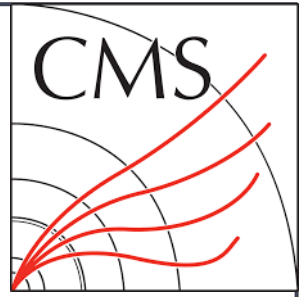


Recent top quark associated measurements with the CMS experiment of the LHC

07/05/2024

Javier del Riego

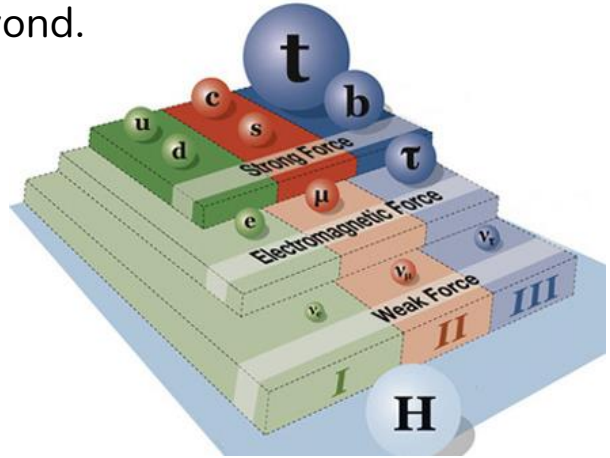
Universidad de Oviedo

Jornadas del ICTEA

Index

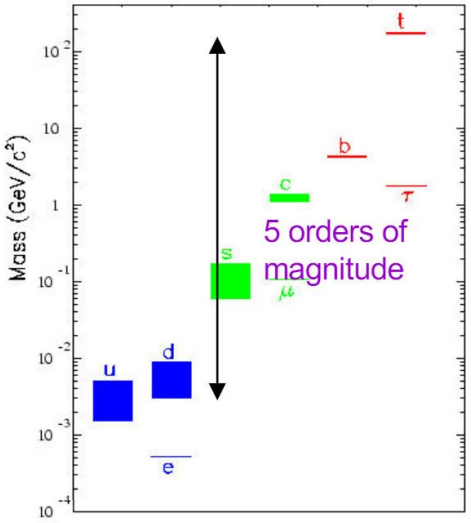
Introduction

- **Top quark** serves as key in understanding the SM and beyond.
- Main reasons:



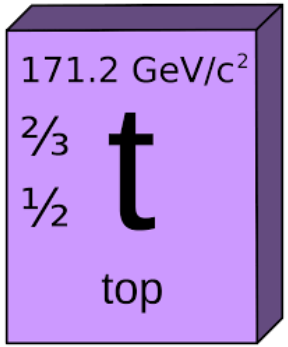
Mass

- Most massive elementary particle in SM:



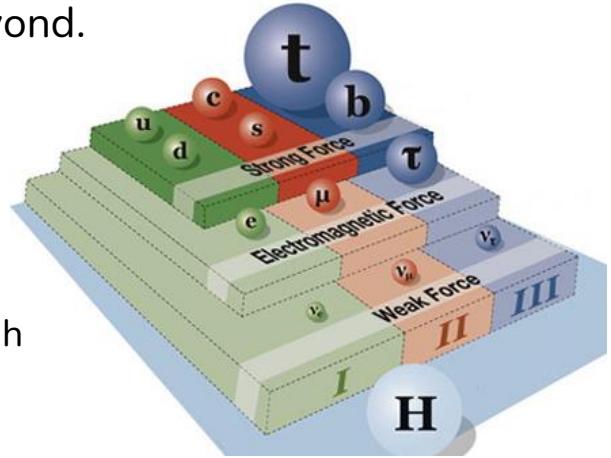
$m_t = 172.5 \pm 0.33\ GeV$ (LHC Run 1 combination)

- Its high mass makes it sensitive to BSM physics postulated at high energies (EFTs as mechanism…)



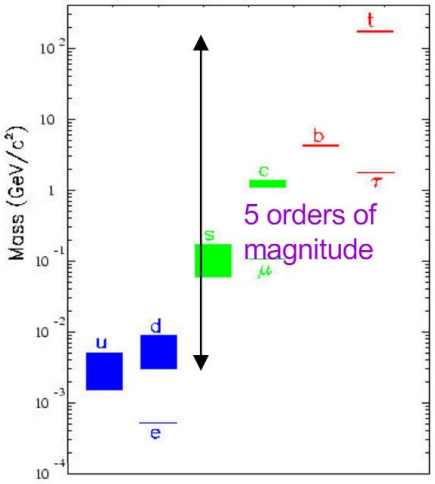
Introduction

- **Top quark** serves as key in understanding the SM and beyond.
- Main reasons:



Mass

$$m_t = 172.5 \pm 0.33\ GeV$$

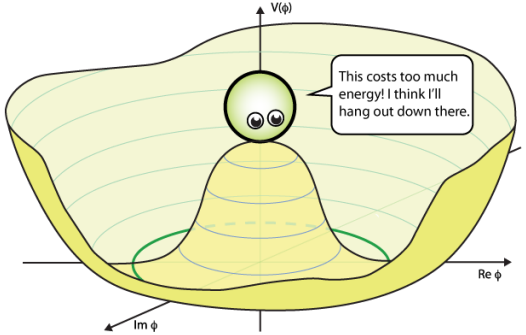


Higgs boson

- Fermions couple to Higgs through Yukawa couplings:

$$y_f = \frac{\sqrt{2}m_f}{v}$$

- Since top has the highest mass, it suffers the strongest coupling to Higgs boson
- Crucial to understand and probe EWSB



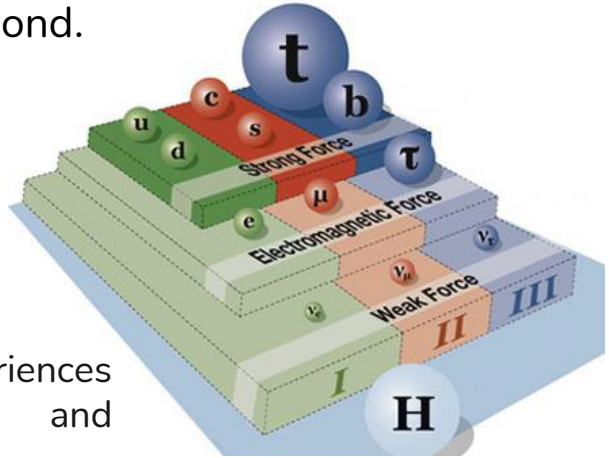
Introduction

- **Top quark** serves as key in understanding the SM and beyond.
- Main reasons:

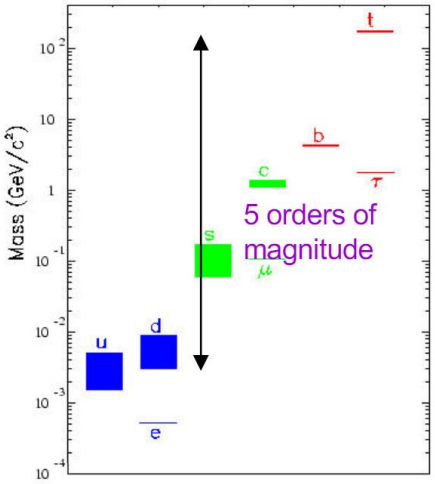
Mass

Higgs boson

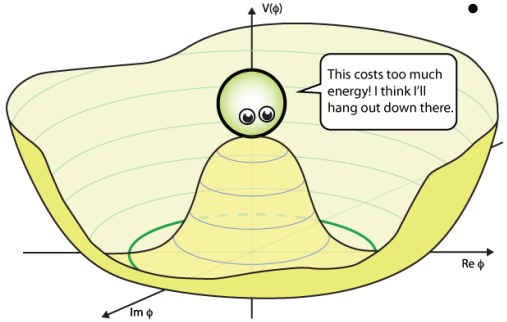
Interactions



$$m_t = 172.5 \pm 0.33\ GeV$$



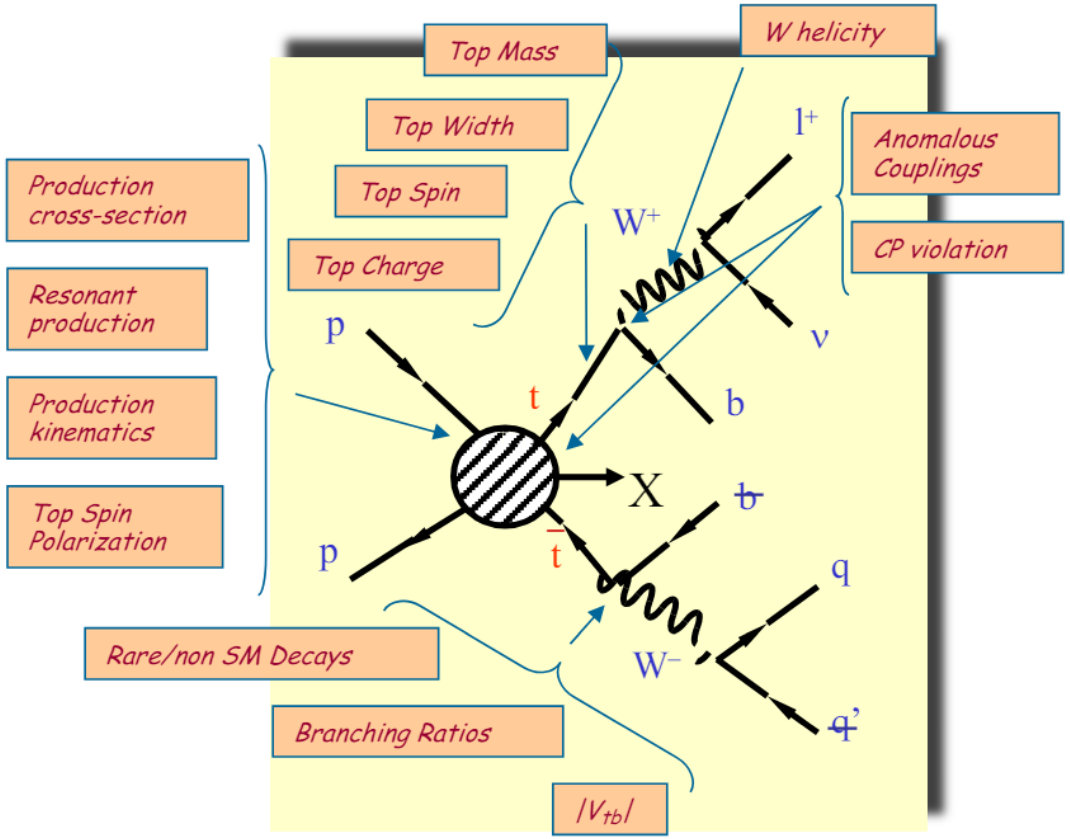
$$y_f = \frac{\sqrt{2}m_f}{v}$$



- Top quark experiences strong, weak and electromagnetic interactions.
- Present in many processes that allow us to measure with high precision the SM and its parameters.

Introduction

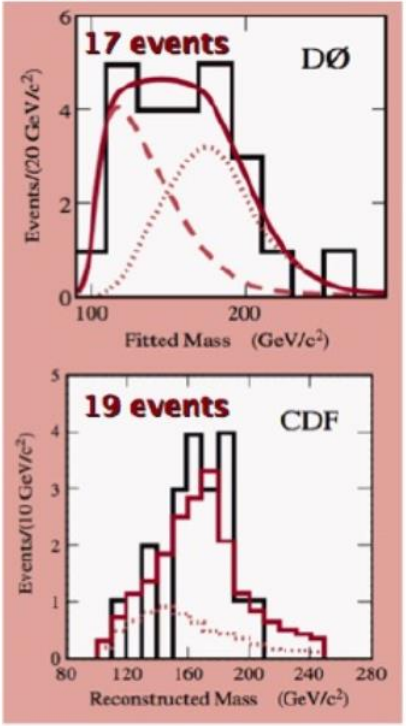
- Handful of observables that can be measured.



History

- Claiming of discovery in 1995 by CDF and D0 at Tevatron ($p\bar{p}$ collider).

10s of tt events

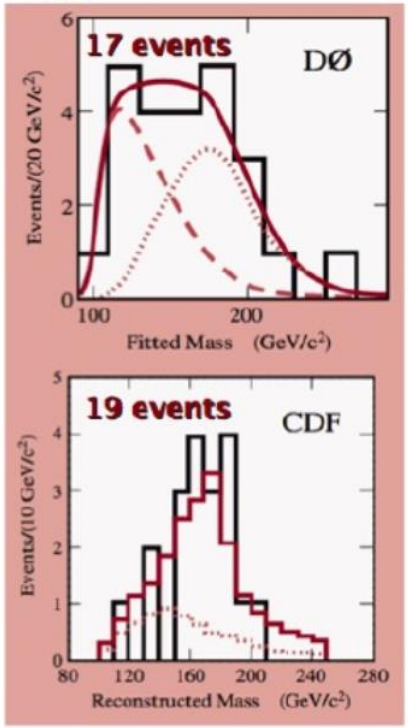


PRL 74, 2632 (1995)
PRL 74, 2626 (1995)

History

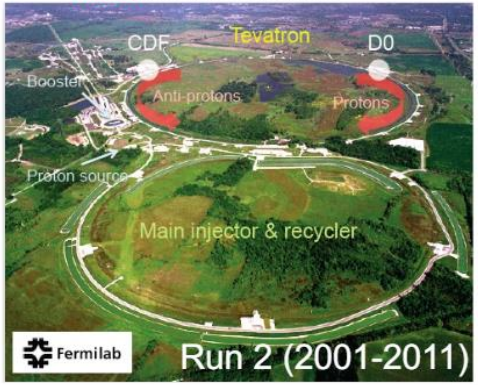
- Run 2 of Tevatron: from discovery to first precision measurements (2002-2005).

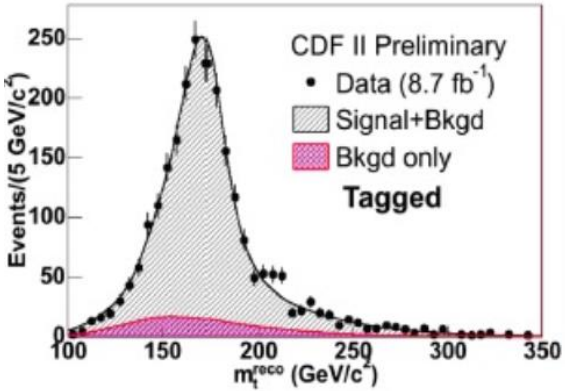
10s of tt events



PRL 74, 2632 (1995)
PRL 74, 2626 (1995)

1000s of tt events

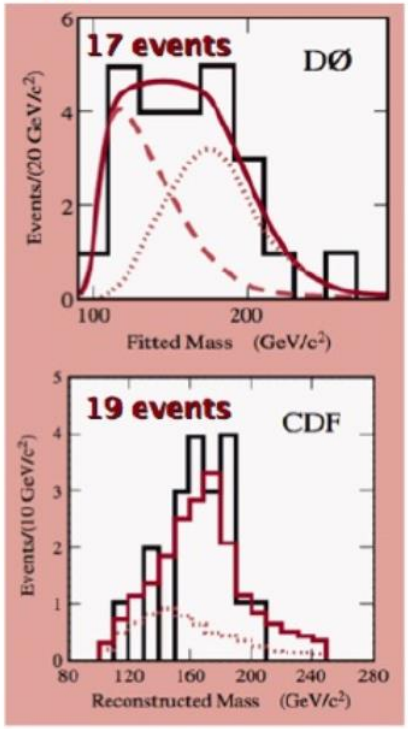




History

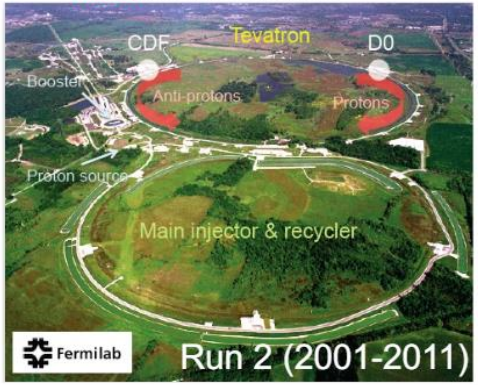
- LHC: top factory. Scrutiny of the top quark far beyond anything previously achieved.

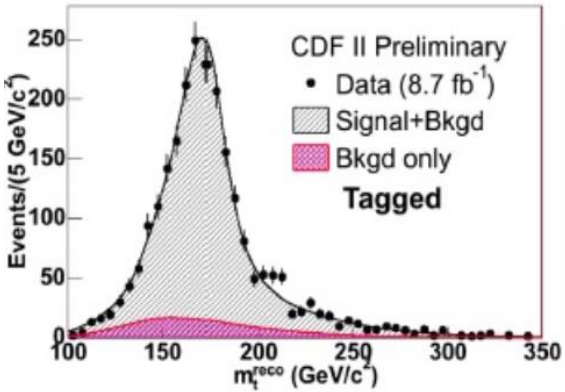
10s of tt events



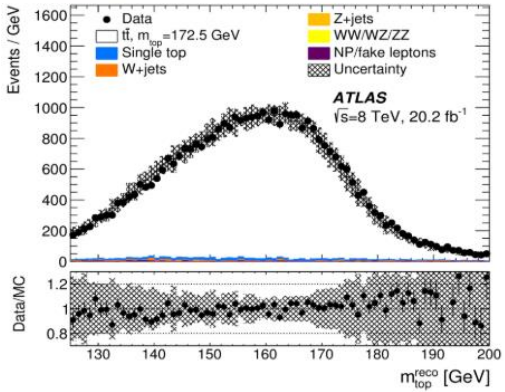
PRL 74, 2632 (1995)
PRL 74, 2626 (1995)

1000s of tt events



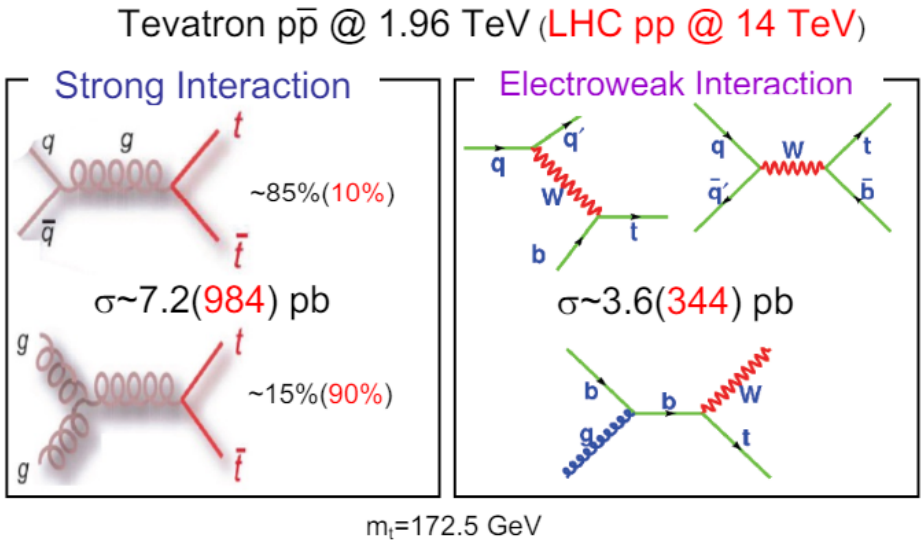


100000s of tt events



History

- At hadron colliders the dominant production process is in pairs, dominated by strong interaction.
- Also electroweak mediated production of single top quarks (~1/2 of $t\bar{t}$ events)

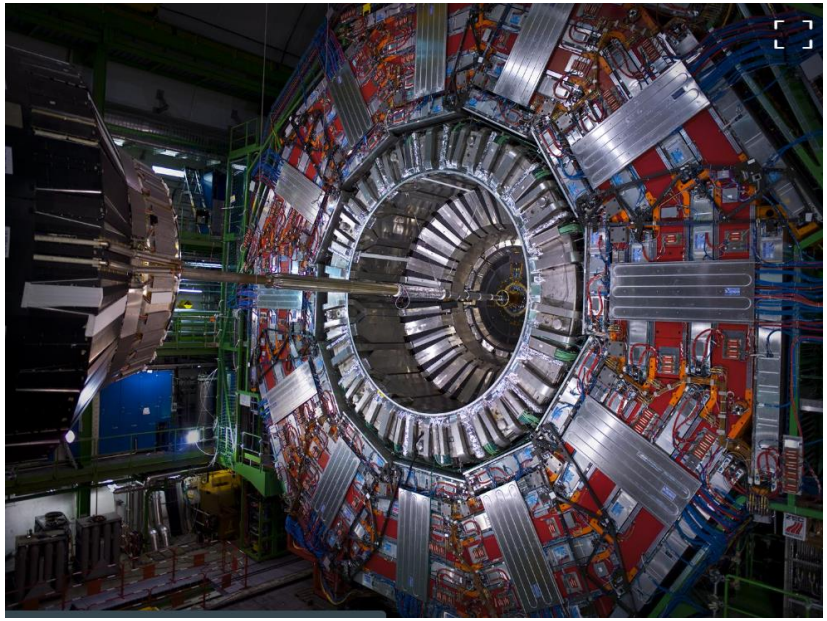


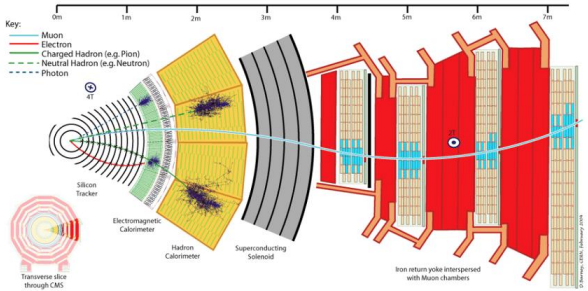
	Number of tt events (*)
Tevatron	~70k
LHC 7 TeV	~0.9M
LHC 8 TeV	~5M
LHC 14 TeV (@ 10^{34} $cm^{-2}s^{-1}$)	**~95M/year**

(*) Produced/experiment

Experimental Setup

- CMS experiment at LHC (CERN).
- Described in previous talks.





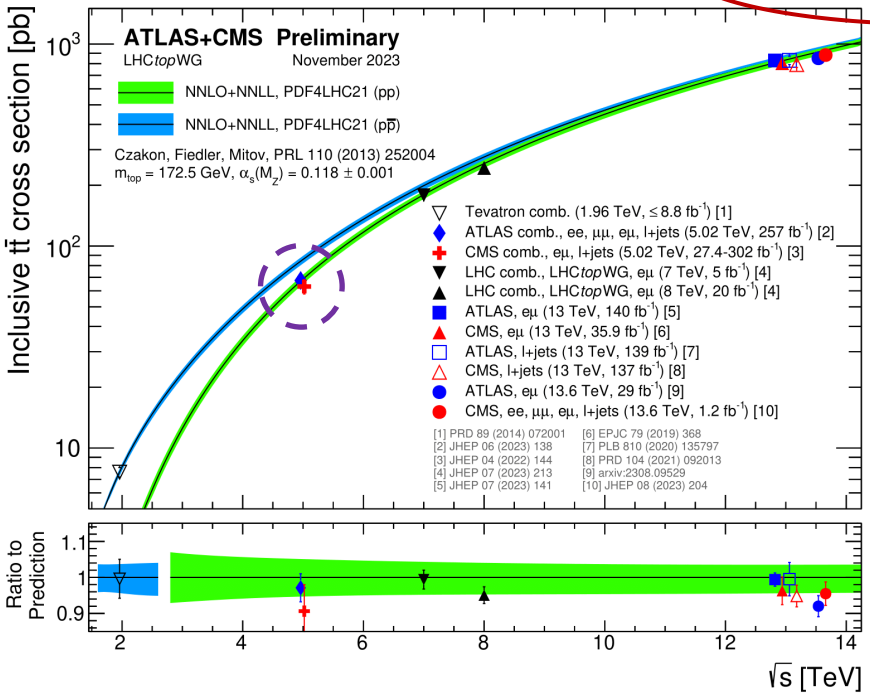
Oviedo's contribution in top

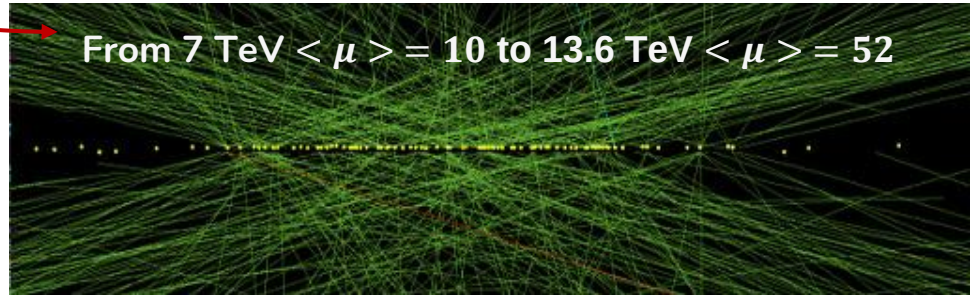
- Oviedo's experimental HEP group has collaborated and leaded many physics analyses in the top quark sector

- This talk will cover the two most recent results:
  - $t\bar{t}$ cross section measurement at 5.02 TeV [1]
  - tW cross section measurement at 13.6 TeV [2]

$t\bar{t}$@5.02 TeV

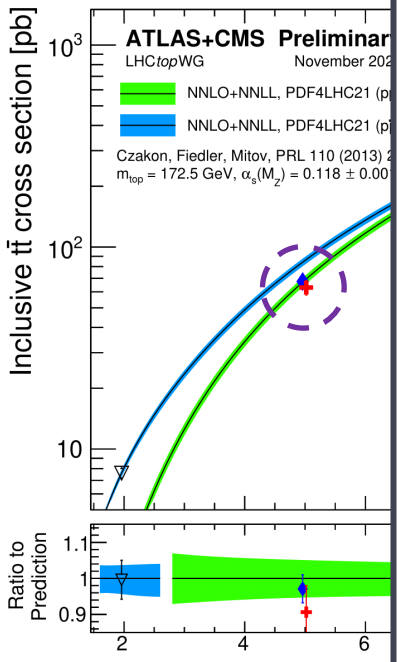
- $t\bar{t}$ cross section measured widely at LHC at different CM energies.
- Plenty of measurements at 7, 8 and 13 TeV (Runs 1-2), not so many at 5 TeV.
- Special interest is **low Pileup** (~2 interactions per bunch crossing).

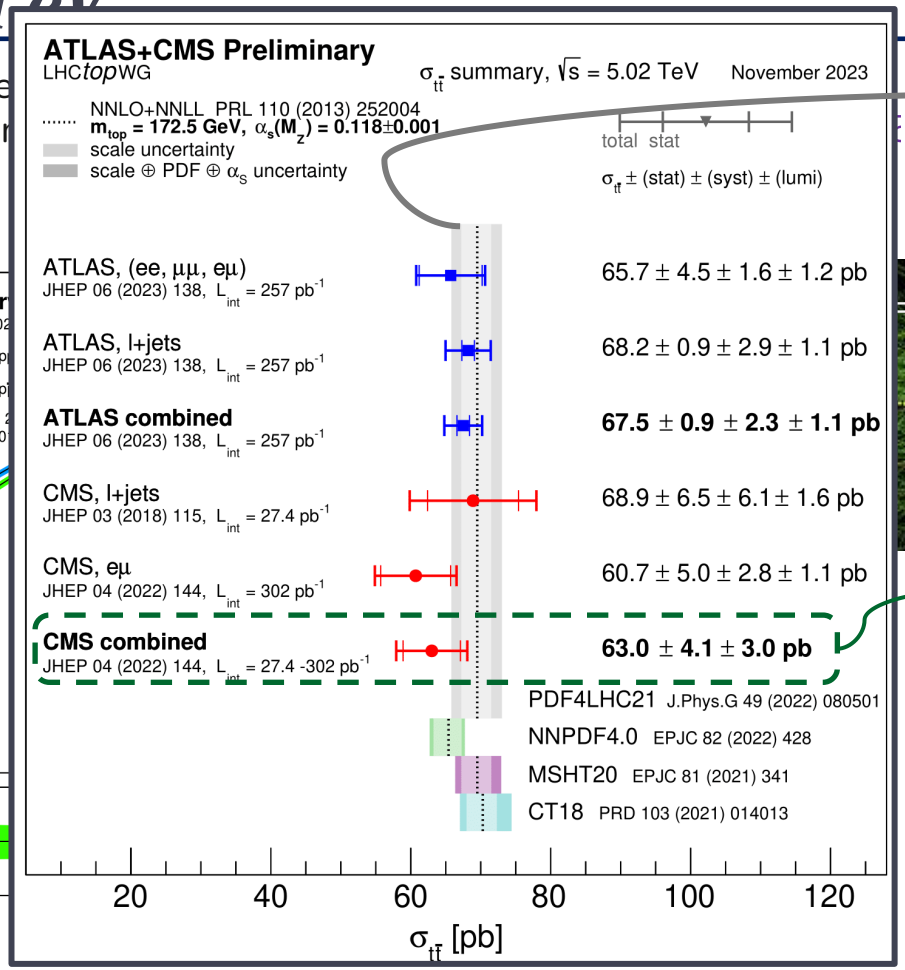




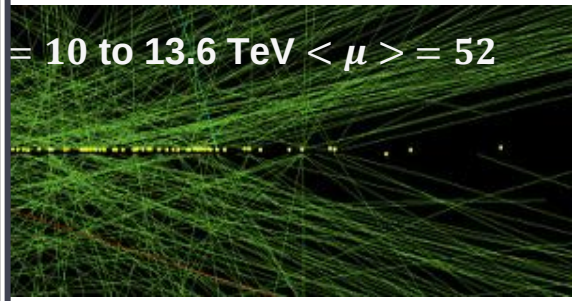
$t\bar{t}$@5.02 TeV

- $t\bar{t}$ cross section me
- Plenty of measurer
- Special interest is





$69.5^{+2.9}_{-3.1}\ pb$
(NNLO in QCD)



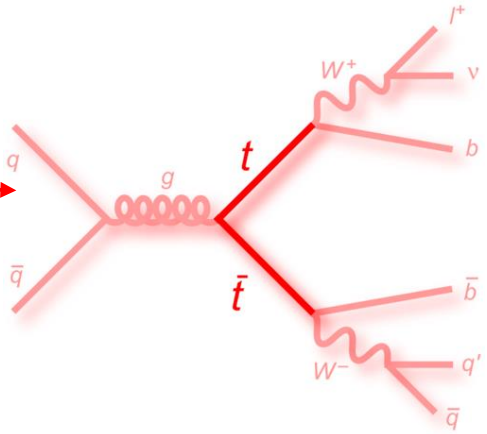
- Reference measurement has 8% of uncertainty, and **statistically dominated**
- Purpose of reducing this uncertainty.

$t\bar{t}$@5.02 TeV

Goal: measure the $t\bar{t}$ **cross section at 5.02 TeV** in the semileptonic final state with the 2017 data 302 pb^{-1} .

- **Select events with:**

- **Exactly 1 lepton (electron or muon)**.
- **At least 3 jets** (clusterings of quarks and gluons)
- **Missing transverse energy > 30 GeV.**
- Events are further categorized into **8 categories** depending on the **number of jets and b-tagged jets, and the lepton flavour** (electron or muon).



- This selection enhances signal ($t\bar{t}$) contribution

$t\bar{t}$@5.02 TeV

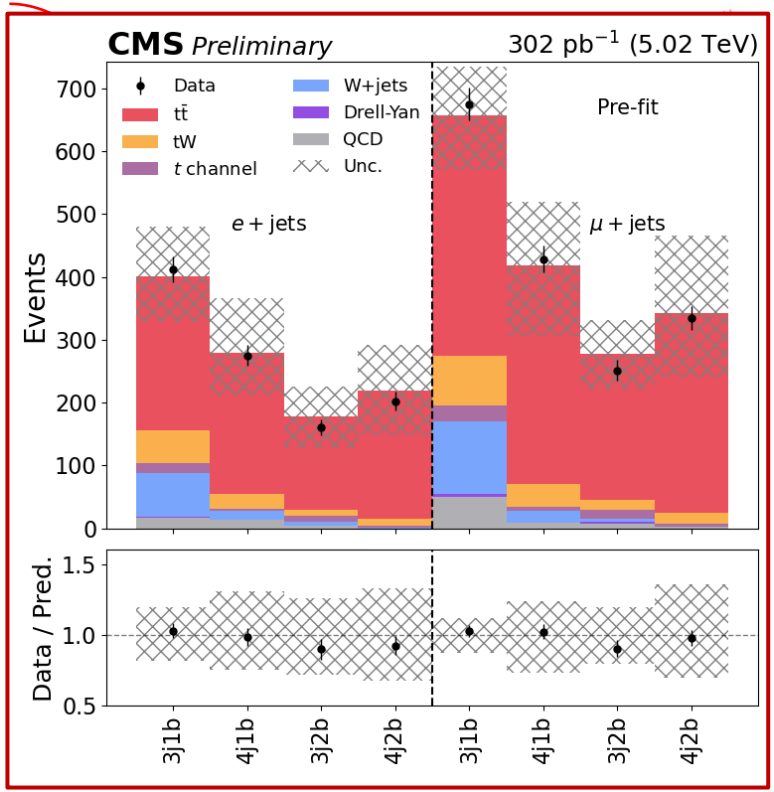
Goal: measure the $t\bar{t}$ **cross section at 5.02 TeV** in the semileptonic final state with the 2017 data 302 pb^{-1} .

- **Select events with:**

- **Exactly 1 lepton (electron or muon)**.
- **At least 3 jets** (clusterings of quarks and gluons)
- **Missing transverse energy > 30 GeV.**
- Events are further categorized into **8 categories** depending on the **number of jets and b-tagged jets, and the lepton flavour** (electron or muon).

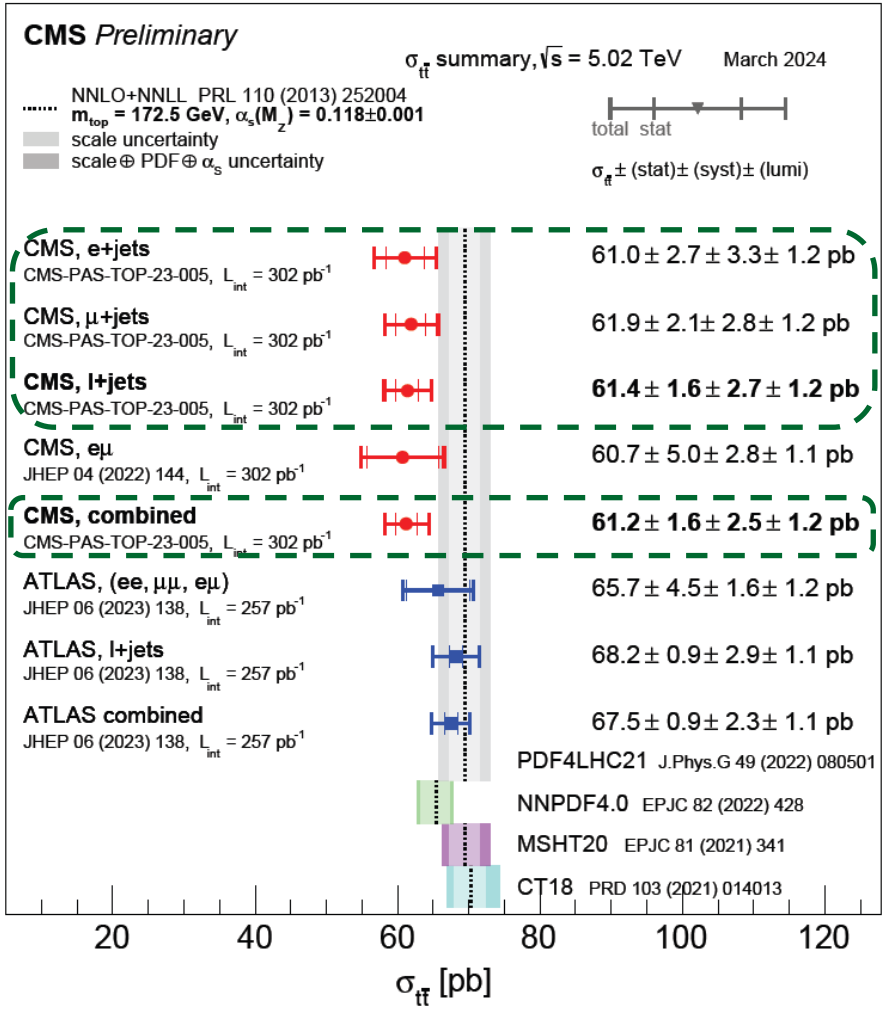
- This selection enhances signal ($t\bar{t}$) contribution

- **Analysis strategy:** perform a maximum likelihood fit to **median(ΔR(j, j')) + MVA Score** (3j1b category). Random forest $t\bar{t}$ vs W+jets.
- **Uncertainties:** experimental (proper of the detector), theoretical ($t\bar{t}$ modeling) and normalization of the background samples.



$t\bar{t}$@5.02 TeV

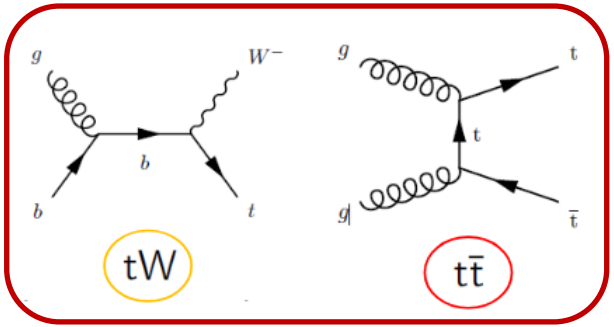
- Result in agreement with previous measurements and theoretical prediction.
- Lowered previous CMS reference measurement's uncertainty by more than 3%.
- No longer statistically dominated.



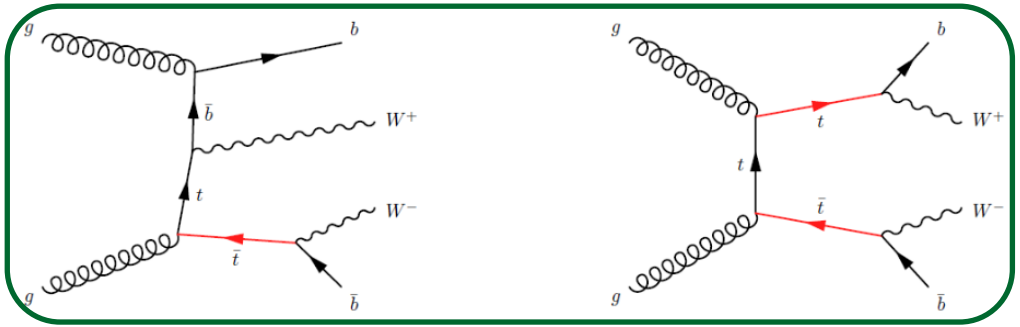
$tW@13.6\ TeV$

- Subleading single top production mechanism at hadron colliders.
- Previous inclusive and differential cross section measurements at 7, 8 and 13 TeV by ATLAS and CMS (Oviedo involved).
- **First single top** LHC measurement at **13.6 TeV** (data collected in 2022).

- **Experimental challenge**: irreducible $t\bar{t}$ background largely dominates signal contribution.



- **Theoretical challenge**: At NLO in QCD, $t\bar{t}$ and tW ***interfere***

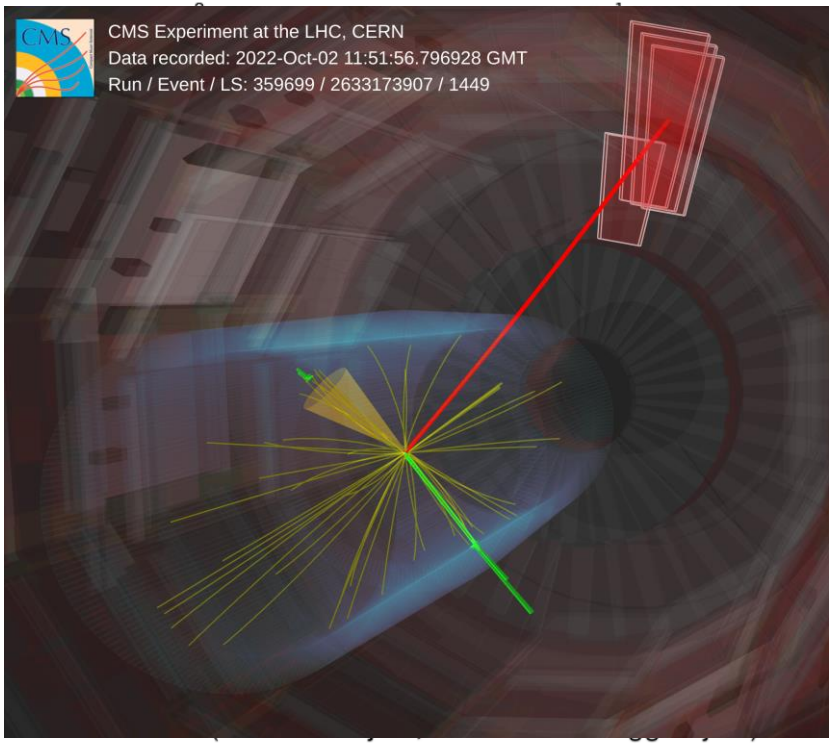


$tW@13.6\ TeV$

Event Selection

- **At least 2 leptons (leading $e^{\pm}\mu^{\mp}$)**.

- **Pairs satisfying:** $m(\ell_1\ell_2) > 20\ GeV$
- **Categorisation**: 1j1b, 2j1b, 2j2b



$tW@13.6\ TeV$

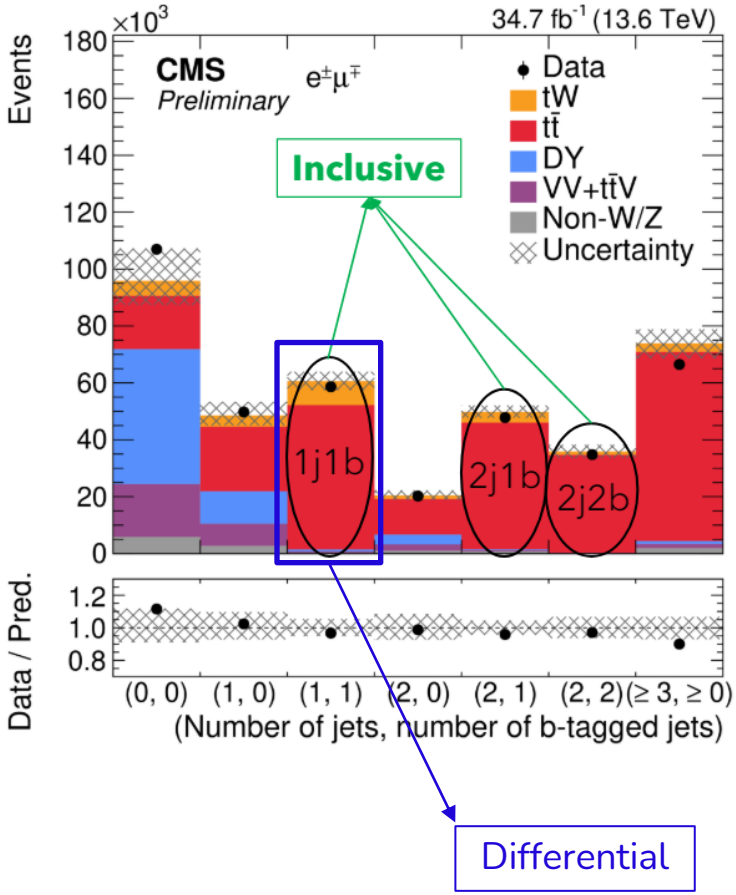
Event Selection

- **At least 2 leptons (leading $e^{\pm}\mu^{\mp}$)**.

- **Pairs satisfying:** $m(\ell_1\ell_2) > 20\ GeV$
- **Categorisation**: 1j1b, 2j1b, 2j2b

Analysis strategy

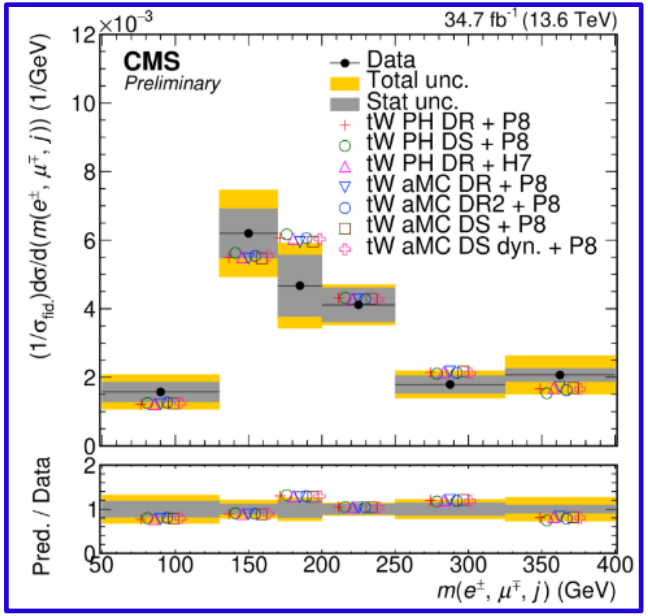
- **Inclusive**: maximum likelihood fit to 3 distributions:
  - **1j1b:** Random Forest MVA discriminating tW vs $t\bar{t}$ vs DY
  - **2j1b:** Random Forest MVA discriminating tW vs $t\bar{t}$
  - **2j2b:** subleading jet pT.
- **Differential**: study of the observables:
  - p_T of leading lepton
  - p_T of jet
  - $\Delta\phi(e,\mu)$
  - $p_z(e,\mu,jet)$
  - $m(e,\mu,jet)$
  - $m_T(e,\mu,jet,p_T^{miss})$



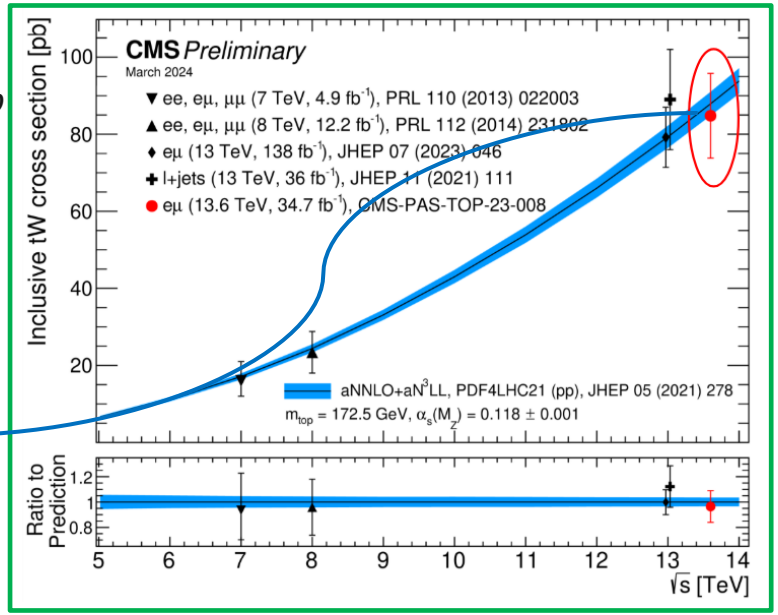
$tW@13.6\ TeV$

Results

- **Inclusive:** $\sigma_{tW} = 84.1 \pm 2.1\ (stat)^{+9.8}_{-10.2}(syst) \pm 3.3(lumi)\ pb$
- Good agreement with theoretical prediction



$87.9 \pm 3.1\ pb$



- **Differential:**
- Compatible results between the SM expectations and the measured cross sections are also observed.

Summary

- Top quark is a key piece in understanding the SM and Beyond.
- Oviedo's experimental HEP group has historically worked on that sector within the CMS experiment at LHC
- This year's public results:
  - Inclusive $t\bar{t}$ cross section at 5.02 TeV. **Most precise CMS measurement at that CM energy**. Interesting scenario for the low pile-up.

$$\sigma_{t\bar{t}} = 61.2^{+1.6}_{-1.5}(stat)^{+2.6}_{-2.3}(syst) \pm 1.2\ (lumi)\ pb$$

  - Inclusive and differential tW cross section at 13.6 TeV. **First single top measurement of LHC at that CM energy.**

$$\sigma_{tW} = 84.1 \pm 2.1\ (stat)^{+9.8}_{-10.2}(syst) \pm 3.3(lumi)\ pb$$

Good agreement with predictions

Thanks for the attention!

Any question?

javier.del.riego.badas@cern.ch