Welcome
and
Introduction

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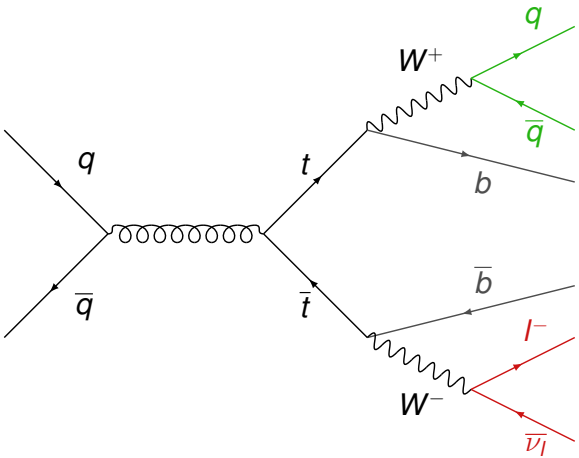
Top-quark pair production

- The top quark is the **heaviest** known elementary particle.
- Top quarks are more likely producted in **quark-antiquark pairs** ($t\bar{t}$).
- With the lifetime of 0.15 fm ($5 \cdot 10^{-25}$ s), top quarks decay **before hadronisation**.
- Produced W bosons can decay either **leptonicaly** or **hadronicaly**.

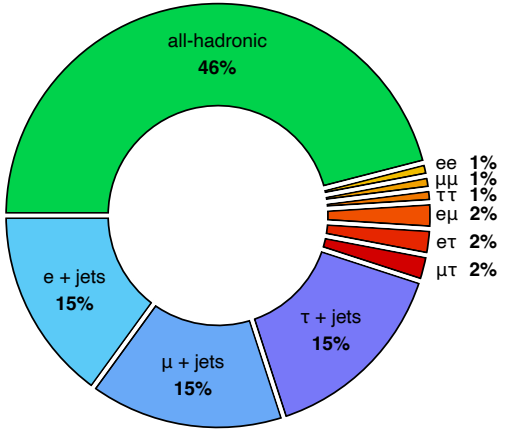


Top-quark pair decay

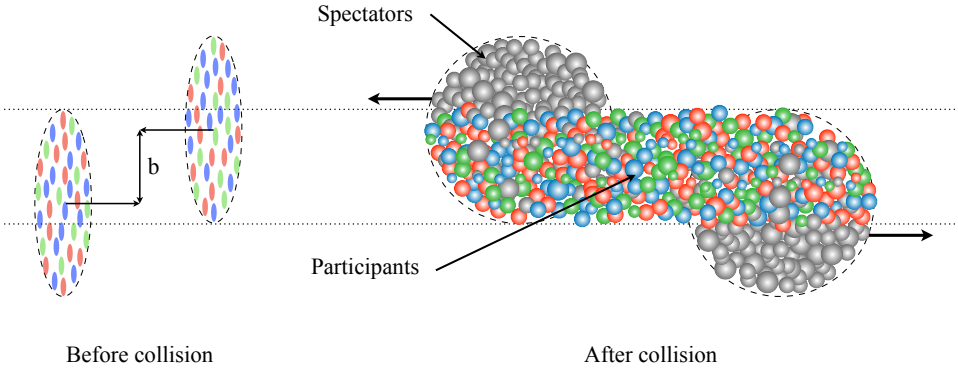
- Three $t\bar{t}$ decay channels are distinguished based on W boson decay:
  - **all-hadronic**,
  - **lepton+jets**,
  - **dilepton**.

- $t\bar{t}$ production was observed in the **dilepton** channel in Pb+Pb collisions (PRL 134 (2025) 142301).

- The **lepton+jets** channel of $t\bar{t}$ decays has not been studied in Pb+Pb collisions yet.



Heavy-ion collisions at the LHC

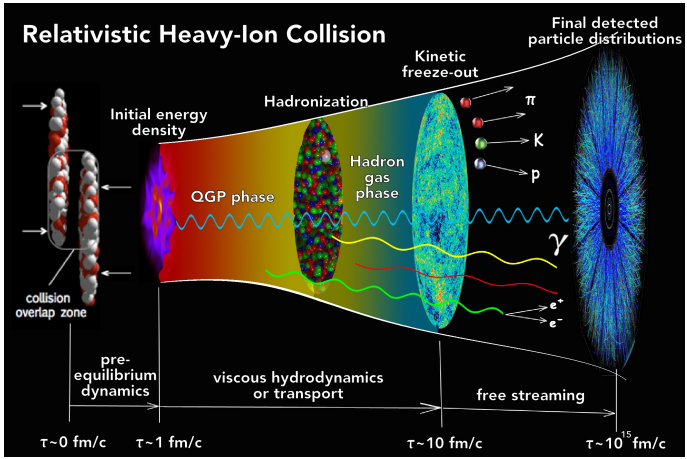


- Heavy-ion collisions are characterised by **high detector activity**.
- $t\bar{t}$ cross section in **Pb+Pb collisions** scales with lead mass number squared (A^2_{Pb}).
- Significant background arises from the **underlying event**.

Quark-gluon plasma

- **Quark-gluon plasma** (QGP) is created in heavy-ion collisions at LHC energies.
- QGP is short-lived with a lifetime of $\sim$ **10 fm/c**.
- Top quarks interact with the **pre-equilibrium stage** of the QGP.
- The **time structure** of the QGP can be studied via hadronically decaying *W* bosons (PRL 120, 232301 (2018)).

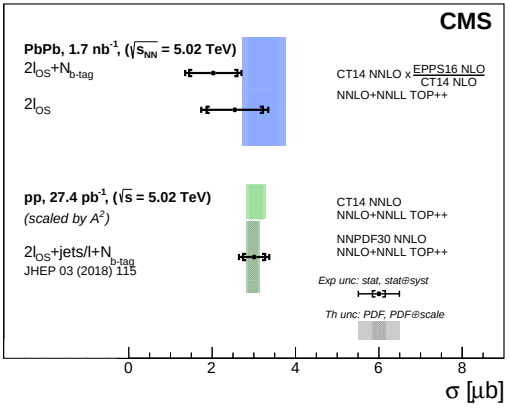
Nucl.Phys.A 1047 (2024) 122874



First evidence of $t\bar{t}$ in Pb+Pb by CMS

- **First evidence** of $t\bar{t}$ production in Pb+Pb collisions by CMS.
- Measurement in the **dilepton** channel.
- Observed significance for two methods:
  3.8 σ (dilepton-only),
  4.0 σ (dilepton + *b*-jets).
- Measured cross sections:
  $\sigma_{t\bar{t}} = 2.54\ ^{+0.84}_{-0.74}\ \mu$b (dilepton-only),
  $\sigma_{t\bar{t}} = 2.03\ ^{+0.71}_{-0.64}\ \mu$b (dilepton + *b*-jets).

PRL 125, 222001 (2020)



First observation of $t\bar{t}$ in Pb+Pb by ATLAS

- **First observation** of $t\bar{t}$ production in Pb+Pb collisions by ATLAS.
- Measurement in the **eμ** channel.
- Observed significance: **5.0** σ.
- Measured cross section: $\sigma_{t\bar{t}} = 3.6\ ^{+1.0}_{-0.9}\ (\text{stat.})\ ^{+0.8}_{-0.5}\ (\text{syst.})\ \mu\text{b}$.
- **Leading contribution** by Iwona Grabowska-Bołd, Matthias Schott, Patrycja Potępa

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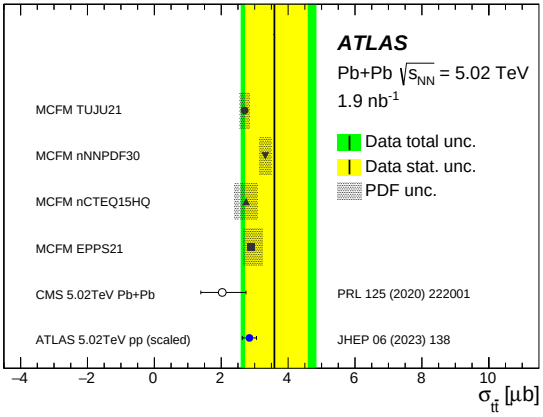
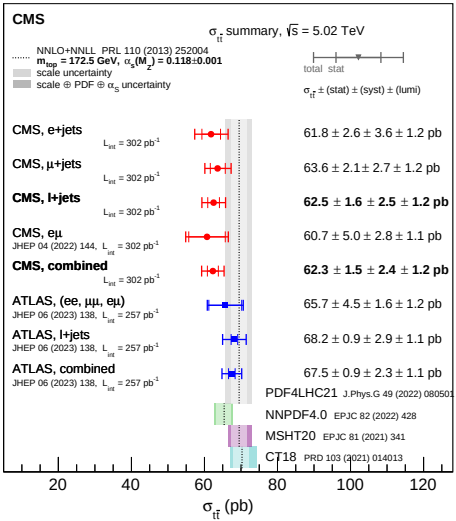


$t\bar{t}$ in 5.02 TeV pp collisions by ATLAS and CMS

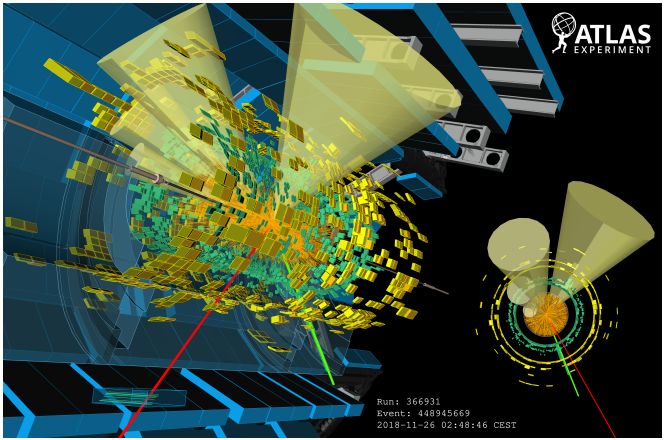
arXiv:2410.21631

- pp at $\sqrt{s} = 5.02$ TeV is a reference system to Pb+Pb collisions at the same energy.
- Measurement combines **lepton+jets** and **dilepton** channels of $t\bar{t}$ decays.
- Very precise cross-section measurements:
  $\sigma_{t\bar{t}} = \mathbf{67.5 \pm 2.7\ pb}$ (ATLAS),
  $\sigma_{t\bar{t}} = \mathbf{62.3 \pm 3.1\ pb}$ (CMS).
- Total relative uncertainties:
  4% (ATLAS),
  5% (CMS).



Motivation

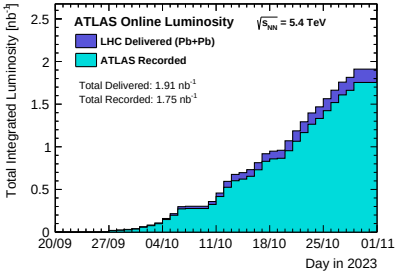
- Study the **lepton+jets** channel of $t\bar{t}$ decays in Pb+Pb for the first time.
- Measure $t\bar{t}$ production **cross section** and **significance**.
- Study **hadronically decaying *W* bosons** from $t\bar{t}$ decays.
- **Major challenges:**
  - Significant underlying event
  - Jet quenching
  - Limited data statistics
  - Complex MC simulation

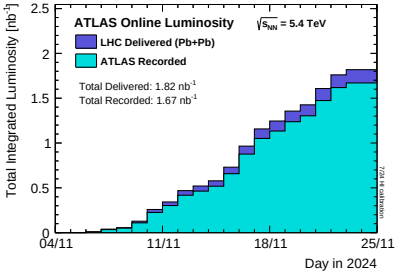


Event display of a 2018 Pb+Pb collision containing a $t\bar{t}$ candidate in the $e\mu$ channel.

Run 3 Pb+Pb data

- New Pb+Pb data at $\sqrt{s_{\mathrm{NN}}} = 5.36$ TeV collected in **Run 3** by ATLAS.
- The Pb+Pb luminosity:
  1.8 nb^{-1} (2023),
  1.7 nb^{-1} (2024).
- HION5 derivation production (jira ATLHI-618):
  2023: prodtask-dev.cern.ch/prodtask/inputlist_with_request/63590/
  2024: prodtask-dev.cern.ch/prodtask/inputlist_with_request/63591/
- **425 pb^{-1}** of *pp* reference data at $\sqrt{s} = 5.36$ TeV also collected in Run 3.





Typical $t\bar{t}$ event selection

ℓ+jets

e+jets

- 1 electron,
- 0 muons,
- at least 4 jets.

μ+jets

- 1 muon,
- 0 electrons,
- at least 4 jets.

Dilepton

ee

- 2 electrons,
- 0 muons,
- opposite sign leptons,
- $m_{\ell\ell} \notin (80 - 100)$ GeV,
- at least 2 jets.

$\mu\mu$

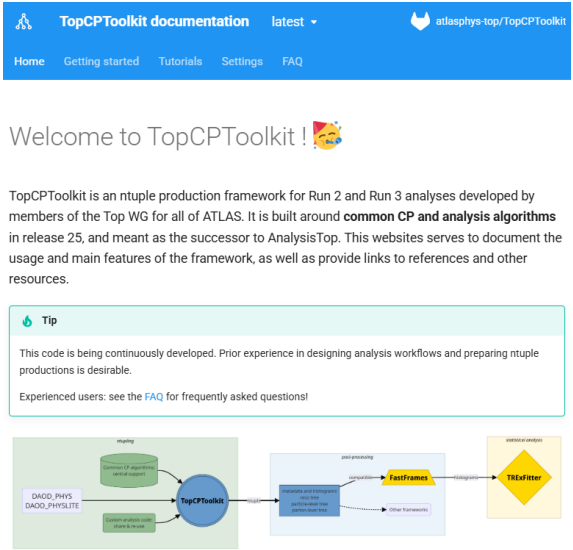
- 2 muons,
- 0 electrons,
- opposite sign leptons,
- $m_{\ell\ell} \notin (80 - 100)$ GeV,
- at least 2 jets.

$e\mu$

- 1 electron,
- 1 muon,
- opposite sign leptons,
- $m_{\ell\ell} > 15$ GeV,
- at least 2 jets.

ATLAS software

- The **TopCPToolkit** framework is recommended for top-quark analyses.
- Tutorial and examples can be found in **documentation**.
- The official framework is shared in **GitLab repository**.
- It can be expanded to **heavy-ion analyses** starting with this **GitLab repository**.



Project overview

Project 1

Track optimisation

Mathias & Mateusz

- Save track variables to the output
- Apply heavy-ion track selection
- Study tracking performance

Project 2

Selection optimisation

Moritz & Kacper

- Implement selection for $t\bar{t}$ events
- Include the ℓ+jet channel selection
- Optimise kinematic cuts in the selection

Project 3

Jet optimisation

Paulina & Emilia

- Study jet quantities in data
- Optimise jet selection in data
- Compare $R = 0.4$ and $R = 0.2$ jets

Useful links

- Grid certificate instructions:
  https://atlassoftwaredocs.web.cern.ch/analysis-software/ASWTutorial/basicSetup/grid_cert/
- TopCPToolkit documentation:
  https://topcptoolkit.docs.cern.ch/latest/
- TopCPToolkit GitLab official:
  https://gitlab.cern.ch/atlasphys-top/reco/TopCPToolkit
- TopCPToolkit GitLab heavy-ion:
  https://gitlab.cern.ch/ppotepa/TopCPToolkit
- Jira with HION5 production:
  https://its.cern.ch/jira/browse/ATLHI-618
- $t\bar{t}$ observation in Pb+Pb:
  PRL 134 (2025) 142301