Single top production and spin correlation of top quark pair in ATLAS

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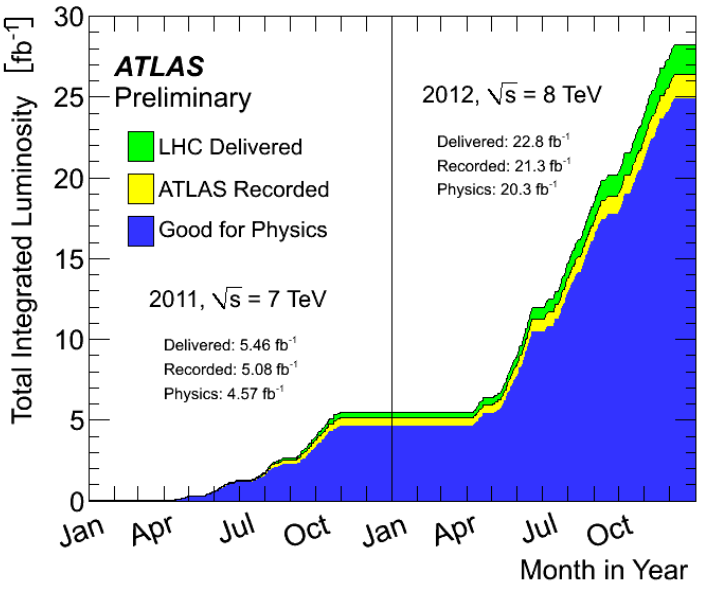
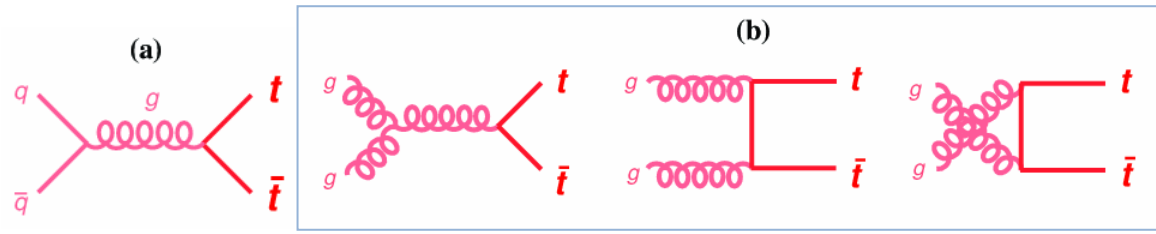


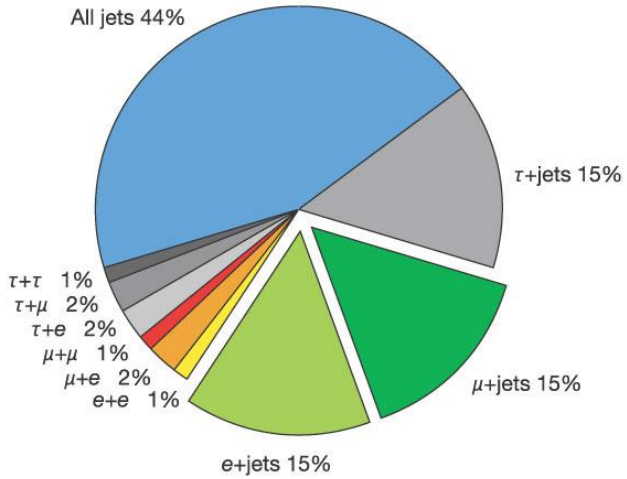
Outline

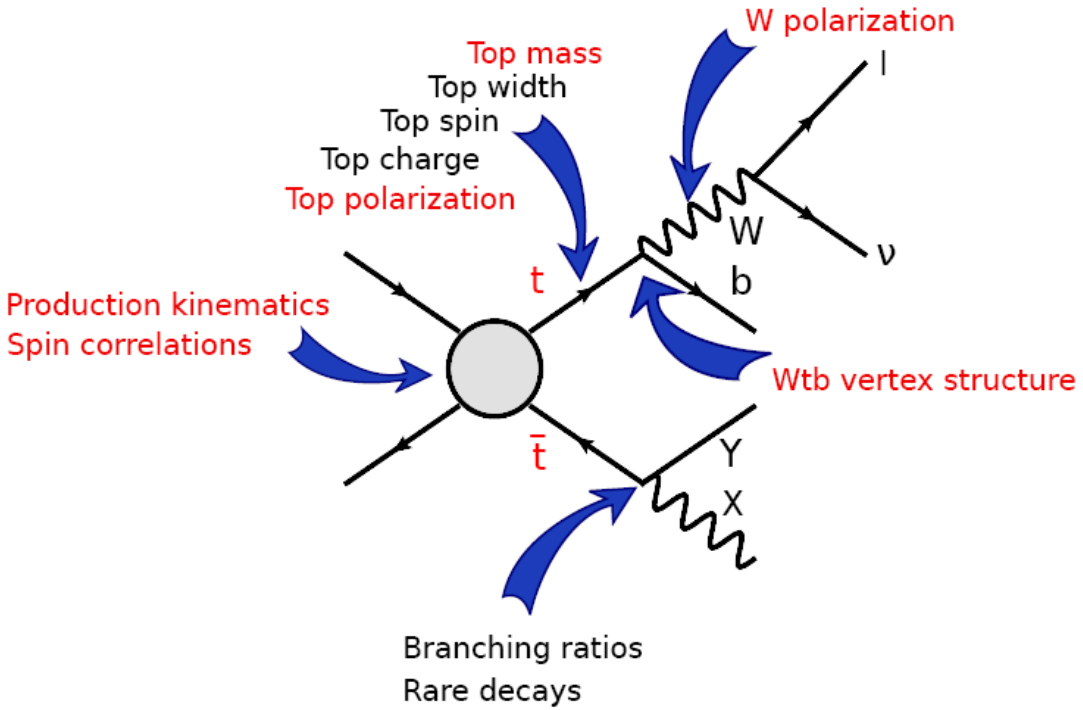
- Introduction
- Single top production associate with W boson
- Top pair spin correlation
- Summary

Top quark production in LHC

- **Top quark Pair** produced:
  - gluon-gluon fusion(87%)
  - quark-quark interaction(13%)
- σ_{tot}=253pb@8TeV
- Top pair decay channels
  - Dilepton(e/μ): ~5%
  - L+jets(e/μ): ~30%
  - All jets

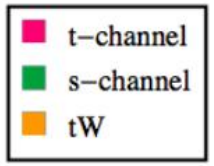


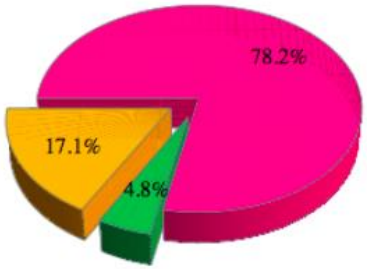


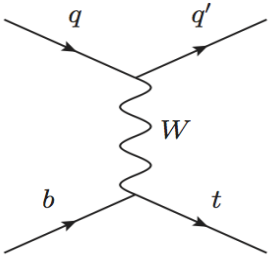


Top quark production in LHC

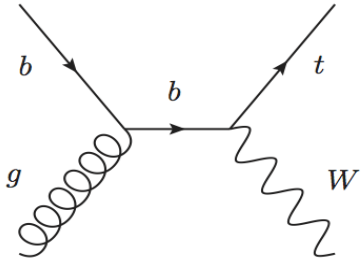
- **Single top** production via electroweak interaction
  - Three production channel.
  - σ_{tot}=114pb@8TeV in LHC
- Direct probe of the W-t-b coupling
- Sensitive to new physics



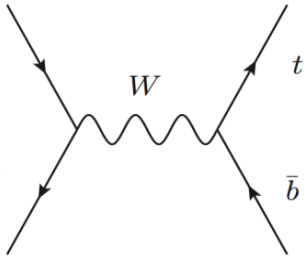




t channel



Wt channel



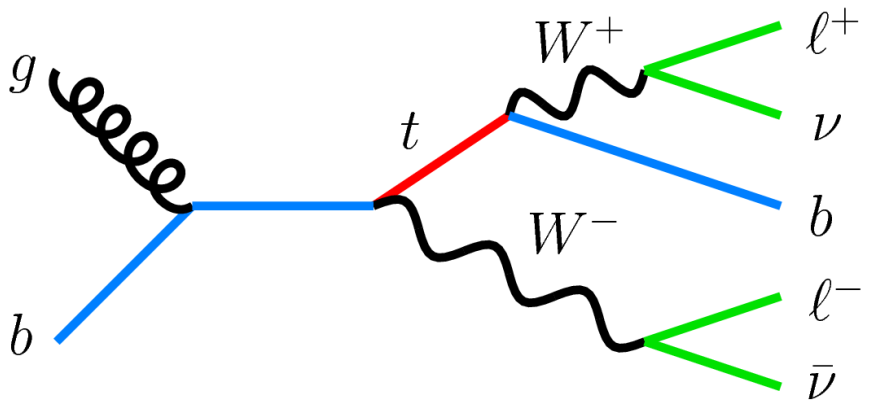
s channel

$\sqrt{s}$ (pb)	σ (t-channel)	σ (Wt)	σ (s-channel)
8 TeV	87.8 ± 3.4 Phys. Rev. D 83, 091503(R) (2011)	22.4 ± 1.5 Phys. Rev. D 82, 054018 (2010)	5.6 ± 0.2 Phys. Rev. D 81, 054028 (2010)

Single top Wt production at 8TeV

arXiv:1510.03752

- LHC is the unique field
- Data: 8TeV, 20.3fb-1



Event selection: ee, μμ and eμ events

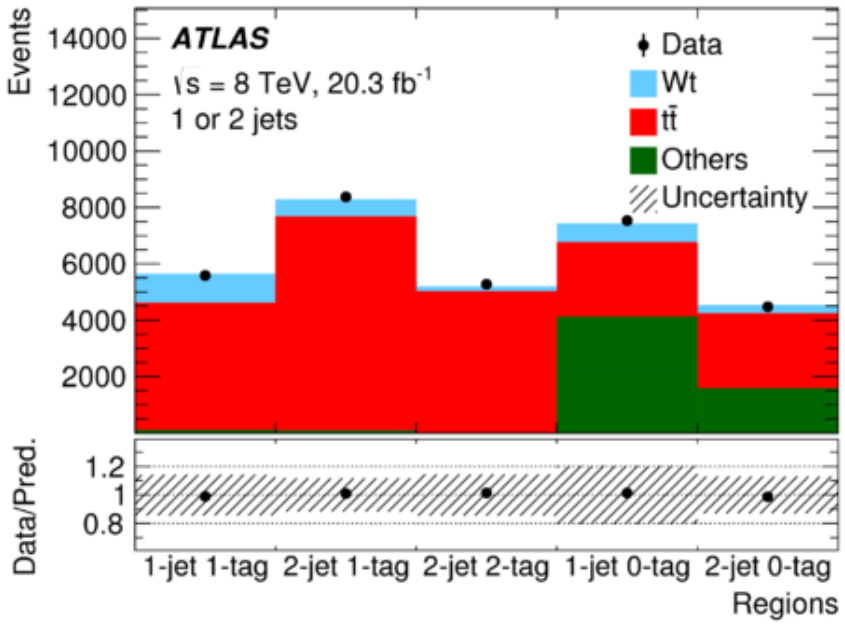
- ✓ Two oppositely charged isolated leptons with p_T>25GeV
- ✓ Z mass window remove
- ✓ 1 or 2 central jets with p_T>20GeV, at least 1 b-jet
- ✓ Btag: MV1 at 70% WP(>0.7892)
- ✓ Set of requirements on Etmiss

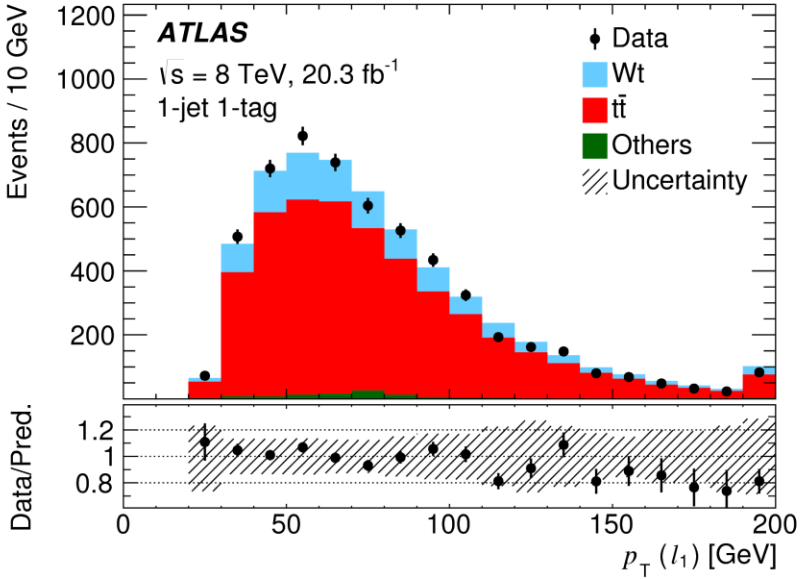
Signal and control regions

- Main signal region: (1-jet 1-tag)
- Four control/signal regions
  - ✓ 2 regions enriched in top pair:

    (2-jet 1-tag) and (2-jet 2-tag)
  - ✓ 2 regions enriched in other BGs:

    (1-jet 0-tag) and (2-jet 0-tag)



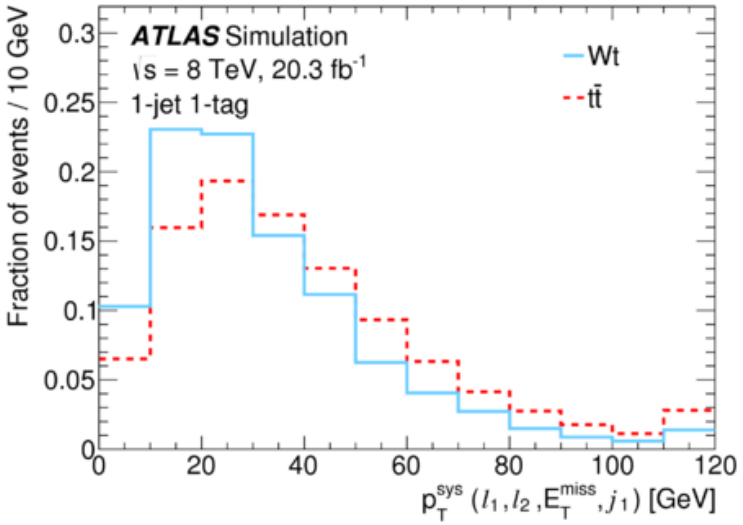


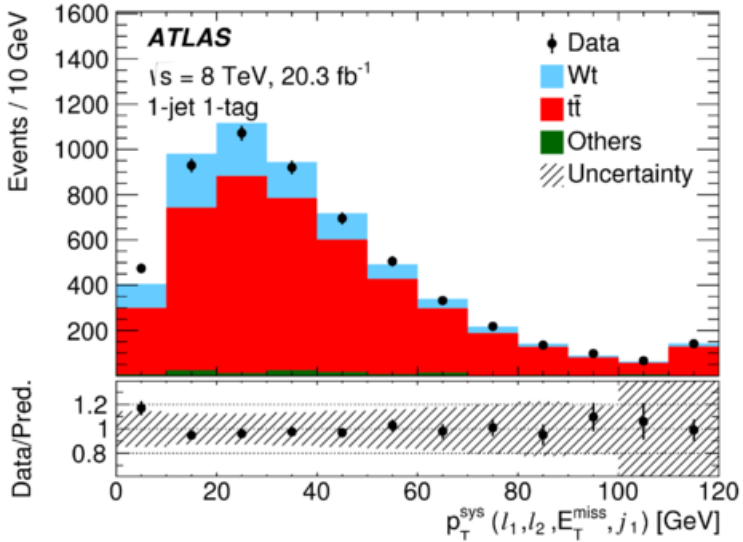
Good MC/data agreement

Separation of Wt signal from background with BDT

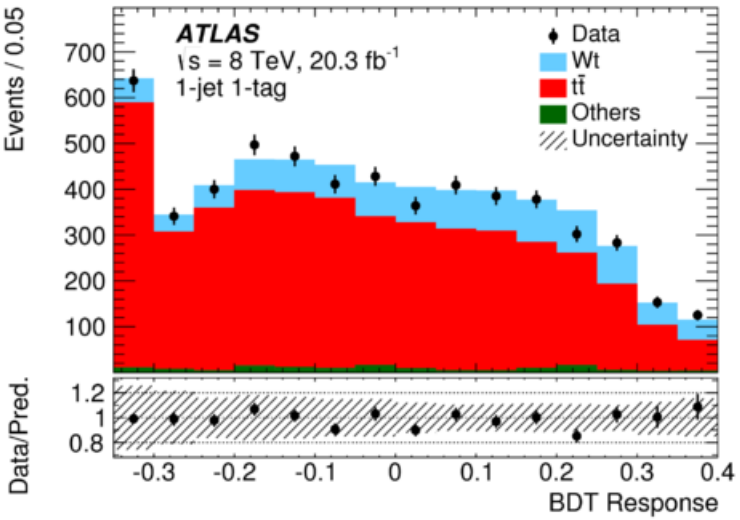
- Create the 5 BDT classifiers for 5 regions
- Various input variables for each BDT

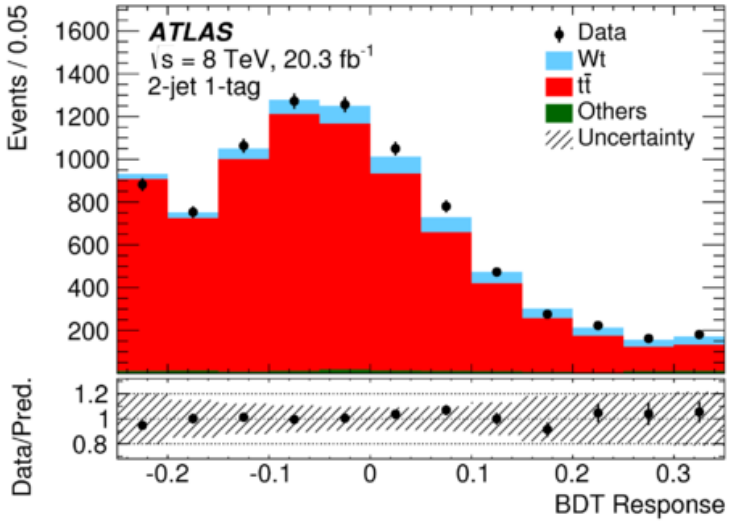
1-jet, 1-tag	
Variable	S ($\times 10^{-2}\%$)
p_T^{sys} $(l_1, l_2, E_T^{miss}, j_1)$	13.8
ΔR (l_1, j_1)	11.4
$\sum E_T$	8.9
$\sigma(p_T^{sys})$ $(l_1, l_2, E_T^{miss}, j_1)$	8.1
m_T (j_1, E_T^{miss})	7.8
$Centrality$ (l_1, l_2)	7.4
p_T^{sys} (l_1, l_2, j_1)	7.1
Δp_T (l_1, l_2)	6.8
Δp_T $((l_1, l_2, j_1),(E_T^{miss}))$	6.7
m (l_2, j_1)	6.1
m_{T2}	5.8
$Centrality$ (l_1, j_1)	5.1
p_T^{sys} (l_1, l_2)	5.0

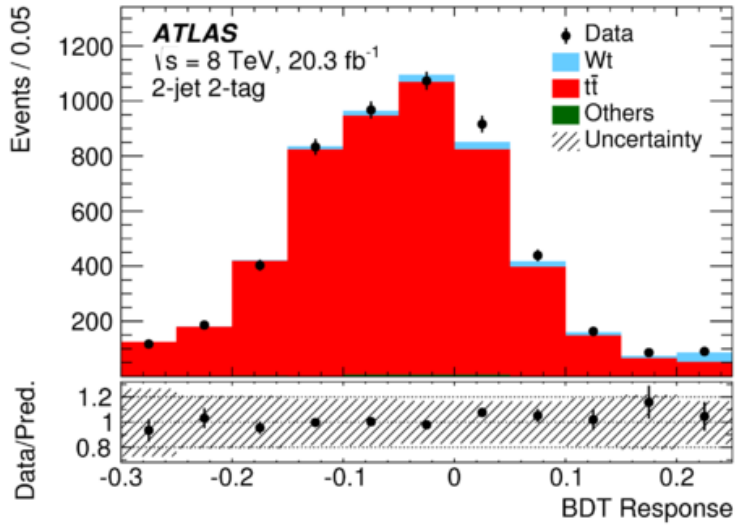




Final BDT response





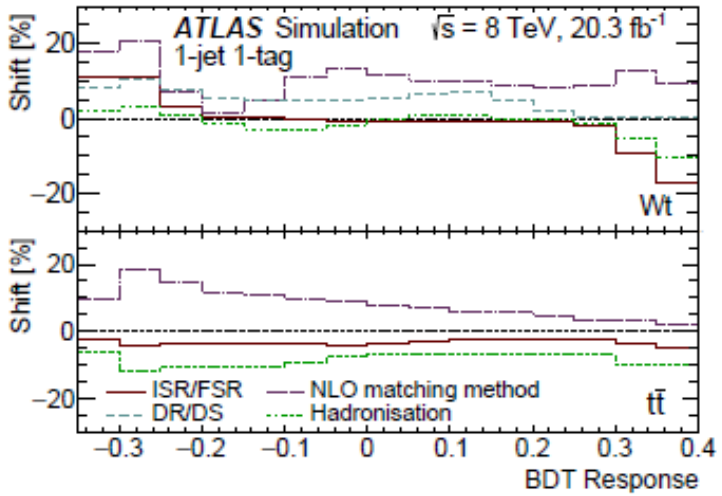


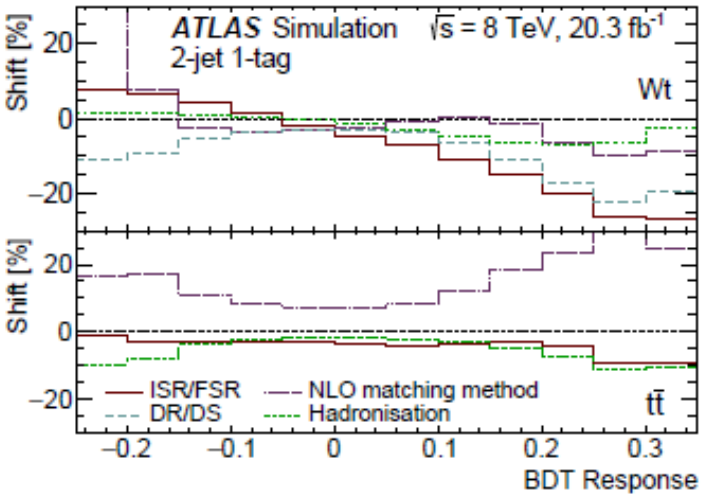
BDT response for regions:

- 1 jet,1 b-tag
- 2 jet, 1 b-tag
- 2 jet, 2 b-tag

Systematic uncertainties

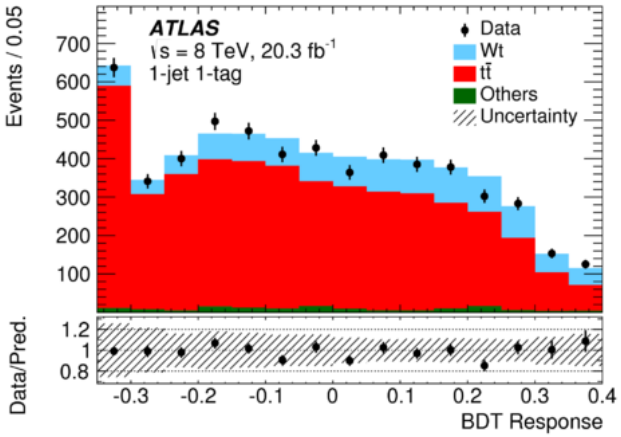
- Lepton
- Jet and Etmiss
- MC
  - PDF, I/FSR
  - Generator and parton shower
  - DS/DR
  - Background normalization

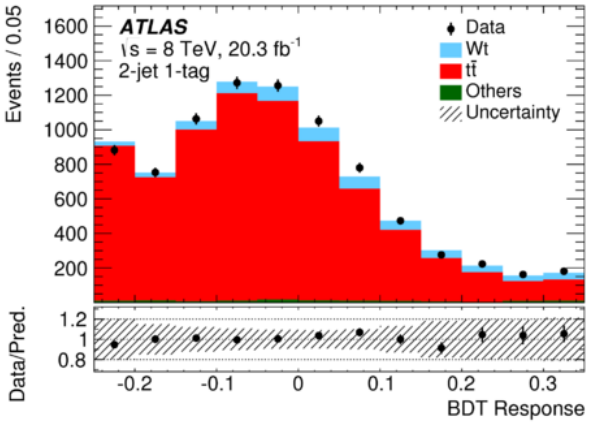


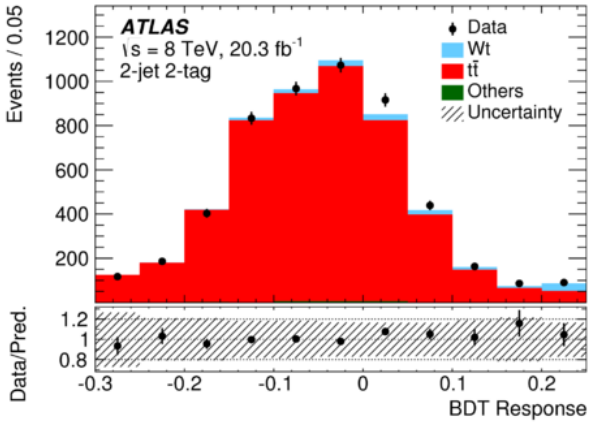


Inclusive Wt production cross section

simultaneous profile likelihood fit to the three BDT classifiers







$$\sigma_{Wt} = 23.0 \pm 1.3\ (\text{stat.})^{+3.2}_{-3.5}\ (\text{syst.}) \pm 1.1\ (\text{lumi.})\ \text{pb}$$

Total uncer. $^{+16}_{-17}\%$ Significance: 7.7σ (6.9σ exp.)

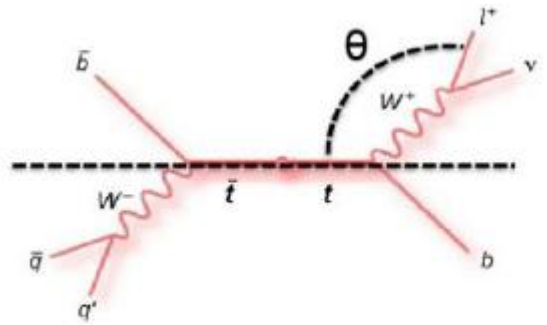
Discovery Wt process in ATLAS, confirm CMS measurement

Top pair spin correlation

CERN-PH-EP-2015-241

θ_1 : Helicity basis:

Between the top spin analyzer direction in the top rest frame and top direction in the $t\bar{t}$ system.



the angle defined between the top product in top rest frame and spin axis.

$$\frac{1}{N}\frac{d^2N}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}(1 + B_1\cos\theta_1 + B_2\cos\theta_2 - C\cos\theta_1\cos\theta_2)$$

$$A = \frac{C}{|\alpha_1\alpha_2|} \quad (C = 0.326 \text{ in SM@NLO})$$

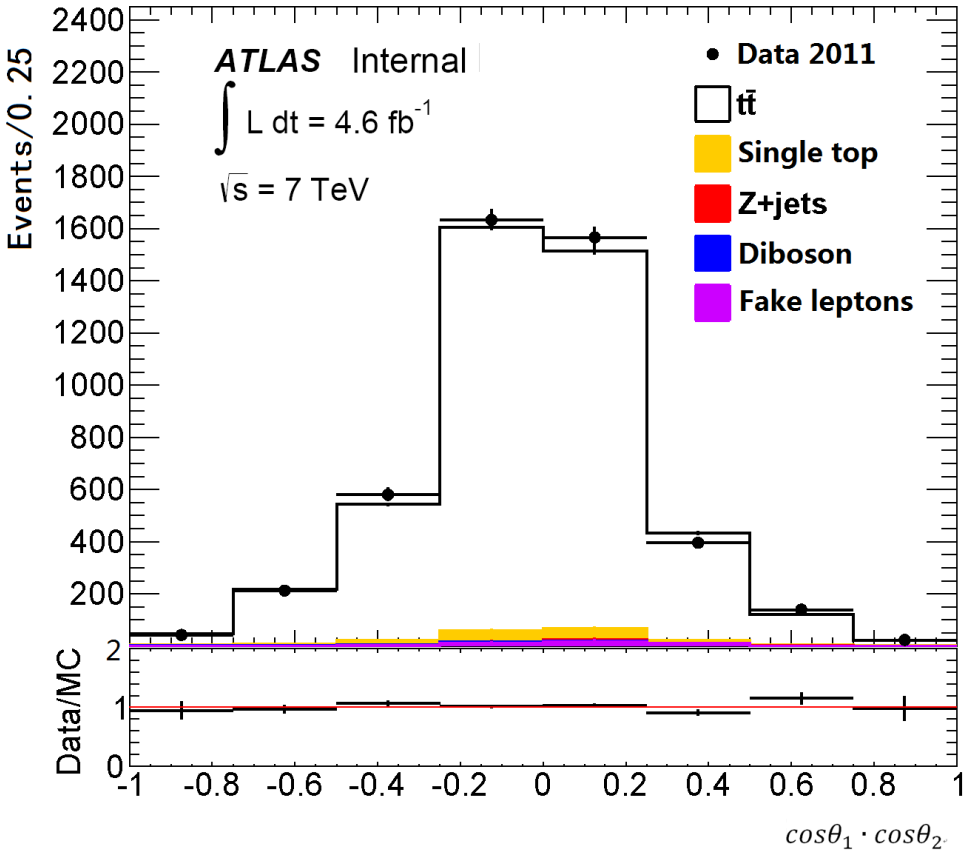
$$A = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow}}$$

Event selection and reconstruction

- two opposite charge leptons, ≥2jets, ≥1b-tagged, large miss momentum
- Two b-jets are paired to two leptons, with smaller invariant mass.
- If no solution found, top mass is shifted from nominal to two sides. Limited [157.5,187.5] with step 1.5GeV
- The second b-jets lepton pairing is tried if failed above
- If more than 1 solutions, the one with smallest $P_T^{\nu} \cdot P_T^{\bar{\nu}}$ is chosen.

$$
\begin{aligned}
p_{\nu,x} + p_{\bar{\nu},x} &= E_x^{\text{miss}}, \\
p_{\nu,y} + p_{\bar{\nu},y} &= E_y^{\text{miss}}, \\
(p_{\ell^-} + p_{\bar{\nu}})^2 &= m_{W^-}^2, \\
(p_{\ell^+} + p_{\nu})^2 &= m_{W^+}^2, \\
(p_{W^-} + p_{\bar{b}})^2 &= m_{\bar{t}}^2, \\
(p_{W^+} + p_{b})^2 &= m_{t}^2,
\end{aligned}
$$

Observed distribution



Bayesian Unfording

$$\hat{n}(C_i)\epsilon_i = \sum_{j=1}^{n_E} n(E_j)P(C_i \mid E_j). \qquad P(C_i \mid E_j) = \frac{P(E_j \mid C_i)P_0(C_i)}{\sum_{l=1}^{n_C} P(E_j \mid C_l)P_0(C_l)}$$

- $P(C_i \mid E_j)$ depends on $P_0(C_i)$, which is a preori probability and introduce bias in the estimator.
- The iteration is applied to reduce this bias

Criteria to stop iteration

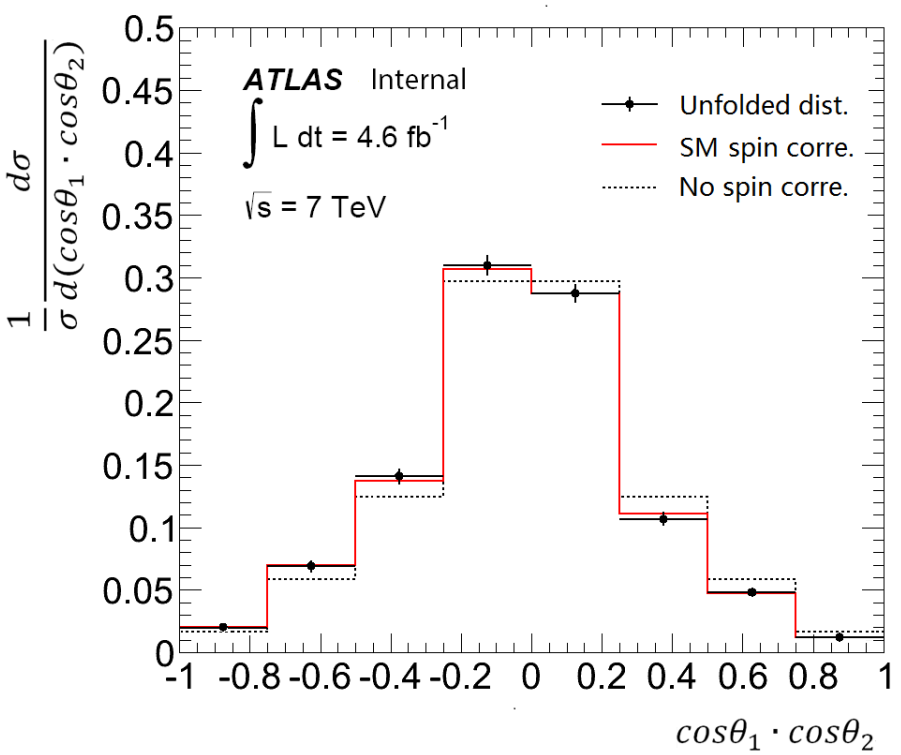
$$\chi^2 = \sum_{j=1}^{N} \sum_{i=1}^{N} (n'_i - n_i)(\sigma_{i,j})^{-1}(n'_j - n_j)^T \qquad \chi^2 / N_{bins} < 1$$

Unfolded distribution

$$C = -9 < \cos\theta_1 \cdot \cos\theta_2 >$$

$$A = \frac{C}{\alpha_1 \times \alpha_2}$$

SM prediction	$0.326^{+0.003}_{-0.002}(\mu)^{+0.013}_{-0.001}(PDF)$



The extracted value for A:

A=0.315±0.061±0.049 Accepted by PRD

First direct measurement of the top pair spin correlation in ATLAS.

Summary

- Discovery single top Wt process.
- Direct measurement top pair spin correlation
- The results are within SM

THANKS!

Backup

Changes compared to previous analysis

- Jet pT: now >20GeV, old>30GeV
- B-tag WP: now 70%, old 80%
- Etmiss: now >20GeV, old: no require

==========

- Signal event is only 56% of previous
- Ttbar: 48% of previous
- Non-top background: 20% of previous

Changes compared to previous analysis

- Analysis region
  - Previous: 1jet 1tag, 2jet >1tag
  - Now: 1jet(1tag, 0tag), 2jet (0tag, 1tag, 2tag)
- MVA training:
  - DR+DS sample used for training
- Systematic uncertainties
  - Latest detector related uncertainties
  - NLO subtraction and parton shower uncertainties were combined into one generator uncertainty
- Bill=>RooStats

Overtraining check

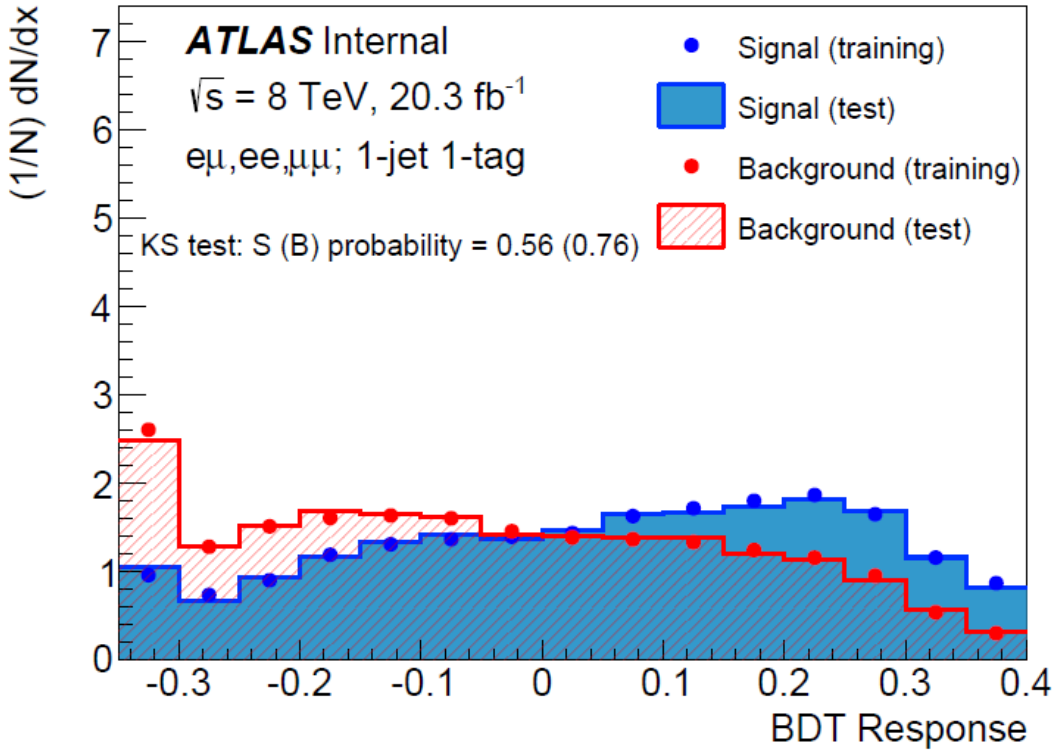


Figure 21: BDT output distribution for the training and testing samples for 1-jet 1-tag events. The blue distribution denote the signal and the red distribution denote the background. The error bar on the points correspond to the MC statistics uncertainty.