) multiplicity (6 orthogonal channels)

~ Common jet selection  $N_{\text{jets}} \geq 2$ ,  $N_{\text{bjets}} \geq 1$



Additional selections to leptons ( $e/\mu$ )

- ~ Specific lepton BDT isolation suppressing leptons from semi-leptonic b-decays,
- ~ BDT to reject charge misID,
- ~ material and internal electron conversion (CO) candidates further suppressed with track invariant masses and conversion radius

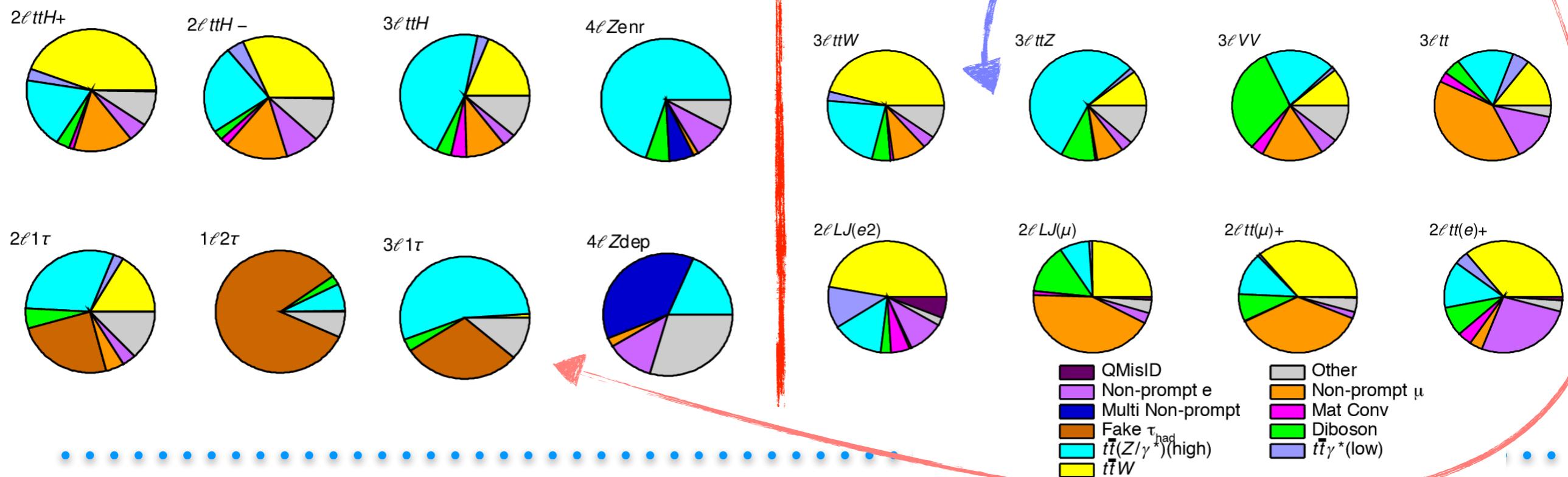


# Categories

~Signal Regions;

- ▶  $2\ell SS0\tau$ : Rectangular cuts on two BDTs (3 bins)
- ▶  $3\ell 0\tau$ : Rectangular cuts on 5D BDTs (3 bins)
- ▶  $4\ell$ : Two signal region (1 bin)
- ▶  $1\ell 2\tau$ : 1D BDT (1 bin)
- ▶  $3\ell 1\tau, 2\ell ss1\tau$ : Cut and count (1 bin)

~Control regions to have power on various source of backgrounds



# Non-prompt lepton background (fakes)

## Electrons

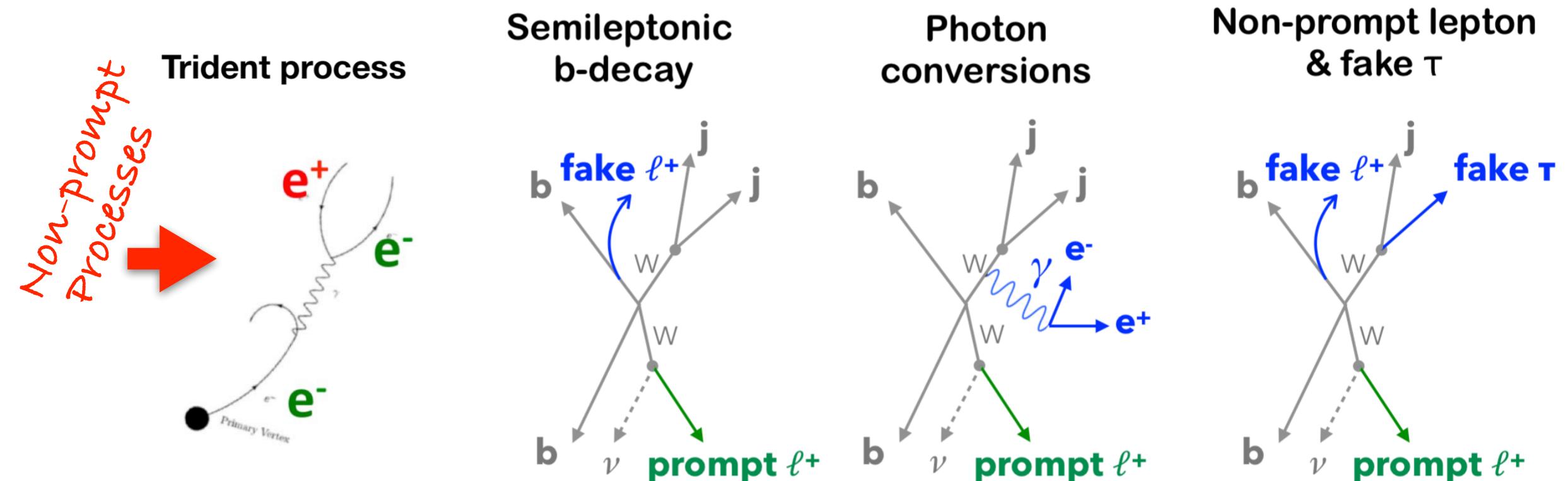
- Heavy flavour decays (b-decay)
- Conversions
- Charge misidentification

## Muons

- Heavy flavour decays (b-decay)
- In-flight decays of  $\pi/K$

## Taus

- Light, heavy jets (quarks, gluons)
- Electrons



~ Dedicated methods/control regions for each background source

- ~ Heavy Flavour, photon conversions (internal( $\gamma^*$ )&material) —> Template Fit Method (semi data-driven)
- ~ Charge misidentification —> 3D Likelihood (data-driven)
- ~  $\tau$  Fakes —> Fake factor (data-driven)

# Fakes Estimate (light leptons)

~ CR categories to the fit model (“low NJets” and conversion CRs)

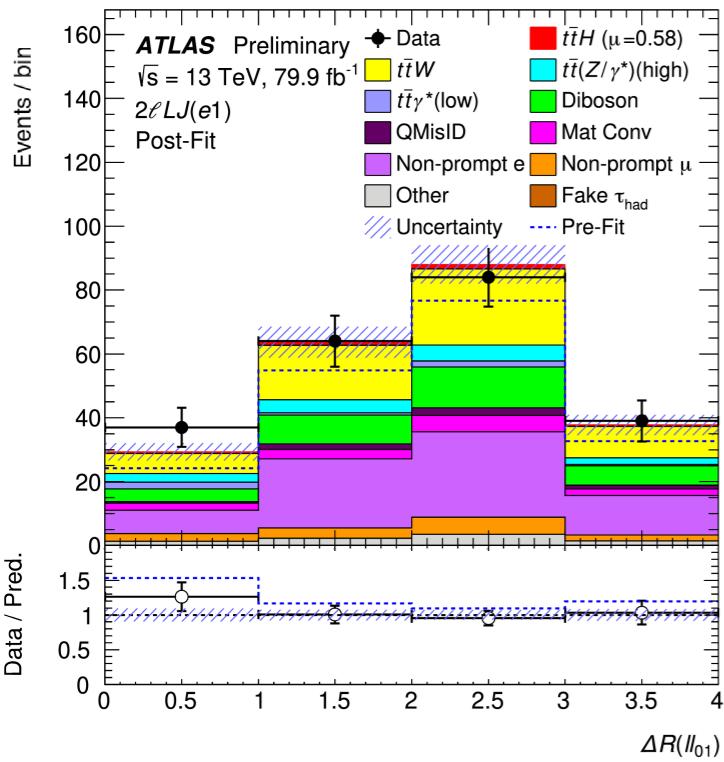
- ▶ 2ISS0 $\tau$ /3I0 $\tau$ :  $\geq 1$  electron passing material / internal conversion selection
- ▶ 2ISS0 $\tau$ : 2-3 jets, enriched in non-prompt leptons and  $t\bar{t}W$

~ Normalisation of;

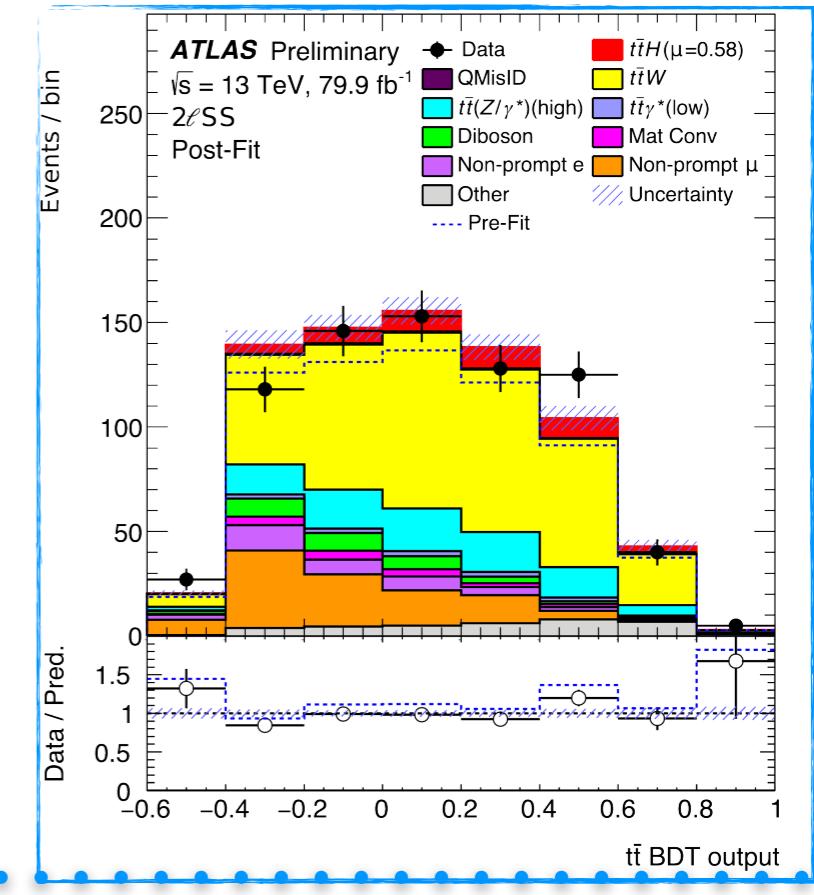
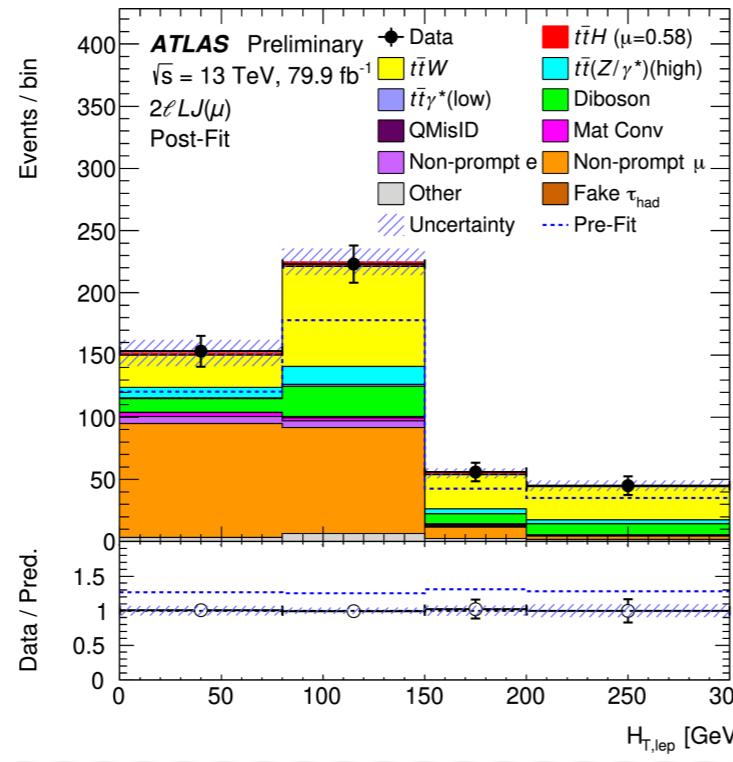
- ▶ non-prompt leptons from b-decay (electrons ( $\hat{\lambda}_e^{had}$ ) & muons ( $\hat{\lambda}_\mu^{had}$ ))
- ▶ electrons from material CO ( $\hat{\lambda}_e^{mat}$ )
- ▶ electron from internal CO [low mass  $\gamma^*$ ] ( $\hat{\lambda}_e^{IntC}$ )
- ▶  $t\bar{t}W$  ( $\hat{\lambda}_{t\bar{t}W}^{2lLJ}, \hat{\lambda}_{t\bar{t}W}^{2lHJ}, \hat{\lambda}_{t\bar{t}W}^{3l}$ )

Shapes from MC simulation, extensive set of systematic uncertainties included

**ee+ $\mu$ e 1b**



**ee+ $\mu$ e 2b**

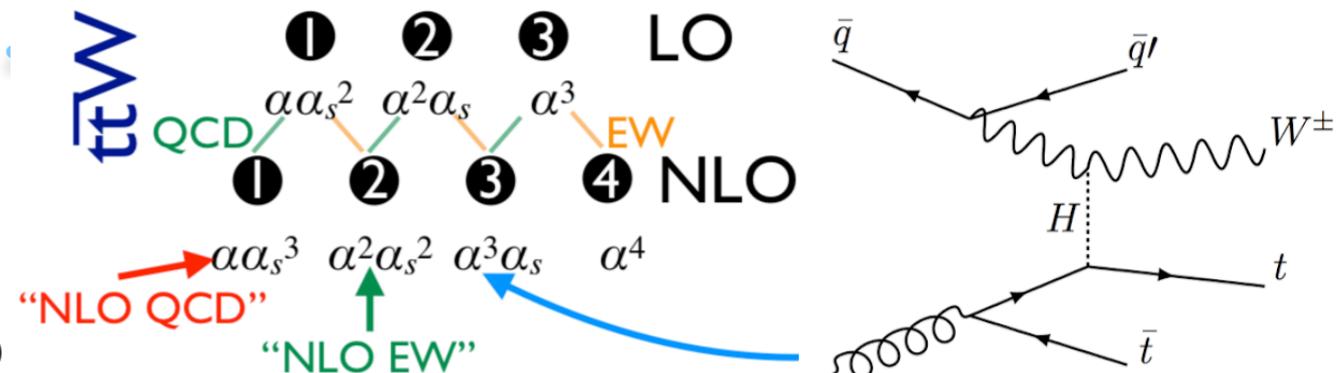
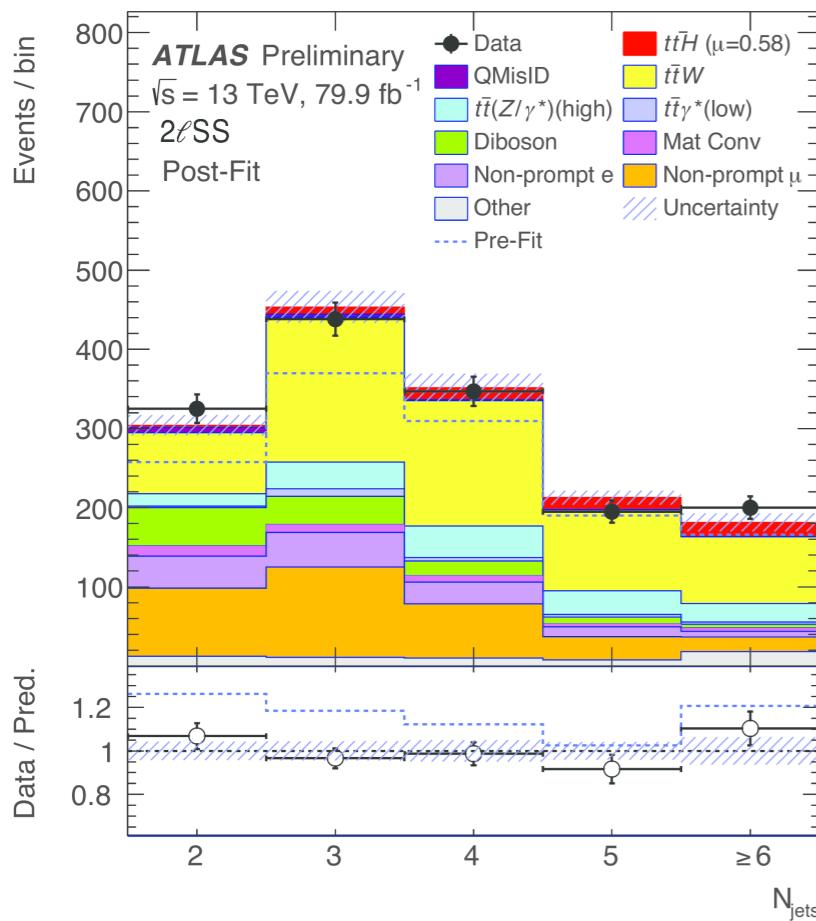


# $t\bar{t}W$ background

- Analysis has many control regions & distinguishes non-prompt lepton background from  $t\bar{t}W$  production

- $t\bar{t}W$  calculation from YR4 is NLO QCD+EW (only the leading NLO EW corrections)

- ▶ 1.09 added for complete NLO EW
  - driven by the  $t\bar{t}W+1$ -jet diagrams with a Higgs boson exchanged in the t-channel
- ▶ 1.11 added for modelling of  $t\bar{t}W+1$ jet ( $t\bar{t}W+0j@NLO \rightarrow t\bar{t}W+0,1j@NLO$ )
  - [JHEP 02 \(2018\) 031](#)
  - [JHEP 07 \(2014\) 079,](#)



13 TeV

	$\mu = H_T/2$
LO <sub>2</sub>	-
LO <sub>3</sub>	0.9
NLO <sub>1</sub>	50.0 (25.7)
NLO <sub>2</sub>	-4.2 (-4.6)
NLO <sub>3</sub>	12.2 (9.1)
NLO <sub>4</sub>	0.04 (-0.02)

- ~ Sees very strong preference for non-prompt leptons ~ MC and much more  $t\bar{t}W$  than expected
  - ▶ nominal fit: float  $t\bar{t}W$  in three different phase space regions
  - ▶ De-correlated  $2\ell$  LNJ,  $2\ell$  HNJ &  $3\ell$   $t\bar{t}W$  NFs

# Systematics

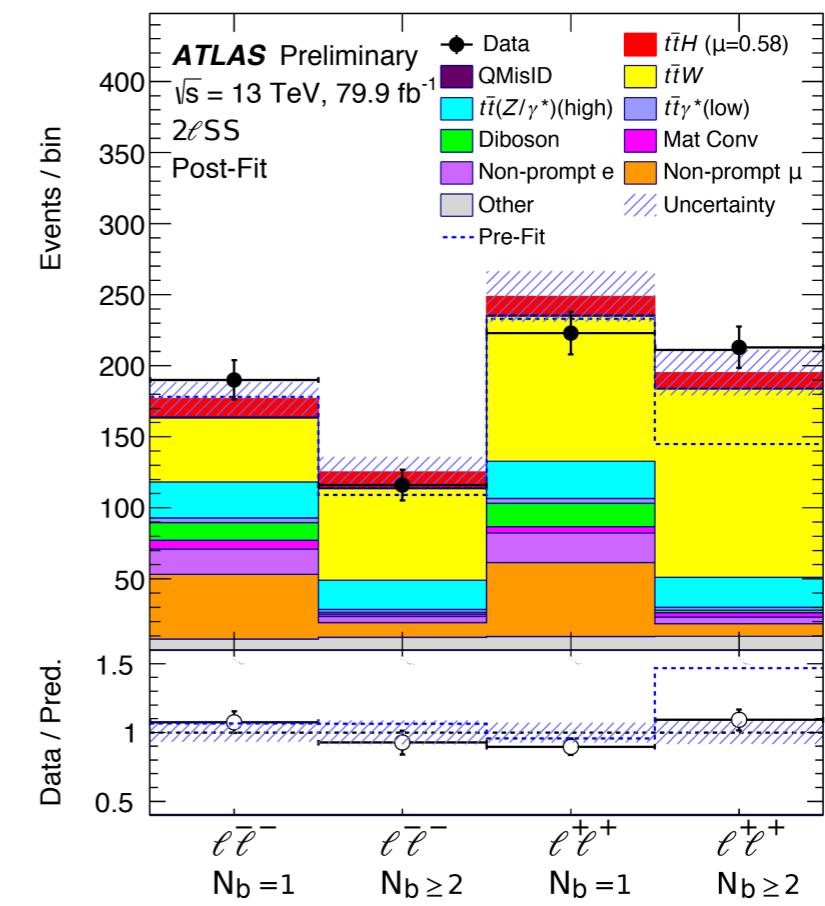
Uncertainty source	$\Delta\hat{\mu}$	
Jet energy scale and resolution	+0.13	-0.13
$t\bar{t}(Z/\gamma^*)$ (high mass) modelling	+0.09	-0.09
$t\bar{t}W$ modelling (radiation, generator, PDF)	+0.08	-0.08
Fake $\tau_{\text{had}}$ background estimate	+0.07	-0.07
$t\bar{t}W$ modelling (extrapolation)	+0.05	-0.05
$t\bar{t}H$ cross section	+0.05	-0.05
Simulation sample size	+0.05	-0.05
$t\bar{t}H$ modelling	+0.04	-0.04
Other background modelling	+0.04	-0.04
Jet flavour tagging and $\tau_{\text{had}}$ identification	+0.04	-0.04
Other experimental uncertainties	+0.03	-0.03
Luminosity	+0.03	-0.03
Diboson modelling	+0.01	-0.01
$t\bar{t}\gamma^*$ (low mass) modelling	+0.01	-0.01
Charge misassignment	+0.01	-0.01
Template fit (non-prompt leptons)	+0.01	-0.01
Total systematic uncertainty	+0.25	-0.22
Intrinsic statistical uncertainty	+0.23	-0.22
$t\bar{t}W$ normalisation factors	+0.10	-0.10
Non-prompt leptons normalisation factors (HF, material conversions)	+0.05	-0.05
Total statistical uncertainty	+0.26	-0.25
Total uncertainty	+0.36	-0.33

~ Additional uncertainties to cover data/MC disagreements as a function of nBjets and Lepton charge for  $t\bar{t}W$

- ▶ For b-jet multiplicity,  $\pm 25(\mp 35)\%$  for 1 ( $\geq 2$ ) b-jets.
- ▶ For total charge distribution,  $\pm 25(\mp 35)\%$  for positive (negative) total charge

~ Most important systematic uncertainties

- ▶ Jet Energy Scale and Resolution
- ▶  $t\bar{t}W$  modelling
- ▶ Norm of  $t\bar{t}(Z/\gamma^*)$  background

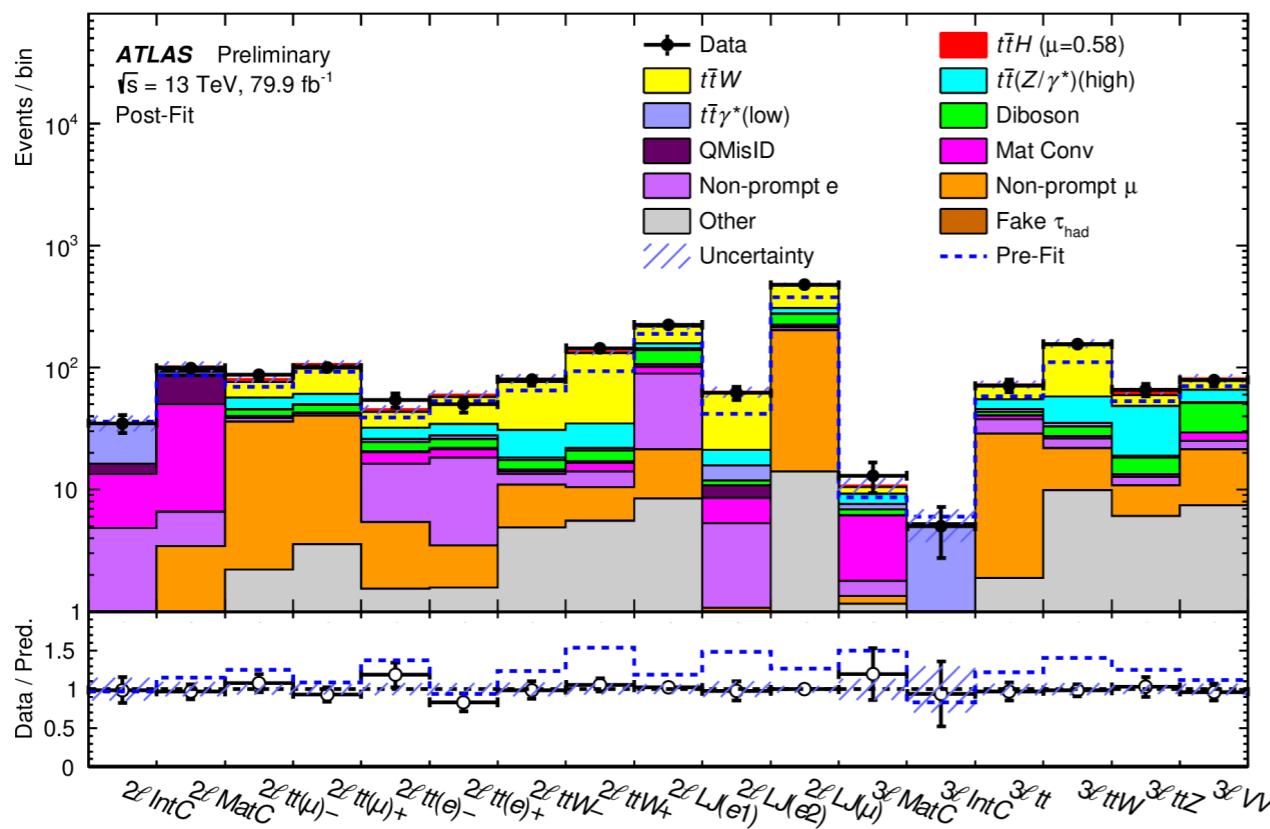


# Fitting of the parameters

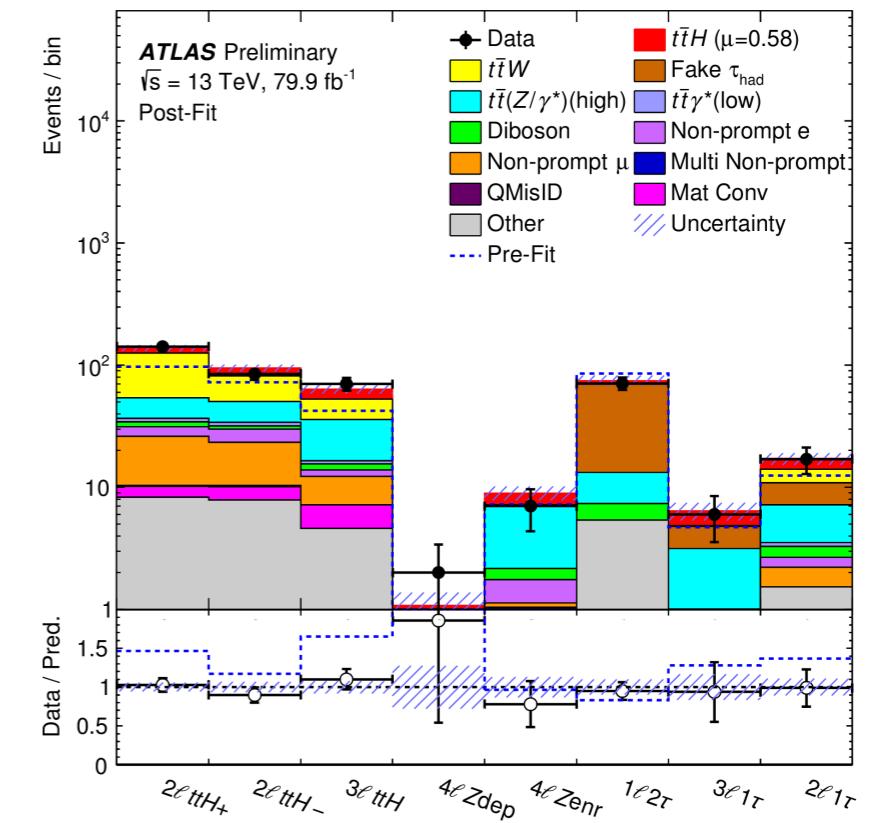
- ~ A maximum-likelihood fit of  $\mu_{t\bar{t}H}$  signal strength is performed on all bins in the 25 event categories
- ~ Simultaneous fit to non-prompt lepton templates,  $t\bar{t}W$  and  $t\bar{t}H$  signal

$\hat{\lambda}_e^{had}$	$\hat{\lambda}_{\mu}^{had}$	$\hat{\lambda}_e^{mat}$	$\hat{\lambda}_e^{IntC}$	$\hat{\lambda}_{t\bar{t}W}^{2lLJ}$	$\hat{\lambda}_{t\bar{t}W}^{2lHJ}$	$\hat{\lambda}_{t\bar{t}W}^{3l}$
$1.12 \pm 0.38$	$1.20 \pm 0.18$	$1.61 \pm 0.48$	$0.83 \pm 0.32$	$1.56 \pm 0.28$	$1.26 \pm 0.19$	$1.68 \pm 0.29$

Summary for control regions

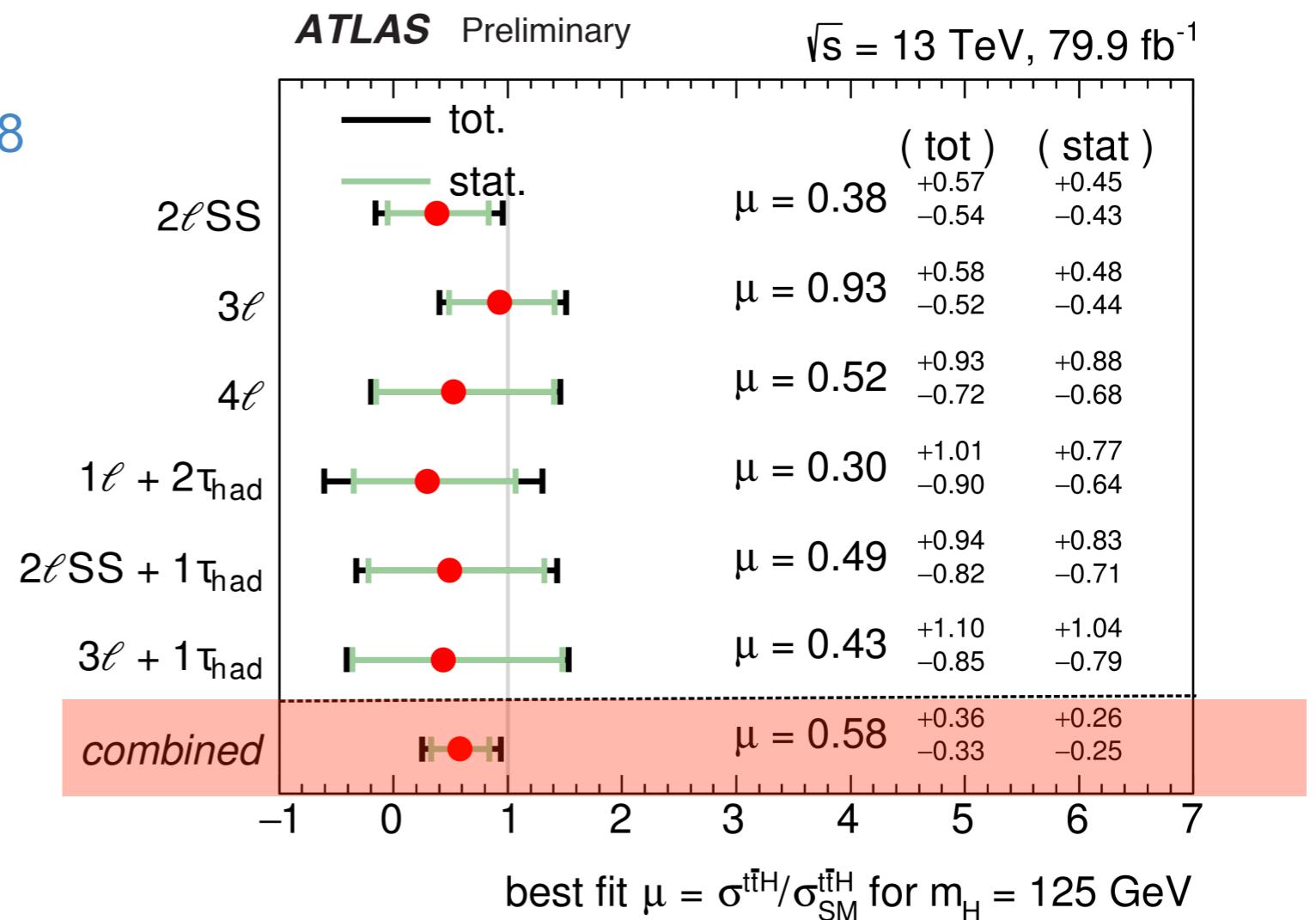
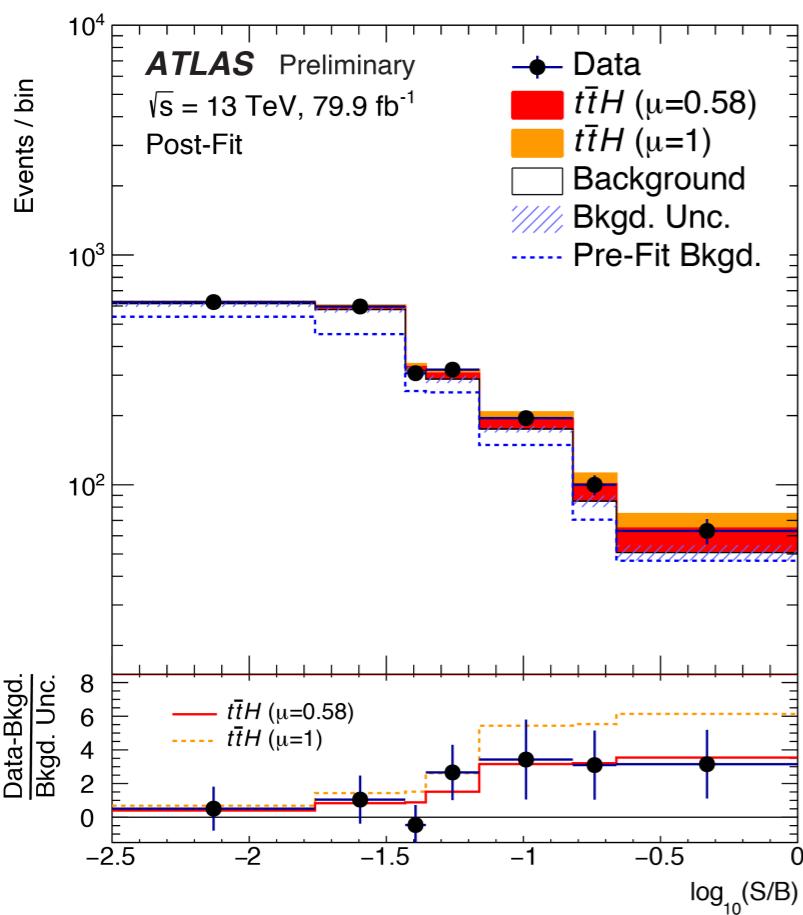


Summary for signal regions



# Results

- Combined  $\mu_{t\bar{t}H}$  with 2015/2016 and 2017 dataset
- Significance with respect to background-only hypothesis = 1.8 ( $3.1\sigma$ )



$$\hat{\sigma}(t\bar{t}H) = 294^{+132}_{-127} \text{ (stat.)}^{+94}_{-74} \text{ (exp.)}^{+73}_{-56} \text{ (bkg. th.)}^{+41}_{-39} \text{ (sig. th.) fb} = 294^{+182}_{-162} \text{ fb}$$

# Conclusion

---

- ~ Search for the  $t\bar{t}H$  production in multileptons has been performed using integrated luminosity of  $80 \text{ fb}^{-1}$  dataset
  - ▶ The measured cross section is consistent with SM prediction
  - ▶ Conference Note -> [LINK](#)
- ~ Next steps: differential cross-sections + coupling properties measurements aka. CP nature of the coupling
- ~ Tensions in the  $t\bar{t}W$  phase space
  - ▶  $t\bar{t}W$  NF measured consistently higher than SM in all the cross-checks
  - ▶ Study of  $t\bar{t}W$  and  $t\bar{t}H$  production will be done with full Run2 data

# Backup



# Objects

.....

Keep	Remove	Cone size ( $\Delta R$ )
electron	electron (low $p_T$ )	0.1
muon	electron	0.1
electron	jet	0.3
jet	muon	$\min(0.4, 0.04 + 10[\text{GeV}]/p_T \text{ (muon)})$
electron	tau	0.2
muon	tau	0.2
tau	jet	0.3

Dilepton triggers (2015)	
$\mu\mu$ (asymm.)	HLT_mu18_mu8noL1
$ee$ (symm.)	HLT_2e12_lhloose_L12EM10VH
$e\mu, \mu e$ ( $\sim$ symm.)	HLT_e17_lhloose_mu14
Dilepton triggers (2016)	
$\mu\mu$ (asymm.)	HLT_mu22_mu8noL1
$ee$ (symm.)	HLT_2e17_lhvloose_nod0
$e\mu, \mu e$ ( $\sim$ symm.)	HLT_e17_lhloose_nod0_mu14
Dilepton triggers (2017)	
$\mu\mu$ (asymm.)	HLT_mu22_mu8noL1
$ee$ (symm.)	HLT_2e24_lhvloose_nod0
$e\mu, \mu e$ ( $\sim$ symm.)	HLT_e17_lhloose_nod0_mu14

## Light lepton preselection

- $pT > 10 \text{ GeV}$ ; central  $\eta$
- Loose LH identification
- Impact parameter cuts to ensure tracks come from PV
- No Isolation

## Hadronic Taus

- $pT > 25 \text{ GeV}$ , central  $\eta$
- Medium tau ID to selection 1-prong and 3-prong hadronic taus.
- Electrons faking 1-prong tau are removed using *EleBDT*.
- B-jet fakes are removed by applying b-jet veto.
- Tau vertex requirements to suppress pileup.

## light & b-jets

- Anti-kT 0.4 jets;  $pT > 25 \text{ GeV}$ , central  $\eta$
- JVT cut for suppressing pileup jets for low  $pT$  jets (less than 60 GeV)
- bTagged jets:
  - MV2c10 70% working point

- Using **HLT\_2e24\_lvloose\_nod0** instead of accidentally prescaled **HLT\_2e17\_lhvloose\_nod0** in data17
- .....

# Lepton definition

	$e$			$\mu$		
	L	$L^*$	T	L	$L^*$	T
FixedCutLoose	No	Yes		No	Yes	
Non-prompt lepton BDT	No	Yes		No	Yes	
Identification	Loose	Tight		Loose		
Charge mis-assignment veto	No	Yes		N/A		
ambiguity bit == 0	No	Yes		N/A		
Transverse impact parameter significance $ d_0 /\sigma_{d_0}$	$< 5$			$< 3$		
Longitudinal impact parameter $ z_0 \sin \theta $	$< 0.5$ mm					

**L = Loose**

**$L^* = \text{Loose} + \text{FixedCutLoose}$**

**T = Tight**

	electron	muon
ID Isolation conv. suppression	TightLH && ambiguityType == 0 FixedCutLoose && PLV < -0.7 $\Delta R_{ll} > 0.5 \&\&  \eta_e  < 2.0$ $!ExtCo \&\& !IntCo$ $> 0.7$ $ d_0 /\sigma(d_0) < 5$ $z_0 \sin \theta < 0.5$ mm	Medium FixedCutLoose && PLV < -0.5
QmisID MVA impact parameter		$ d_0 /\sigma(d_0) < 3$ $z_0 \sin \theta < 0.5$ mm

- **Material conversion candidates** have a reconstructed displaced vertex with radius  $r > 20$  mm that includes the track associated with the electron
  - The invariant mass of the associated track and the closest (in  $\Delta\eta$ ) opposite-charge track reconstructed in the silicon detector, calculated at the conversion vertex, is required to be  $< 100$  MeV.
- **Internal conversion candidates** are required to fail the requirements for material conversions, and the di-track invariant mass, this time calculated at the primary vertex, is also required to be  $< 100$  MeV.
- **Very tight** electron candidates are tight electrons that fail the internal conversion and material conversion requirements, and have  $|\eta| < 2$ .
  - The latter requirement rejects a small fraction of electrons with a *large charge misidentification rate* because of the limited number of hits used in the track reconstruction.

# Conversions

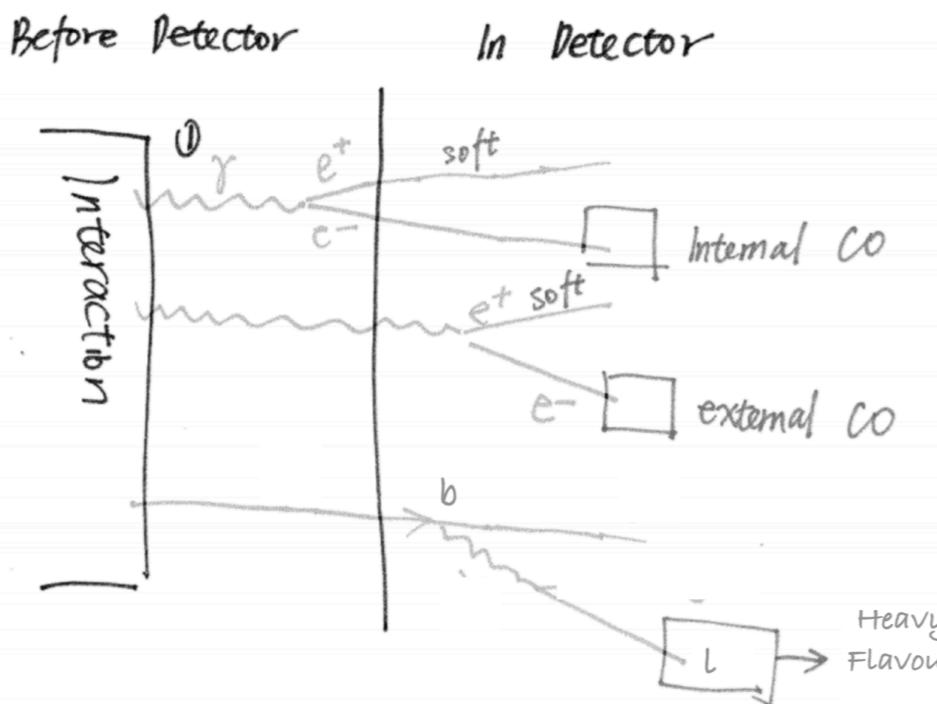
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Despite **e/gamma ambiguity**==0 bit, large fractions of conversions in tight selection.

- ▶ **Internal Conversion:** electron with truth  $r < 20$  mm
- ▶ **External Conversion:** electron with truth  $r \geq 20$  mm

The idea of identifying conversions is to reconstruct reconstructed virtual photon

- ▶ based on the invariant mass of two (opposite charge) tracks belonging to the same electron cluster.
- ▶ Conversion electrons tend to have more than one track ass. to the cluster/internal conv. mostly exactly 2 track.



ExtConv: Conversion vertex found  $r > 20\text{mm}$  and  $0 < m_{\text{trk,trk}}$  (at CV)  $< 100\text{ MeV}$   
IntConv: !ExtConv and  $0 < m_{\text{trk,trk}}$  (at PV)  $< 100\text{ MeV}$

# Simulation samples

Process	Generator	ME order	Parton shower	PDF	Tune
$t\bar{t}H$	POWHEG-BOX [23,24]	NLO	PYTHIA 8	NNPDF3.0 NLO [25]/ NNPDF2.3 LO [48]	A14
	(POWHEG-BOX)	(NLO)	(HERWIG7)	(NNPDF3.0 NLO/ MMHT2014 LO [49])	(H7-UE-MMHT)
$tHqb$	MG5_AMC	LO	PYTHIA 8	CT10 [50]	A14
$tHW$	MG5_AMC	NLO	HERWIG++	CT10/ CTEQ6L1 [51,52]	UE-EE-5
$t\bar{t}W$	SHERPA 2.2.1 (MG5_AMC)	MEPs@NLO (NLO)	SHERPA (PYTHIA 8)	NNPDF3.0 NNLO (NNPDF3.0 NLO/ NNPDF2.3 LO)	SHERPA default (A14)
$t\bar{t}(Z/\gamma^*)$	MG5_AMC	NLO	PYTHIA 8	NNPDF3.0 NLO/ NNPDF2.3 LO	A14
	(SHERPA 2.2.0)	(LO multileg)	(SHERPA)	(NNPDF3.0 NLO)	(SHERPA default)
$t\bar{t} \rightarrow W^+ b W^- \bar{b} l^+ l^-$	MG5_AMC	LO	PYTHIA 8	NNPDF3.0 LO	A14
$tZ$	MG5_AMC	LO	PYTHIA 6	CTEQ6L1	Perugia2012
$tWZ$	MG5_AMC	NLO	PYTHIA 8	NNPDF2.3 LO	A14
$t\bar{t}t, t\bar{t}t\bar{t}$	MG5_AMC	LO	PYTHIA 8	NNPDF2.3 LO	A14
$t\bar{t}W^+ W^-$	MG5_AMC	LO	PYTHIA 8	NNPDF2.3 LO	A14
$t\bar{t}$	POWHEG-BOX	NLO	PYTHIA 8	NNPDF3.0 NLO/ NNPDF2.3 LO	A14
Single top ( $t$ -, $Wt$ -, $s$ -channel)	POWHEG-BOX [53,54]	NLO	PYTHIA 8	NNPDF3.0 NLO/ NNPDF2.3 LO	Perugia2012
$VV, qqVV, VVV$	SHERPA 2.2.2	MEPs@NLO	SHERPA	NNPDF3.0 NNLO	SHERPA default
$Z \rightarrow l^+ l^-$	SHERPA 2.2.1	MEPs@NLO	SHERPA	NNPDF3.0 NLO	SHERPA default

# Offline selection criteria

Channel	Selection criteria
Common	$N_{\text{jets}} \geq 2$ and $N_{b\text{-jets}} \geq 1$
2 $\ell$ SS	<p>Two same-charge (SS) very tight (<math>T^*</math>) leptons, <math>p_T &gt; 20</math> GeV            No <math>\tau_{\text{had}}</math> candidates  <math>m(\ell^+\ell^-) &gt; 12</math> GeV for all SF pairs  <b>13 categories:</b> enriched with <math>t\bar{t}H</math>, <math>t\bar{t}W</math>, <math>t\bar{t}</math>, mat. conv, int. conv., split by lepton flavour, charge, jet and <math>b</math>-jet multiplicity</p>
3 $\ell$	<p>Three loose (L) leptons with <math>p_T &gt; 10</math> GeV; sum of light-lepton charges = <math>\pm 1</math>            Two SS very tight (<math>T^*</math>) leptons, <math>p_T &gt; 15</math> GeV            One OS (w.r.t the SS pair) loose-isolated (<math>L^*</math>) lepton, <math>p_T &gt; 10</math> GeV            No <math>\tau_{\text{had}}</math> candidates  <math>m(\ell^+\ell^-) &gt; 12</math> GeV and <math> m(\ell^+\ell^-) - 91.2</math> GeV  <math>&gt; 10</math> GeV for all SFOS pairs  <math> m(3\ell) - 91.2</math> GeV  <math>&gt; 10</math> GeV  <b>7 categories:</b> enriched with <math>t\bar{t}H</math>, <math>t\bar{t}W</math>, <math>t\bar{t}Z</math>, <math>VV</math>, <math>t\bar{t}</math>, mat. conv, int. conv</p>
4 $\ell$	<p>Four loose-isolated (<math>L^*</math>) leptons; sum of light lepton charges = 0  <math>m(\ell^+\ell^-) &gt; 12</math> GeV and <math> m(\ell^+\ell^-) - 91.2</math> GeV  <math>&gt; 10</math> GeV for all SFOS pairs  <math>m(4\ell) &lt; 115</math> GeV or <math>m(4\ell) &gt; 130</math> GeV  <b>2 categories:</b> Zenr (Z-enriched; 1 or 2 SFOS pairs) or Zdep (Z-depleted; 0 SFOS pairs)</p>
1 $\ell$ 2 $\tau_{\text{had}}$	<p>One tight (T) lepton, <math>p_T &gt; 27</math> GeV            Two OS <math>\tau_{\text{had}}</math> candidates            At least one tight <math>\tau_{\text{had}}</math> candidate  <math>N_{\text{jets}} \geq 3</math></p>
2 $\ell$ SS1 $\tau_{\text{had}}$	<p>2<math>\ell</math>SS selection, except: One medium <math>\tau_{\text{had}}</math> candidate  <math>N_{\text{jets}} \geq 4</math></p>
3 $\ell$ 1 $\tau_{\text{had}}$	<p>3<math>\ell</math> selection, except:            One medium <math>\tau_{\text{had}}</math> candidate, of opposite charge to the total charge of the light leptons            Two SS tight (T) leptons</p>

# Systematic components

Systematic uncertainty	Components	Systematic uncertainty	Components
Luminosity (N)	1	<b><math>t\bar{t}H</math> modelling</b>	
Pileup modelling	1	Renormalisation and factorisation scales	3
<b>Physics objects</b>		Parton shower and hadronisation model	1
Electron	8	Higgs boson branching ratio	4
Muon	11	Shower tune	1
Tau	7	PDF	32
Jet energy scale and resolution	28	<b><math>t\bar{t}W</math> modelling</b>	
Jet vertex fraction	1	Radiation	1
Jet flavour tagging	17	Generator	1
$E_T^{\text{miss}}$	3	PDF	32
Total (Experimental)	77	Extrapolation	4
<b>Data-driven background estimates</b>		<b><math>t\bar{t}(Z/\gamma^*)</math> (high mass) modelling</b>	
Non-prompt light-lepton estimates ( $3\ell$ , $3\ell 1\tau_{\text{had}}$ )	1	Cross section (N)	2
Fake $\tau_{\text{had}}$ estimates	6	Generator	1
Electron charge misassignment	2	Renormalisation and factorisation scales	3
Total (Data-driven reducible background)	9	Shower tune	1
<b>Template fit uncertainties</b>		<b><math>t\bar{t}</math> modelling</b>	
Material conversions	1	Radiation	1
Internal conversions	1	<b><math>WZ</math> modelling</b>	
HF non-prompt leptons	18	HF composition (N)	3
LF non-prompt leptons	2	Shower tune	1
Total (Template fit)	22	<b>Other background modelling</b>	
		Cross section (N)	22
		Total (Signal and background modelling)	120
		Total (Overall)	218

# Some checks

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- Cross-check across years

**2015+2016**

$$\hat{\mu} = 0.68^{+0.50}_{-0.45}$$

**2017**

$$\hat{\mu} = 0.52^{+0.45}_{-0.40}$$

*t̄W NF also found to be high in both datasets*

- Comparison wrt. 36/fb t̄H publication [[Phys. Rev. D 97 \(2018\) 072003](#)]

*current fit model + t̄W fixed to SM and no extrapolation*

*uncertainties → μ consistent with previous result*

- Comparison wrt. 36/fb t̄W publication [[Phys. Rev. D 99 \(2019\) 072009](#)]

*comparable results wrt.*

$$\hat{\lambda}_{t\bar{t}W} = 1.19 \pm 0.26$$

*(expressed wrt. 1.2x YR4)*

# Correlation matrix - ttW vs ttH

