Single-top-quark production in standard modes (ATLAS + CMS)

11th International Workshop on Top Quark Physics

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UNIVERSITÄT BONN

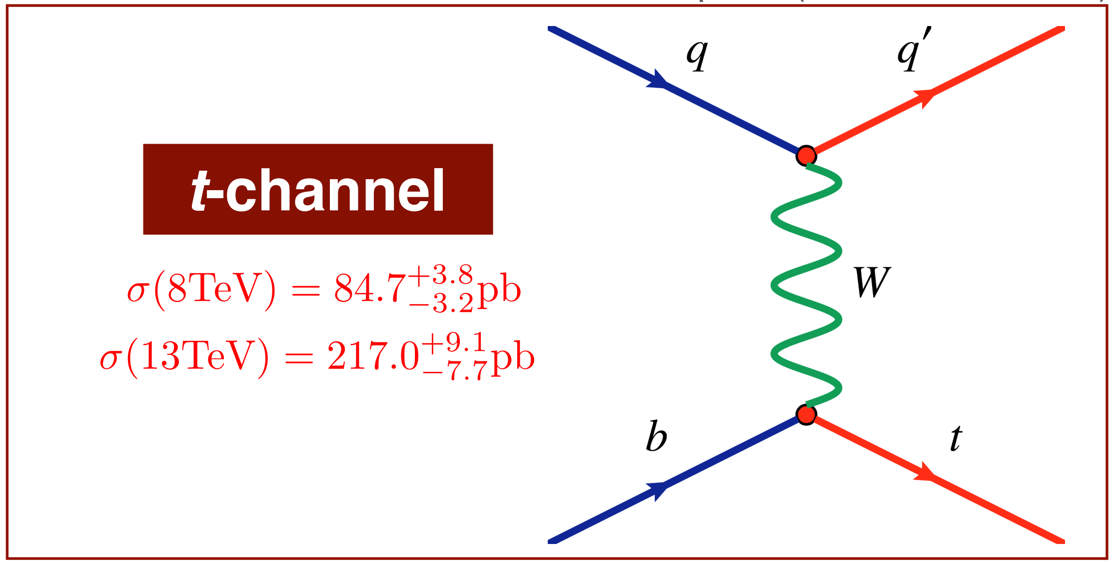
Single-top-quark production

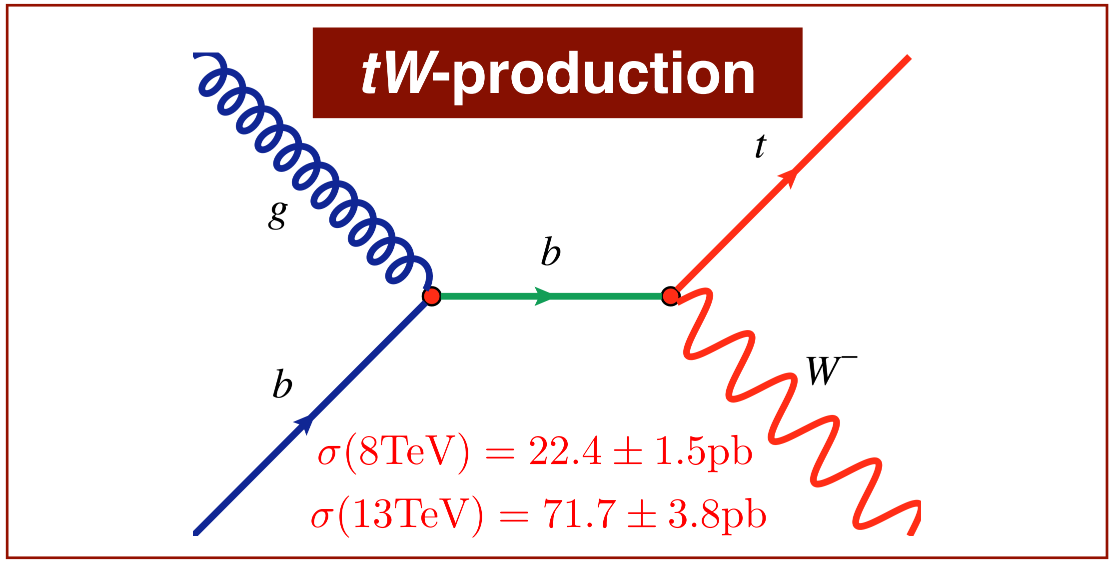
Why is the single top quark interesting?

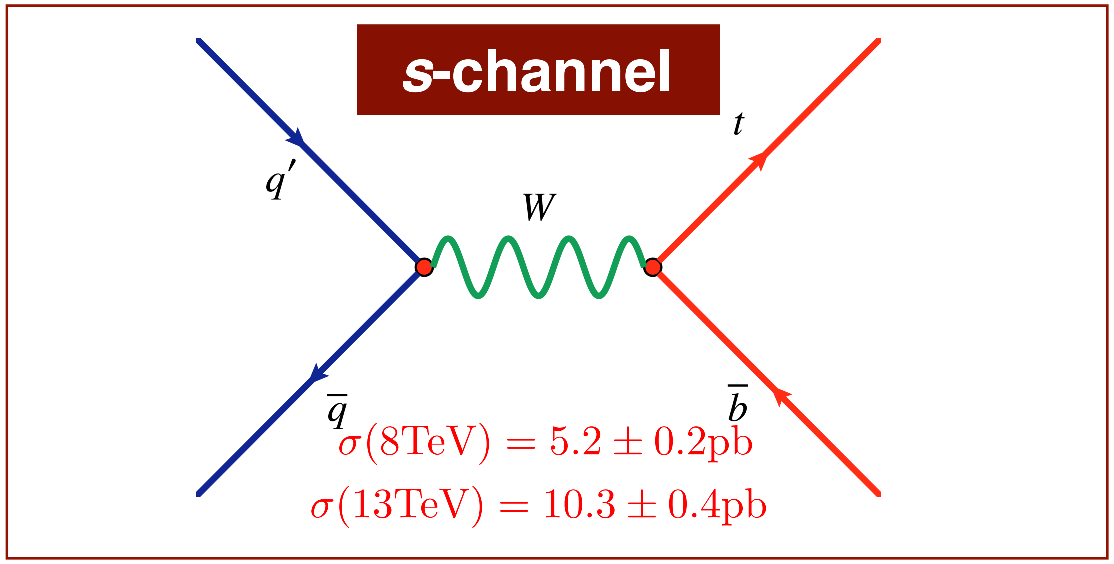
- **Important test of the SM**
  - *Wtb* vertex: $|V_{tb}|$
  - Top-quark mass measurement
- **Powerful probe for BSM physics:**
  - Production modes sensitive to new physics
  - *Wtb* anomalous couplings
  - FCNC in production
- **Constrain PDFs**
  - Sensitive to *u/d*-quark ratio in PDFs
  - Test of *b*-quark PDFs
- **Tune MC generators**
  - Data-predictions comparison via unfolded distributions
- **Background for Higgs/SUSY searches**

Single-top-quark rare processes covered in next talk

Cross-sections from LHCTopWG (calculated @NLO)

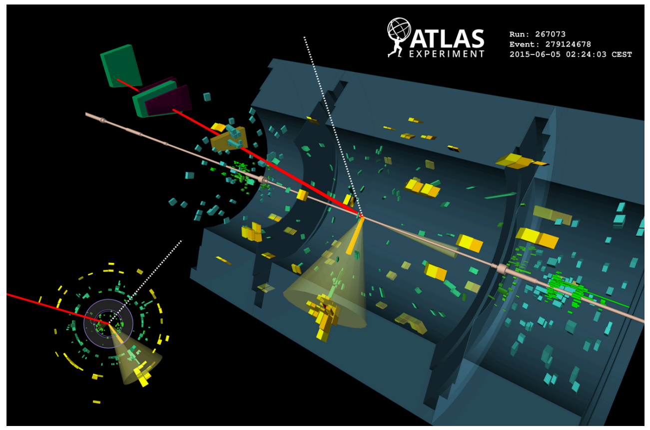
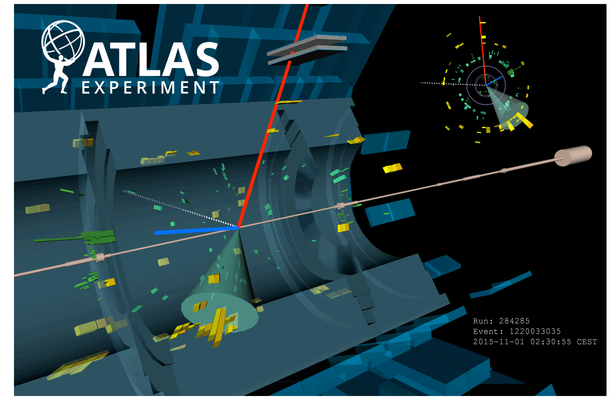
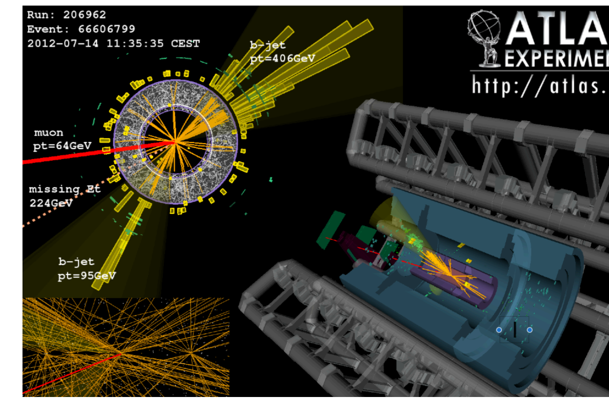






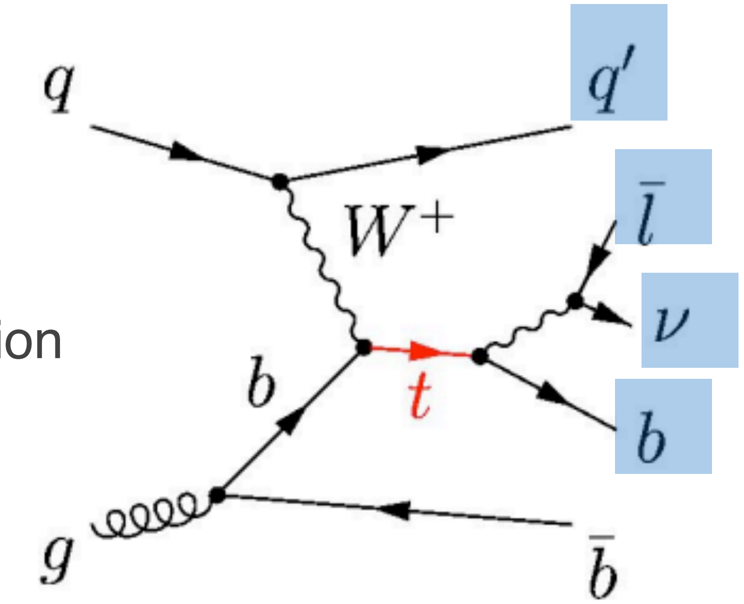
Single-top-quark results with ATLAS & CMS

- ATLAS and CMS results @8TeV and @13TeV

fully/ partially covered in this talk	**t-channel** 	**tW-channel** 	**s-channel** 
8TeV	**CMS:** JHEP06(2014)090 **ATLAS:** EPJC77(2017)531	**CMS:** PRL.112.231802 **ATLAS:** JHEP01(2016)064 **Combination:** ATLAS-CONF-2016-023	**CMS:** HEP09(2016)027 **ATLAS:** PLB756(2016)228–246
13TeV	**CMS:** CMS-PAS-TOP-17-011 **ATLAS:** JHEP04(2017)086	**CMS:** arxiv:1805.07399(inclusive) **ATLAS:** JHEP01(2018)063 (inclusive) EPJC78(2018)186 (differential) arXiv:1806.04667 (interference)	no results @13TeV (but hopefully soon!)

t-channel @ 13TeV

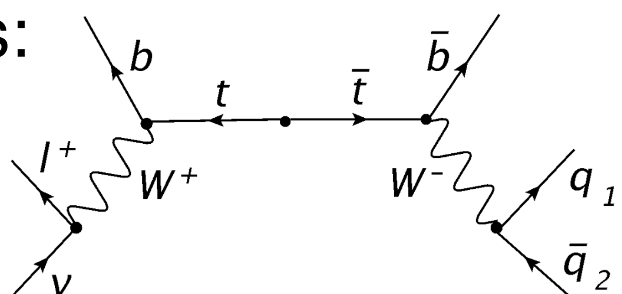
- *t*-channel signature (single lepton decay):
  - One isolated **lepton (e,μ)**
    - **e:** p_T>35GeV, $|\eta|$<2.1 and isolation requirement (I_{rel} < 0.06)
    - **μ:** p_T>26GeV, $|\eta|$<2.4 and isolated requirement (I_{rel} < 0.06)
    - additional lepton veto: e(p_T>10GeV) or **μ**(p_T>10GeV) + relaxed isolation
  - Two high-p_T Anti-k_t jets (p_T> 40GeV) and $|\eta|$<4.7
    - one ***b*-tagged jet** (40% eff, light mistag 0.1%)
  - Missing transverse energy (**MET**) from the neutrino
    - e: MET > 30GeV
    - μ: $m_T(W)$> 50GeV



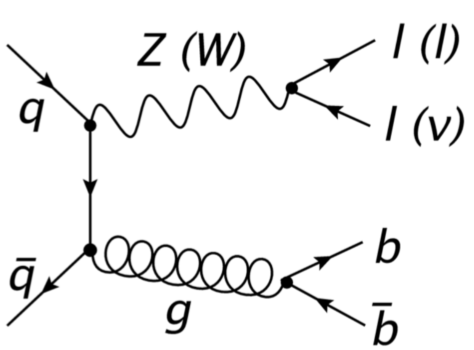
POWHEG 2.0 (4FS) PYTHIA8.2 CUETP8M1 NNPDF3.0

- Backgrounds:

$t\bar{t}$



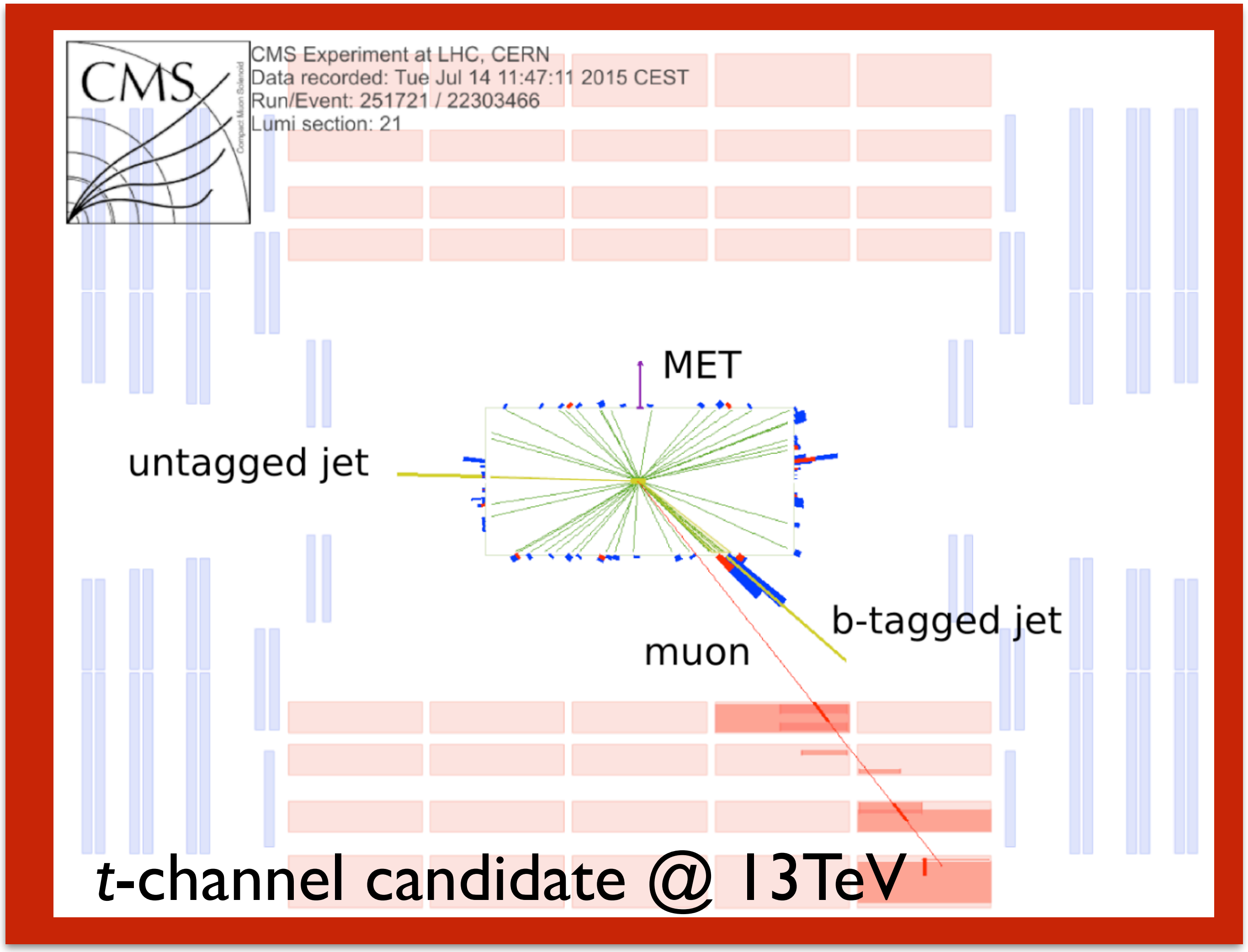
POWHEG 2.0 PYTHIA8.2
CUETP8M2T4 NNPDF3.0



W+jets

MG5_aMC@NLO2.2.2(FxFx) PYTHIA8.2
CTUETP8M1 NNPDF3.0

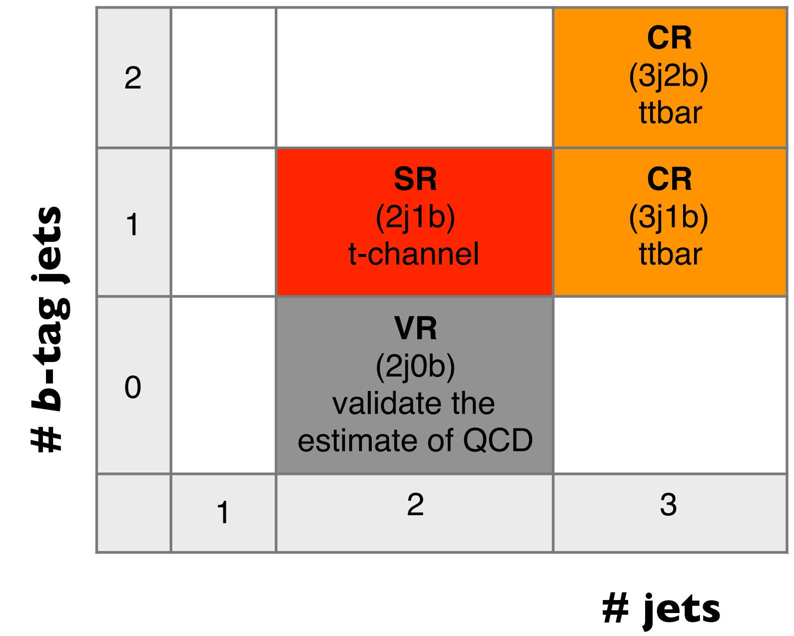
  - Mostly estimated from MC
  - QCD from data (fit to m_T(W) and MET)



Different categories (n-jets, m-*b*tags)

Event yields in the Signal Region (SR)

Process	μ^+	μ^-	e^+	e^-
Top quark pair production	81172 ± 13480	81572 ± 13517	64839 ± 10331	65205 ± 10185
tW	8755 ± 1799	8762 ± 1843	6837 ± 1406	6885 ± 1387
W/Z+jets	38199 ± 12334	33373 ± 10568	23907 ± 8064	21494 ± 6811
QCD	6732 ± 3241	6713 ± 3235	11282 ± 5430	10605 ± 5109
Single top quark *t*-channel	23628 ± 2918	14574 ± 1883	15103 ± 1840	9395 ± 1188
Total expected	158486 ± 18870	144994 ± 17658	121969 ± 14374	113584 ± 13400
Observed	166446	151440	124857	116206

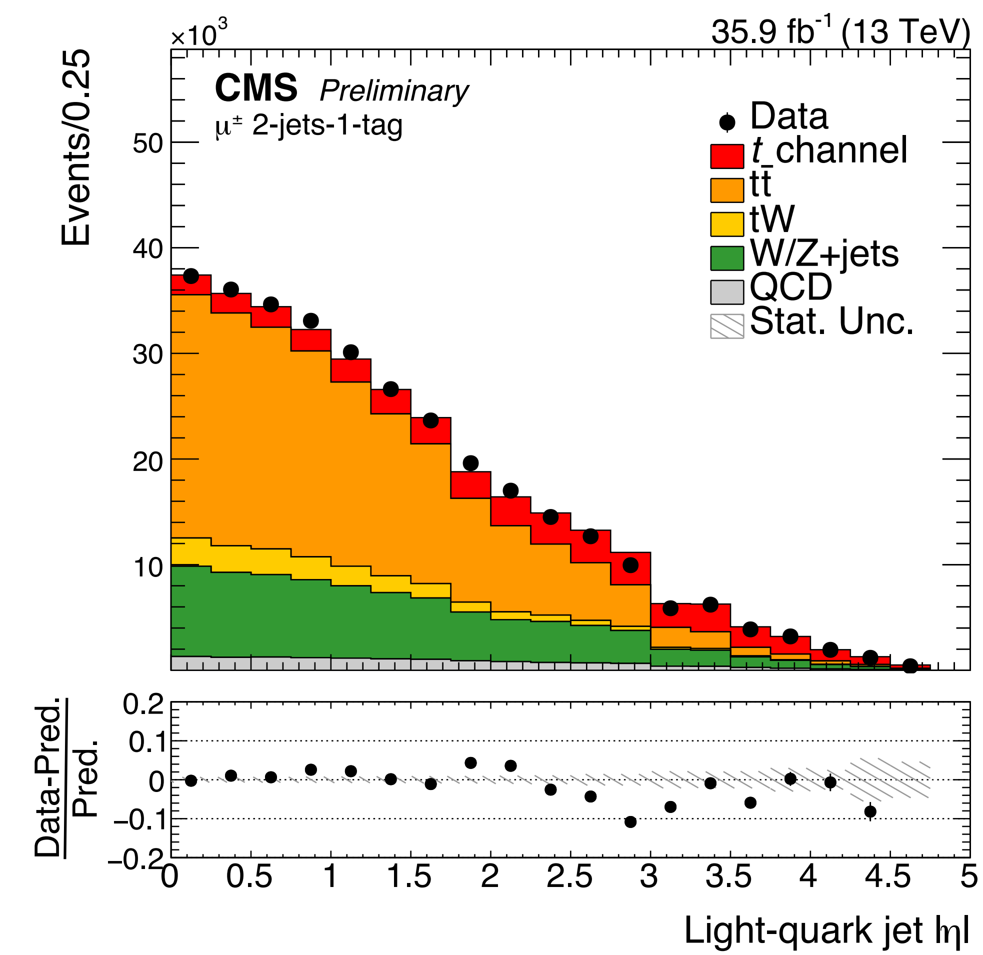


BDT to separate signal from background

- BDT trained in 2j1b (separately for *e* and *μ*)
- 10(11) variables for e(*μ*)

Variable	Description
Light-quark jet $\lvert\eta\rvert$	Absolute value of the pseudorapidity of the light-quark jet
Dijet mass	Invariant mass of the light-quark jet and the b-tagged jet associated to the top quark decay
Top quark mass	Invariant mass of the top quark reconstructed from the lepton, the neutrino and the b-tagged jet associated to the top quark decay
ΔR (lepton, b jet)	ΔR between the momentum vectors of the lepton and the b-tagged jet associated to the top quark decay
$\cos(\theta^*)$	Cosine of the angle between the lepton and the light-quark jet in the rest frame of the top quark

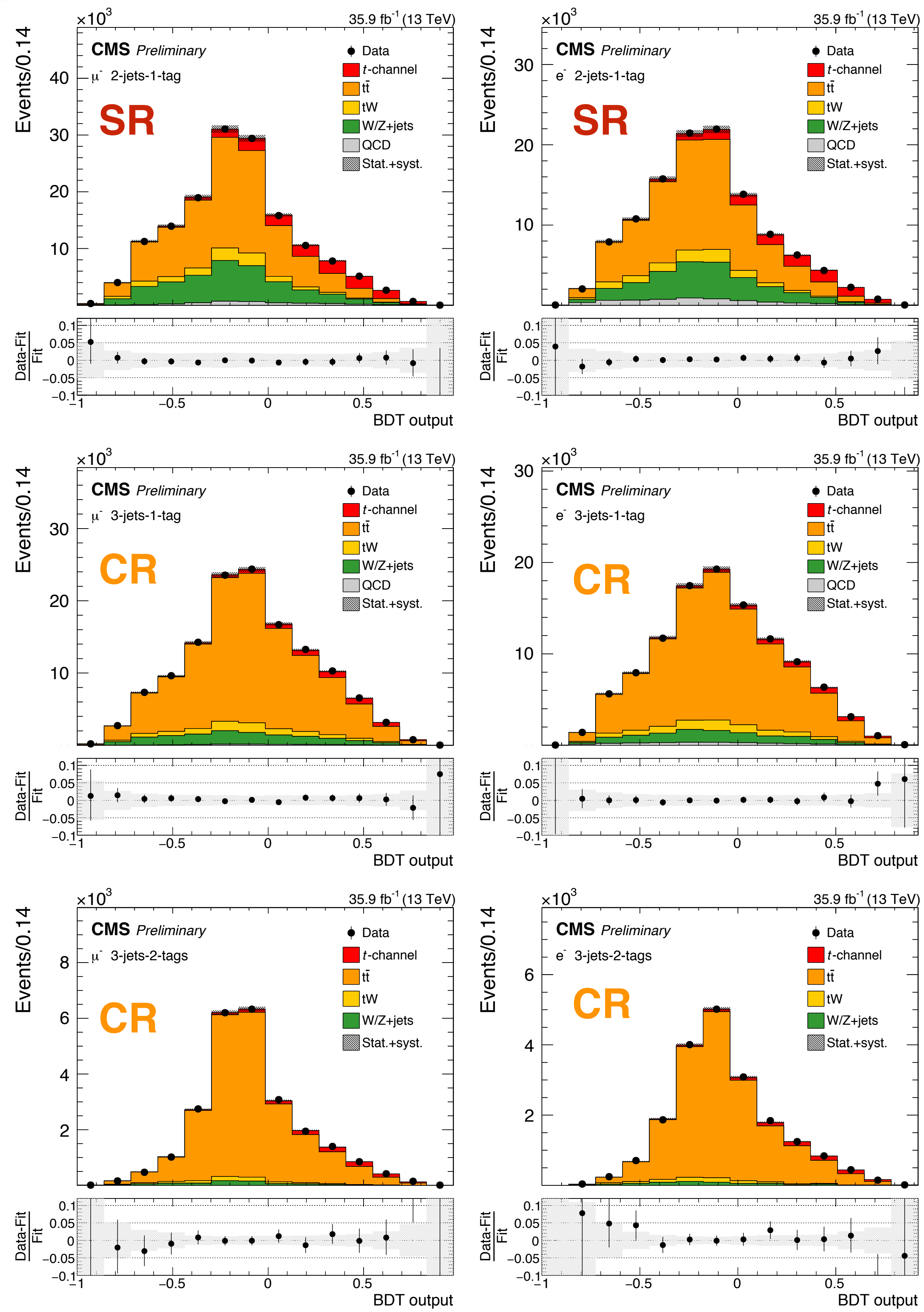
Most important 5 variables



t-channel @ 13TeV

- **BDT applied to SR and CR** (for different charge/flavour lepton)

- **Maximum Likelihood fit**
  - Simultaneous fit on 12 BDT distributions (e-mu, 2j1b, 3j1b, 3j2b, lepton charge)
  - CR used to constrain $t\bar{t}$
  - Free parameters:
    - μ for t-quark cross-section
    - μ for $\bar{t}$-quark cross-section
    - μ for $R_{t\text{-ch}} = \sigma(t)/\sigma(\bar{t})$
  - Two fit procedures (correlations included):
    1. $\mu(\bar{t})$ and $\mu(R_{t\text{-ch}})$
    2. $\mu(\bar{t})$ and $\mu(t)$ → reproduces $R_{t\text{-ch}}$



t-channel @ 13TeV

- **Systematic uncertainties**
  - Profiled uncertainties
    - Included in the fit as NP
  - External uncertainties (signal modelling)
    - Analysis redone with varied templates
    - Uncertainty as 0.5*|up-down|
  - Luminosity (± 2.5%)

		$\Delta R/R$	$\Delta\sigma/\sigma(\mathrm{t})$	$\Delta\sigma/\sigma(\bar{\mathrm{t}})$
Signal modelling	PDF t channel	1.4	0.7	0.6
	PS-scale t channel	1.1	12.5	13.8
	ME-PS scale matching t channel	0.2	1.5	1.8
	μ_R/μ_F scale t channel	0.1	6.3	6.2
	QCD normalization	2.1	1.7	3.8
	JES	1.9	6.6	8.4
	$\mathrm{t\bar{t}}$ modeling and normalization	1.9	0.8	3.2
	Top quark p_T	1.2	4.0	5.2
	MC sample size	0.9	1.8	0.5
	μ_R/μ_F scale	0.8	1.0	0.3
	Pileup	0.4	1.4	1.8
	Muon and electron efficiencies	0.3	0.1	0.5
	JER	0.2	0.4	0.7
	b tagging	0.2	1.2	1.4
	PDF	0.1	0.1	0.2
	Unclustered energy	0.1	0.4	0.6
	W/Z+jets normalization	0.1	0.9	0.9
	tW normalization	< 0.1	0.2	0.2

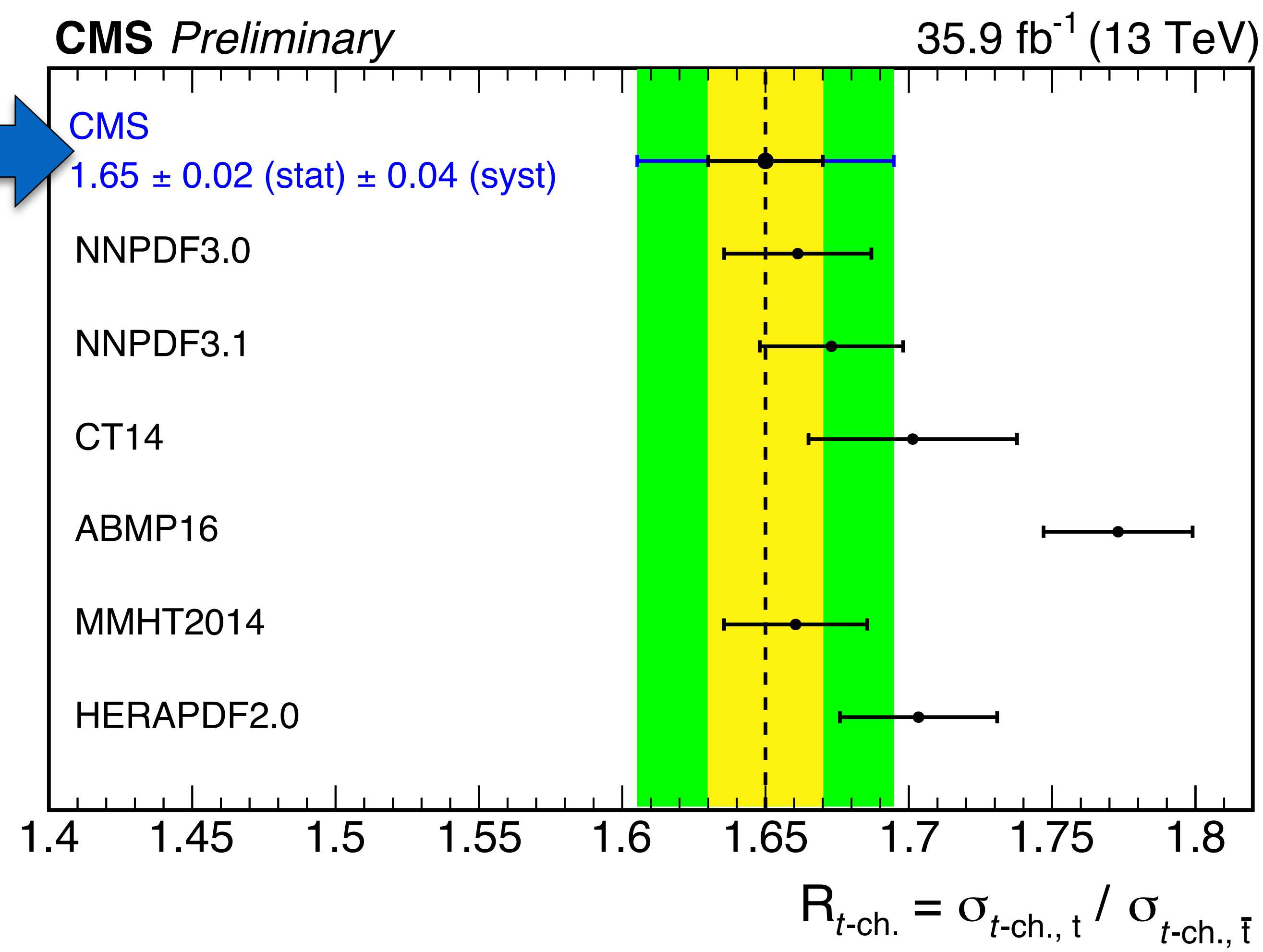
***t*-channel** $\sigma_{\text{t-chan,t}} = 136.3 \pm 1.1(\text{stat}) \pm 3.4(\text{prof}) \pm 19.4(\text{ext}) \pm 3.4(\text{lumi})\text{pb}$ (15%)

***t̄*-channel** $\sigma_{\text{t-chan},\bar{t}} = 82.7 \pm 1.1(\text{stat}) \pm 2.7(\text{prof}) \pm 12.6(\text{ext}) \pm 2.1(\text{lumi})\text{pb}$ (16%)

$R_{t\text{-ch}}$ $R_{\mathrm{t}} = 1.65 \pm 0.02(\text{stat}) \pm 0.03(\text{prof}) \pm 0.03(\text{ext})\text{pb}$ (3%)

t-channel @ 13TeV

- **$R_{t\text{-ch}}$ compared with predictions**
  - In general good agreement
  - ABMP16 2σ away from the expectation



- ***t*-channel total cross-section:**

$$\sigma_{\text{t-chan}} = 219.0 \pm 1.5(\text{stat}) \pm 33.0(\text{syst})\text{pb}$$

(stat. unc. uncorrelated and syst. unc. correlated between *t* and $\bar{t}$ cross-sections)

$$|f_{\rm LV} V_{\rm tb}| = 1.00 \pm 0.05\,(\text{exp}) \pm 0.02\,(\text{theo}).$$

ATLAS ***t*-channel cross-sections, V_{tb} and R_t measured at 13TeV @3.2fb^{-1}**

cross-sections

$$\sigma_{\text{t-chan,t}} = 156 \pm 5(\text{stat}) \pm 27(\text{syst}) \pm 3(\text{lumi})\text{pb}$$

$$\sigma_{\text{t-chan},\bar{t}} = 91 \pm 4(\text{stat}) \pm 18(\text{syst}) \pm 2(\text{lumi})\text{pb}$$

V_{tb} and R_t

$$|f_{LV} V_{tb}| = 1.07 \pm 0.09$$

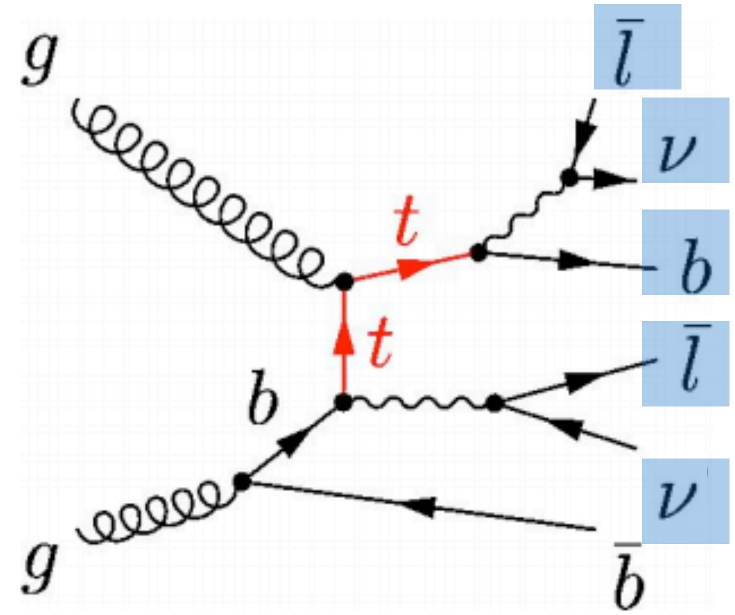
$$R_t = 1.72 \pm 0.09(\text{stat}) \pm 0.18(\text{syst})$$

(Rt plots @8TeV and @13 TeV shown in the backup)

tW production @ 13 TeV

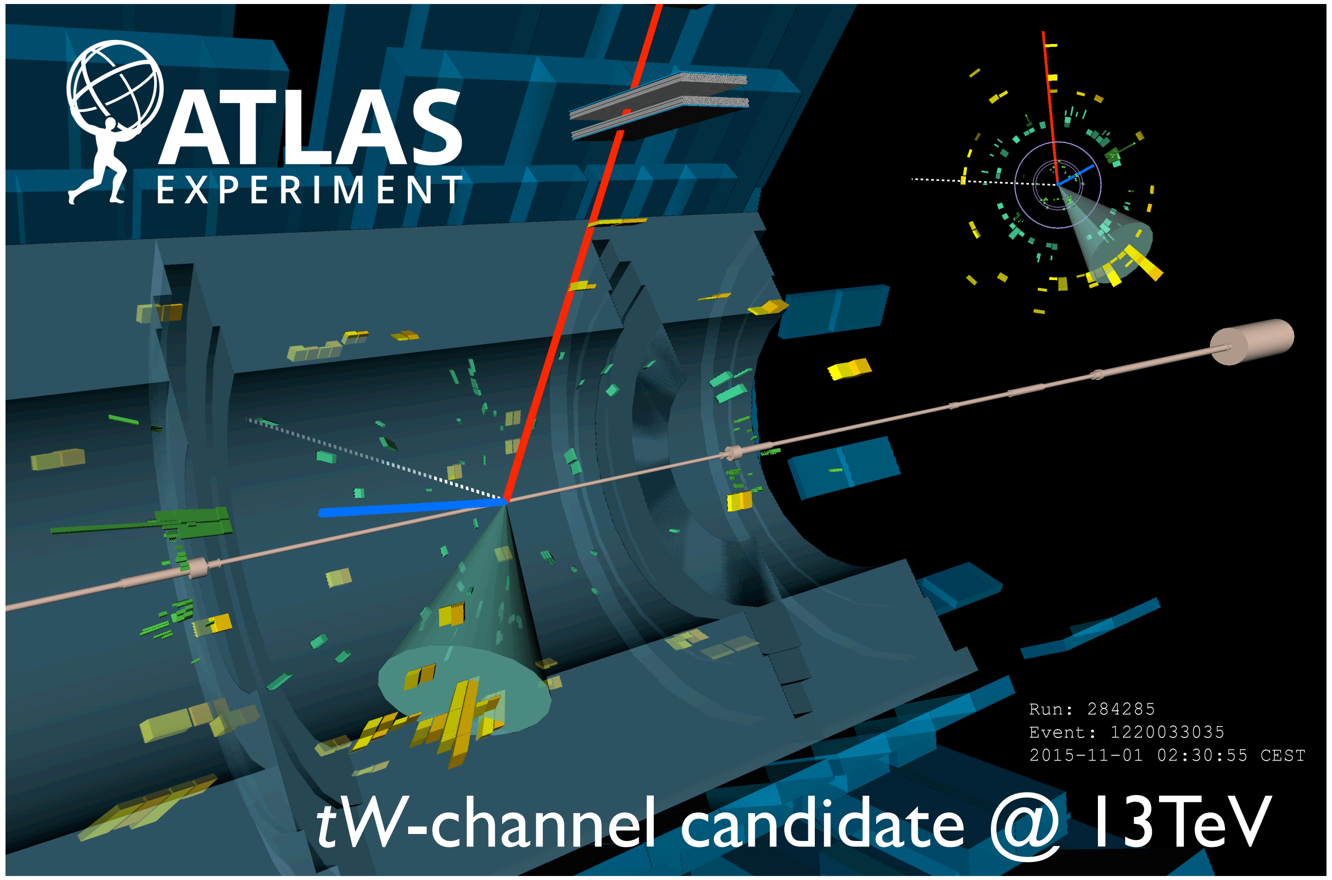
ATLAS and CMS have measured the **inclusive**, **fiducial** and **differential** *tW* cross-section

(presented in Top2017 and also in the YSF Top2018)



- *tW*-channel signature (dilepton decay):
  - Two opposite charged isolated **leptons**
  - Missing transverse energy (**MET**)
  - One central high-p_T jet (***b*-tagged jet**)

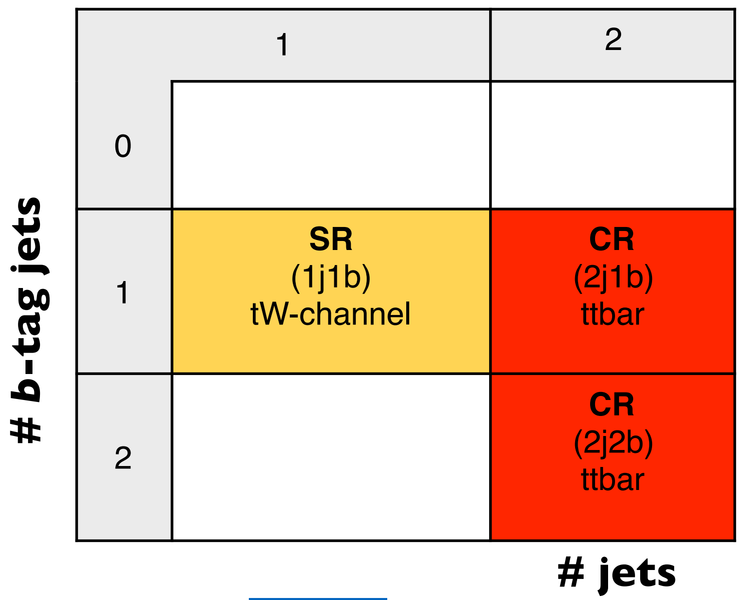
Cuts	CMS	ATLAS
Leptons	*eμ* OS (p_T>20GeV)	ee/*μμ*/*eμ* OS (p_T(1)>27GeV)
Jets	p_T > 30GeV (loose jets 20 <p_T<30GeV)	p_T > 25GeV
b-tag	70% eff.	77 eff.
MET	—	triangular cut (MET & m_{ll})

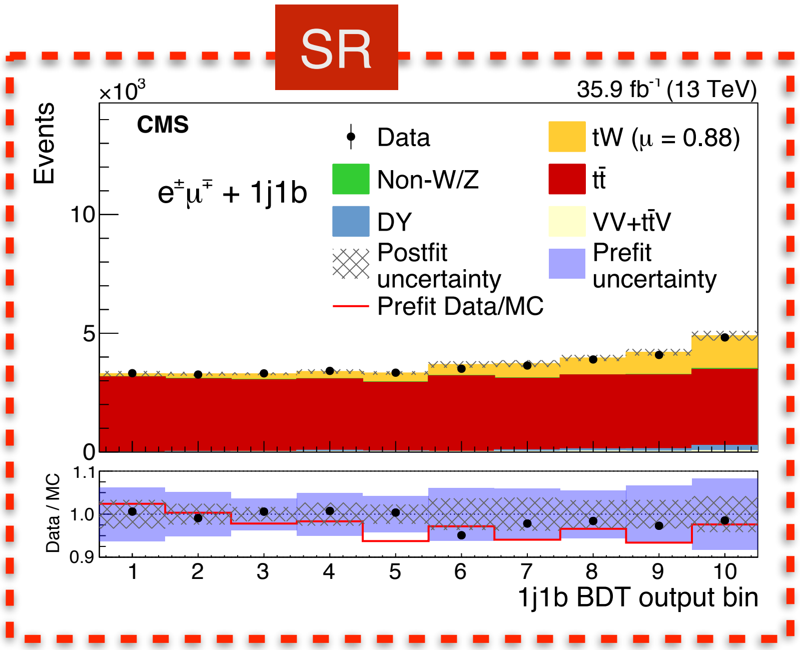


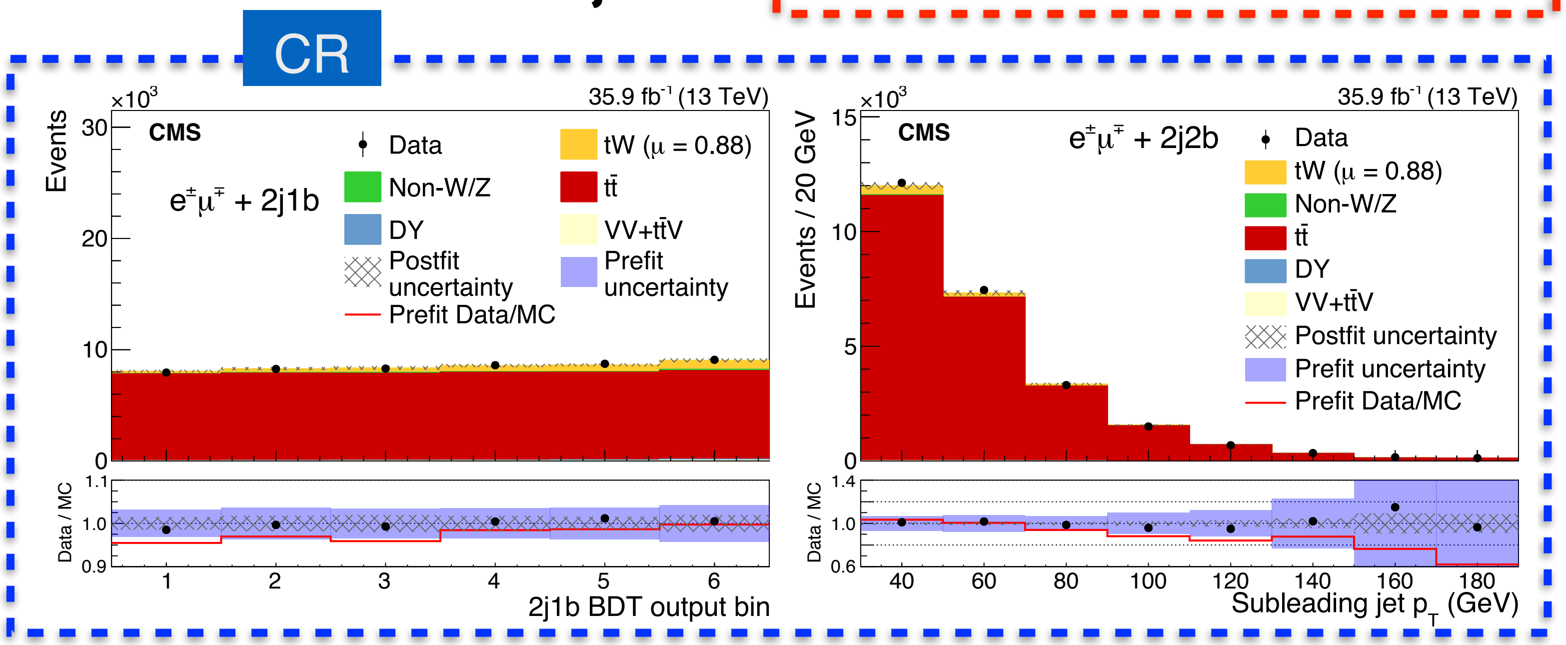
- Main background $t\bar{t}$

tW inclusive CMS

- **S-B separation**: BDT in the 1j1b and 2j1b
- **ML fit** to the **BDT** distribution in 1j1b/2j2b and **$p_T(j_2)$** in 2j2b





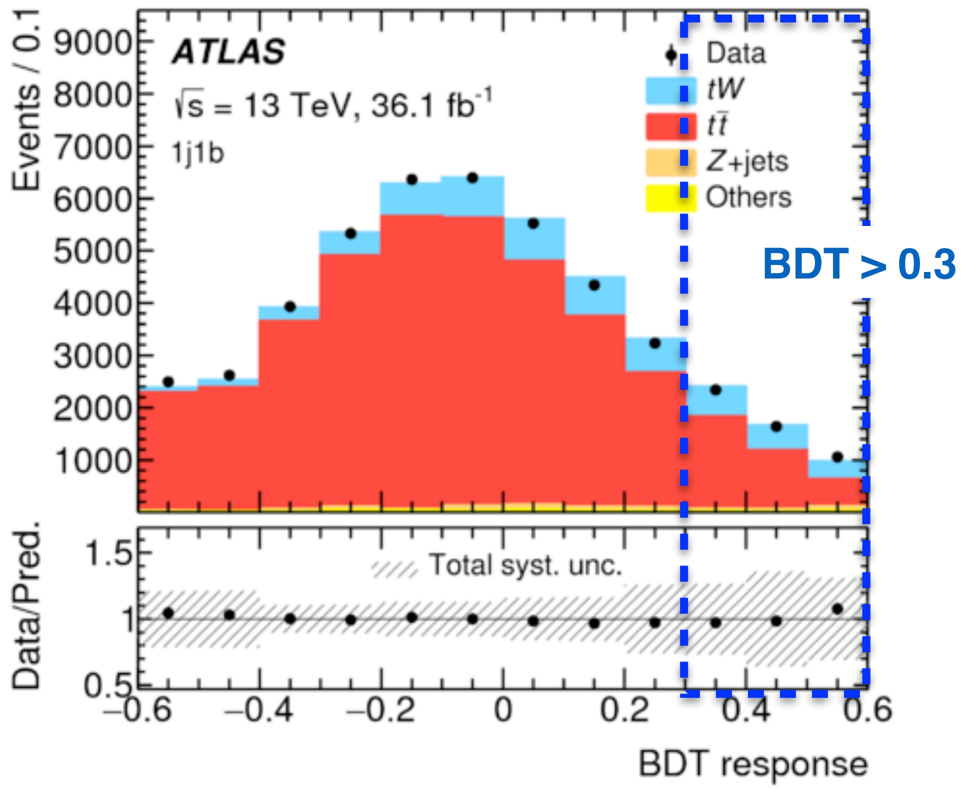


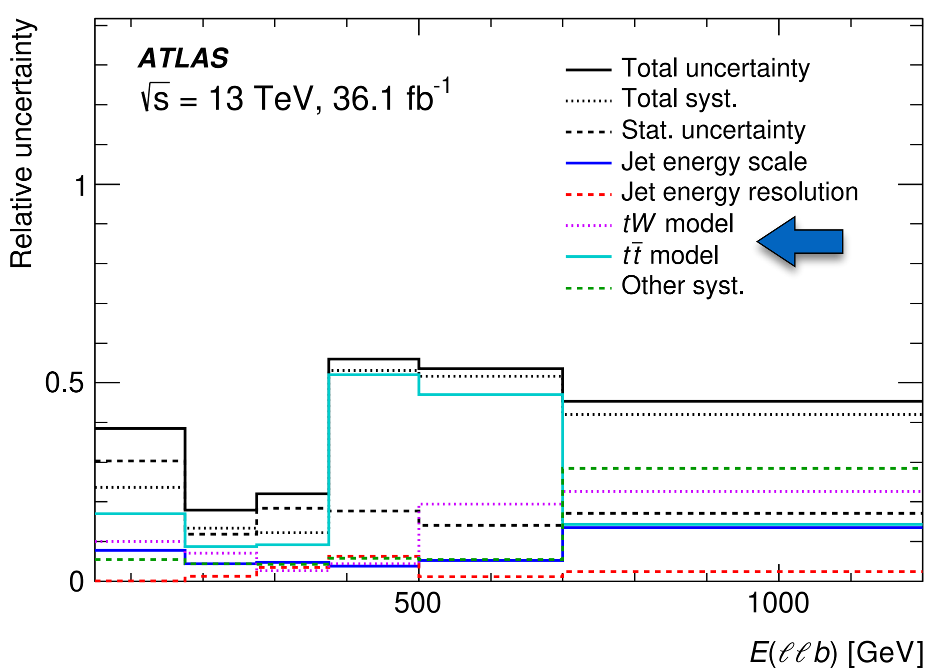
$$\sigma_{tW} = 63.1 \pm 6.6 pb$$ (11%)

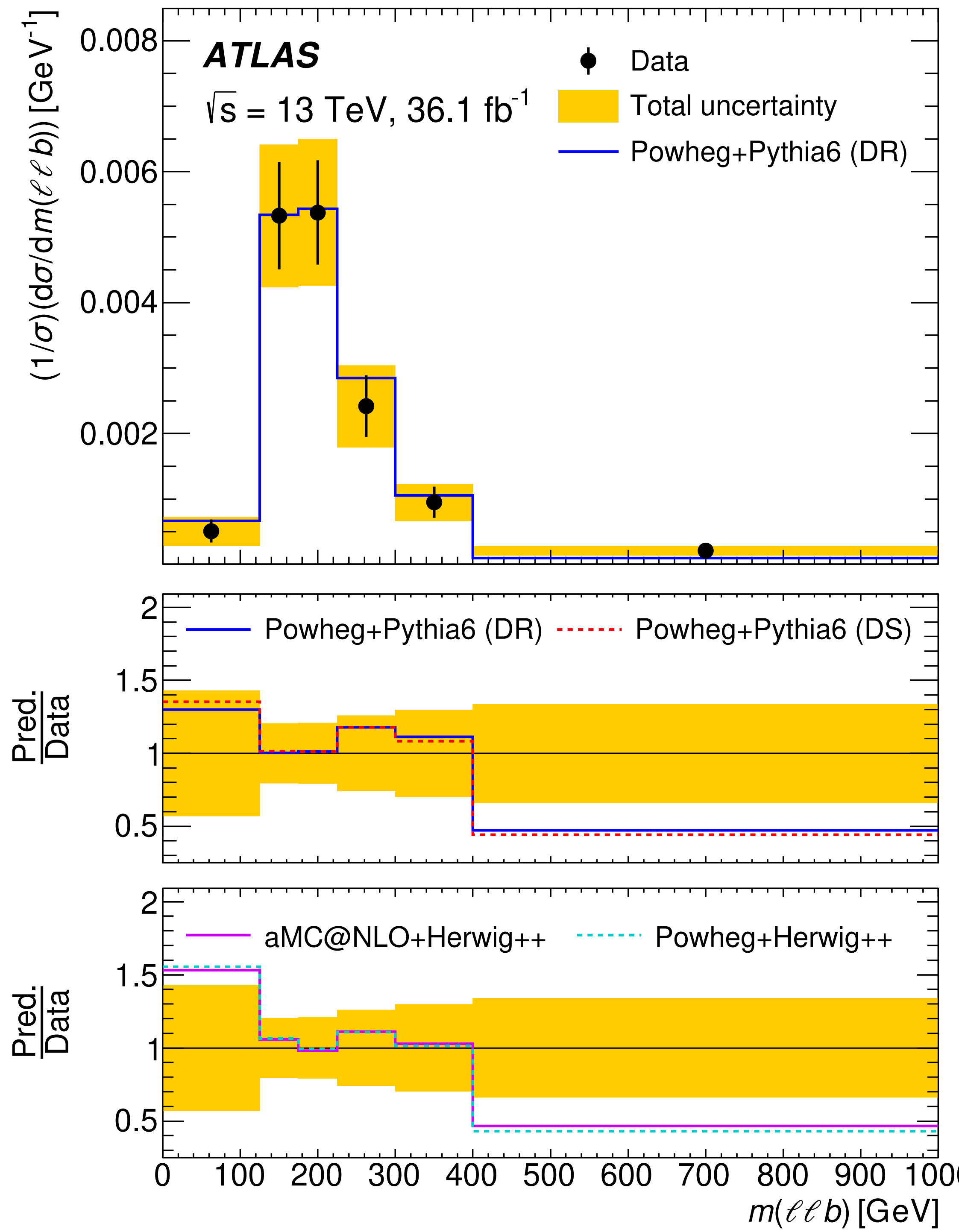
Source	Uncertainty (%)
Experimental	
Trigger efficiencies	2.7
Electron efficiencies	3.2
Muon efficiencies	3.1
JES	3.2
Jet energy resolution	1.8
b tagging efficiency	1.4
Mistag rate	0.2
Pileup	3.3
Modeling	
$t\bar{t}$ μ_R and μ_F scales	2.5
tW μ_R and μ_F scales	0.9
Underlying event	0.4
Matrix element/PS matching	1.8
Initial-state radiation	0.8
Final-state radiation	0.8
Color reconnection	2.0
B fragmentation	1.9
Semileptonic B decay	1.5
PDFs	1.5
DR-DS	1.3
Background normalization	
$t\bar{t}$	2.8
VV	0.4
Drell–Yan	1.1
Non-W/Z leptons	1.6
$t\bar{t}V$	0.1
MC finite sample size	1.6
Full phase space extrapolation	2.9
Total systematic (excluding integrated luminosity)	10.1
Integrated luminosity	3.3
Statistical	2.8
Total	11.1

tW differential ATLAS

- **S-B separation**: BDT in the 1j1b (BDT cut > 0.3 (S:B=1:2)
- Back. subtracted data **unfolding to particle level**
- Unfolded distributions for: E(b), E(llb), $m_T(ll\nu\nu b)$, $m(l_1b)$,m(llb),$m(l_2b)$



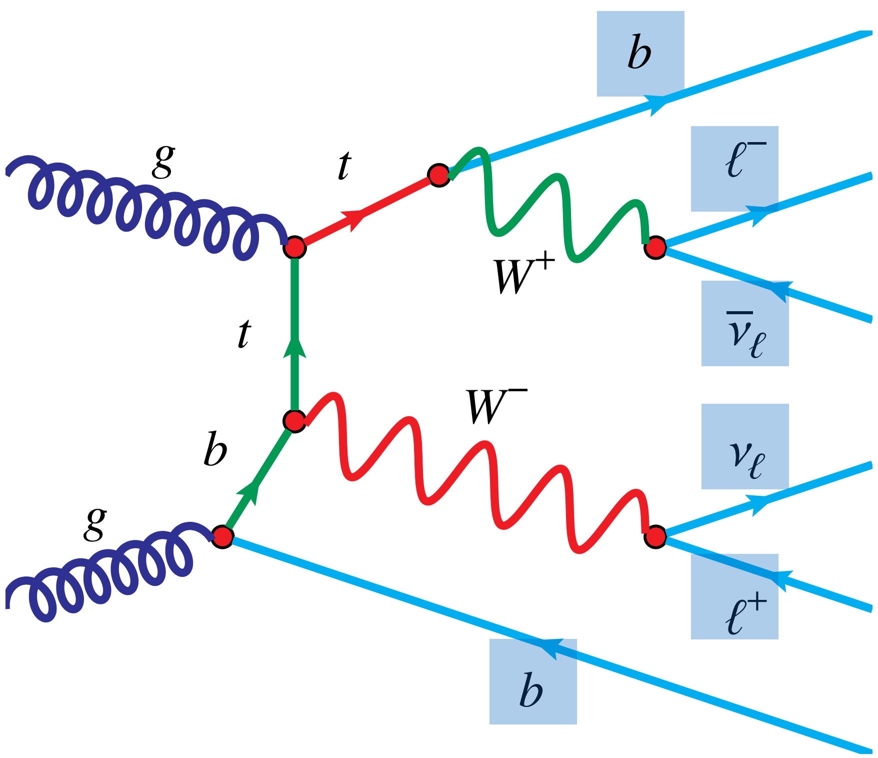




More details in Carls's talk

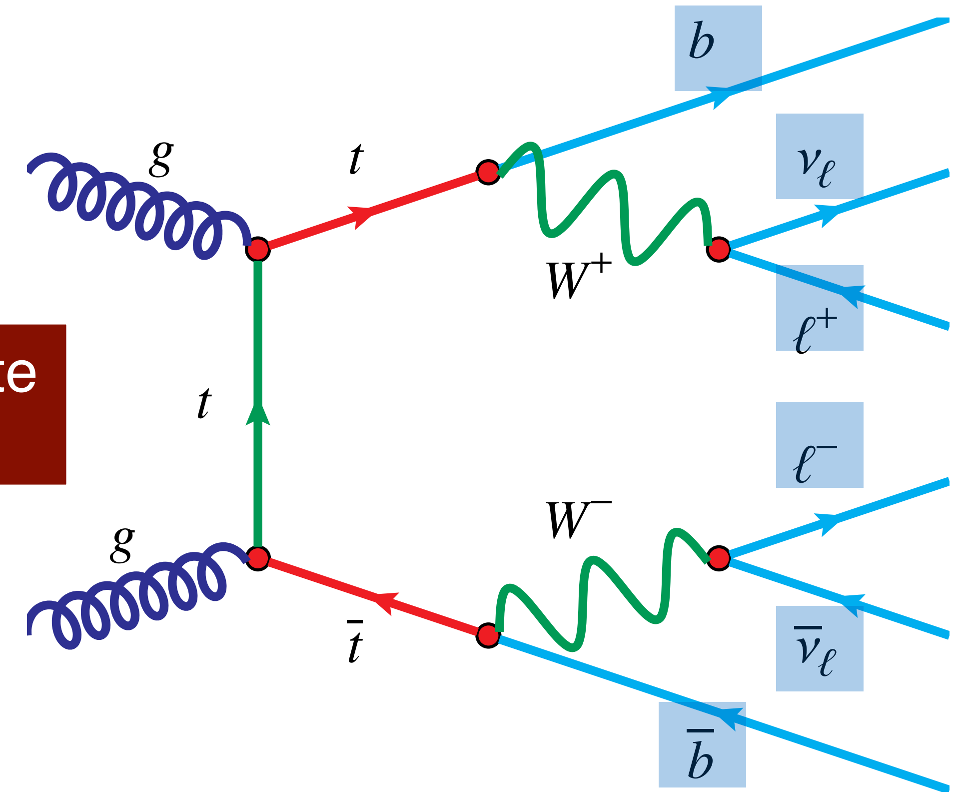
Interference: tW and tt

- *tW* interfere with $t\bar{t}$ beyond LO:



single resonant

same final state
WW*bb*



double resonant

- Standard calculations factorise both processes (narrow-width approx.)
  - Different interference schemes used to estimate the impact of this effect
- Size of the interference depends on the phase space → large impact on searches

Interference: tW and tt

- The NLO corrections to the LO *tW* amplitude:

$$| A_{tW} |^2 = | A_{t\bar{t}} |^2 + | A_{tWb} |^2 + 2Re\{A^*_{t\bar{t}} \cdot A_{tWb}\}$$

$t\bar{t}$ @LO — tW@NLO — interference

- **Different alternatives used to handle the interference @NLO**
  - **Diagram Removal (DR):** *JHEP07(2008)029*
    - removes all $t\bar{t}$ diagram contributions, also interference ($A_{t\bar{t}}$=0)

$$| A_{tW} |^2_{DR} = | A_{tWb} |^2$$

  - **Diagram Removal 2 (DR2):** *EPJC77(2017)34*
    - removes $t\bar{t}$ LO contribution but keep interference term

$$| A_{tW} |^2_{DR2} = | A_{tWb} |^2 + 2Re\{A^*_{t\bar{t}} \cdot A_{tWb}\}$$

  - **Diagram Subtraction (DS):** *JHEP07(2008)029*
    - cancels the resonant $t\bar{t}$ contribution with local sub. term
    - includes interference

$$| A_{tW} |^2_{DS} = | A_{t\bar{t}} + A_{tWb} |^2 - C_{2t}$$

  - **4lbb (lvlvbb):** *EPJC76(2016)691*
    - implemented in PowHeg, no narrow-width approx., interference is automatically handled

Interference: tW and tt

- The NLO corrections to the LO *tW* amplitude:

$$|A_{tW}|^2 = |A_{t\bar{t}}|^2 + |A_{tWb}|^2 + 2Re\{A^*_{t\bar{t}} \cdot A_{tWb}\}$$

tt̄ @LO — tW@NLO — interference

- **Different alternatives used to handle the interference @NLO**
  - ➡ **Diagram Removal (DR):** *JHEP07(2008)029*
    - removes all tt̄ diagram contributions, also interference ($A_{t\bar{t}}$=0)

    $$|A_{tW}|^2_{DR} = |A_{tWb}|^2$$

  - ➡ **Diagram Removal 2 (DR2):** *EPJC77(2017)34*
    - removes tt̄ LO contribution but keep interference term

    $$|A_{tW}|^2_{DR2} = |A_{tWb}|^2 + 2Re\{A^*_{t\bar{t}} \cdot A_{tWb}\}$$

  - ➡ **Diagram Subtraction (DS):** *JHEP07(2008)029*
    - cancels the resonant tt̄ contribution with local sub. term
    - includes interference

    $$|A_{tW}|^2_{DS} = |A_{t\bar{t}} + A_{tWb}|^2 - C_{2t}$$

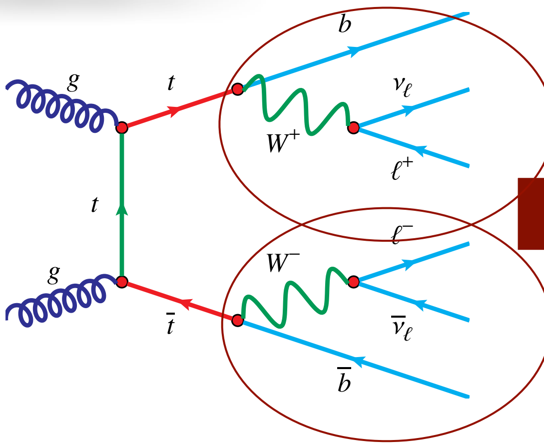
  - ➡ **4lbb (lvlvbb):** *EPJC76(2016)691*
    - implemented in PowHeg, no narrow-width approx., interference is automatically handled

New approach to test interference models:
differential cross-section measurements as a function of a variable sensitive to interference effects

Interference: tW and $t\bar{t}$

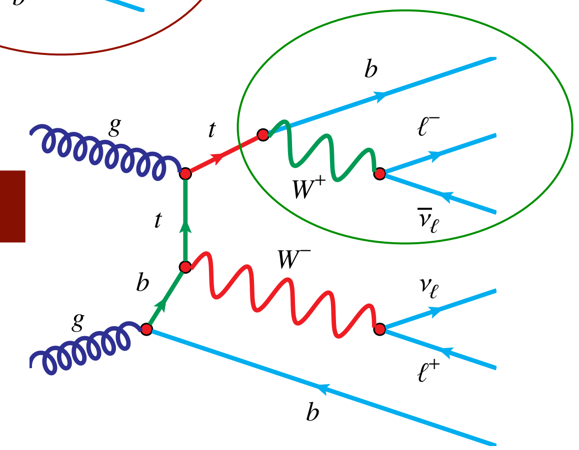
- **Discriminant to exploit the differences between both processes: m(*bW*)**
  - In $t\bar{t}$: $m^2(\mathbf{bW}) \sim m^2_t$
  - In *tWb:* one pair is off from m_t

- ***WWbb (dilepton)* is considered as signal**
  - Lepton used as a proxy for the *W*: m(*bl*)



$t\bar{t}$ production

two *(b,l) pairs from top*



tW production

one *(b,l) pair from top*

Discriminant:

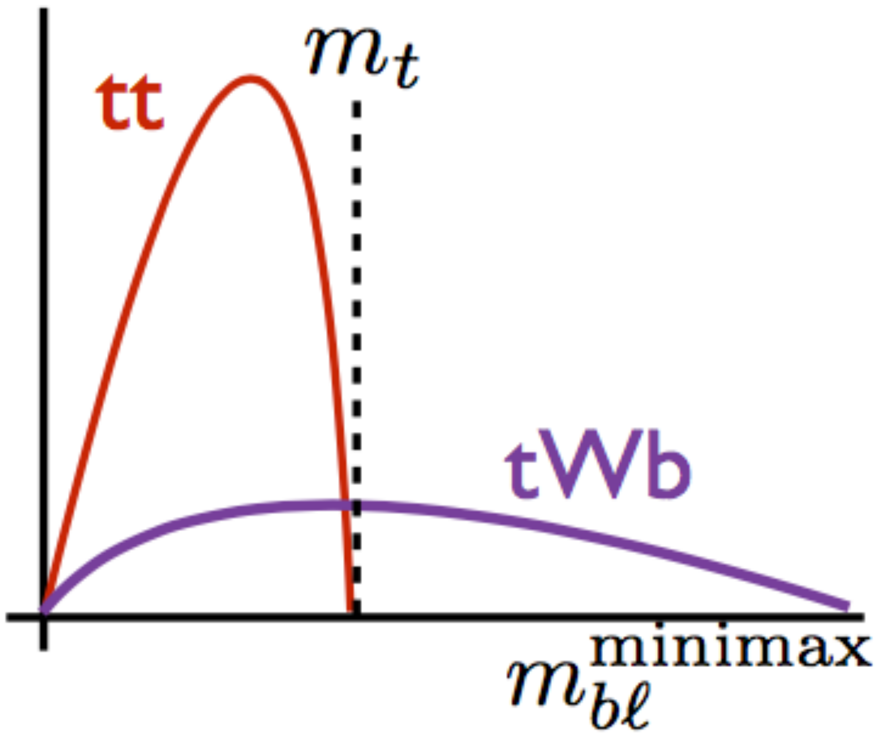
$$\min\{\max\{m(b_1l_1),m(b_2l_2)\},\max\{m(b_1l_2),m(b_2l_1)\}\}$$

<u>**For $t\bar{t}$:**</u>

- When *b*-jet/lepton correctly assigned: $m(bl) \leq m_t$
- Correct assignment not known a priory:
  - $\min\{\max\{m(b_1l_1),m(b_2l_2)\},\max\{m(b_1l_2),m(b_2l_1)\}\} \leq m_t$

<u>**For *tWb*:**</u>

- One m(*bl*) smaller than m_t, the other could be larger
  - $\min\{\max\{m(b_1l_1),m(b_2l_2)\},\max\{m(b_1l_2),m(b_2l_1)\}\} \geq m_t$



Interference: tW and tt

- **Event selection in the SR**

Selection	Signal
Signal leptons	= 2 (Tight leptons with p_T>28GeV, Iηl<2.5)
Lepton charges	opposite
Lepton flavor	all: ee/μμ/eμ
$\|m_{\ell\ell} - m_Z\| < 15$ GeV	veto + m(ll) > 10GeV for same-flavour lepton pair
b-tagged jets 60% eff. WP	= 2 (p_T > 25GeV, Iηl<2.5)
b-tagged jets 85% eff. WP	= 2 (veto third loose-ID *b*-jet)

- *WWbb* signal accounts for the 95% of the events after the selection

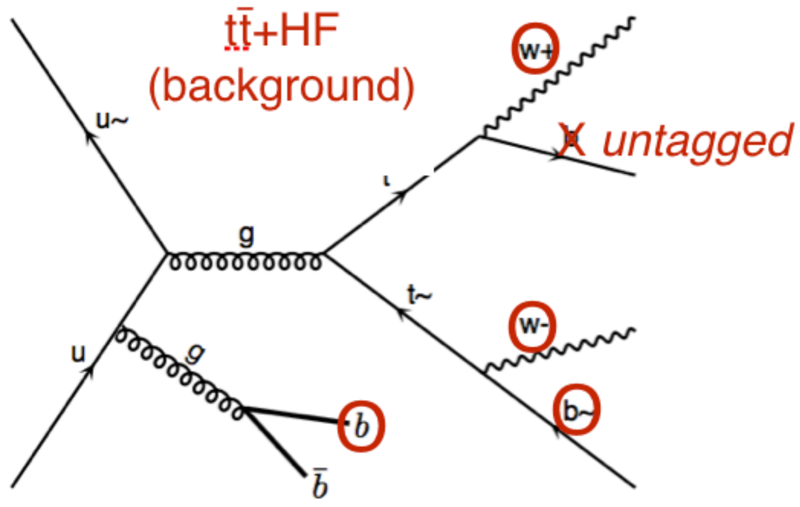
- **Background**:
  - $t\bar{t}$V and VV+jets (MC based)
  - non-prompt and misidentify leptons (CR using same-charge lepton pair)
  - Z+jets (SF derived from a CR)
  - $t\bar{t}$ + heavy-flavour (SF derived from a CR)

Interference: tW and tt

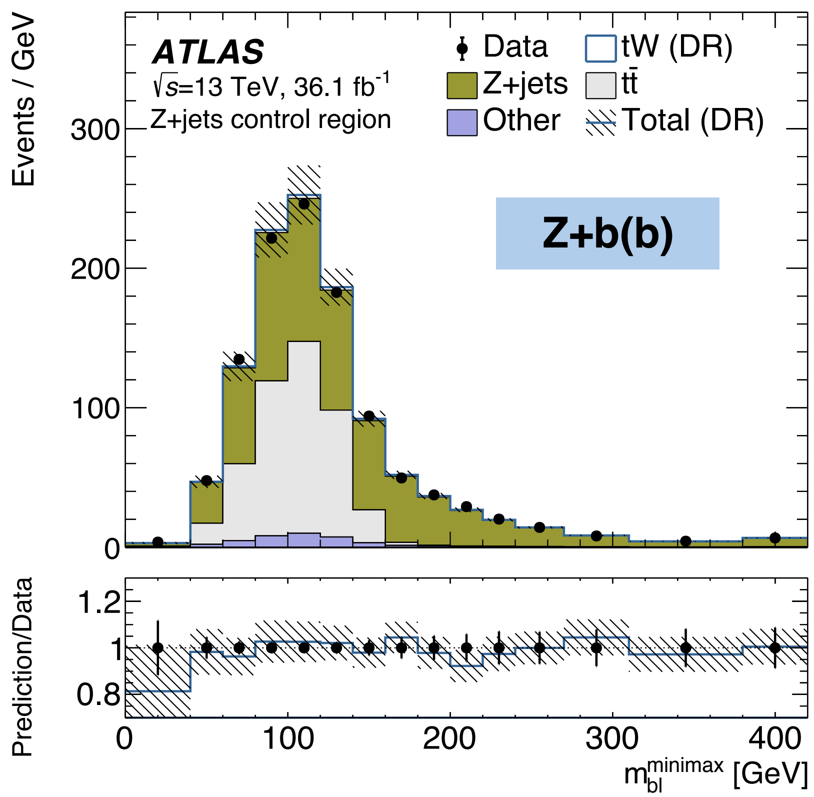
Control regions

Selection	Z+b(b) Z CR	tt+HF jets 3b CR
Signal leptons	= 2	= 2
Lepton charges	opposite	opposite
Lepton flavor	$ee/\mu\mu$	–
$\lvert m_{\ell\ell} - m_Z \rvert < 15$ GeV	require	veto
b-tagged jets 85% eff. WP	= 2	≥ 3
b-tagged jets 60% eff. WP	= 2	≥ 3

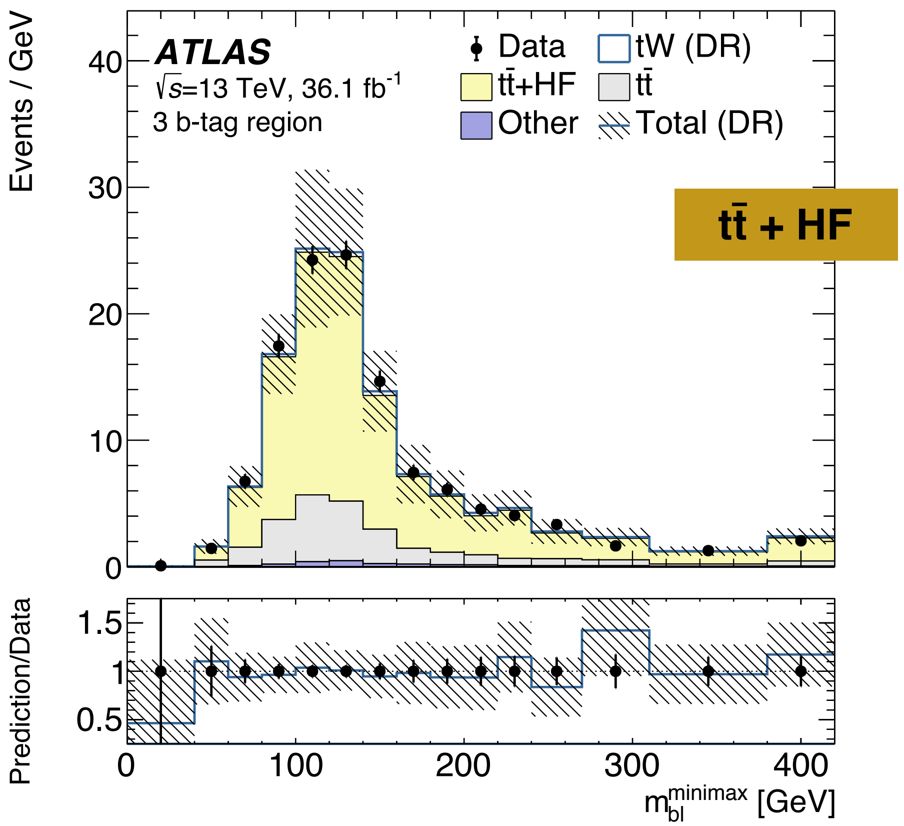
- $t\bar{t}$ with extra *b*-jets can populate region for high values of m(*lb*)



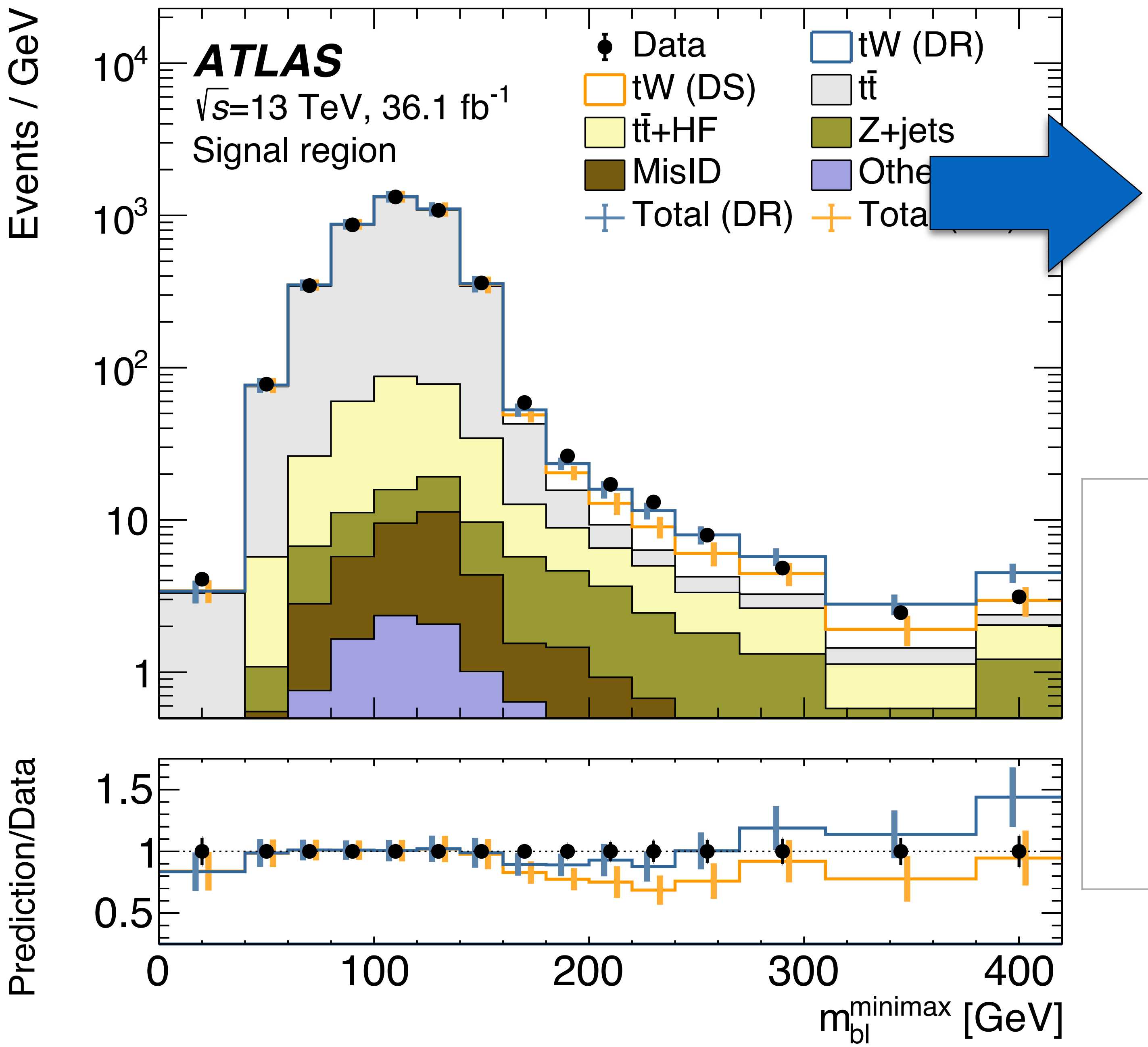
- data-MC normalisation factor



- data-MC normalisation factor derived



- Final discriminant at reconstructed level
  - More *tW* events in the tail
  - Prediction for both *tW* interference schemes (**DR** and **DS**) shown



- **Unfolded to particle level**
  - *tWb+tt̄* signal unfolded
  - All backgrounds subtracted
  - Using Bayesian iterative method

- **Particle level definition:**
  - leptons before radiation
  - jets built form stable truth particles (*b*-tagged if B-hadron associated)
  - Same cuts as reconstructed level applied
  - Events with more than 2 b-jets (p_T>5GeV) are rejected

Interference: tW and tt

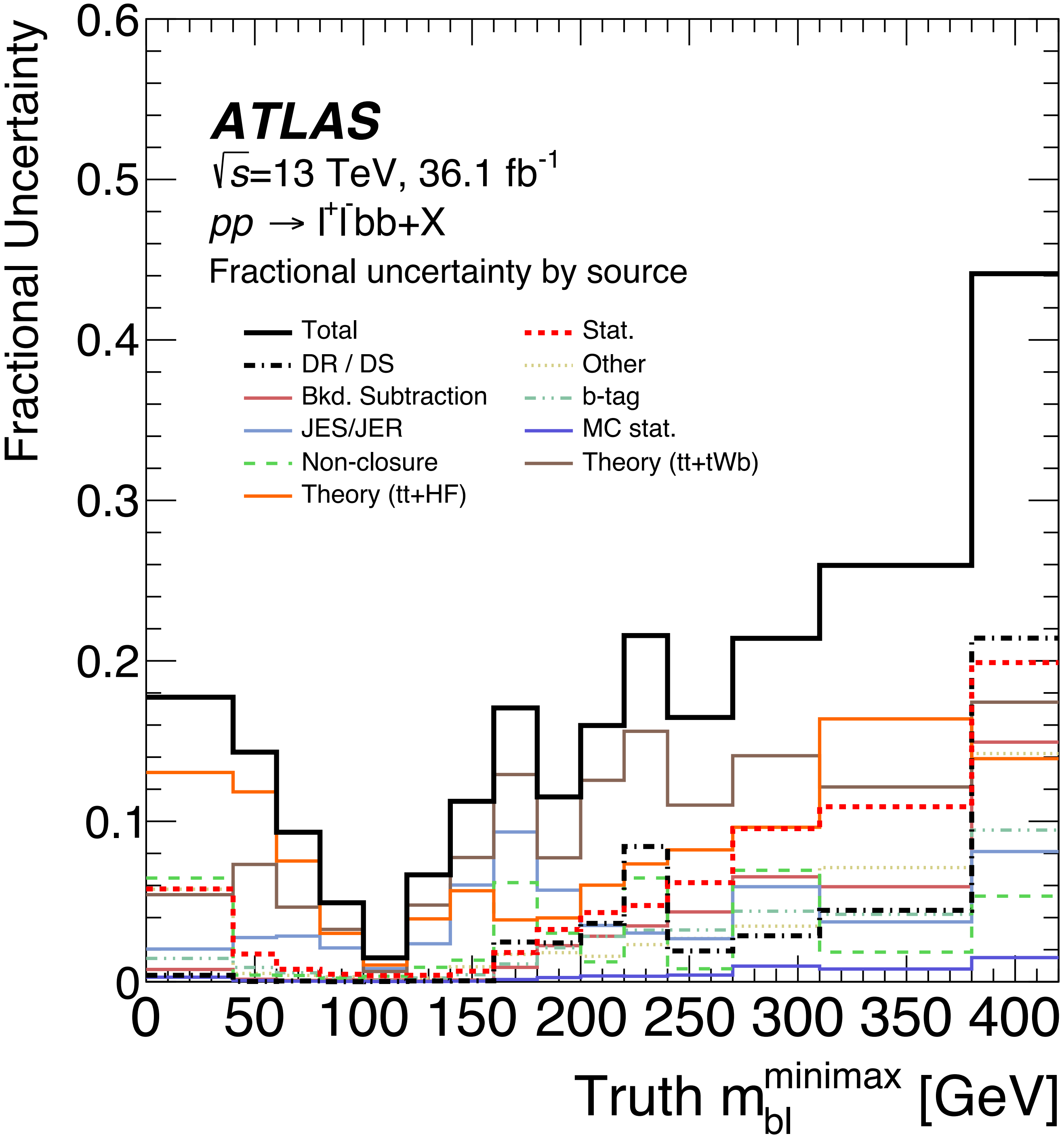
◉ Systematic uncertainties on the unfolded distribution

- Modelling uncertainties (1%-22%)

dominant

  - **tt + tW modelling**
    - total cross-section uncertainty
    - MC samples with alternative settings
  - **tt + HF modelling**
    - PowHeg+Py6 - Sherpa $t\bar{t}+b\bar{b}$
  - DR-DS:
    - Procedure repeated with DS

- Reco. uncertainties (1%-14%)
  - ***b*-tagging efficiency**
  - **Jet energy scale**



Interference: tW and tt

lvlvbb(PWH+PY8)

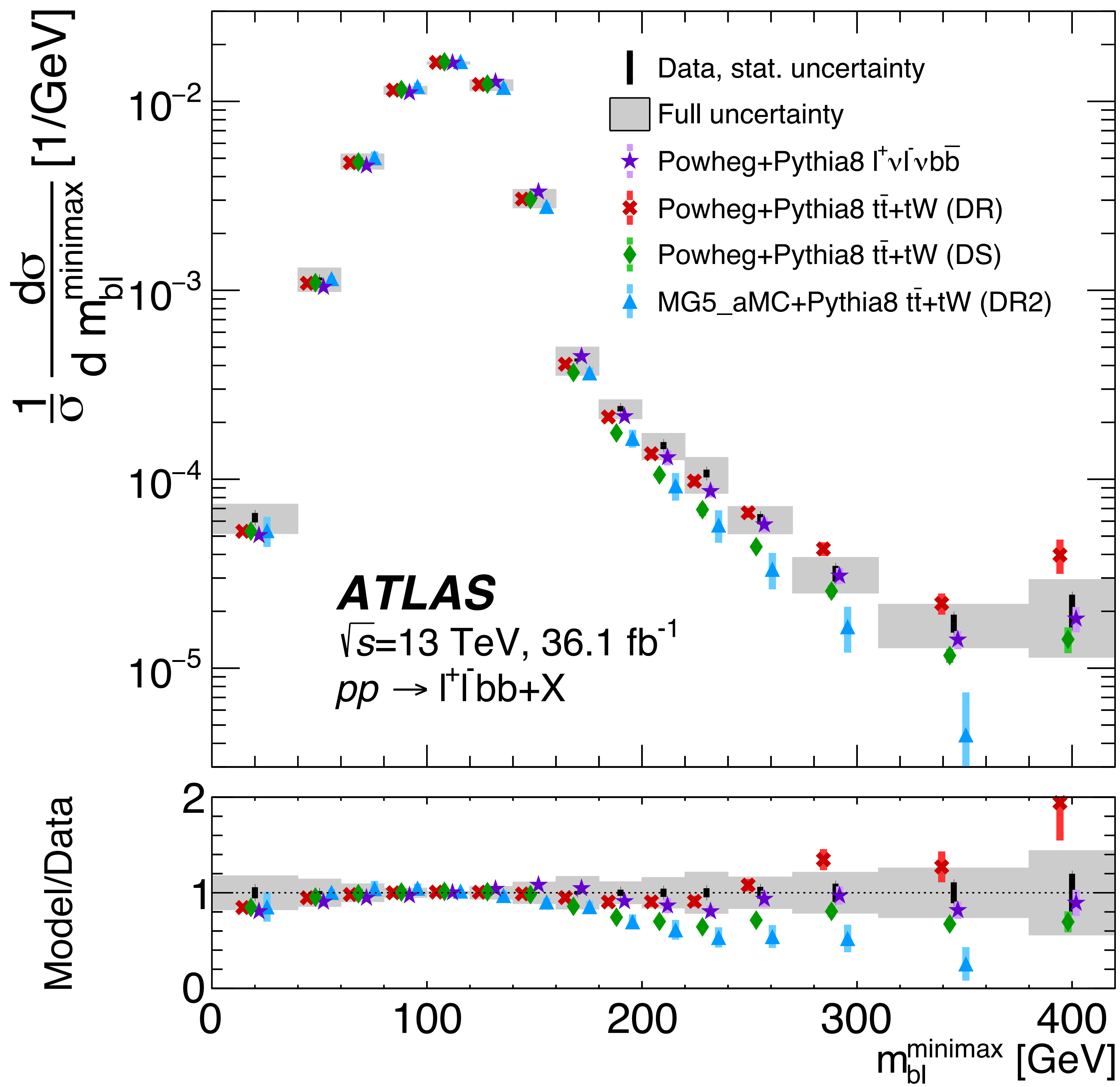
- data well described across the full range

PWH+PY8 (DR/DS)

- good agreement in the core of the distributions (< 200 GeV)
- In the tail:
  - **DR**/**DS** predictions diverge
  - consistent with data at ~2σ

PWH+PY8 (DR2)

- clearly under predicts the data in the tail



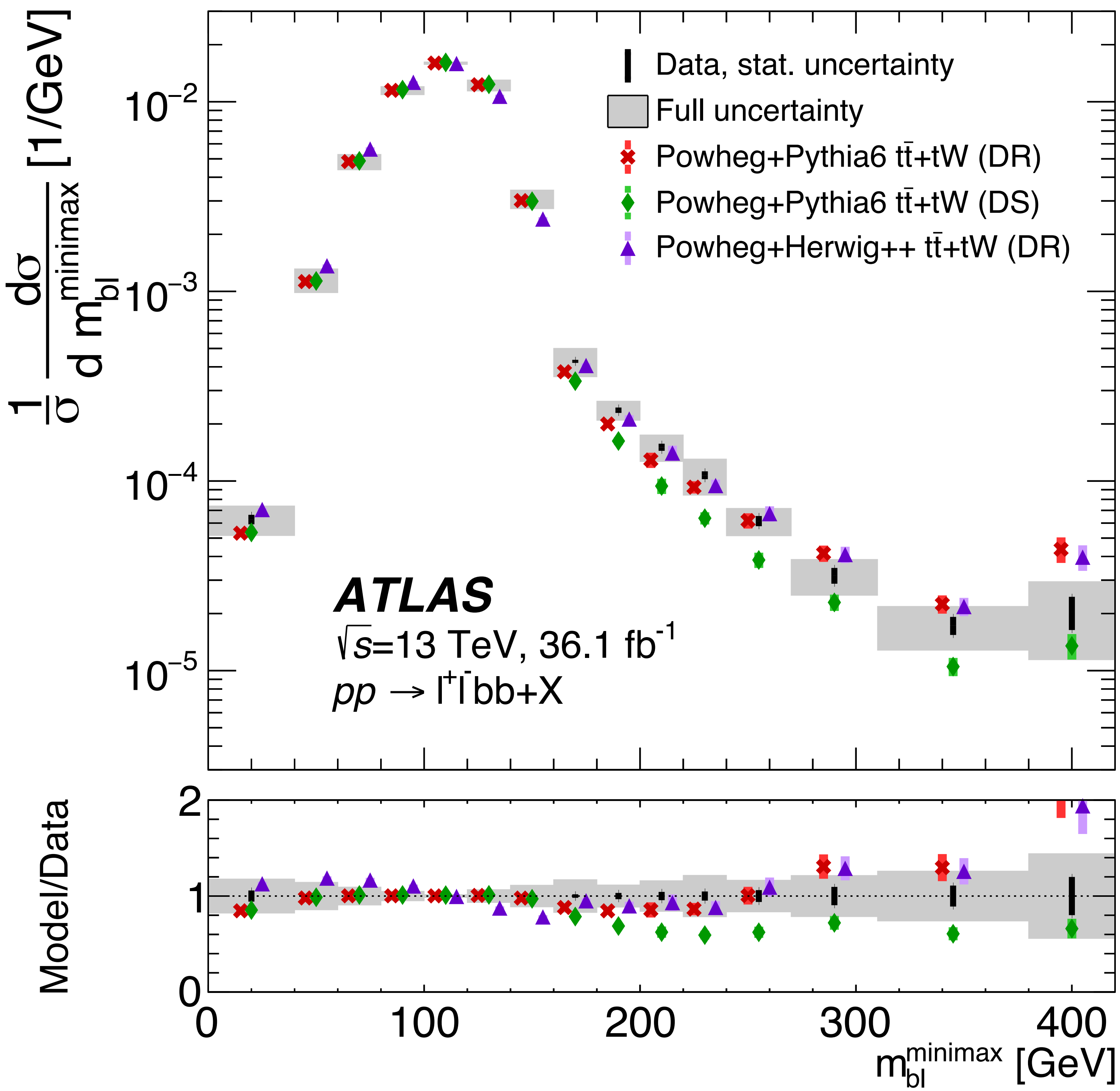
Interference: tW and tt

PWG+HW++

- Sample used to estimate the parton shower uncertainty
  - Most significant below the m_t

PWH+PY6 (DR/DS)

- PWH+PY6 used for unfolding
- DR/DS predictions using PY6 show the same trend as PY8



Summary

t-channel production @13TeV (CMS)

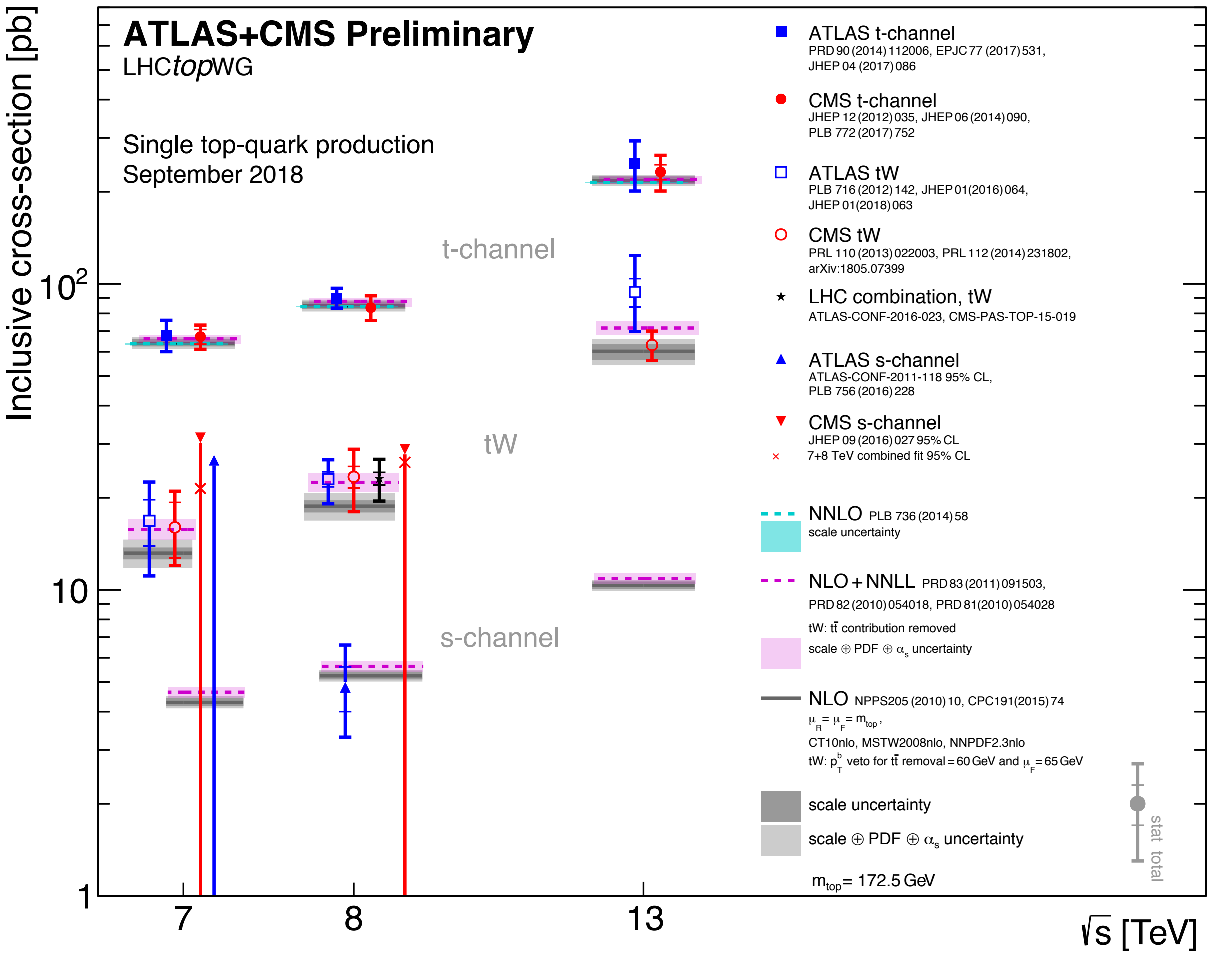
- Measurement for top/anti-top *t*-channel cross-section
- Precise $R_{t\text{-ch}}$ (~3% unc.) → good agreement with most of the predictions

tW process measured inclusively (CMS/ATLAS) and differentially (ATLAS)

First studies on $t\bar{t}$+*tW* in a region sensitive to the interference (ATLAS)

- DR-DS differ each other but within 2σ of the data
- *lvlvbb* (including interference) shows good agreement over the full range

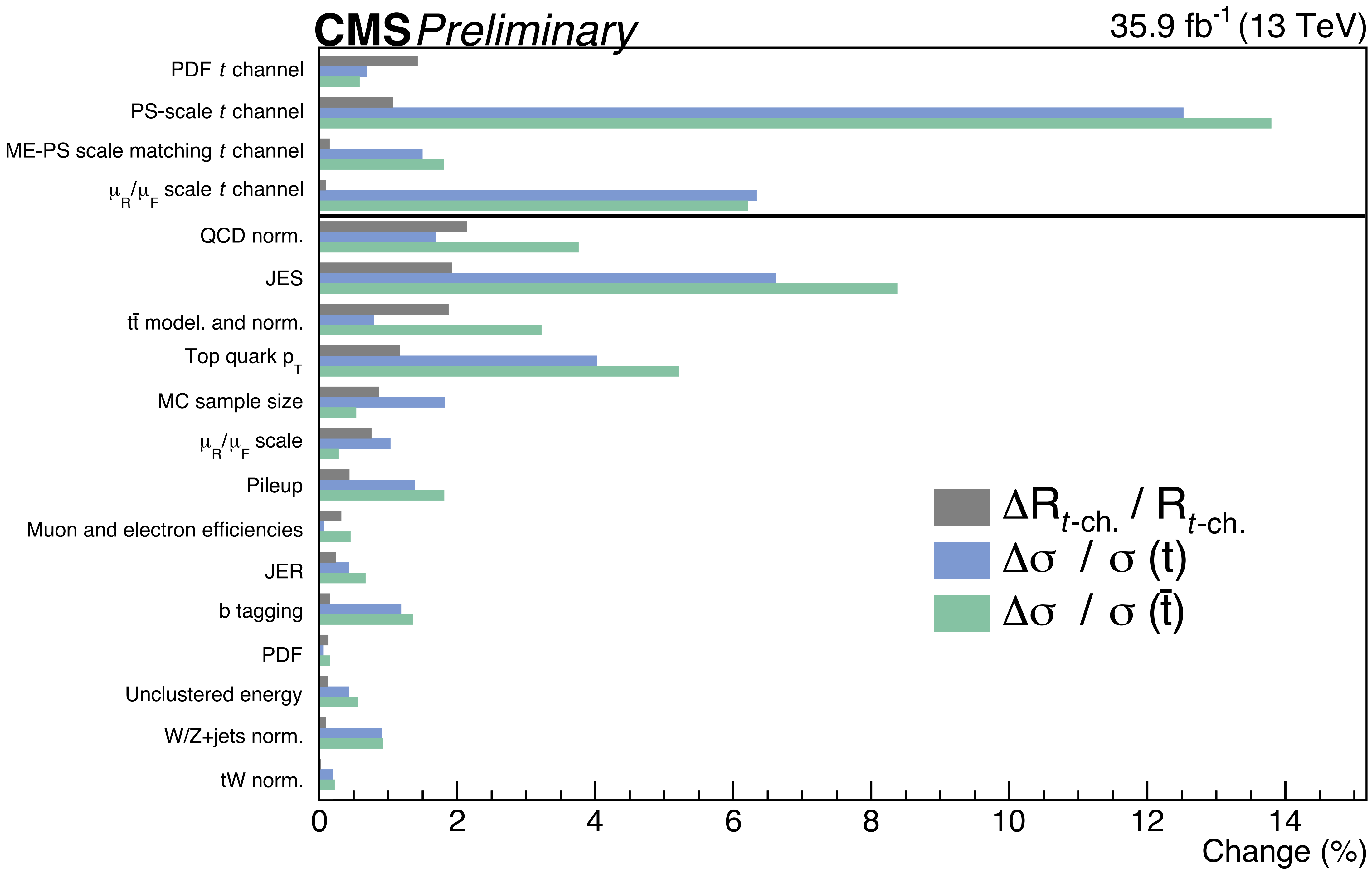
More single-top analysis in progress, stay tuned!



Backup

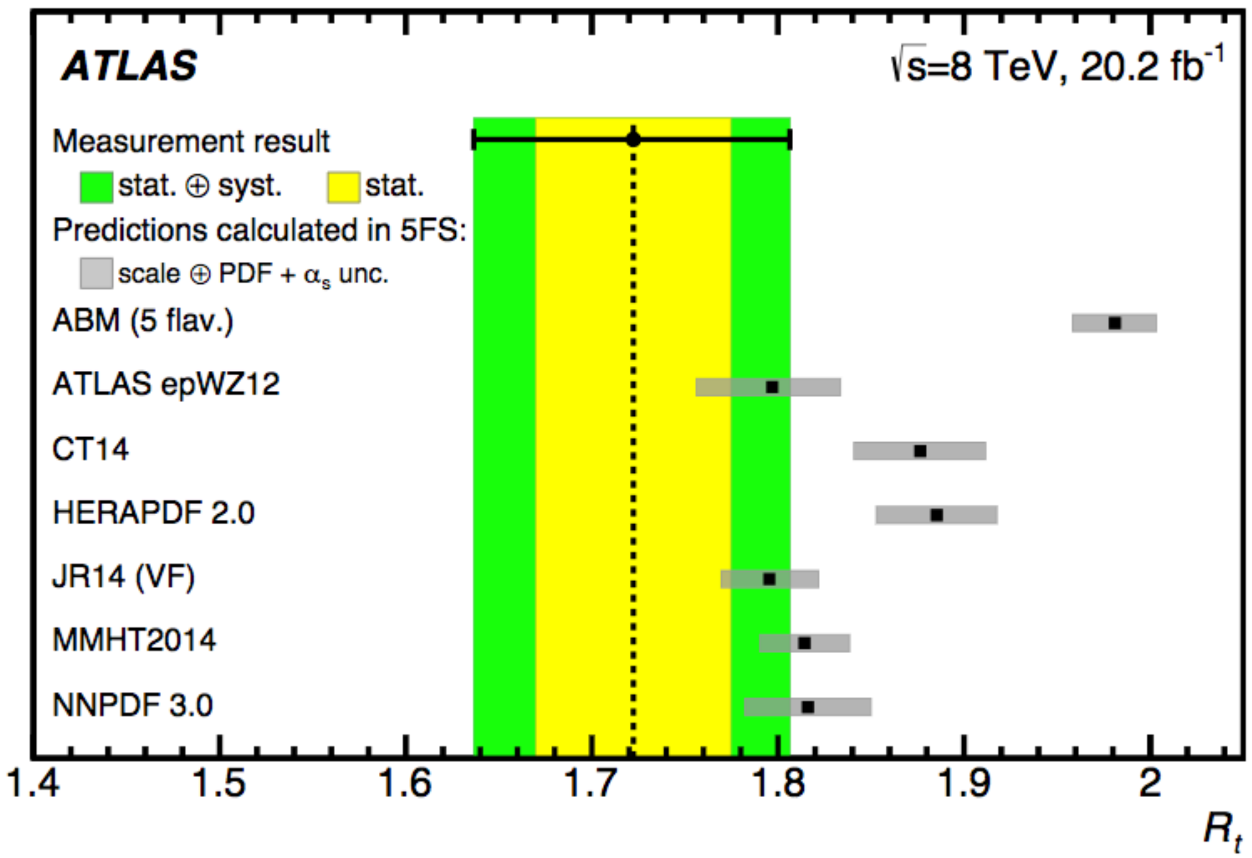
t-channel @ 13TeV

Systematic uncertainties

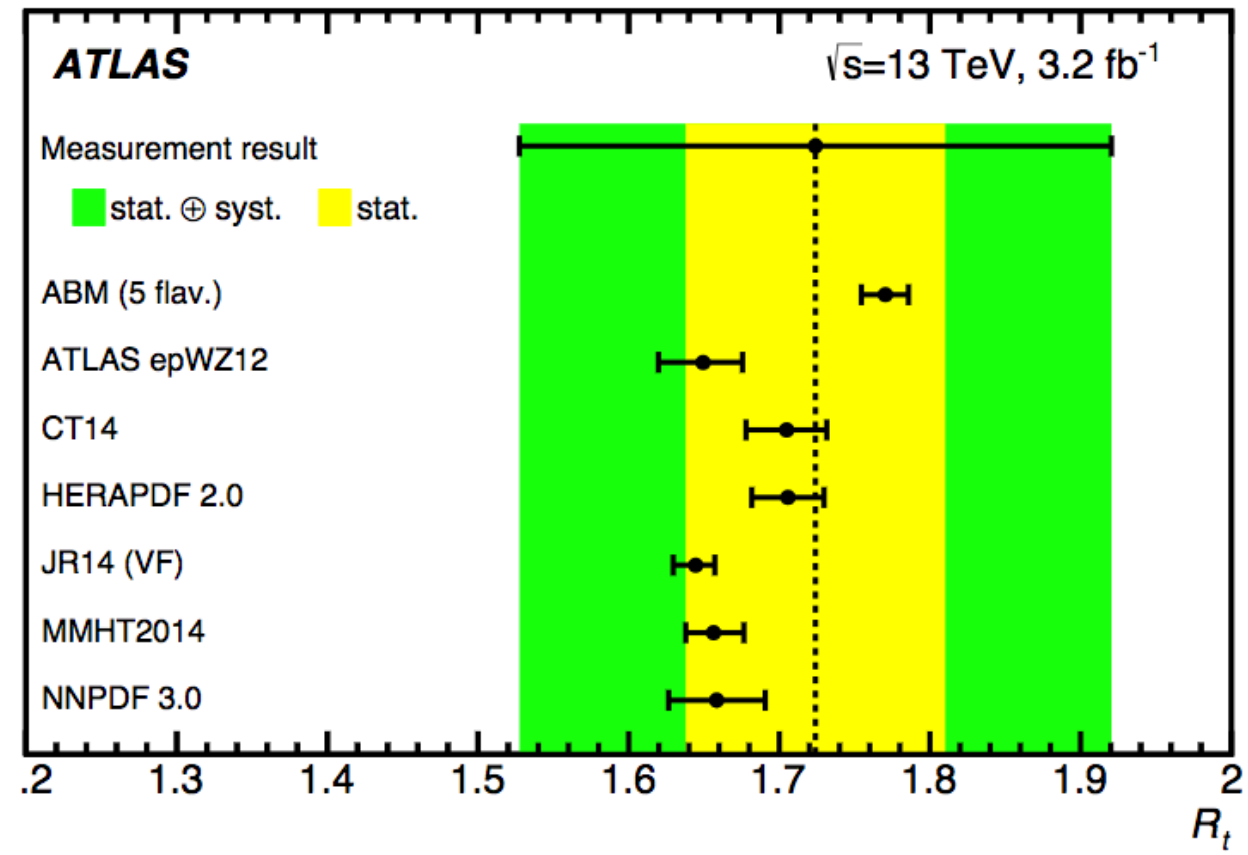


$R_{t\text{-}ch}$ @ 8/13TeV

@ 8TeV



@ 13TeV

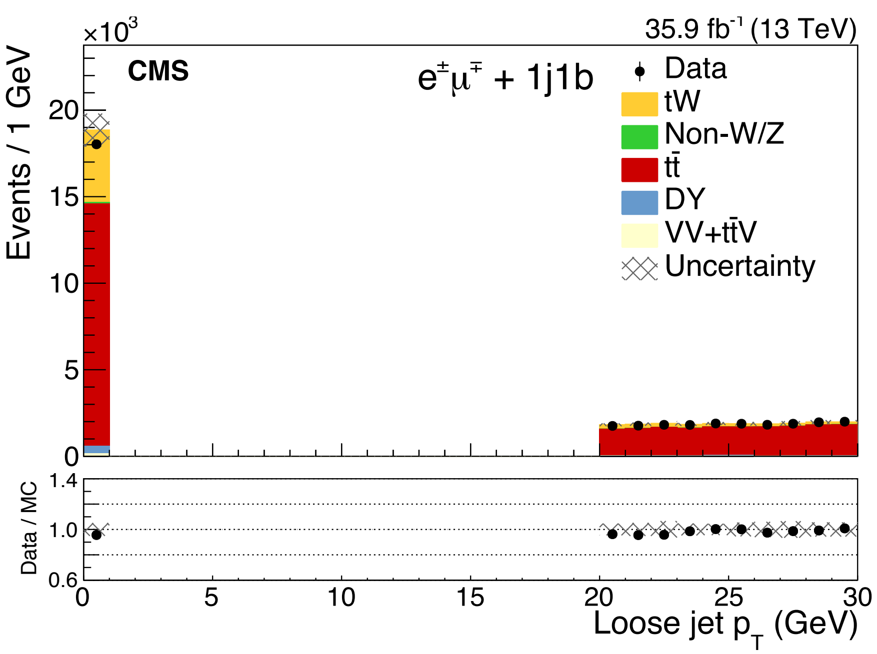


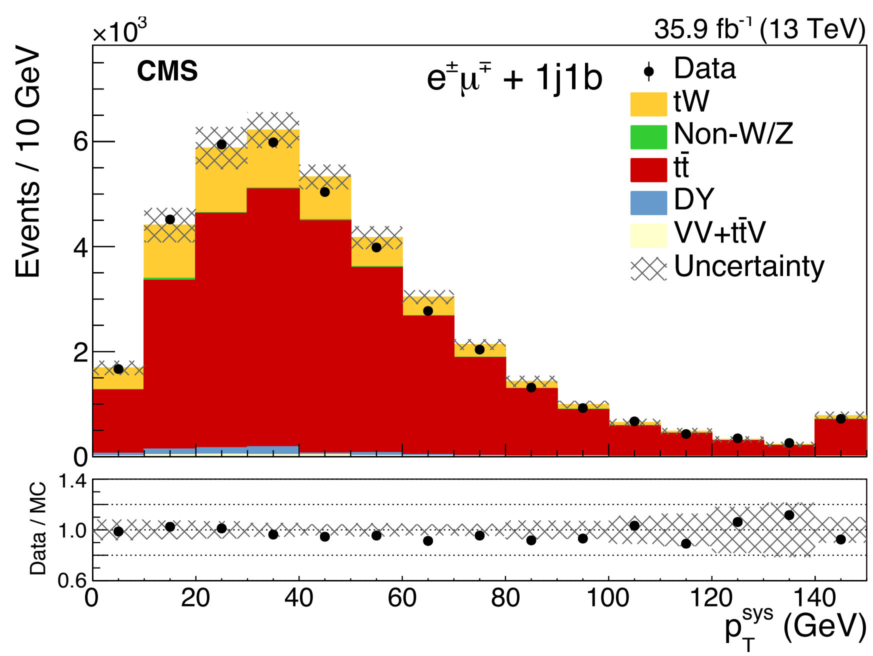
tW inclusive CMS

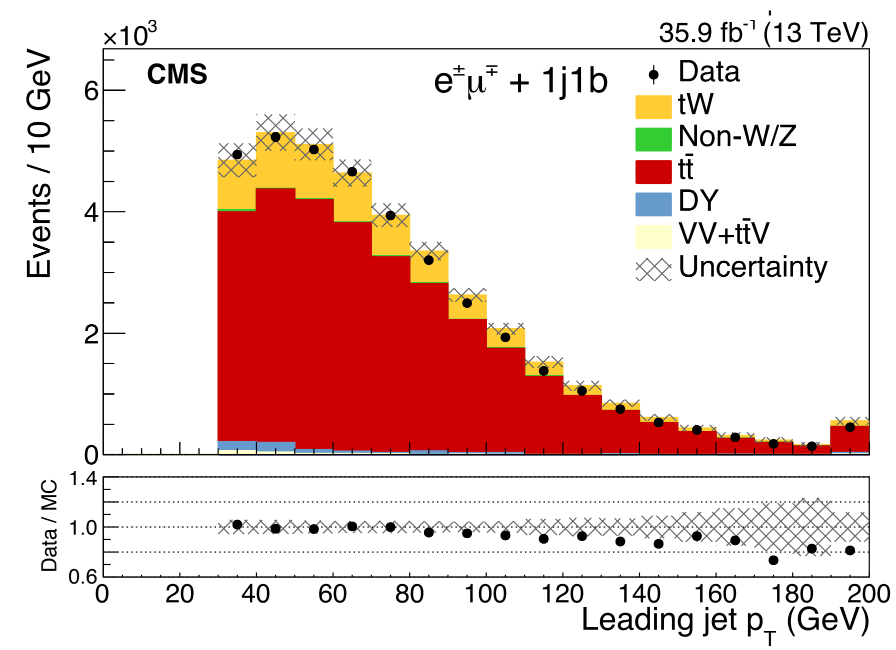
- **Selection:**
  - isolated e and μ with OS and p_T> 20GeV
  - Jets with pT > 30GeV
  - Loose jets 20GeV < p_T < 30GeV
  - *b*-tagging (70% efficiency)

# b-tag jets \ # jets	1	2
0		
1	**SR** (1j1b) tW-channel	**CR** (2j1b) ttbar
2		**CR** (2j2b) ttbar

- **Signal-Back separation**: BDT in the 1j1b and 2j1b
  - Most important variables in 1j1b region: pT(loose-jets), p_T^{sys}, p_T(*b*-jet), p_T(e)+p_T(mu)/H_T, #loose jets, centrality…

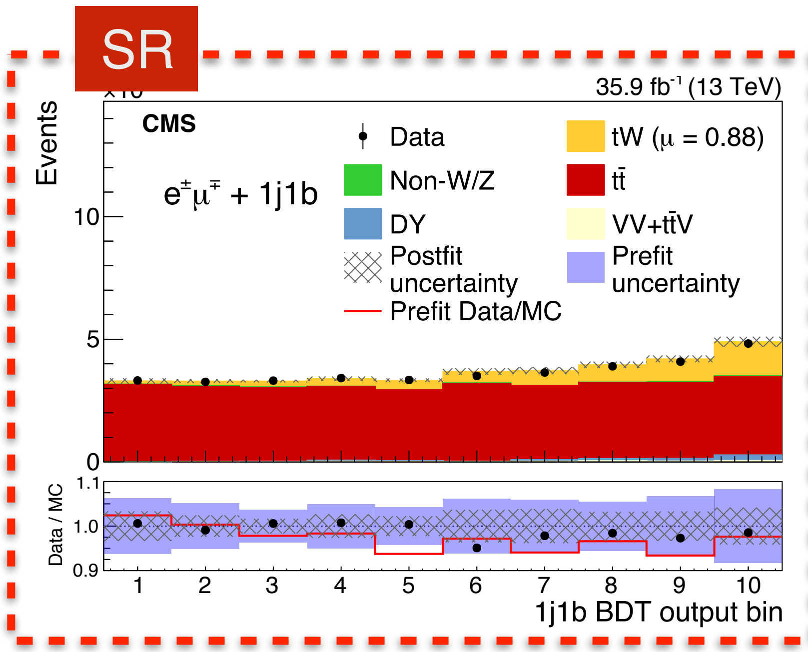


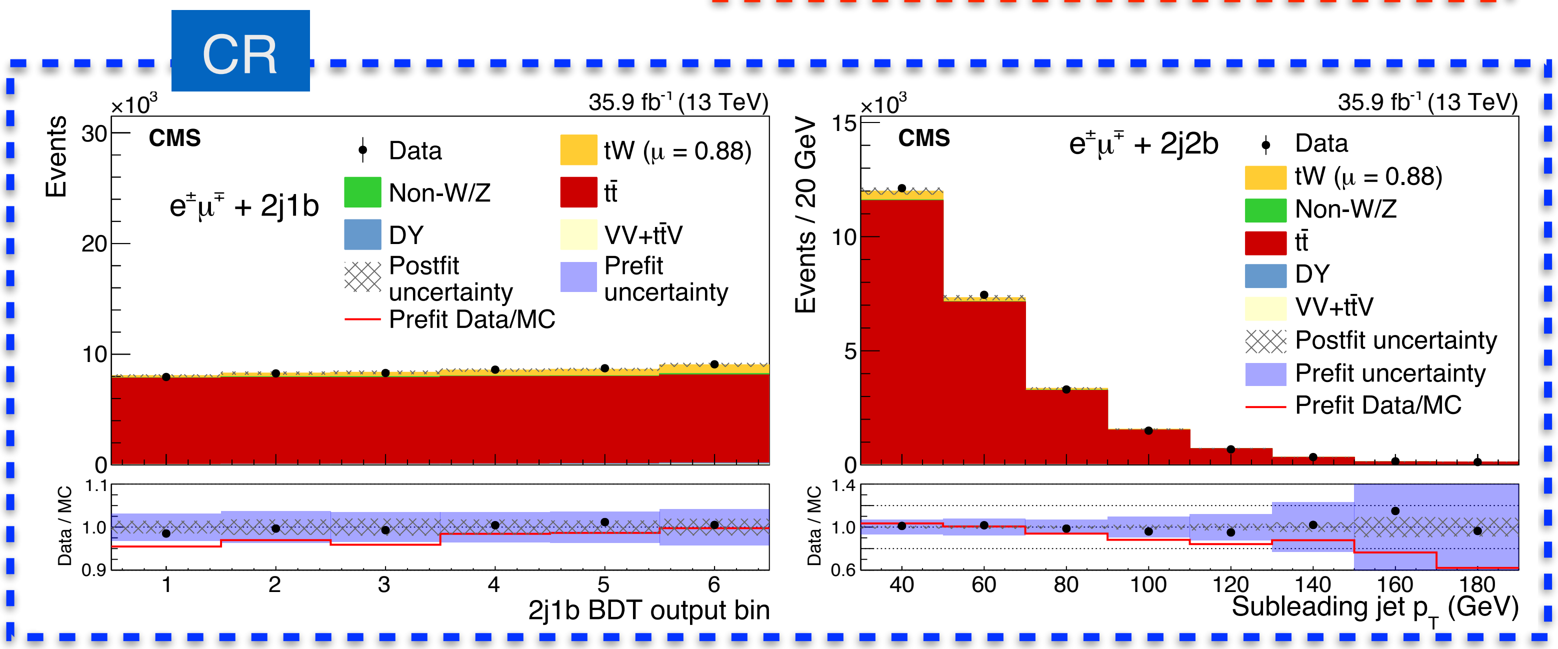




tW inclusive CMS

- **ML fit** to the **BDT** distribution in 1j1b and 2j1b and $\mathbf{p_T(j_2)}$ in 2j2b





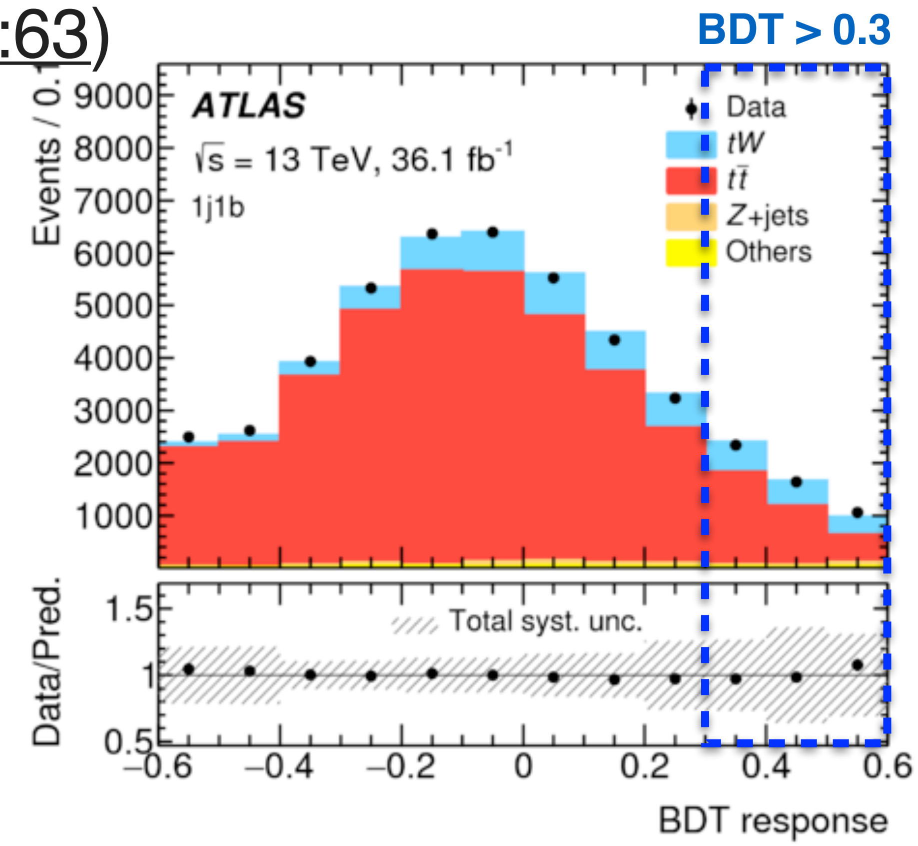
$$\sigma_{tW} = 63.1 \pm 6.6 pb$$

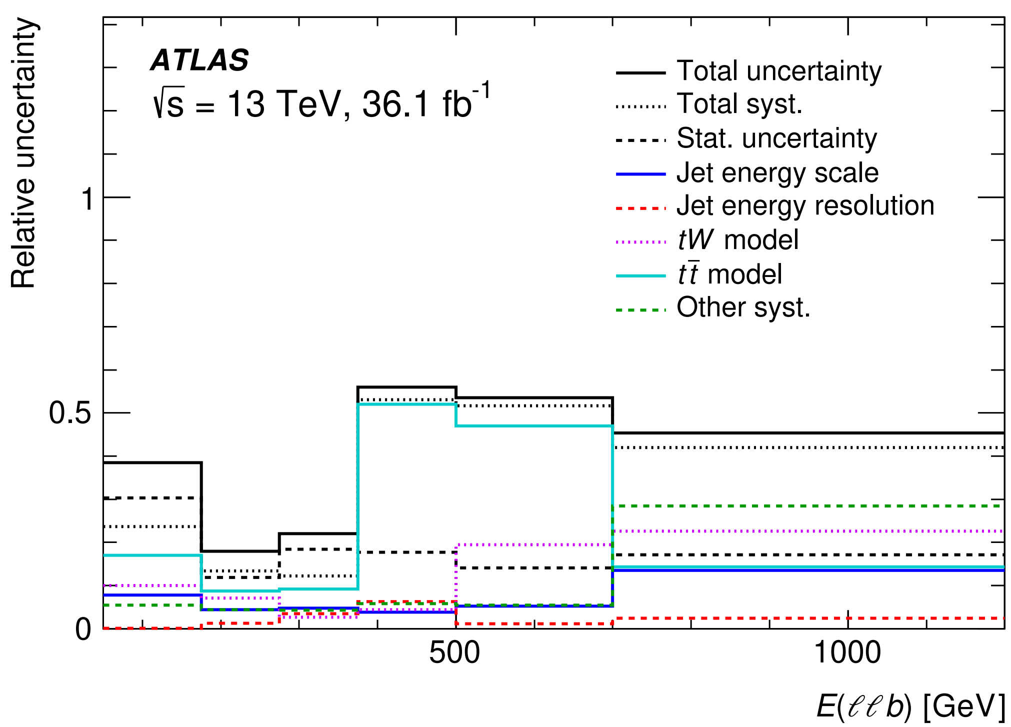
(10% uncertainty)

Source	Uncertainty (%)
Experimental	
Trigger efficiencies	2.7
Electron efficiencies	3.2
Muon efficiencies	3.1
JES	3.2
Jet energy resolution	1.8
b tagging efficiency	1.4
Mistag rate	0.2
Pileup	3.3
Modeling	
$t\bar{t}$ μ_R and μ_F scales	2.5
tW μ_R and μ_F scales	0.9
Underlying event	0.4
Matrix element/PS matching	1.8
Initial-state radiation	0.8
Final-state radiation	0.8
Color reconnection	2.0
B fragmentation	1.9
Semileptonic B decay	1.5
PDFs	1.5
DR-DS	1.3
Background normalization	
$t\bar{t}$	2.8
VV	0.4
Drell–Yan	1.1
Non-W/Z leptons	1.6
$t\bar{t}V$	0.1
MC finite sample size	1.6
Full phase space extrapolation	2.9
Total systematic (excluding integrated luminosity)	10.1
Integrated luminosity	3.3
Statistical	2.8
Total	11.1

tW differential ATLAS

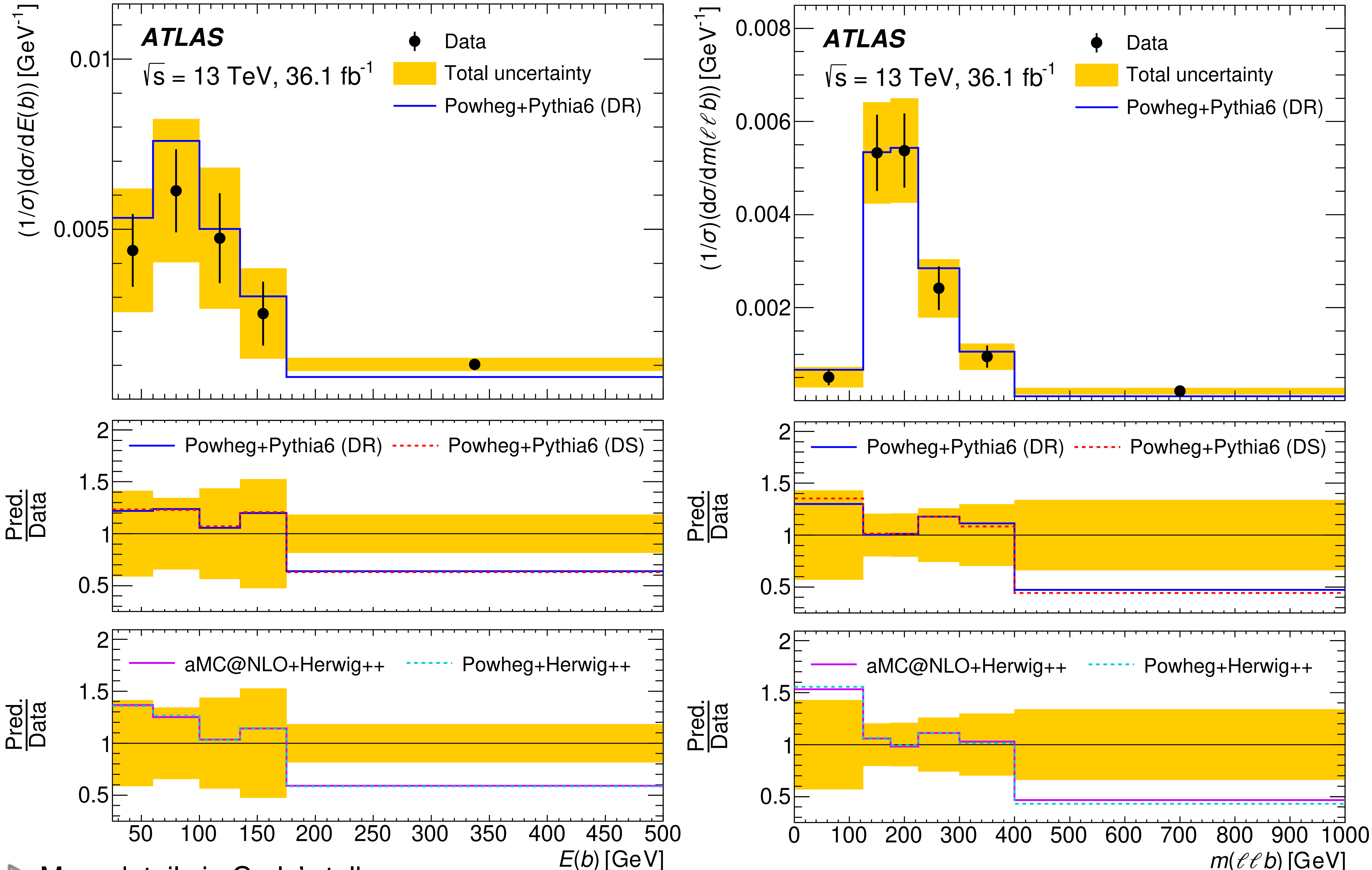
- Inclusive measurement with $3.2 fb^{-1}$ (JHEP(2018)2018:63)
- Differential measurements performed with $36 fb^{-1}$ (EPJC78(2018)186)
  - **Signal-Background separation**
    - BDT in 1j1b SR
    - BDT cut > 0.3 (S:B 1:5(1:2) before(after)cut)
  - **Back. subtracted data unfolding to particle level**
    - D'Agostini iterative method
    - Iterations chosen to keep bias & stat. error low
  - **Unfolded distributions for**
    - E(b), E(llb), m_T(llvvb), m(l_1b),m(llb),m(l_2b)
  - **Largest syst. uncertainties**
    - tW and tt modelling
    - statistics





More details in Carls's talk

tW differential ATLAS



- More details in Carls's talk

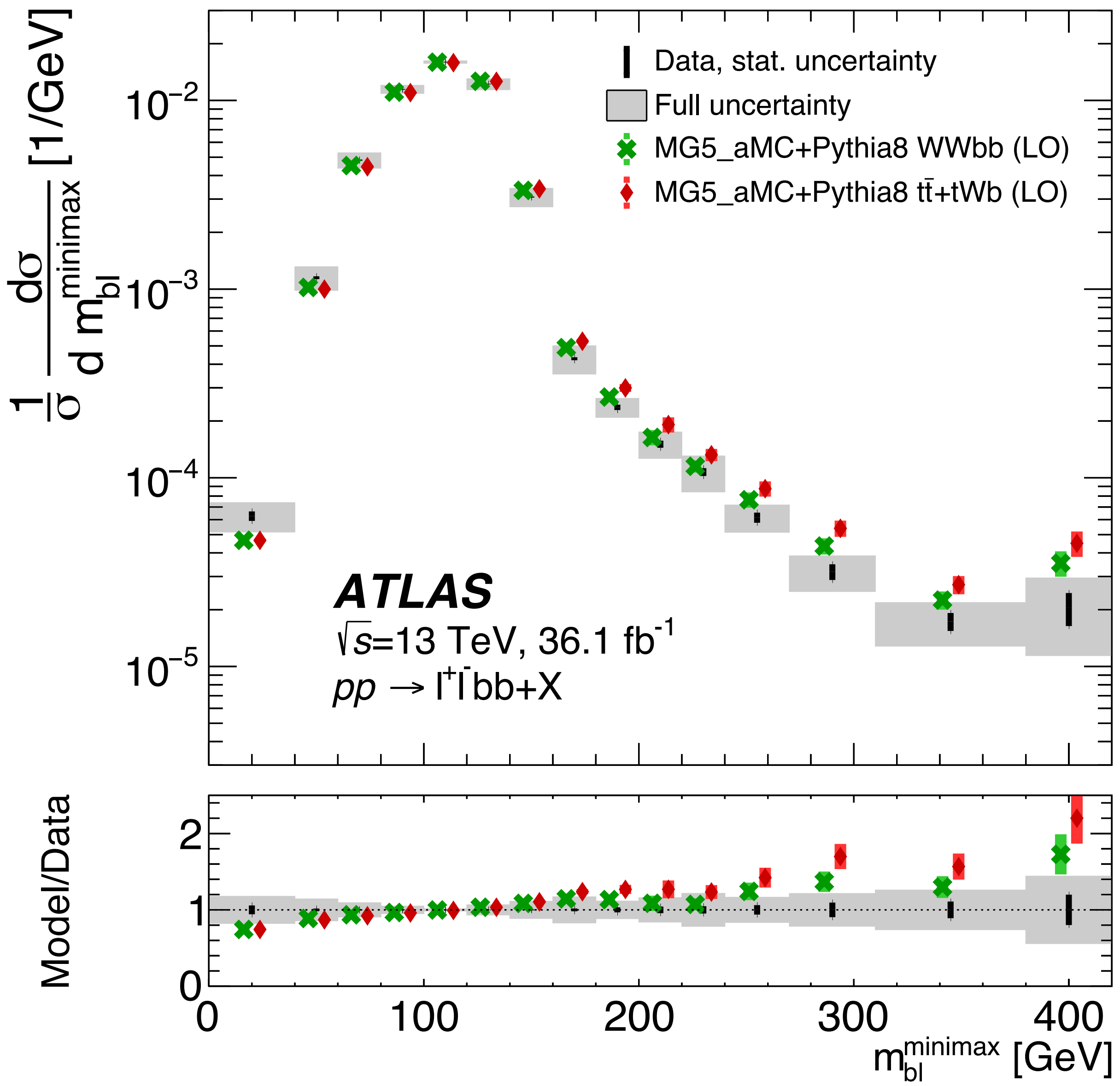
tW @ 13 TeV - ATLAS

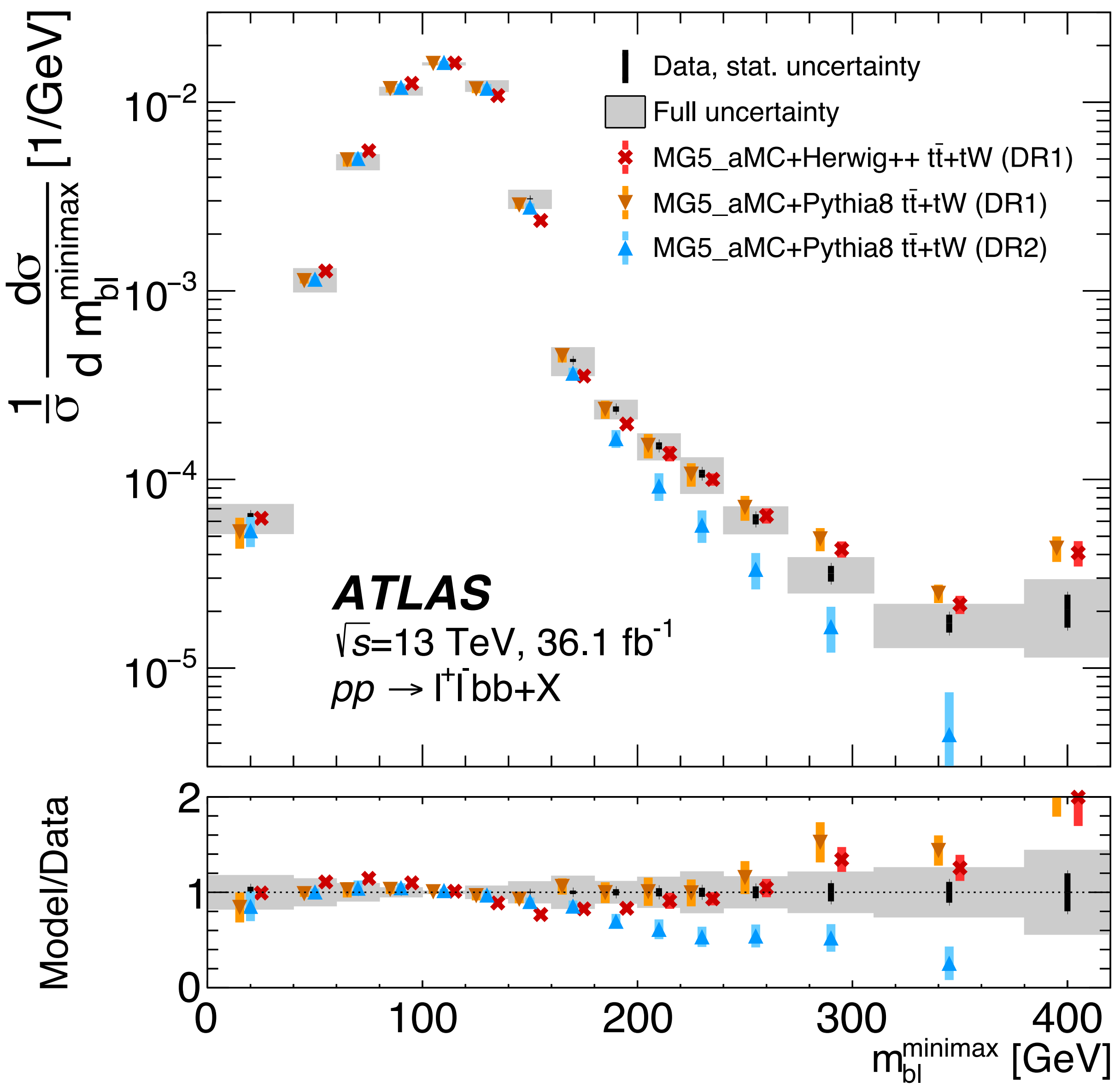
Observable	$E(b)$		$m(\ell_1 b)$		$m(\ell_2 b)$		$E(\ell\ell b)$		$m_T(\ell\ell\nu\nu b)$		$m(\ell\ell b)$	
Degrees of freedom	4		5		3		5		3		5	
Prediction	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p
Powheg+Pythia 6 (DR)	4.8	0.31	5.7	0.34	2.6	0.45	8.1	0.15	2.0	0.56	4.0	0.55
Powheg+Pythia 6 (DS)	5.0	0.29	6.1	0.30	2.6	0.46	9.1	0.11	2.4	0.49	4.4	0.50
aMC@NLO+Herwig++	5.6	0.23	5.4	0.37	2.4	0.49	8.7	0.12	1.8	0.61	3.6	0.61
Powheg+Herwig++	6.2	0.18	8.1	0.15	2.3	0.52	11.0	0.05	2.0	0.57	5.2	0.40
Powheg+Pythia 6 radHi	4.8	0.30	5.3	0.38	2.5	0.48	7.9	0.16	1.9	0.60	3.7	0.60
Powheg+Pythia 6 radLo	5.0	0.29	5.8	0.33	2.6	0.45	8.4	0.14	2.1	0.56	4.0	0.55

- Overall good modelling by all generators
  - Small difference between radLo/radHi
  - Small difference between Diagram removal (DR)- Diagram Subtraction (DS)
  - PowHeg+Herwig++ disfavoured in some bins

- MC tends to be softer than data (specially in E(llb))

Interference: tW and tt





- LO Madgraph samples generated **with** and **without** interference
- Used by searches to estimate the effect size when DR/DS difference is large

- MadGraph allow for a direct comparison of **DR1** vs **DR2**
  - Poor modelling of DR2 due to the interference and not the choice of generator