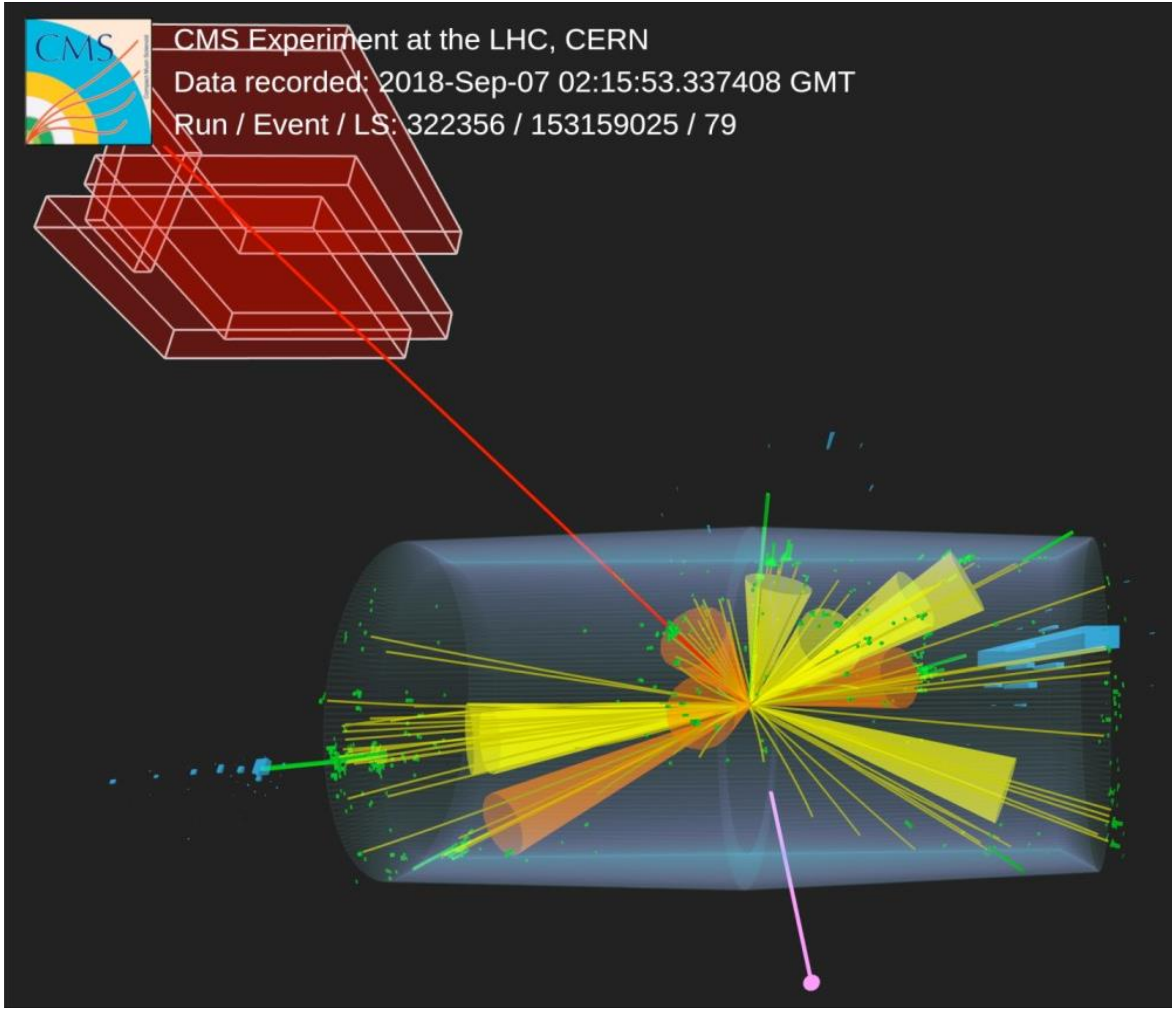
Observation of four top quark production in proton-proton collisions at $\sqrt{s} = 13$ TeV

Margarida Sousa

July 13, 2023



arXiv:2305.13439

Introduction

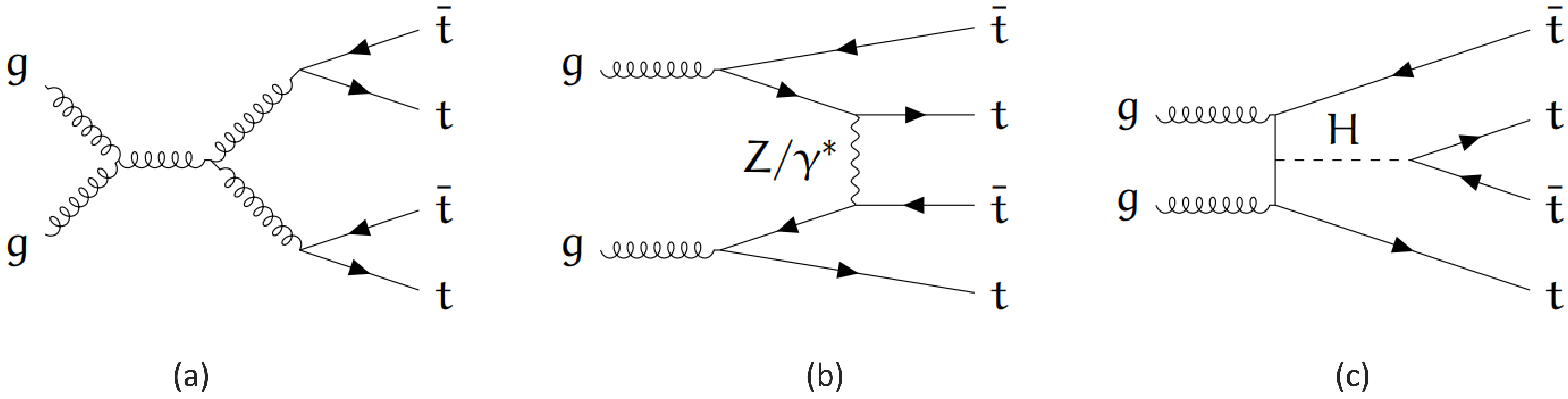


Figure 1: Examples of Feynman diagrams that provide important contributions to $t\bar{t}t\bar{t}$ production. (a) involves only the strong interaction; (b) involves both strong and electroweak interactions with the exchange of a Z boson or virtual photon; (c) involves both strong and electroweak interactions with the exchange of a Higgs boson.

The CMS detector and event reconstruction

- Superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T.
- Within the solenoid volume are a silicon pixel and strip tracker, an electromagnetic calorimeter and a hadron calorimeter.
- Muons are detected in gas-ionization chambers embedded in the steel magnetic flux-return yoke outside the solenoid.

- Events of interest are selected using a two-tiered trigger system.
- A global particle-flow (PF) algorithm is used to reconstruct and identify each individual particle in an event, with an optimized combination of information from the various elements of the CMS detector.

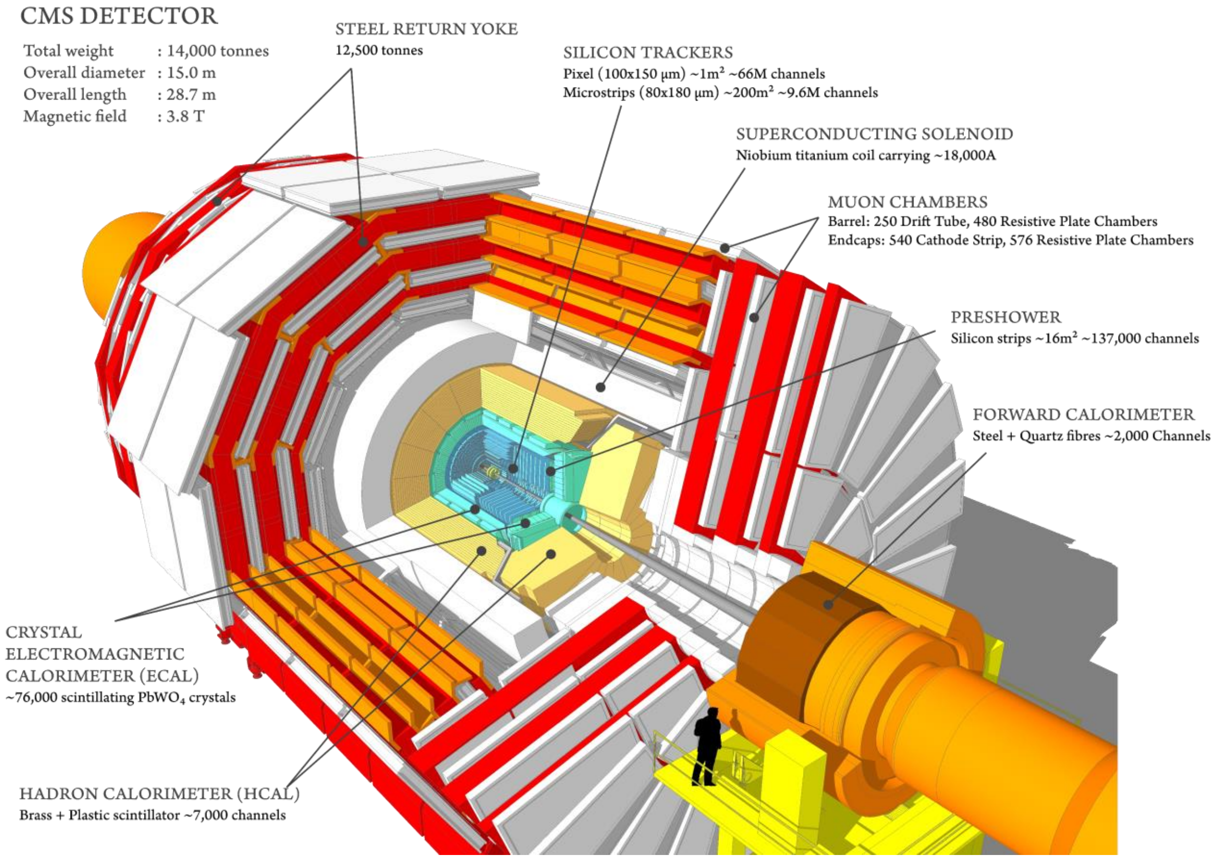


Figure 2: CMS detector.

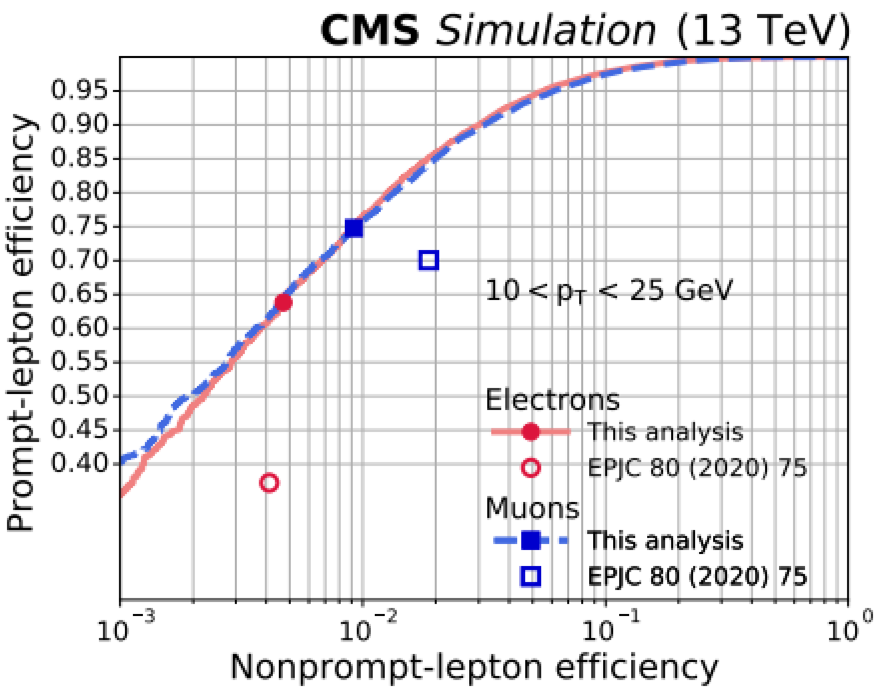
Simulated event samples

- Simulated event samples of the signal and background processes are generated with Monte Carlo generators and used to determine the four top quark signal acceptance, estimate most background contributions, and provide training data for the machine-learning discriminants.

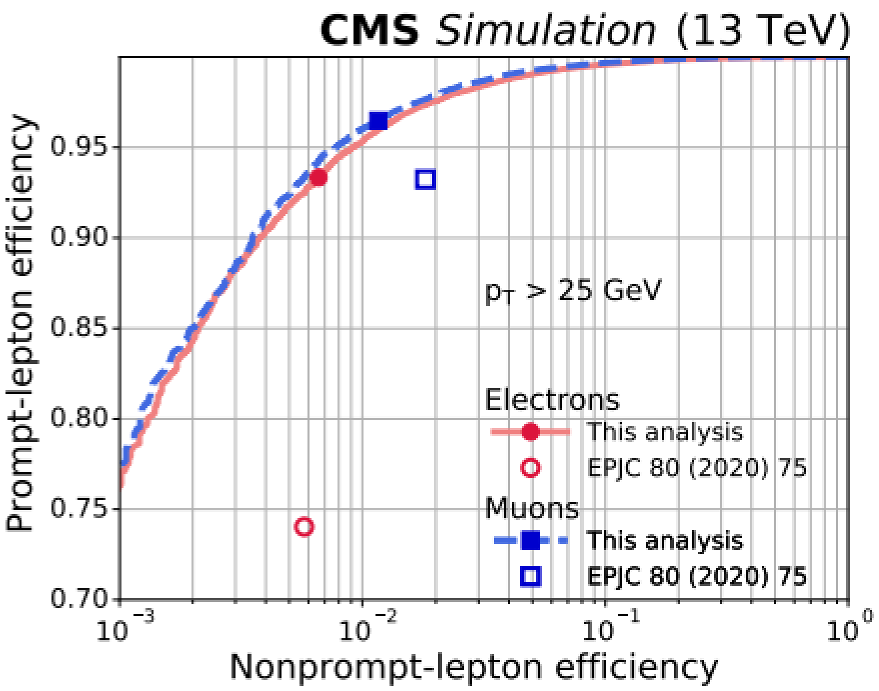
Lepton selection

- Electrons reconstructed were in the range $|\eta| < 2.5$.
- Electrons in the barrel–endcap transition region $1.44 < |\eta| < 1.57$ were removed.
- The curvature of the electron track is evaluated with three different methods to estimate the electron charge.
- Background from charge mismeasurements were reduce by a factor of five with an efficiency of about 97%.
- Muons were reconstructed in the range $|\eta| < 2.4$.
- Gradient boosted decision trees (BDTs) were employed.
- Two sets of lepton ID criteria a labelled “loose” and “tight”.

Lepton selection



(a)



(b)

Figure 3: Efficiency of selecting prompt leptons as a function of the misidentification probability for nonprompt leptons evaluated in simulated $t\bar{t}$ events for the electron and muon ID BDT, shown for leptons with (a) $10 < p_T < 25$ GeV; (b) $p_T > 25$ GeV. Indicated with filled markers are the efficiencies for the ID criteria applied in this measurement and with empty markers those for the ID criteria applied in a previous paper (2020).

Event selection and search strategy

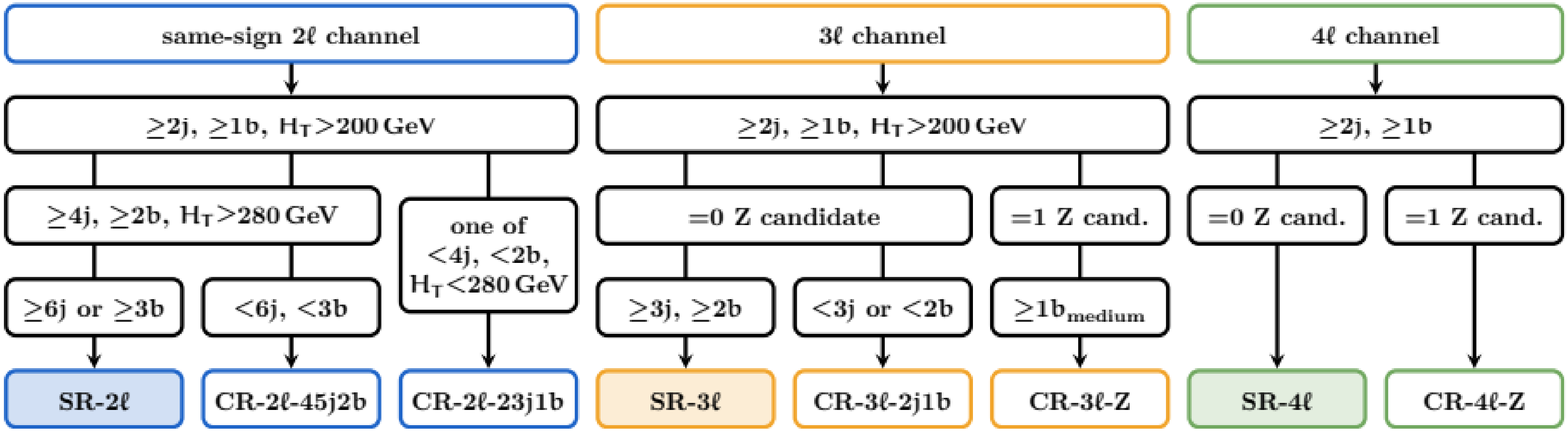
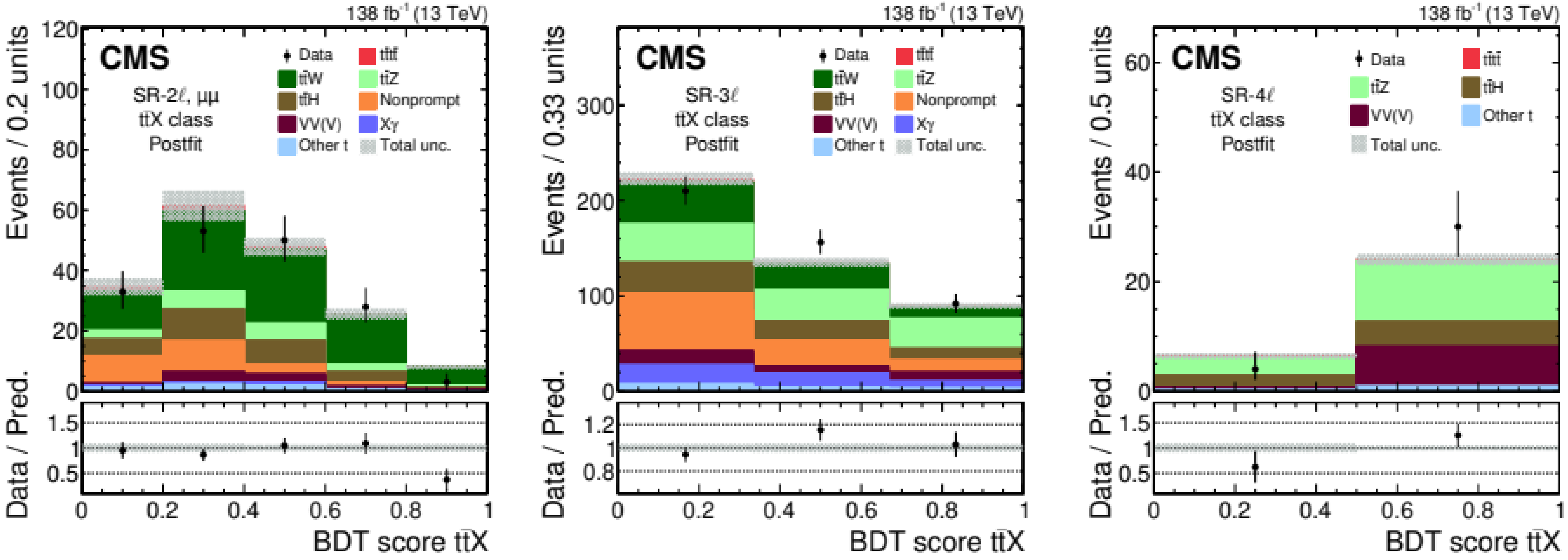


Figure 4: Schematic representation of the event selection and categorization.

- "Z candidate": opposite-sign same-flavour lepton pair with $|m(\ell\ell) - m_Z|$ < 15 GeV

Background estimation



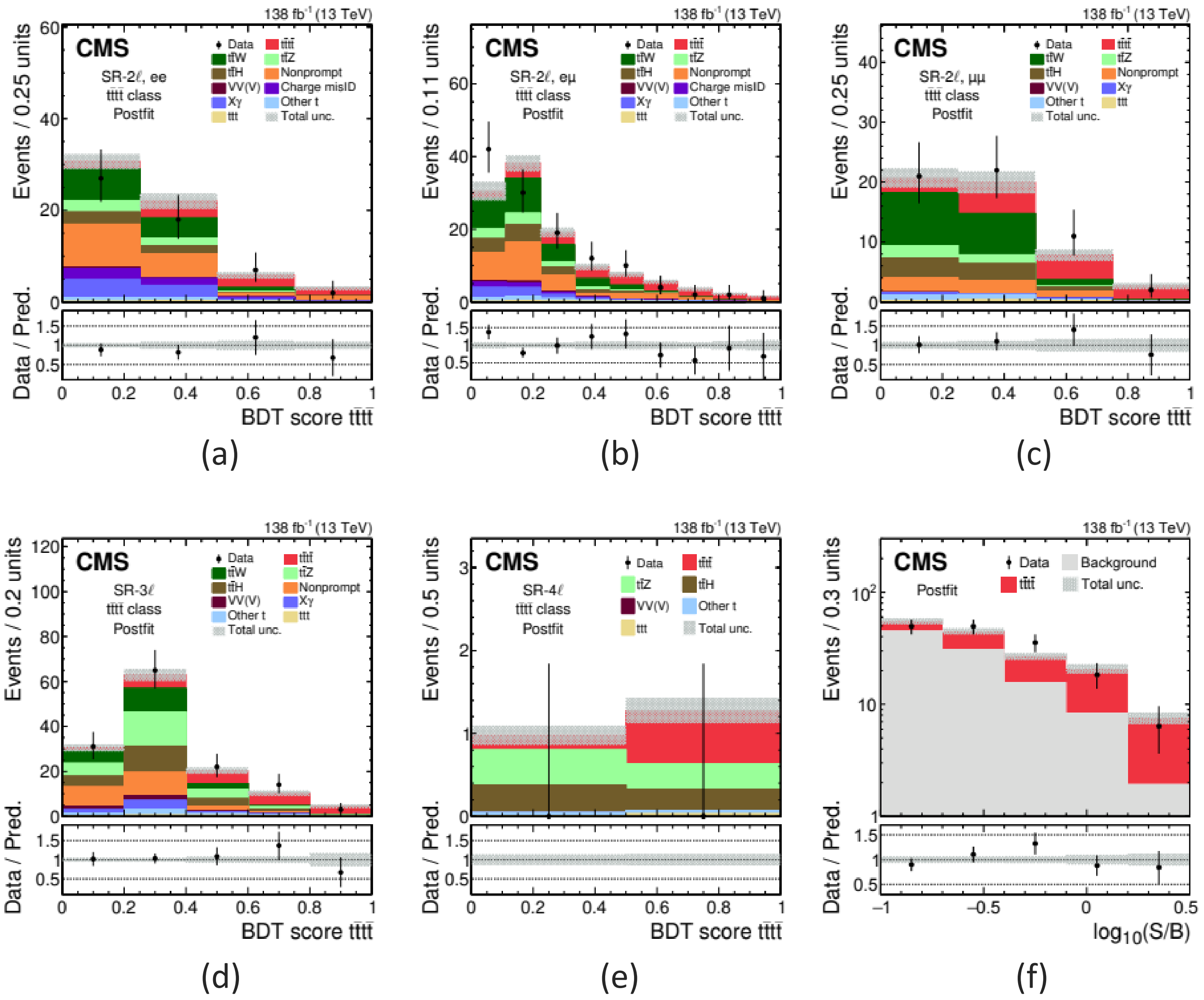
(a) (b) (c)

Figure 5: Comparison of the number of observed and predicted events in the BDT score $t\bar{t}X$ for (a) SR-2ℓ; (b) SR-3ℓ; (c) SR-4ℓ. The vertical bars on the points represent the statistical uncertainties in the data, and the hatched bands the total uncertainty in the predictions. The signal and background yields are shown with their best fit normalizations from the simultaneous fit to the data(“postfit”).

Results

Figure 6: Comparison of the number of observed and predicted events in the BDT score $t\bar{t}t\bar{t}$ for (a) SR-2ℓ, ee; (b) SR-2ℓ, eμ; (c) SR-2ℓ, μμ (d) SR-3ℓ; (e) SR-4ℓ.

(f) Comparison for all SRs combined as a function of $\log_{10}(S/B)$. Bins with $\log_{10}(S/B) < -1$ are not included, bins with $\log_{10}(S/B) > 0.5$ are included in the last bin.



Results

- Cross section measured:

$$\sigma(t\bar{t}t\bar{t}) = 17.7\,^{+3.7}_{-3.5}\,(\text{stat})\,^{+2.3}_{-1.9}\,(\text{syst})\,\text{fb} = 17.7\,^{+4.4}_{-4.0}\,\text{fb}$$

$$\sigma(t\bar{t}W) = 990 \pm 58\,(\text{stat}) \pm 79\,(\text{syst})\,\text{fb} = 990 \pm 98\,\text{fb}$$

$$\sigma(t\bar{t}Z) = 945 \pm 43\,(\text{stat}) \pm 69\,(\text{syst})\,\text{fb} = 945 \pm 81\,\text{fb}$$

- Cross section SM prediction:

$$\sigma(t\bar{t}t\bar{t}) = 13.4\,^{+1.0}_{-1.8}\,\text{fb}$$ *arXiv:2212.03259*

$$\sigma(t\bar{t}W) = 722 \pm 74\,\text{fb}$$ *arXiv:2108.07826*

$$\sigma(t\bar{t}Z) = 859 \pm 80\,\text{fb}$$ *arXiv:2001.03031*

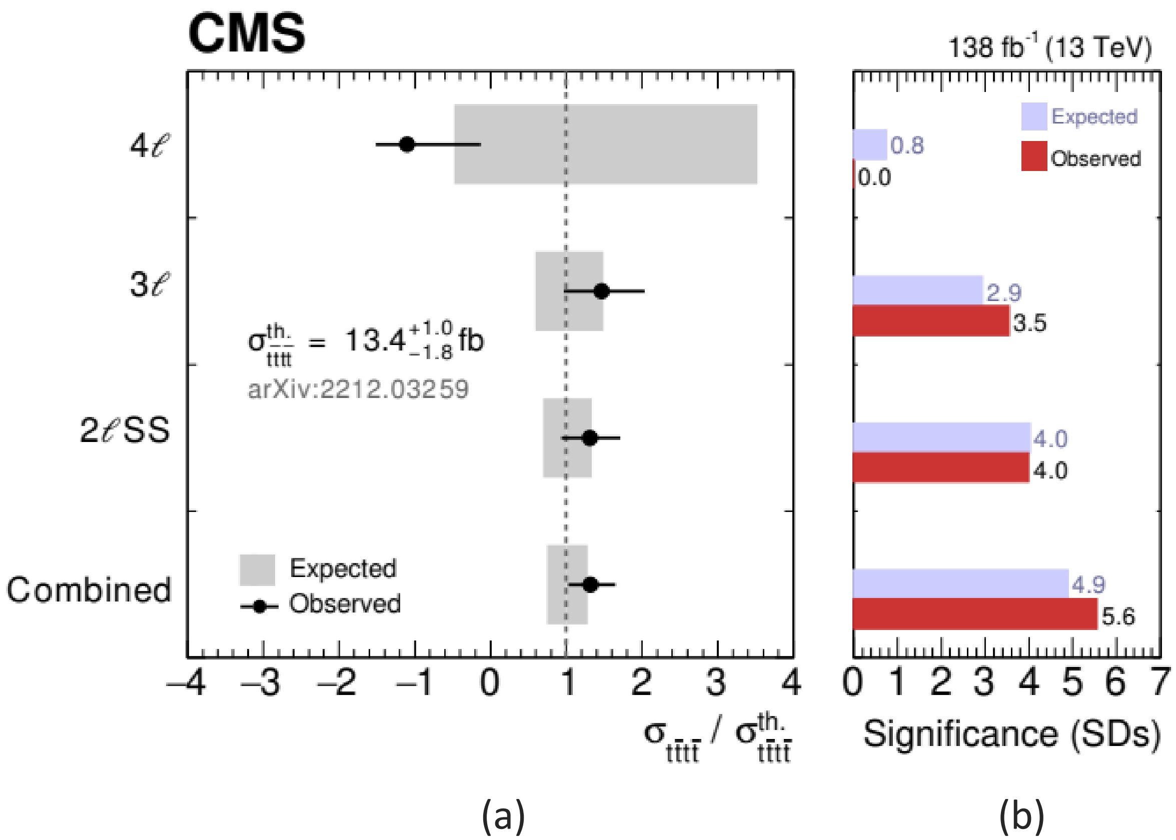


Figure 7: Comparison of fit results in the channels individually and in their combination. (a) Values of the measured cross section relative to the SM prediction from *arXiv:2212.03259*, where the displayed uncertainty does not include the uncertainty in the SM prediction. (b) Expected and observed significance, with the printed values rounded to the first decimal.

Thank you for your attention