The Most Precise $\sigma_{t\bar{t}}$ Measurement in the Lepton+Jets Channel with the ATLAS Detector

arXiv:2207.01354

La Thuile 2023

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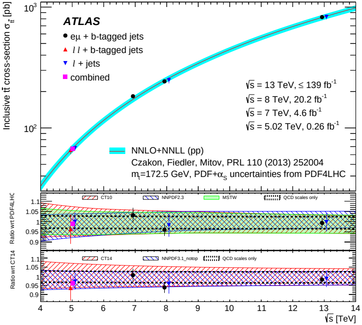
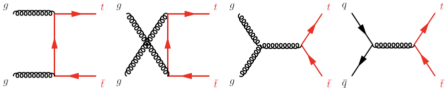
March 9, 2023

Outline

Motivation

- 257 pb^{-1} of data collected by ATLAS in 2017 with $\sqrt{s} = 5.02$ TeV
- Allows for a measurement of $\sigma_{t\bar{t}}$ in a pileup free environment
- Gluon PDF at high Bjorken x sensitive to $\sigma_{t\bar{t}}$ measured at low $\sqrt{s}$
- CMS measured $\sigma_{t\bar{t}}$ in the dilepton and single-lepton channels - arXiv:2112.09114
  - $\sigma_{t\bar{t}} = 62.6 \pm 4.1(\text{stat.}) \pm 3.0(\text{syst.} + \text{lumi.})$ pb ($\pm 7.9\%$)
  - NNLO+NNLL prediction: 68.2 pb





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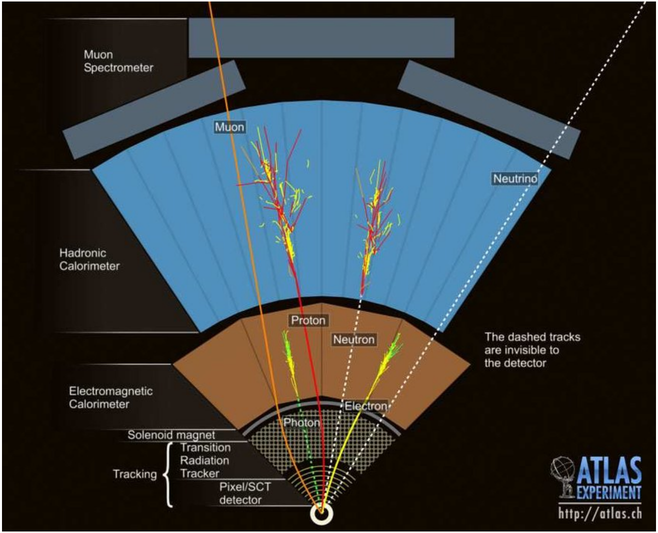
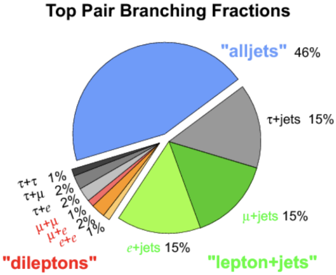
The ATLAS Detector

- General purpose detector used to probe SM and BSM physics



Analysis Strategy

- Measure $\sigma_{t\bar{t}}$ in single-lepton and dilepton channels separately then combine
- Dilepton channel:
  - Excellent purity but low statistics
  - Cut-and-count method used to measure $\sigma_{t\bar{t}}$ in both SF and OF dilepton events
- Single-lepton channel:
  - Higher statistics but lower purity
  - A Boosted Decision Tree (BDT) trained to separate signal and background
  - Binned profile-likelihood fit of BDT output used to extract $\sigma_{t\bar{t}}$
- Results combined using the Convino tool - arXiv:1706.01681

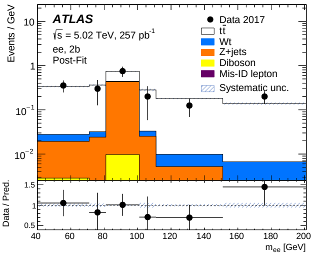


Dilepton Channel

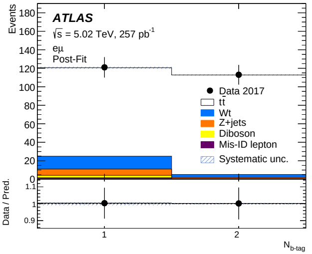
arXiv:2207.01354

- Double tagging formalism used for both SF and OF events for the first time!

$$N^{\ell\ell}_{1,m} = L\sigma_{t\bar{t}}\,\epsilon_{\ell\ell}\,2\epsilon^{\ell\ell}_{b}(1-C^{\ell\ell}_{b}\epsilon^{\ell\ell}_{b})\,f^{\ell\ell,t\bar{t}}_{1,m} + \sum_{k=\mathrm{bkg}} s^{k}_{1}\,f^{\ell\ell,k}_{1,m},$$
$$N^{\ell\ell}_{2,m} = L\sigma_{t\bar{t}}\,\epsilon_{\ell\ell}\,C^{\ell\ell}_{b}(\epsilon^{\ell\ell}_{b})^{2}\,f^{\ell\ell,t\bar{t}}_{2,m} + \sum_{k=\mathrm{bkg}} s^{k}_{2}\,f^{\ell\ell,k}_{2,m}$$



- Single lepton trigger, 2 OS leptons with $p_T > 18$ GeV
- Jet $p_T > 25$ GeV with 1 or 2 b-tags
- Cuts on m_{ll} and E_T^{miss}
- Measure $\sigma_{t\bar{t}}$, ϵ_b^{ll}, S_1^Z, and S_2^Z

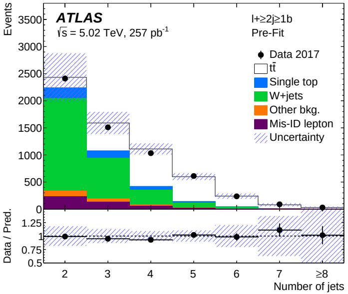


Single-lepton Channel

arXiv:2207.01354

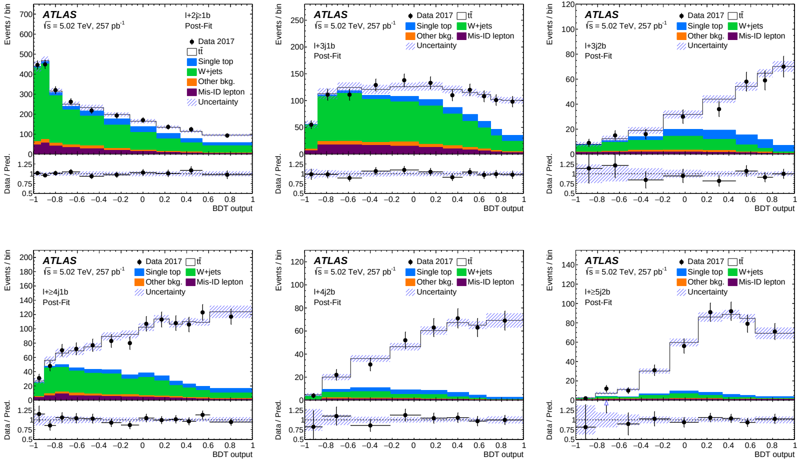
- Exactly one electron or muon candidate
- Lepton $p_T > 25$ GeV and $|\eta| < 2.5$
- ≥ 2 jets with $p_T > 20$ GeV and $|\eta| < 2.5$
- Events classified into 6 regions based on number of jets and b-tagged jets
- Cuts on MET and m_T^W applied to reduce mis-identified lepton background

Region name	Jet multiplicity	b-jet multiplicity
ℓ+2j≥1b	2	≥ 1
ℓ+3j 1b	3	1
ℓ+3j 2b	3	2
ℓ+≥4j 1b	≥ 4	1
ℓ+4j 2b	4	2
ℓ+≥5j 2b	≥ 5	2



BDT Distributions

- Good agreement between prediction and data in the BDT distributions for the 6 regions - arXiv:2207.01354



Combination

- Convino tool used to combine Dilepton and single-lepton results - arXiv:1706.01681
- Minimize $\chi^2 = \chi_S^2 + \chi_U^2 + \chi_P^2$
  - χ_S^2: The statistical uncertainty of each measurement
  - χ_U^2: The correlations between systematic uncertainties and any constraints from data
  - χ_P^2: Gaussian penalty term for systematic uncertainties and encodes prior information on correlations between systematic uncertainties

Results

- SL: $68.2 \pm 0.9(\text{stat.}) \pm 2.9(\text{syst.}) \pm 1.1(\text{lumi.}) \pm 0.2(\text{beam})$ pb
- DL: $65.7 \pm 4.5(\text{stat.}) \pm 1.6(\text{syst.}) \pm 1.2(\text{lumi.}) \pm 0.2(\text{beam})$ pb
- Comb: $67.5 \pm 0.9(\text{stat.}) \pm 2.3(\text{syst.}) \pm 1.1(\text{lumi.}) \pm 0.2(\text{beam})$ pb

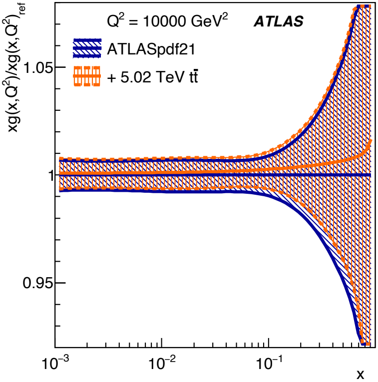
arXiv:2207.01354

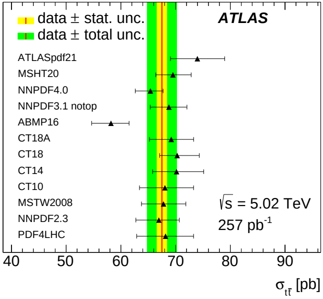
- Predicted $\sigma_{t\bar{t}} = 68.2$ pb
- 4.5% $\sigma_{t\bar{t}}$ uncertainty is the **most precise** single-lepton measurement by ATLAS at any energy!
- 3.9% overall uncertainty after combination

Category	$\delta\sigma_{t\bar{t}}$ [%] Dilepton	Single lepton	Combination
$t\bar{t}$ generator†	1.2	1.0	0.8
$t\bar{t}$ parton-shower/hadronisation*,†	0.3	0.9	0.7
$t\bar{t}$ h_{damp} and scale variations†	1.0	1.1	0.8
$t\bar{t}$ parton distribution functions†	0.2	0.2	0.2
Single-top background	1.1	0.8	0.6
W/Z + jets background*	0.8	2.4	1.8
Diboson background	0.3	0.1	< 0.1
Misidentified leptons*	0.7	0.3	0.3
Electron identification/isolation	0.8	1.2	0.8
Electron energy scale/resolution	0.1	0.1	< 0.1
Muon identification/isolation	0.6	0.2	0.3
Muon momentum scale/resolution	0.1	0.1	0.1
Lepton-trigger efficiency	0.2	0.9	0.7
Jet-energy scale/resolution	0.1	1.1	0.8
$\sqrt{s}$ = 5.02 TeV JES correction	0.1	0.6	0.5
Jet-vertex tagging	< 0.1	0.2	0.2
Flavour tagging	0.1	1.1	0.8
E_T^{miss}	0.1	0.4	0.3
Simulation statistical uncertainty*	0.2	0.6	0.5
Data statistical uncertainty*	6.8	1.3	1.3
Total systematic uncertainty	3.1	4.2	3.7
Integrated luminosity	1.8	1.6	1.6
Beam energy	0.3	0.3	0.3
Total uncertainty	7.5	4.5	3.9

Effect of 5.02 TeV Measurement on Gluon PDF

- Effect of combined $\sigma_{t\bar{t}}$ at $\sqrt{s} = 5.02$ TeV on the new ATLASpdf21 measured using `xFitter` tool
- Including $\sigma_{t\bar{t}}$ results in slight enhancement of gluon PDF for $x > 0.1$





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Conclusions

- The most precise $\sigma_{t\bar{t}}$ measurement in the single-lepton channel by ATLAS is now the $\sqrt{s} = 5.02$ TeV measurement!
- The single $\sigma_{t\bar{t}}$ at $\sqrt{s} = 5.02$ TeV has a visible effect on the gluon PDF at high x when added to ATLASpdf21!
- Special runs like the $\sqrt{s} = 5$ TeV campaign are a largely untapped pool of interesting physics
- Unique challenges with such runs but also unique opportunities!

Backup

Double-tagging Formalism

- Use double-tagging formalism for OF events

$$\begin{aligned} N_{1,m}^{\ell\ell} &= L\sigma_{t\bar{t}}\,\epsilon_{\ell\ell}\,2\epsilon_b^{\ell\ell}(1 - C_b^{\ell\ell}\epsilon_b^{\ell\ell})\,f_{1,m}^{\ell\ell,t\bar{t}} &+ \sum_{k=\mathrm{bkg}} s_1^k\, f_{1,m}^{\ell\ell,k}, \\ N_{2,m}^{\ell\ell} &= L\sigma_{t\bar{t}}\,\epsilon_{\ell\ell}\,C_b^{\ell\ell}(\epsilon_b^{\ell\ell})^2\,f_{2,m}^{\ell\ell,t\bar{t}} &+ \sum_{k=\mathrm{bkg}} s_2^k\, f_{2,m}^{\ell\ell,k} \end{aligned}$$

- $N_1(N_2)$: Number of events with 1 (2) b-tags
- L: Luminosity
- $\epsilon_{e\mu}$: The efficiency for an event to pass the $e\mu$ selection
- ϵ_b: Probablity for a jet to be reconstructed and pass the b-tagging criteria
- C_b: b-tagging correlation coefficient
- s^k: Scale factors for backgrounds (k)
  - $s^k = 1$ for all backgrounds except Z+jets
  - $k =$ Wt, diboson, Z+jets and fake leptons