Measurement and reinterpretation of $t\bar{t}t\bar{t}$ production with the ATLAS detector in pp collisions at √s = 13 TeV

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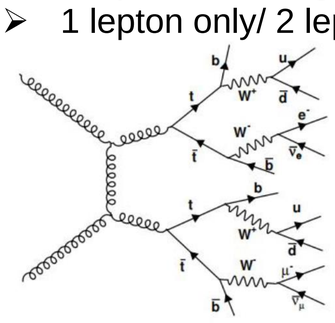
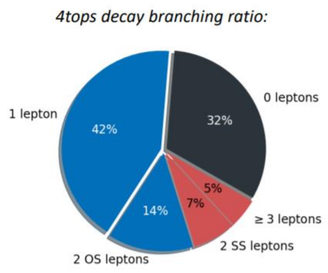
Measurement of $t\bar{t}t\bar{t}$ production with ATLAS detector

- Four-top-quark production is predicted in SM
  - The heaviest final state on ALTAS in SM prediction
  - Its cross section is sensitive to the magnitude and CP properties of the Yukawa coupling of the top quark to the Higgs
  - A sensitive probe for new physics, such as EFT, 2HDM model
- $t\bar{t}t\bar{t}$ will decay into $W^+W^-W^+W^-$ bbbb. Depending on decay mode of the W bosons, it mainly has 2 channels:
  - 2 lepton same sign/ 3 leptons (2LSS/3L)
  - 1 lepton only/ 2 lepton opposite sign (1L/2LOS)





- **Object definition** [1] [2]**:**

Objects	2LSS/3L	1L/2LOS
Electron/Muon	pT > 28 GeV	pT > 10 GeV
Small-R jet	Anti-kt R = 0.4, pT > 25GeV, |η| < 2.5	
Large-R jet	Anti-kt R = 1.0, pT > 200GeV, |η| < 2.0	
b-tagging	MV2c10 multivariate algorithm	

- **Event selection :**

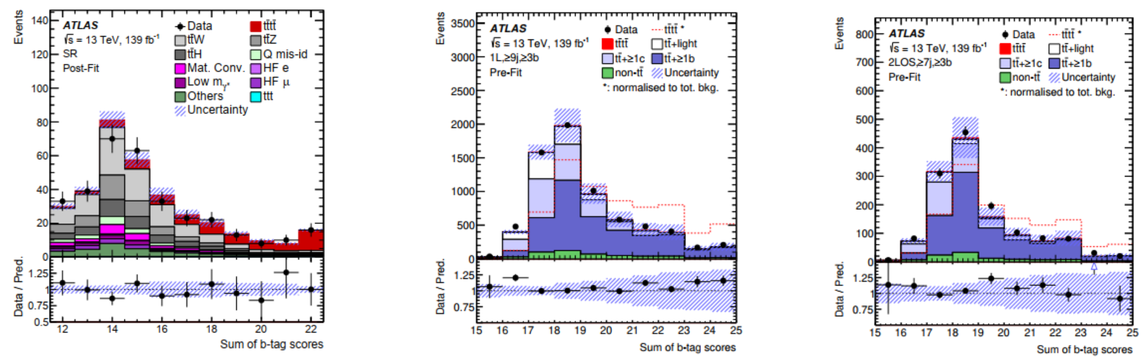
2LSS/3L

- Lepton cut: 2 leptons/ multi-lepton with Z-veto
- Jet number: >= 6 jets
- b jets: >= 2 b jets
- H_T> 500 GeV

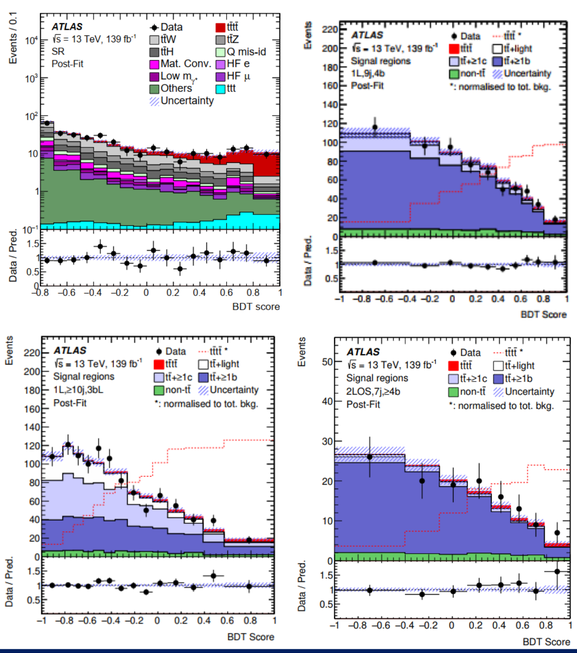
1L/2LOS

- Lepton cut: 1 lepton/ 2 lepton opposite sign
- Jet number: 8-10 jets (5-8 jet for 2LOS)
- b jets: >= 4 b jets
- Events with 3 b jets should >=10 jets (3 bjets and >=8 jets for 2LOS)

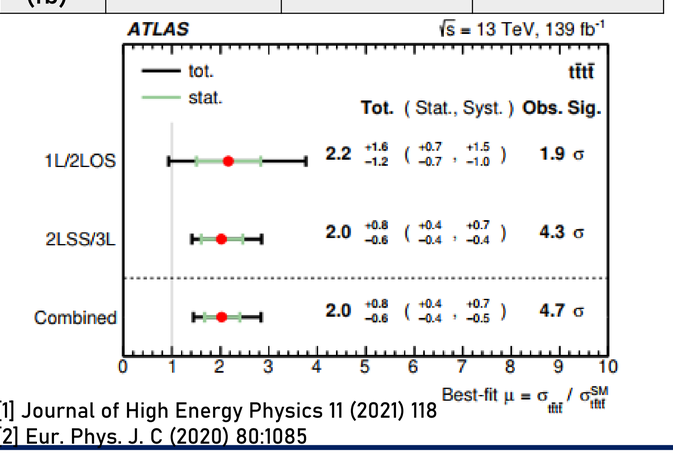
- **Background modelling:**
  - Common backgrounds: ttW , ttZ , ttH , single top-quark or W/Z boson+ jets
  - 1L/2LOS dominant background: $t\bar{t}$ + jets
  - 2LSS/3L dominant backgrounds: ttW and fake/non-prompt background



- **MVA Method**: using Boost Decision Tree (BDT) to extract signal for fitting



	2LSS/3L	1L/2LOS	Combination
significance	4.3 (2.4)σ	1.9 (1.0)σ	4.7 (2.6)σ
$\sigma(t\bar{t}t\bar{t})$ (fb)	24^{+7}_{-6}	26^{+17}_{-15}	24^{+7}_{-6}



[1] Journal of High Energy Physics 11 (2021) 118
[2] Eur. Phys. J. C (2020) 80:1085

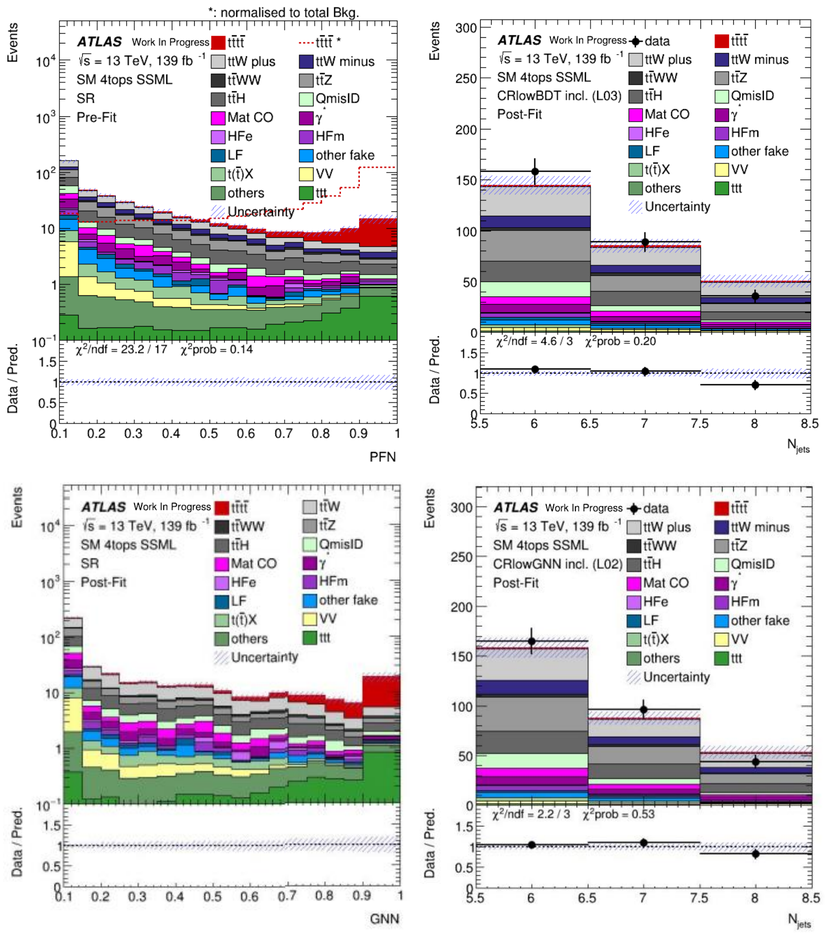
Updated 2LSS/3L channel analysis

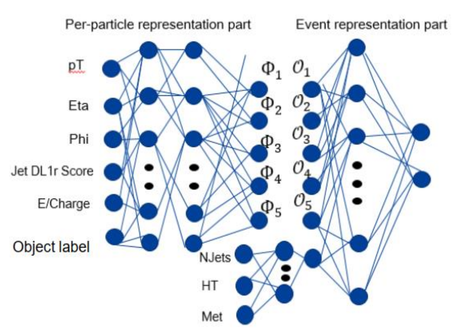
Big improvement in expected sensitivity(~50%) seen after optimizations in objection definition, background modelling and MVA method.

- **New Object definition**:

Objects	Definitions
Electron/Muon	lepton pT > 15 GeV, PLIV isolation
Small-R jet	Anti-kt R = 0.4, PFlow jet, pT > 20GeV
Large-R jet	Anti-kt R = 1.0, LCTopo jet, pT > 200GeV, |η| < 2.0
b-tagging	77% efficiency, deep-learning neural network (DL1r)

- Use **template fit method** to estimate fake/non-prompt backgrounds from $t\bar{t}$ in CRs
- Use **data-driven method** to estimate ttW + jets to suppress the dominant systematics

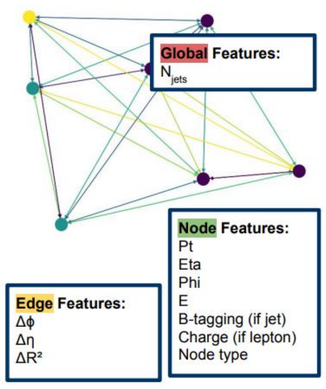




- **Improvements on MVA methods**

I. **Particle Flow Network (PFN)** can take using of jet/lepton's information to classify signal and backgrounds.

II. **Graph Neutral Network (GNN)** puts jet/lepton's information into different nodes and edges to construct graph structure for training
  - Trained by k-Fold method to improve performance
  - Check data/MC agreement in low MVA region



Preliminary EFT reinterpretation results

EFT fitting in four tops (on going)

- Express Lagrangian into matrix form to obtain the linear and quadratic coefficients

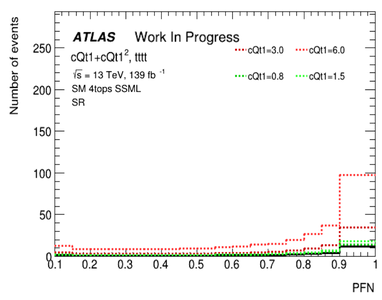
$$\sigma_{t\bar{t}t\bar{t}} = \sigma^{SM}_{t\bar{t}t\bar{t}} + \frac{1}{\Lambda^2}\vec{C}^T \cdot \vec{\sigma}^{(1)} + \frac{1}{\Lambda^4}\vec{C}^T \sigma^{(2)} \vec{C}.$$

- Fit curve of increased XS versus EFT parameters in each SR bin and apply that to the SM 4top μ

➢ Assume $\sigma(t\bar{t}t\bar{t})$ is contributed by one EFT parameter only (no cross terms)

Sensitive EFT parameters in 4 top

$$\mathcal{O}^1_{tt} = (\bar{t}_R\gamma^\mu t_R)(\bar{t}_R\gamma_\mu t_R),$$
$$\mathcal{O}^1_{QQ} = (\bar{Q}_L\gamma^\mu Q_L)(\bar{Q}_L\gamma_\mu Q_L),$$
$$\mathcal{O}^1_{Qt} = (\bar{Q}_L\gamma^\mu Q_L)(\bar{t}_R\gamma_\mu t_R),$$
$$\mathcal{O}^8_{Qt} = (\bar{Q}_L\gamma^\mu T^A Q_L)(\bar{t}_R\gamma_\mu T^A t_R),$$



PFN fitting result

EFT parameters	cQQ1	cQt1	ctt1	cQt8
Expected 95% C.L. intervals	[-2.7, 3.2]	[-2.7, 2.3]	[-1.4, 1.4]	[-4.3, 5.2]

Outlook

- Expected significance of $t\bar{t}t\bar{t}$ process for the reinterpretation 2LSS/3L channel analysis can reach about 3.6σ
- Big improvements on expected significance compared with previous results (2.6σ)

MVA Method	Realistic Asimov significance (σ)
XGBoost	3.4
PFN	3.5
GNN	3.6

- Projection after combining improved 2LSS/3L results with existing 1L/2LOS results:
  - Expected significance reaches 3.8 σ
  - Observed significance > 5σ
  - Expect first observation of $t\bar{t}t\bar{t}$ production with full Run 2 data