Measurements of rare top processes with the ATLAS detector

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On behave of ATLAS collaboration

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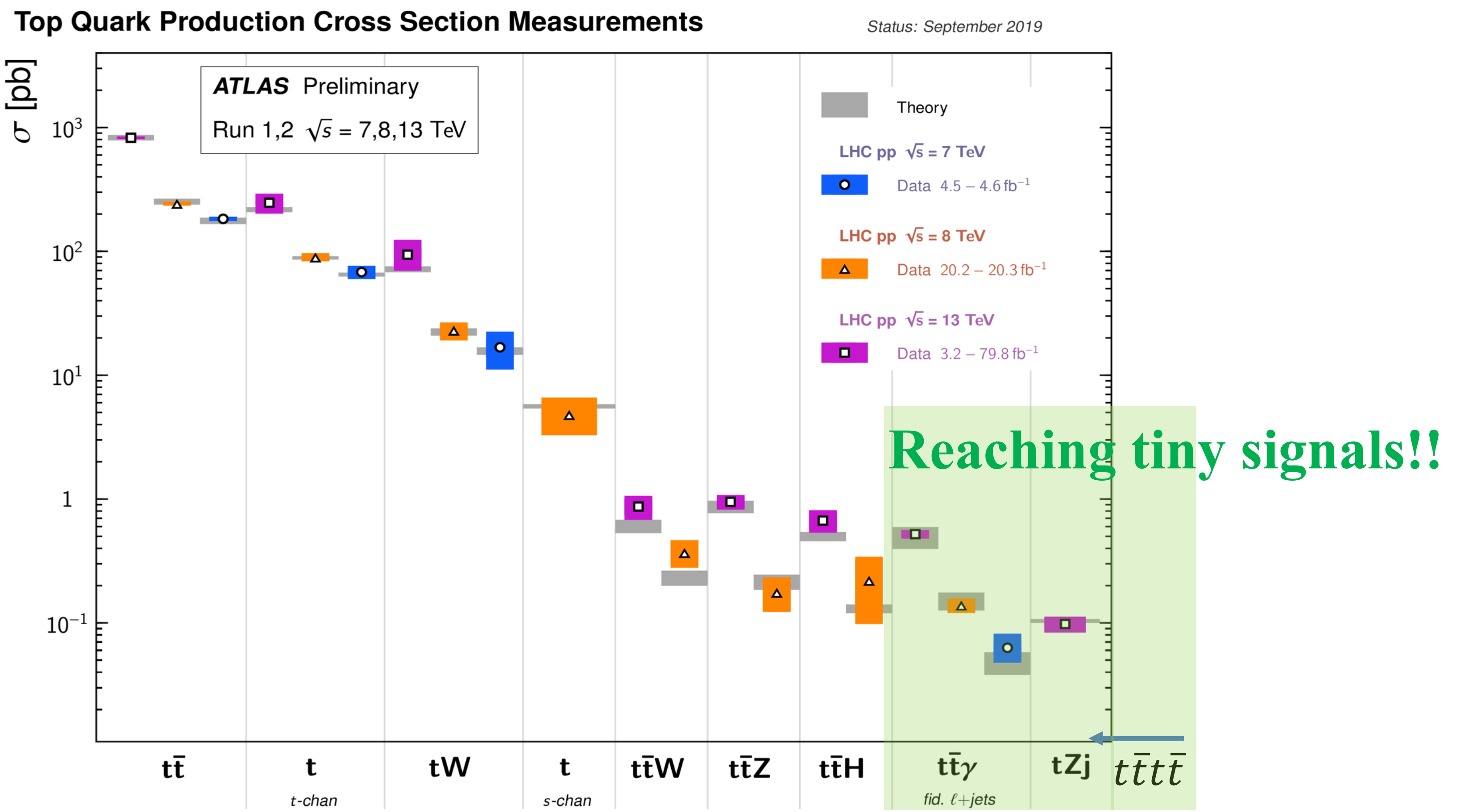
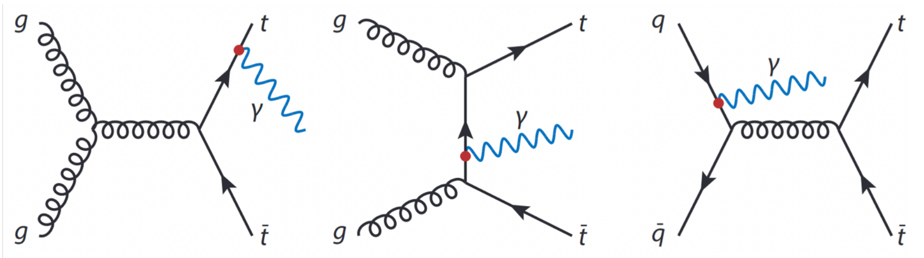
Rare processes with top quarks

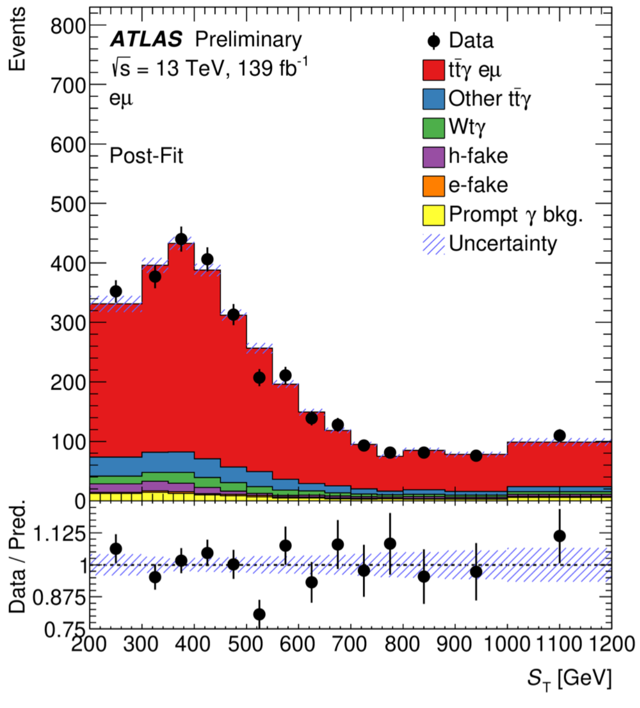
- Top quarks are special and can play an important role in the electroweak symmetry breaking and pin down new physics.
- This talk mainly focus on: $t\bar{t}+\gamma, t+Z, t\bar{t}t\bar{t}$



$t\bar{t}+\gamma$ production ATLAS-CONF-2019-042

- $t\bar{t}+\gamma$ can be produced via radiative production or radiative decay
  - Probe top-γ coupling
  - Enhanced $t\bar{t}$ charge asymmetry in $t\bar{t}+\gamma$





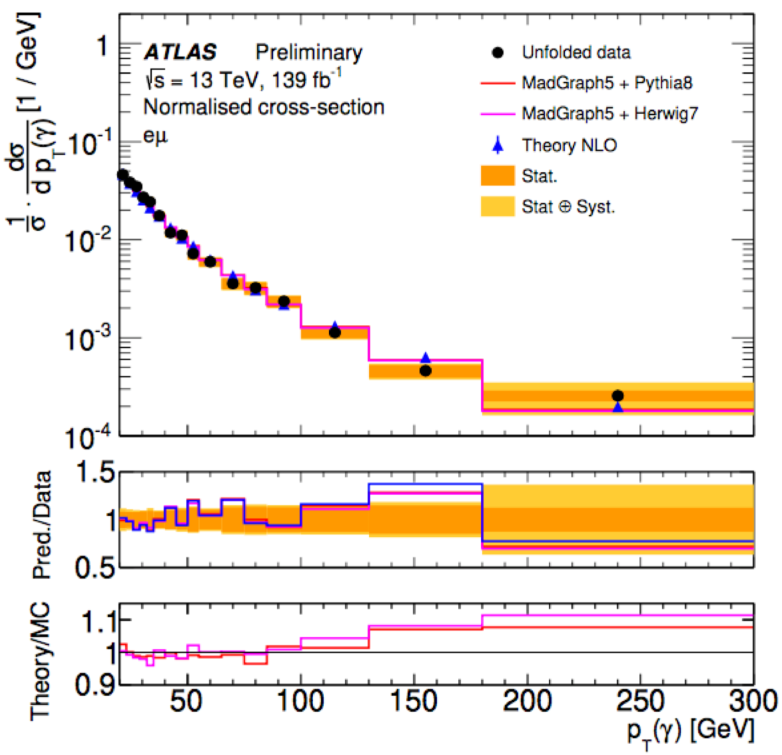
- Event selection: ($t\bar{t} \rightarrow e\mu$+jets)
  - At least 2 jets and at least 1 b-tagged (85% WP)
- Major backgrounds: $Wt\gamma$, fake photons, non-prompt leptons
- Cross section measurement:
  - Binned profile likelihood fit of S_T

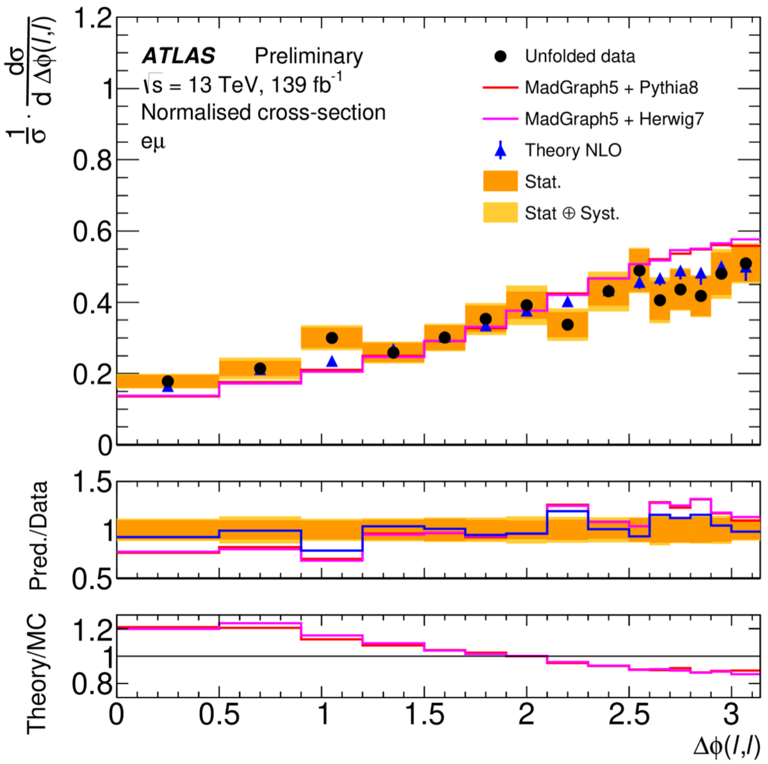
    S_T: scalar sum of all transv. momenta, incl. E_T^{miss}
  - σ^{fid}=44.2$\pm$0.9(stat.)$^{+2.6}_{-2.4}$(sys.) fb
  - Slightly larger than **NLO prediction (*first full offshell computation)** of 39.5 fb

*JHEP **10** (2018) 158

$t\bar{t}+\gamma$ production ATLAS-CONF-2019-042

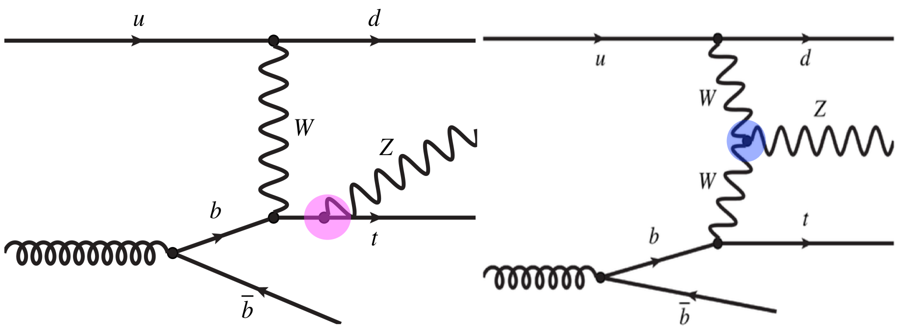
- Compare both LO MadGraph simulation and **full offshell NLO prediction** with the data:
  - Both describe most of the shape of the measured differential distributions
  - The shape of the $\Delta\phi(\ell\ell)$ is not perfectly modelled by the LO MadGraph simulation, NLO prediction gives better description

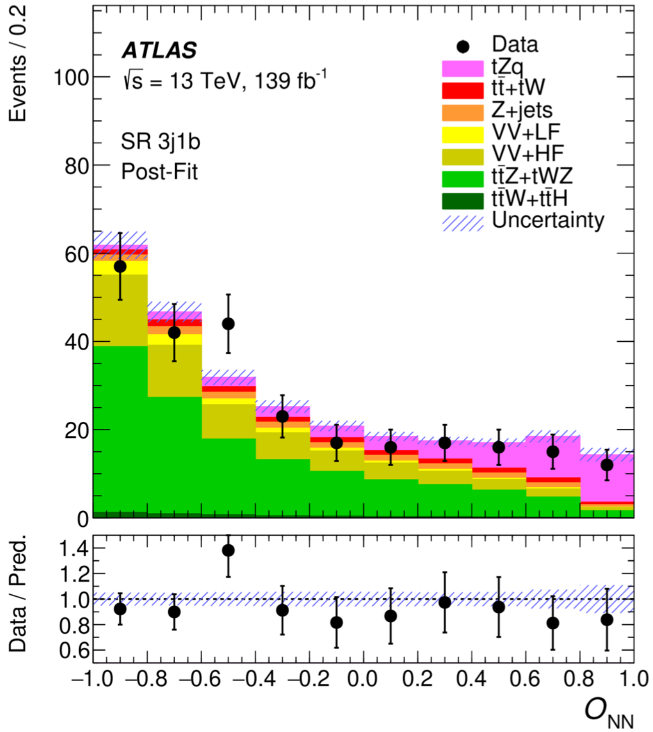




$t + Z$ production (tZq) arXiv:2002.07546, Submitted to: JHEP

- $t + Z$ arising form ISR/FSR or via triple gauge coupling
  - Probing tZ and WWZ gauge coupling





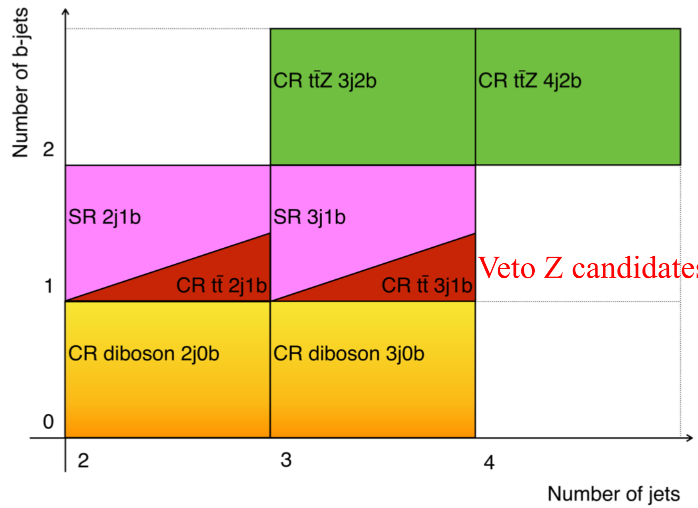
- **Event selection:** 3ℓ final state

  BR$(tZq \to b\ell\nu\ell^{\pm}\ell^{\mp}q)$~3% but experimentally easier

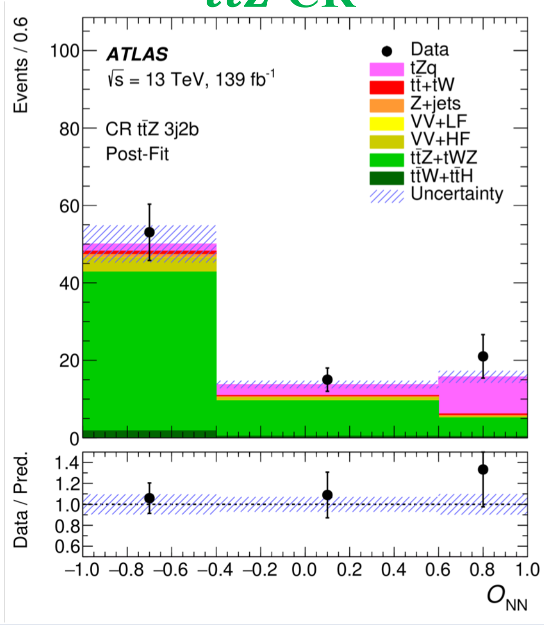
  - Z candidate $|m_{\ell^+\ell^-} - m_Z|$ <10 GeV
  - 2 or 3 jets (including forward region) with 1 b-tagged (70% WP)
- **Neural network** used to separate signal and background

$t + Z$ production (tZq) [arXiv:2002.07546](https://arxiv.org/abs/2002.07546), Submitted to: JHEP

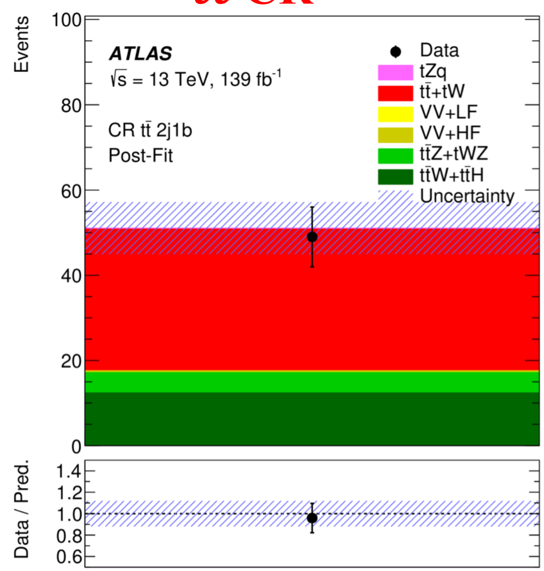
- **Main backgrounds:**
  - $t\bar{t}Z$, Diboson, non-prompt leptons ($t\bar{t}$, Z+jets)
- **Analysis strategy:**
  - Event categorized based on number of jets and b-tagged jets
  - Combined fit of signal and control regions
  - 6 control regions are used to adjust normalization as well as reduce systematics



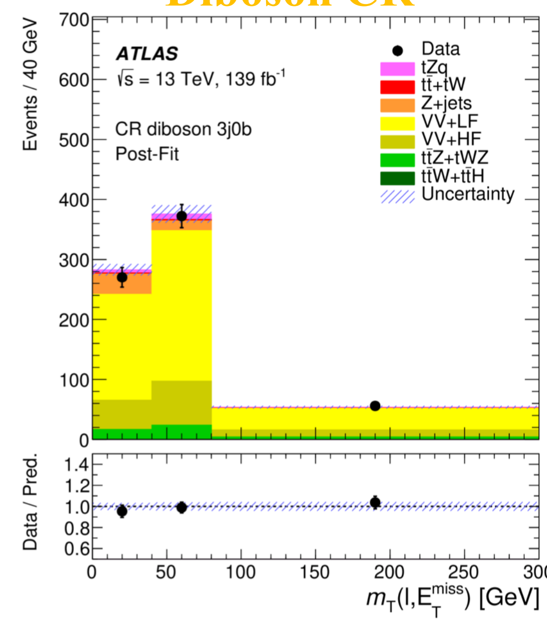
$t\bar{t}Z$ CR



$t\bar{t}$ CR

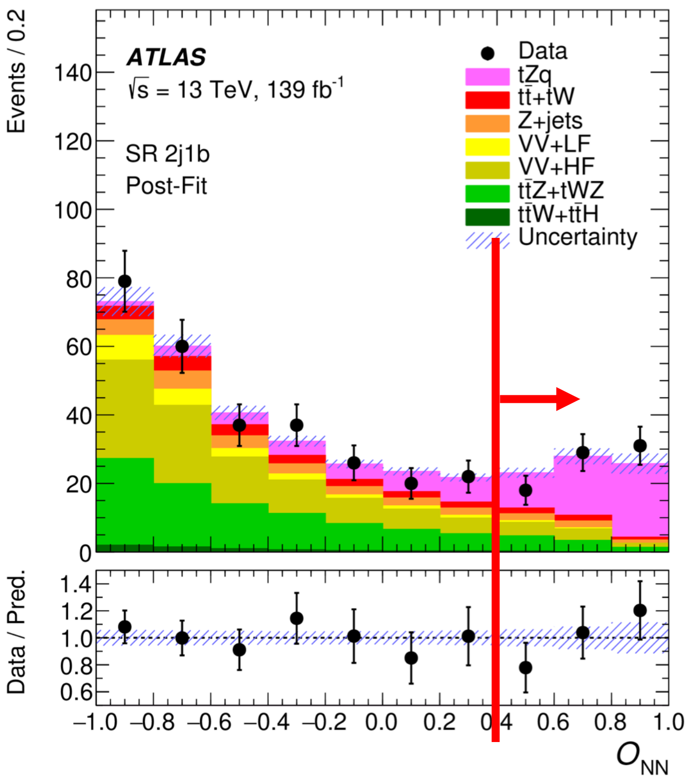


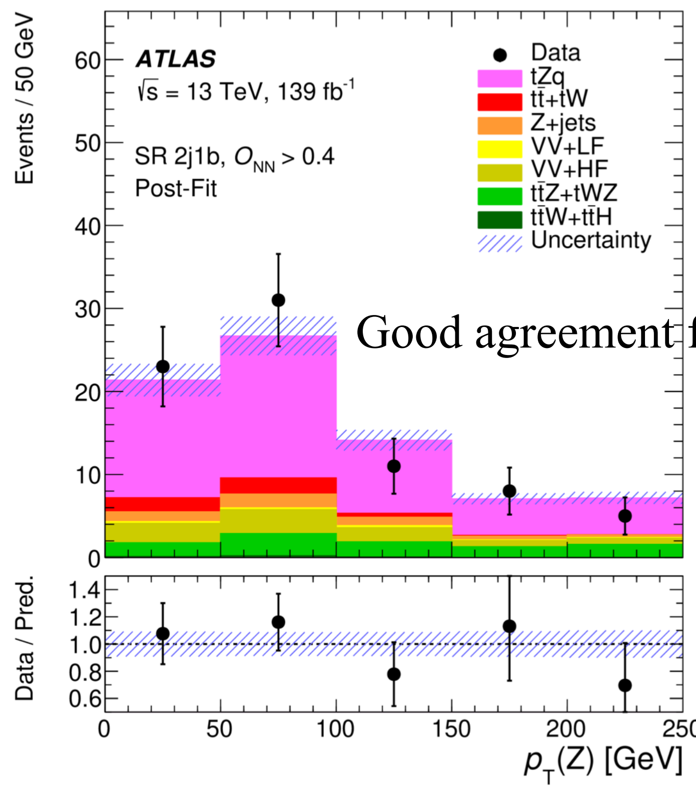
Diboson CR



$t + Z$ production (tZq) *arXiv:2002.07546*, Submitted to: JHEP

- **$t + Z$ is observed by ATLAS using full Run 2 data:**
  - Significance much greater than 5σ
  - $\sigma(tZq \rightarrow t\ell^{\pm}\ell^{\mp}q, m_{\ell^+\ell^-} > 30$ GeV $) = 97 \pm 13(\text{stat.}) \pm 7(\text{sys.})$ fb
  - Compatible with the SM prediction of 102 fb

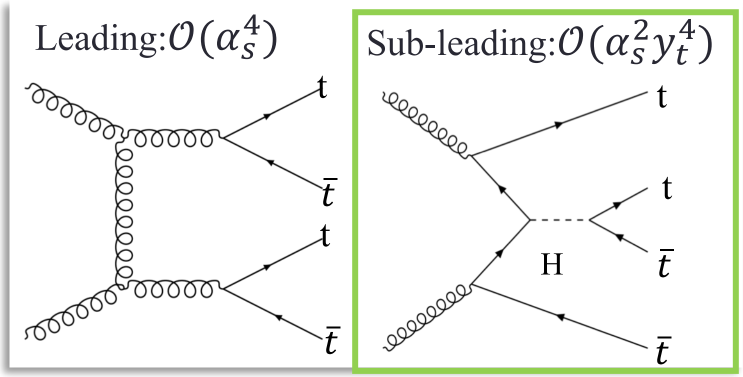


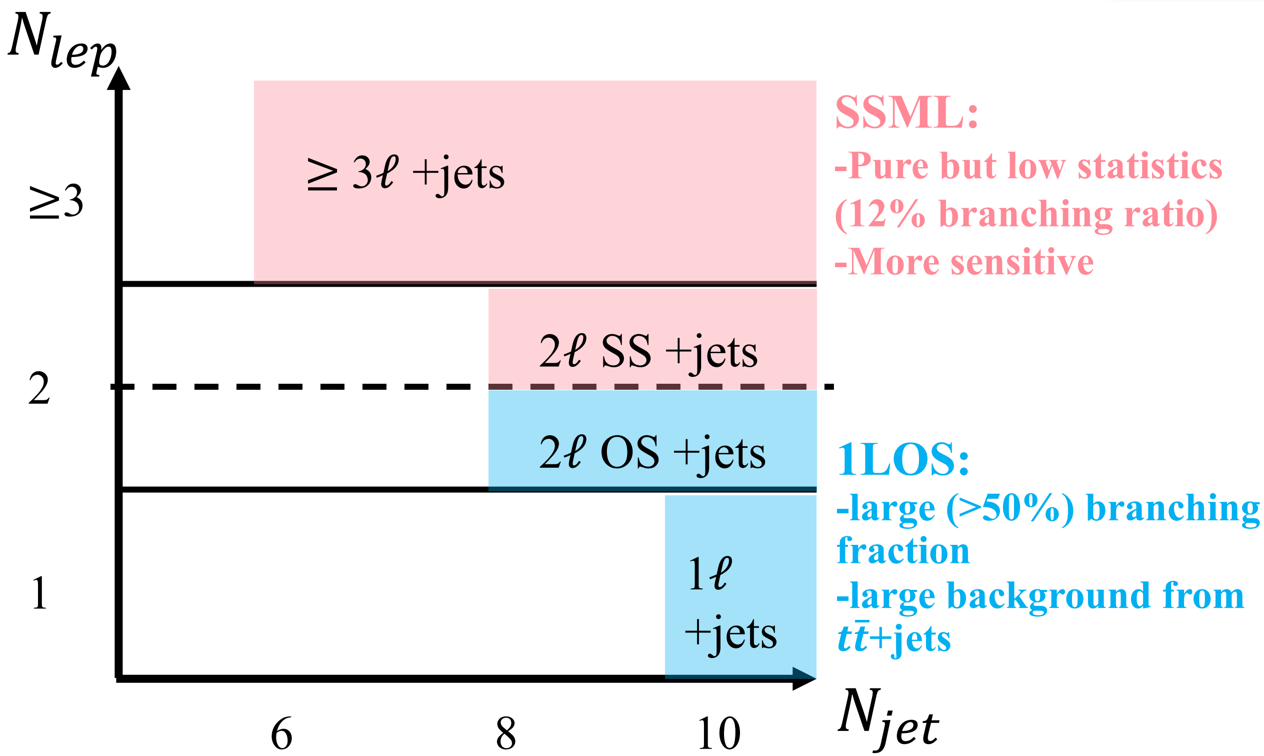


Good agreement for $p_T(Z)$

$t\bar{t}t\bar{t}$ production JHEP 12 (2018) 039 Phys. Rev. D 99 (2019) 052009

- $t\bar{t}t\bar{t}$ is a very tiny process in SM, not observed yet
  - $\sigma(t\bar{t}t\bar{t})_{NLO} \sim 12$ fb
- Sensitive to top Yukawa coupling
- Extremely high energy scale production makes it naturally sensitive to many BSM models



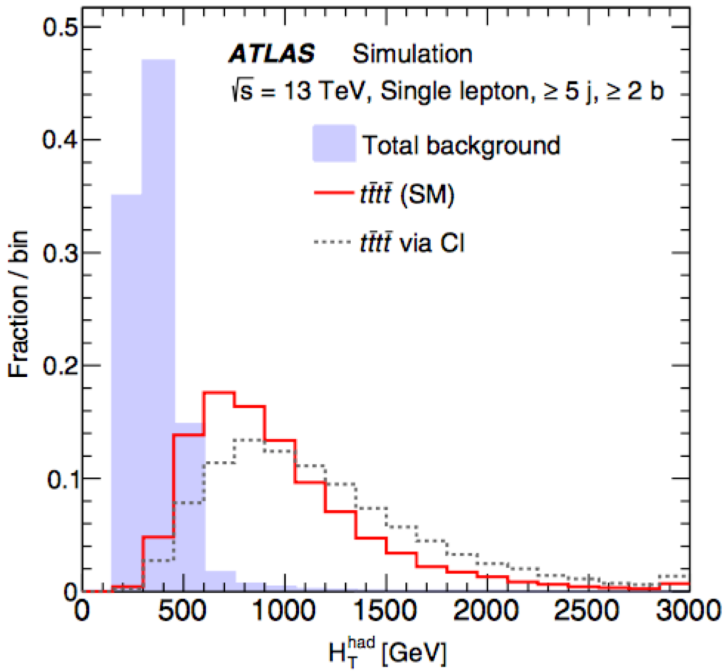


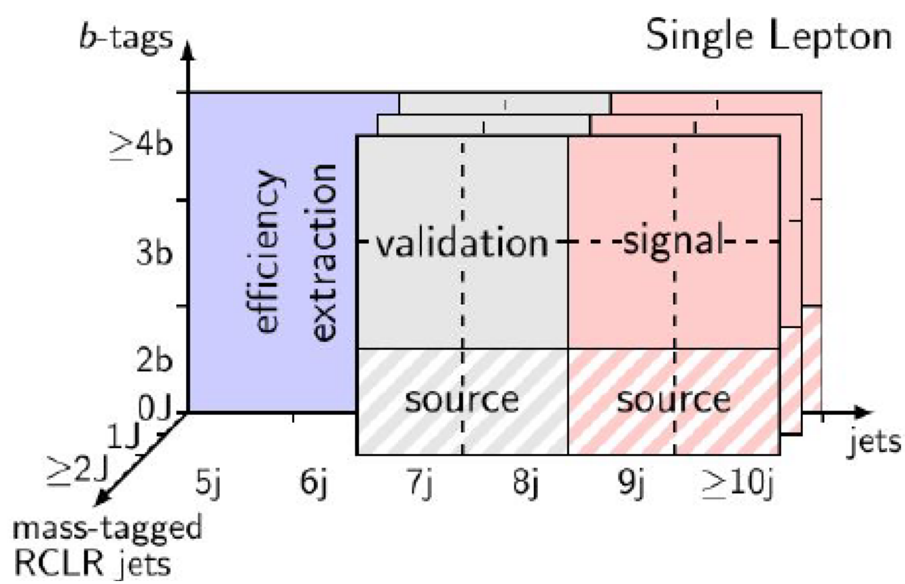
$t\bar{t}t\bar{t}$ production has many signatures to explore

- Very high jet and b-jet multiplicities
- Large hadronic activity
- Split based on number of leptons and lepton charges

$t\bar{t}t\bar{t}$ production 1L/OS [Phys. Rev. D 99 (2019) 052009]

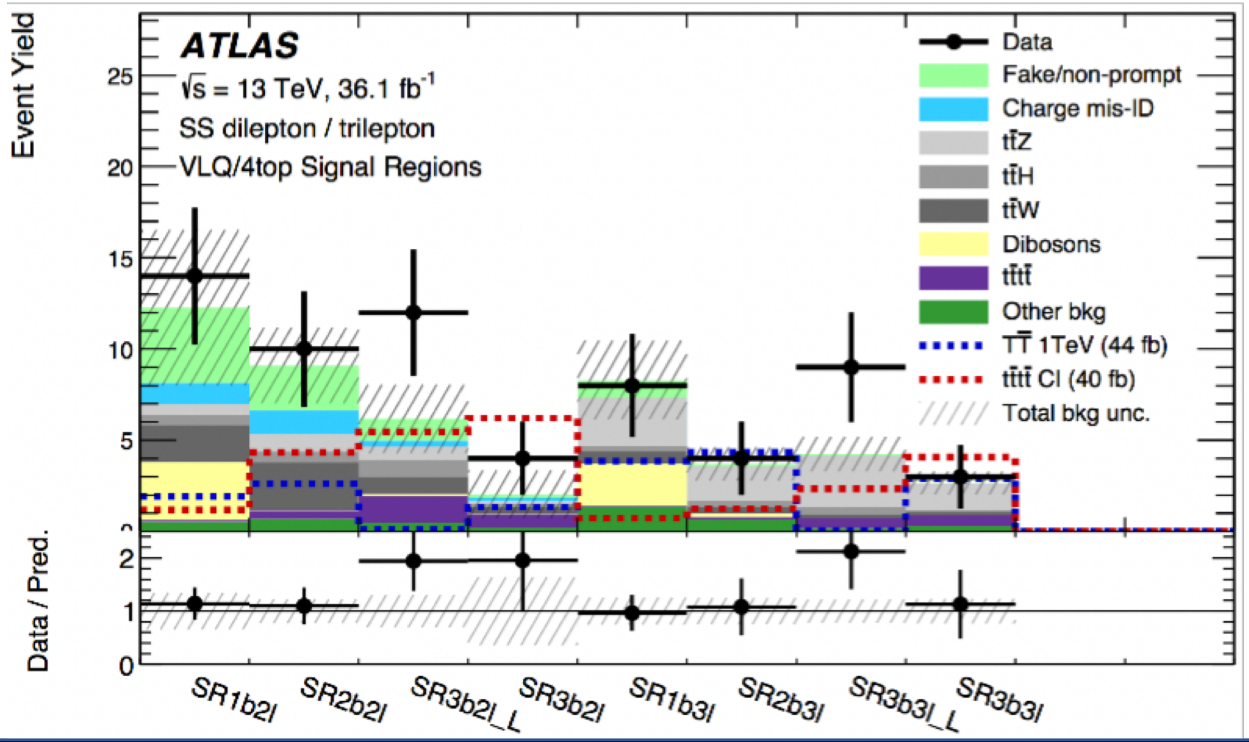
- Analysis strategy:
  - Split event according to N_{jet}, N_{b-tag} and number of mass-tagged reclustered jets (N_{RCjets})
  - Fit H_T in all signal regions
- $t\bar{t}b\bar{b}$ background estimation obtained from data
  - Efficiency measured at low N_{jet}
  - Reweight data in low N_{b-tag} and high N_{jet}





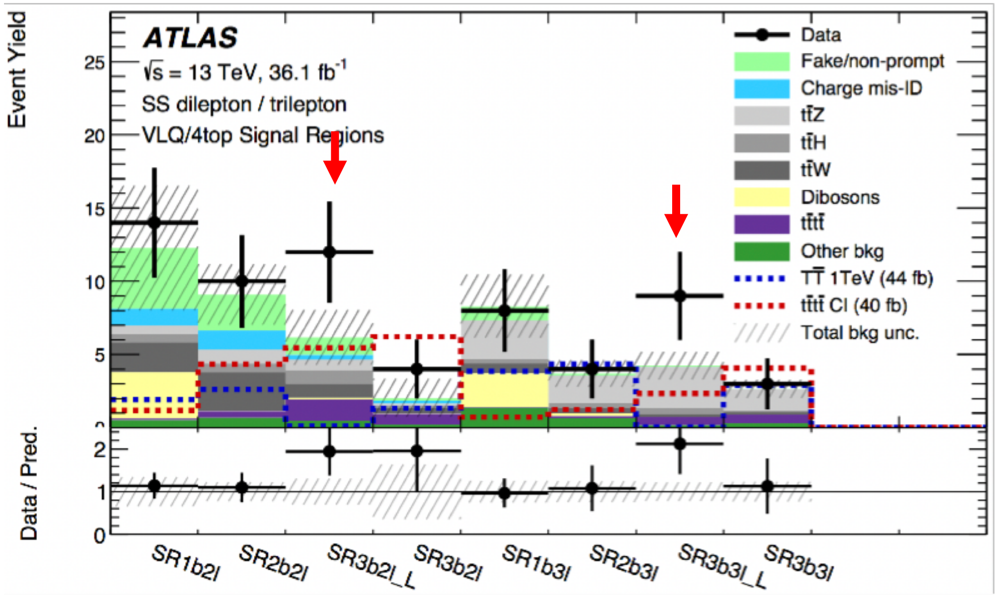
$t\bar{t}t\bar{t}$ production SS/ML JHEP 12 (2018) 039

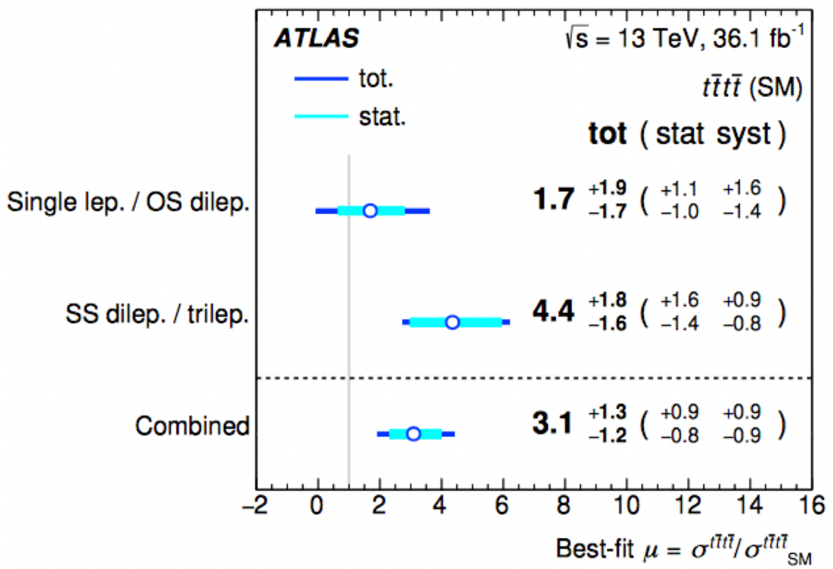
- Analysis strategy:
  - Event categorized according to N_ℓ, N_{jet}, N_{b-tag}
  - Each category split into signal and validation regions using H_T and E_T^{miss}
- Backgrounds: $t\bar{t}$V, charge mis-ID, non-prompt leptons



$t\bar{t}t\bar{t}$ production [Phys. Rev. D 99 (2019) 052009]

- 1L/OS+SS/ML results:
  - Observed (expected) 95% CL upper limit on cross-section:
    47 (33) fb = 5.1 (3.6)$\times\sigma_{SM}$
  - Observed (expected) significance 2.8 (1.0) σ
    - SS/ML: 3.0 (0.8) σ
    - 1L/OS: 1.0(0.6) σ
  - Fluctuation in data from 3b regions in SSML





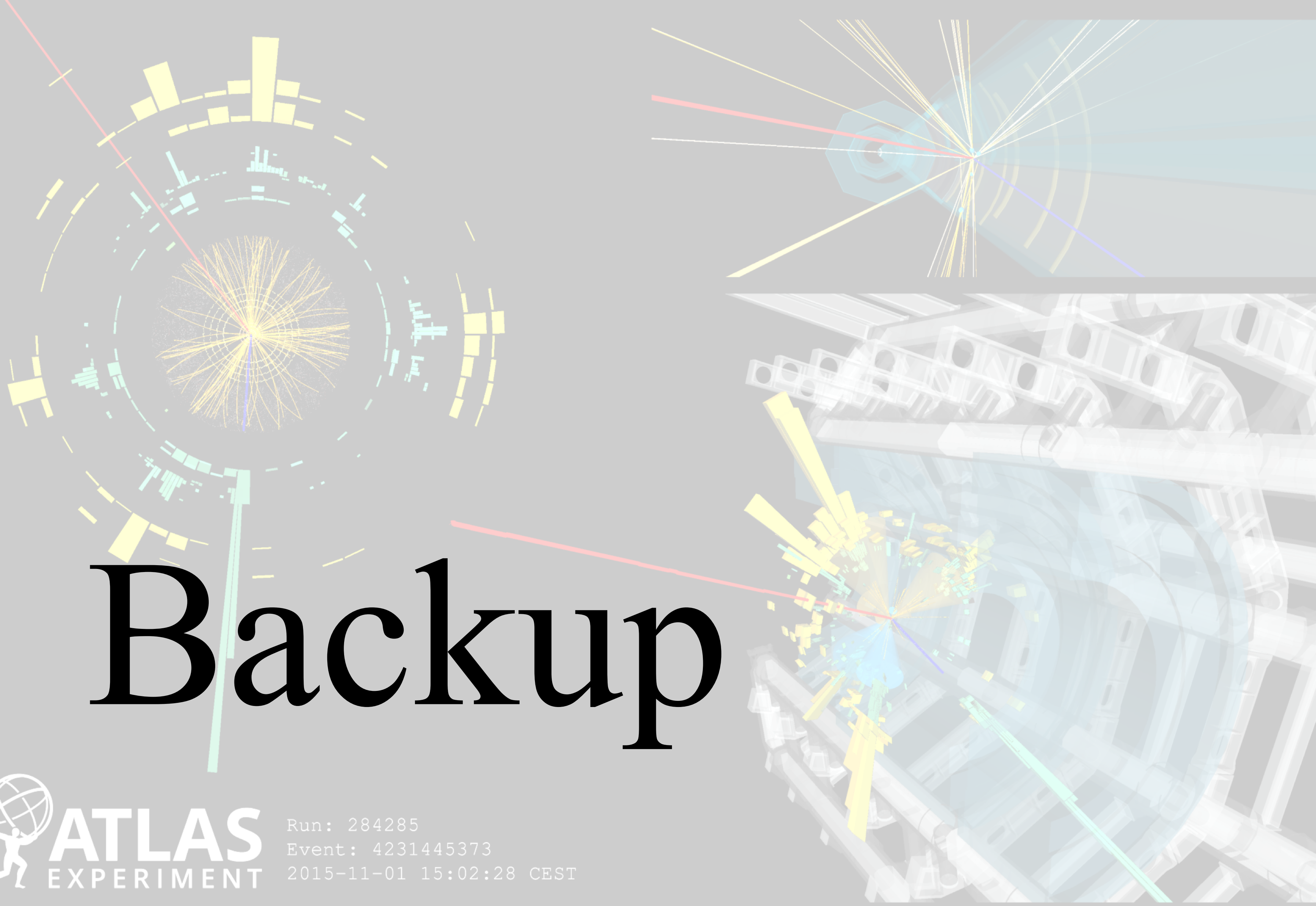
Conclusion

- Rare processes with top quarks are sensitive to the beyond SM physics
- Many rare processes with top quarks are explored in ATLAS
- Experimental challenge: large backgrounds and very small signal cross sections
- With increasing statistical sensitivity, precise theoretical predictions (also for backgrounds) become more and more important to make the most out of the data!

Thank you for listening!

Stay safe and healthy!

Backup


ATLAS
EXPERIMENT
Run: 284285
Event: 4231445373
2015-11-01 15:02:28 CEST

$t\bar{t} + \gamma$ production ATLAS-CONF-2019-042

	e+*μ* signal region
Trigger	Single-*e*/single-*μ* trigger
Leptons	1 electron, p_T > 25 GeV
	1 muon, p_T > 25 GeV
	opposite sign
	M_{ll} > 15 GeV
Jets	2 or more (*R*=0.4)
b-tags	1 or more (85% efficiency)
Photons	1 photon, p_T > 20 GeV

Category	Uncertainty
Signal modelling	3.4%
Background modelling	2.2%
Photons	2.0%
Luminosity	1.9%
Jets	1.8%
Flavour-tagging	1.1%
MC statistics	0.5%
Others	1.7%
Total syst.	5.5%

$t\bar{t}+\gamma$ production ATLAS-CONF-2019-042

- $t\bar{t}+\gamma$ can be produced via radiative production or radiative decay
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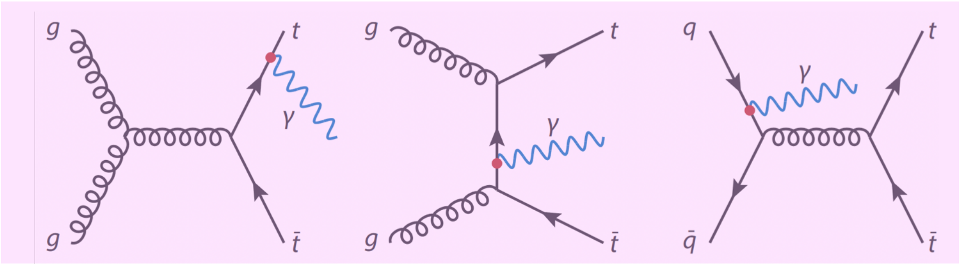
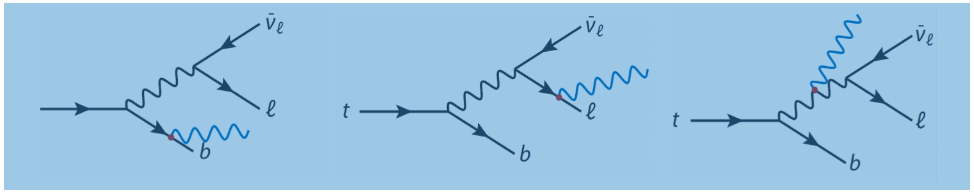
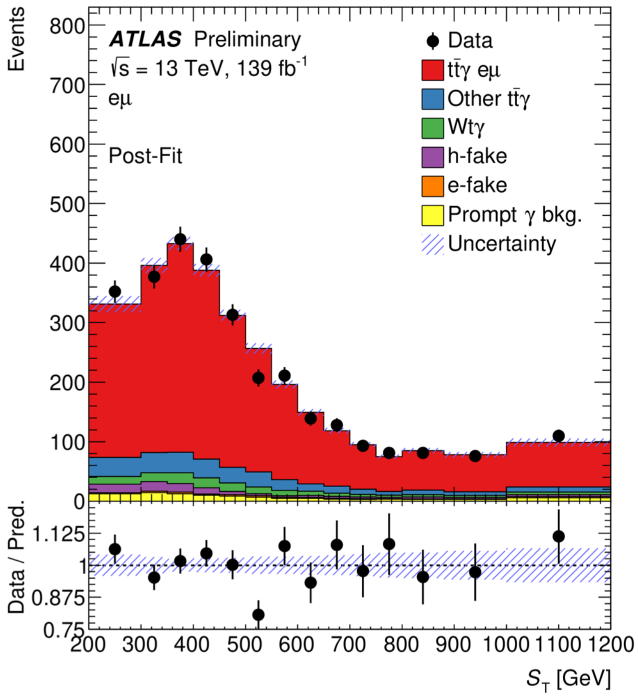
  - Enhanced $t\bar{t}$ charge asymmetry in $t\bar{t}+\gamma$

photon radiation on top of $t\bar{t}$ production



photon radiation during top decay





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Common selections			
Exactly 3 leptons (e or μ) with $\lvert\eta\rvert < 2.5$ $p_T(\ell_1) > 28$ GeV, $p_T(\ell_2) > 20$ GeV, $p_T(\ell_3) > 20$ GeV $p_T(\text{jet}) > 35$ GeV			
SR 2j1b	CR diboson 2j0b	CR $t\bar{t}$ 2j1b	CR $t\bar{t}Z$ 3j2b
≥ 1 OSSF pair $\lvert m_{\ell\ell} - m_Z\rvert < 10$ GeV 2 jets, $\lvert\eta\rvert < 4.5$ 1 b-jet, $\lvert\eta\rvert < 2.5$	≥ 1 OSSF pair $\lvert m_{\ell\ell} - m_Z\rvert < 10$ GeV 2 jets, $\lvert\eta\rvert < 4.5$ 0 b-jets	≥ 1 OSDF pair No OSSF pair 2 jets, $\lvert\eta\rvert < 4.5$ 1 b-jet, $\lvert\eta\rvert < 2.5$	≥ 1 OSSF pair $\lvert m_{\ell\ell} - m_Z\rvert < 10$ GeV 3 jets, $\lvert\eta\rvert < 4.5$ 2 b-jets, $\lvert\eta\rvert < 2.5$
SR 3j1b	CR diboson 3j0b	CR $t\bar{t}$ 3j1b	CR $t\bar{t}Z$ 4j2b
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$t\bar{t}t\bar{t}$ production 1L/OS *Phys. Rev. D 99 (2019) 052009*

Requirement	Single-lepton	Dilepton
Trigger	Single-lepton triggers	
Leptons	1 isolated	2 isolated, opposite-sign
Jets	≥ 5 jets	≥ 4 jets
b-tagged jets	≥ 2 b-tagged jets	
Other	$E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV	$m_{\ell\ell} > 50$ GeV
	$E_{\mathrm{T}}^{\mathrm{miss}} + m_{\mathrm{T}}^{W} > 60$ GeV	$\lvert m_{\ell\ell} - 91\ \mathrm{GeV}\rvert > 8$ GeV