Measurement of top quark pair production in association with a vector boson

ATLAS EXPERIMENT

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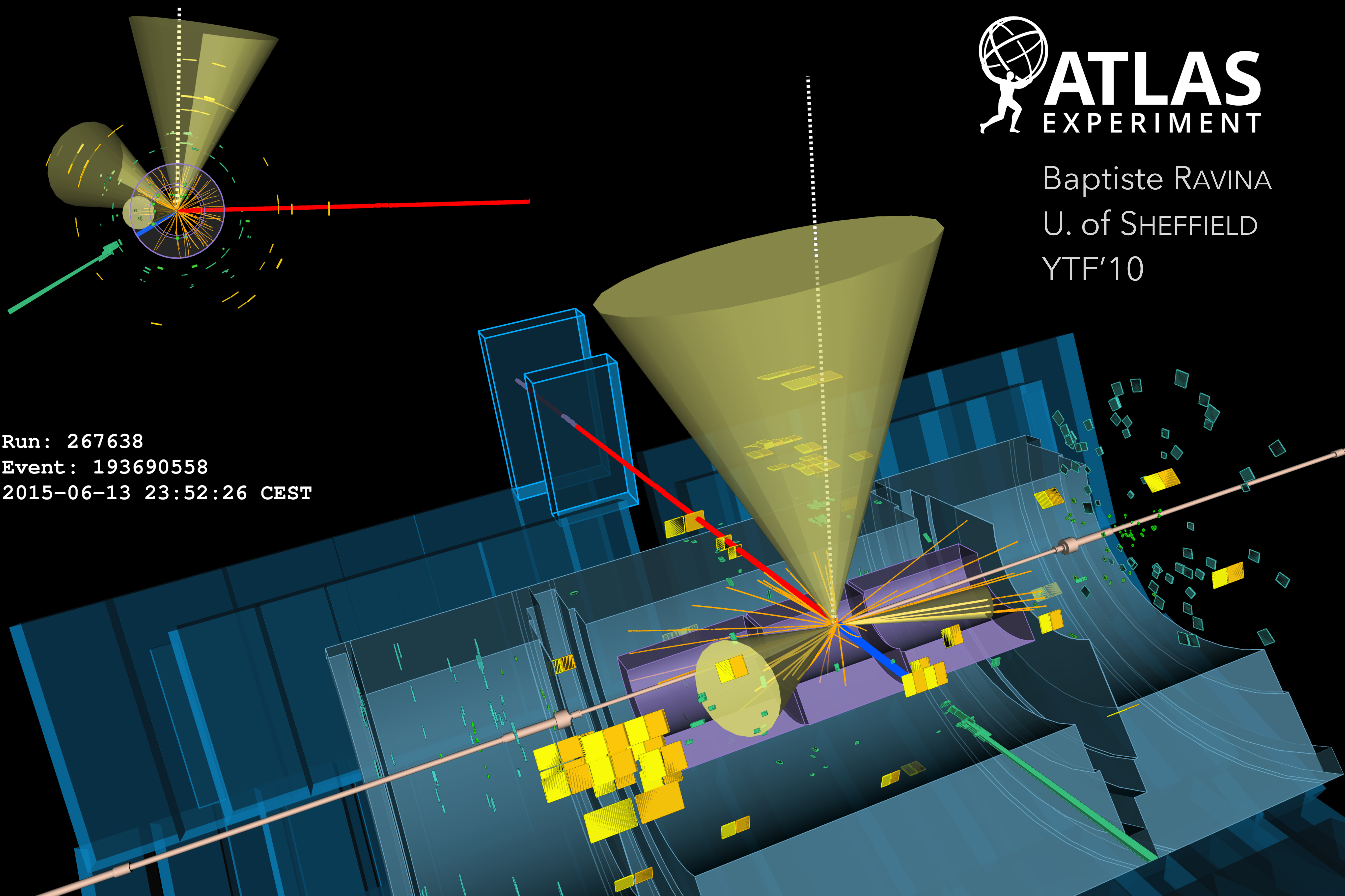
YTF'10

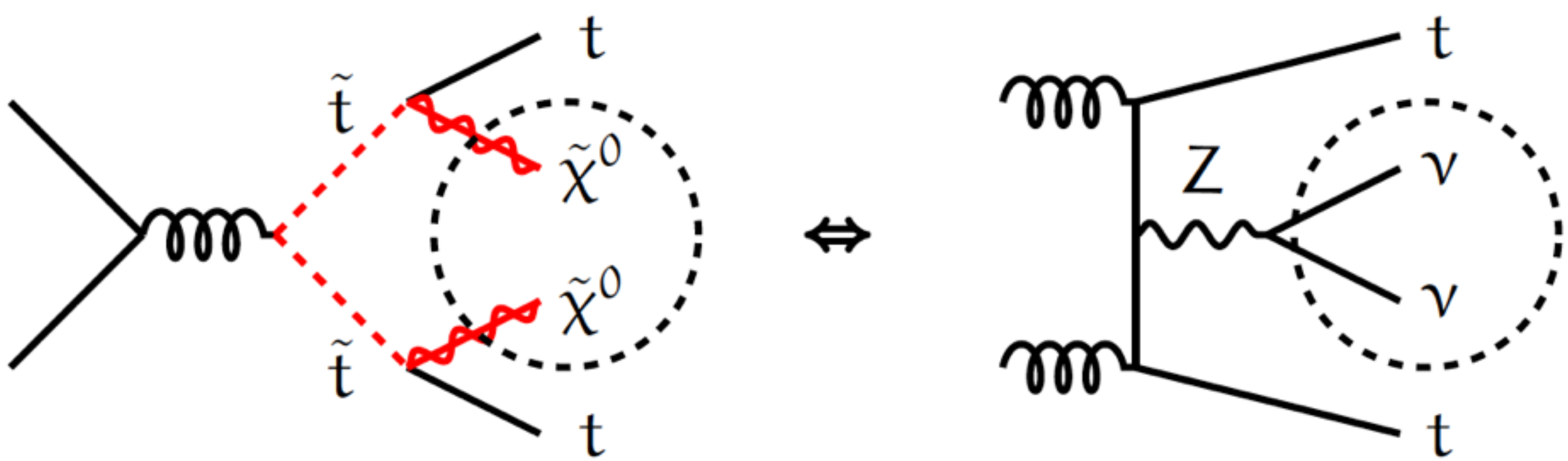


Why Top still interesting?

- With final Tevatron data set and the ever growing LHC data sample: top quark studies very interesting until today!
- What can we learn?
  - Is the top really the "SM top", or something else?
    → need to measure its production cross section and properties and compare with SM calculations
  - Top quark: only quark decaying before it hadronises
    → can study a bare quark
    For example can study spin of a quark directly (as it transfers it to the decay products before it could hadronise); or study a quark's charge
  - Top production and decay: via strong and electroweak forces
    → we can learn more about these forces
    For example: W helicity in top decays
  - Top as window to new physics (since it is the heaviest known particle)
    → searches for many new physics models in the top sector
  - Large top samples at LHC: use top events to develop new tools
    → for example tools to access the colour flow between jet pairs

STOLEN

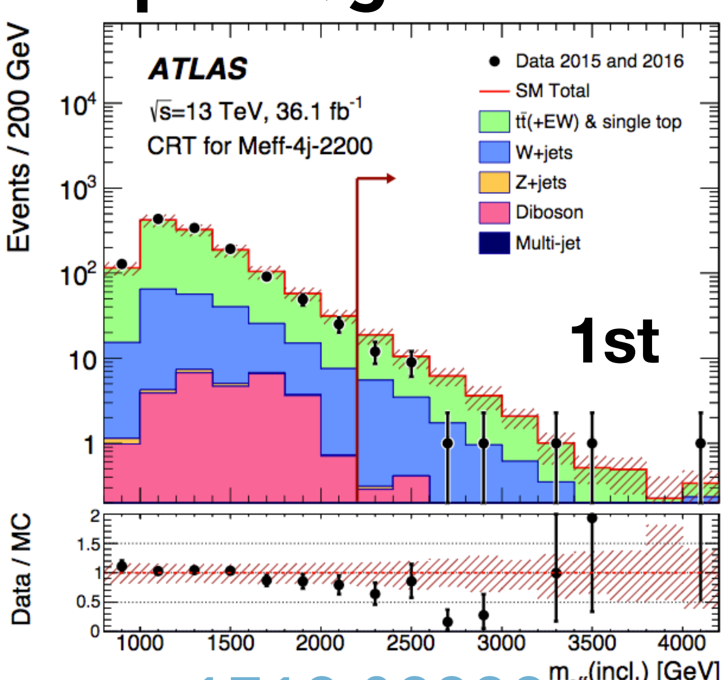
Background in BSM searches



ttbar + MET (+leptons) : generic BSM signal

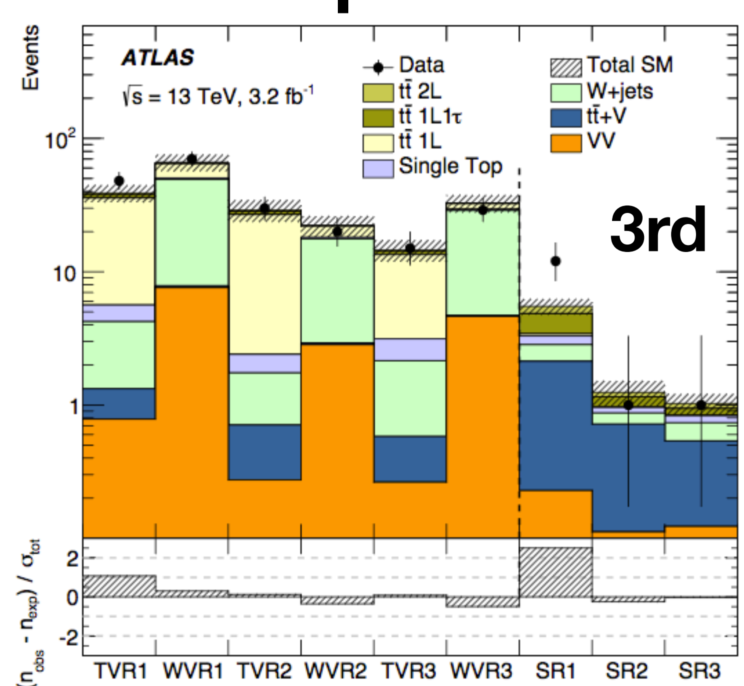
irreducible background

squarks/gluinos + 0L



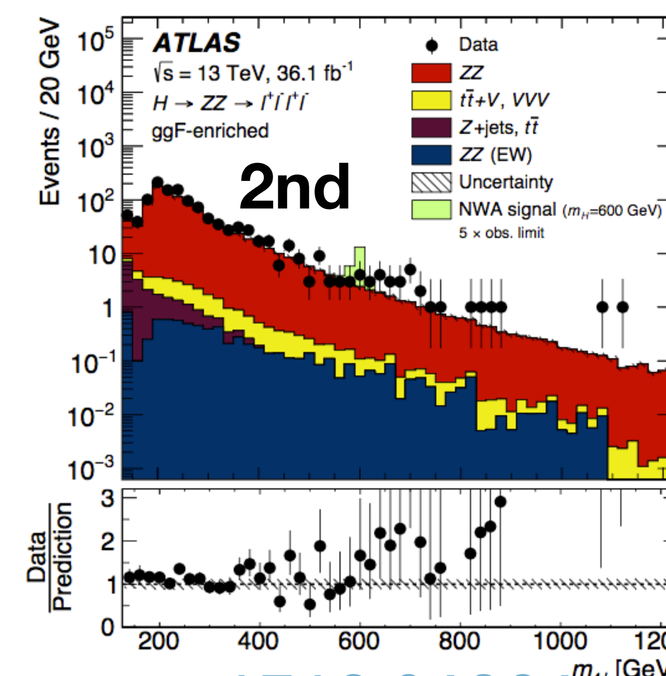
1712.02332

stop + 1L



1606.03903

BSM Higgs + 2L



1712.06386

Summary of results

			[1609.01599](1609.01599) [1509.05276](1509.05276)	[1711.02547](1711.02547) [1510.01131](1510.01131)
$\sqrt{s}$	σ	Theory (NLO)	ATLAS	CMS
8 TeV	$t\bar{t}Z$	215 ± 30 fb	176^{+58}_{-52} fb (4.2σ)	242^{+65}_{-55} fb (6.4σ)
	$t\bar{t}W$	232 ± 32 fb	369^{+100}_{-91} fb (5σ)	382^{+117}_{-102} fb (4.8σ)
13 TeV	$t\bar{t}Z$	0.84 ± 0.10 pb	0.9 ± 0.3 pb (3.9σ)	0.99 ± 0.15 pb $(> 5\sigma)$
	$t\bar{t}W$	0.60 ± 0.11 pb	1.5 ± 0.8 pb (2.2σ)	0.77 ± 0.17 pb (5.3σ)
			only 3 fb^{-1}!	***36 fb^{-1}***

Future plans:

- full Run 2 dataset ➡ top sector precision measurement
- differential cross-section ➡ BSM effects / EFT interpretation
- open new channels (all-hadronic) ➡ *(challenging)* background for BSM
- boosted vs resolved techniques ➡ connect with other analyses (ttH)

Summary of results

509.01599
509.05276

1711.02547
1510.01131

ATLAS	CMS

but more channels than CMS!

nly 3 fb^{-1}!	***36 fb^{-1}***

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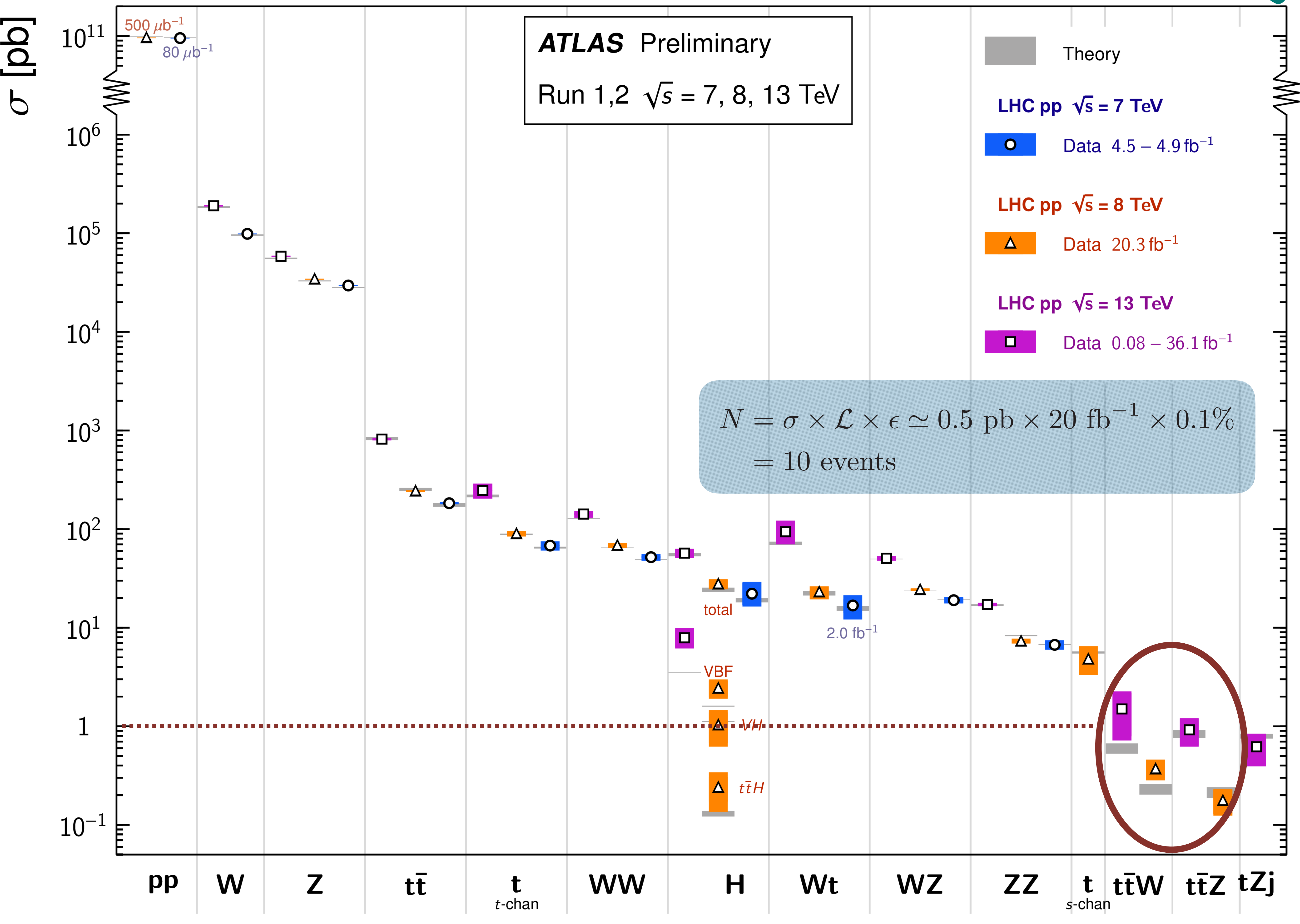
Standard Model Total Production Cross Section Measurements

Status: July 2017



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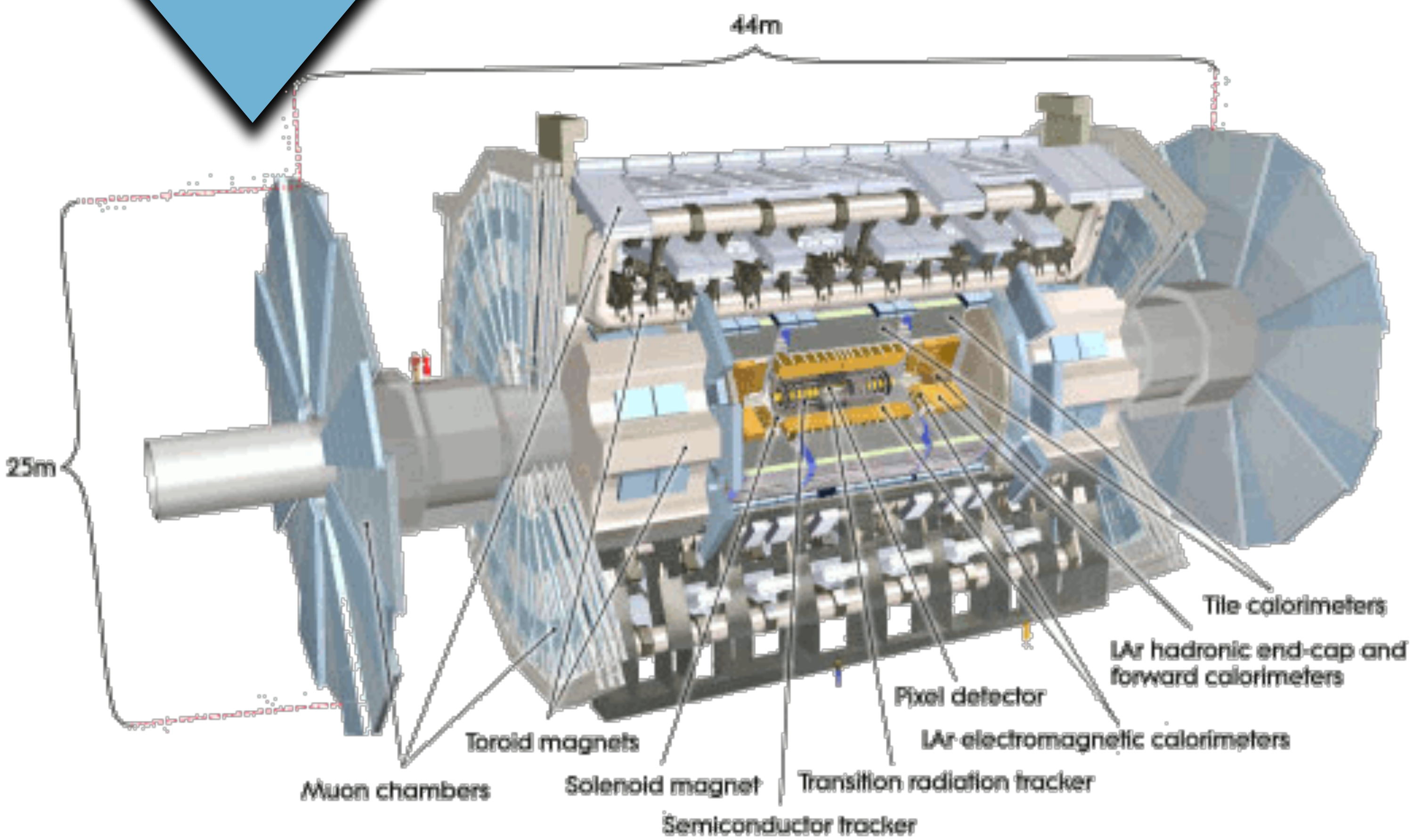
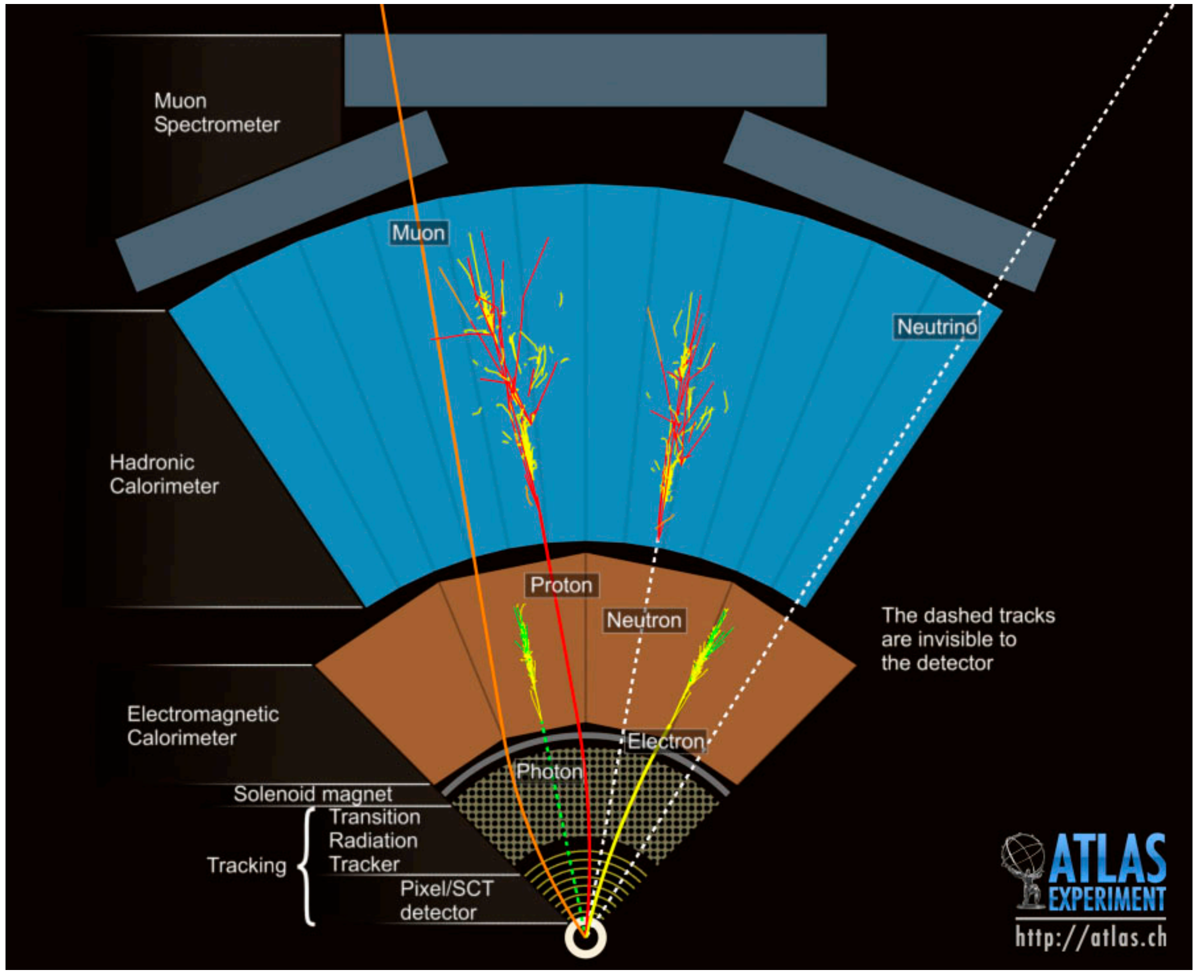
The ATLAS detector





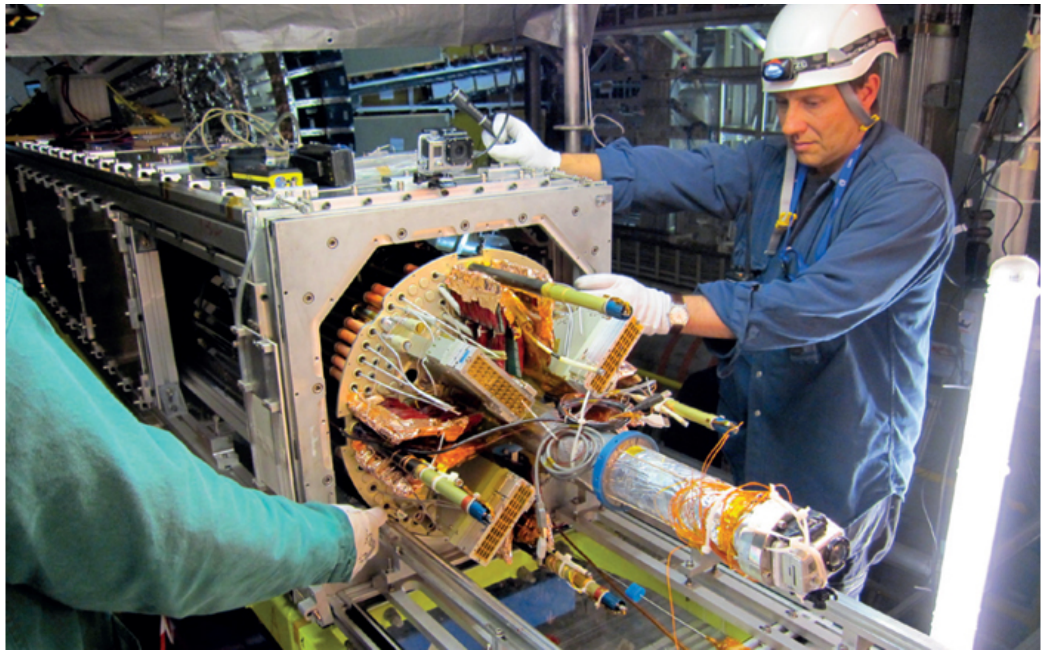
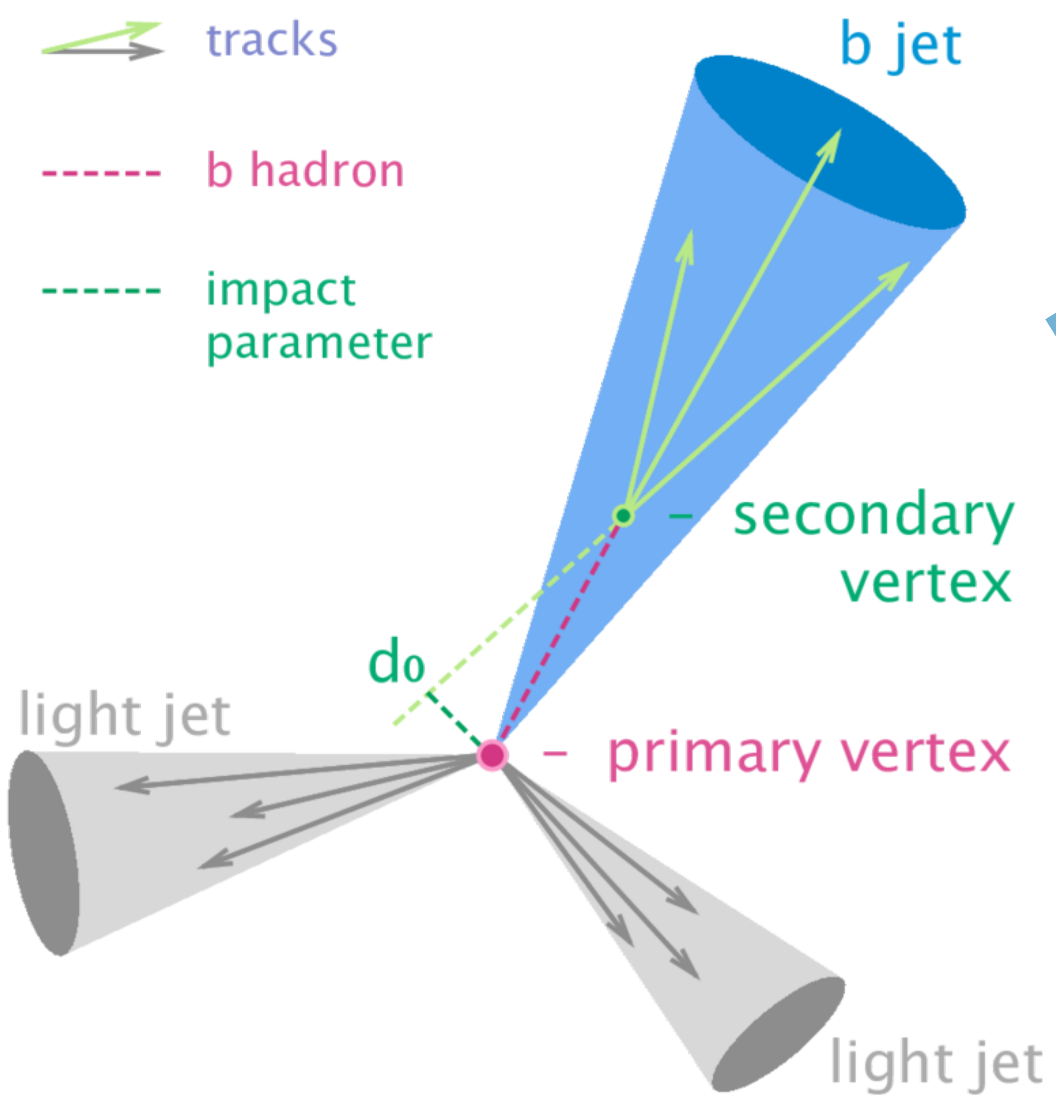
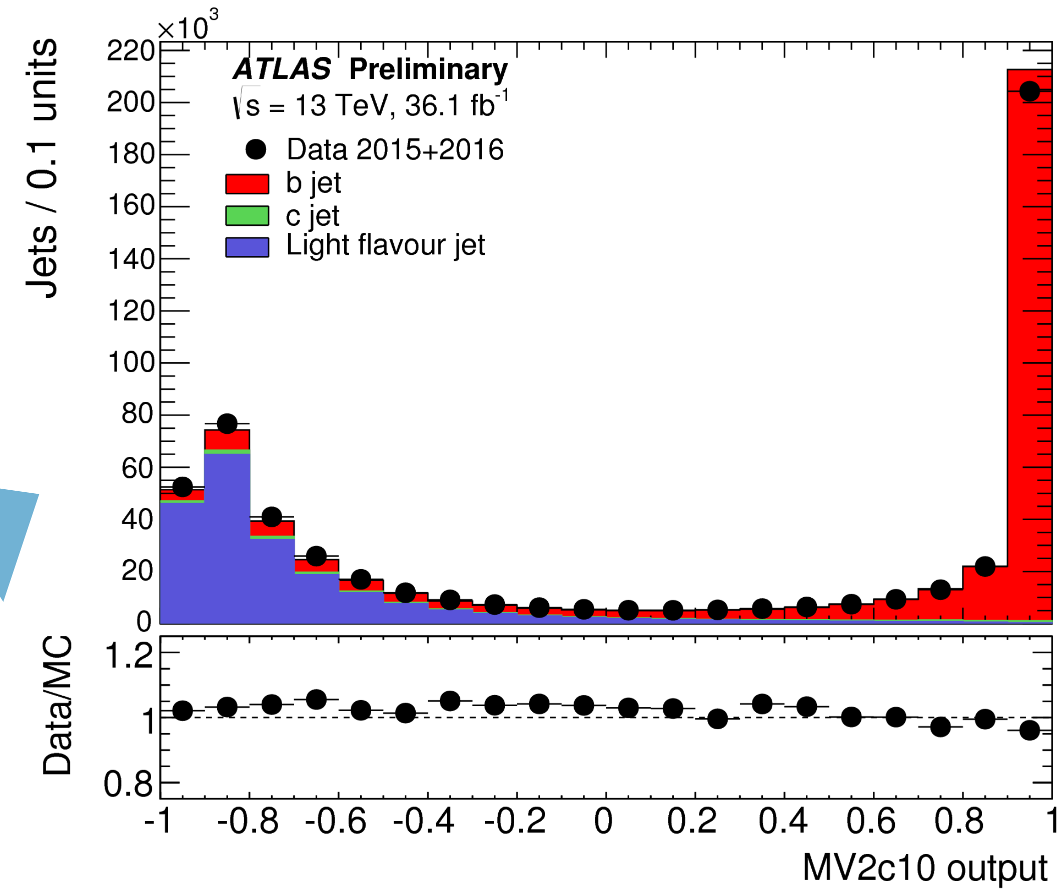
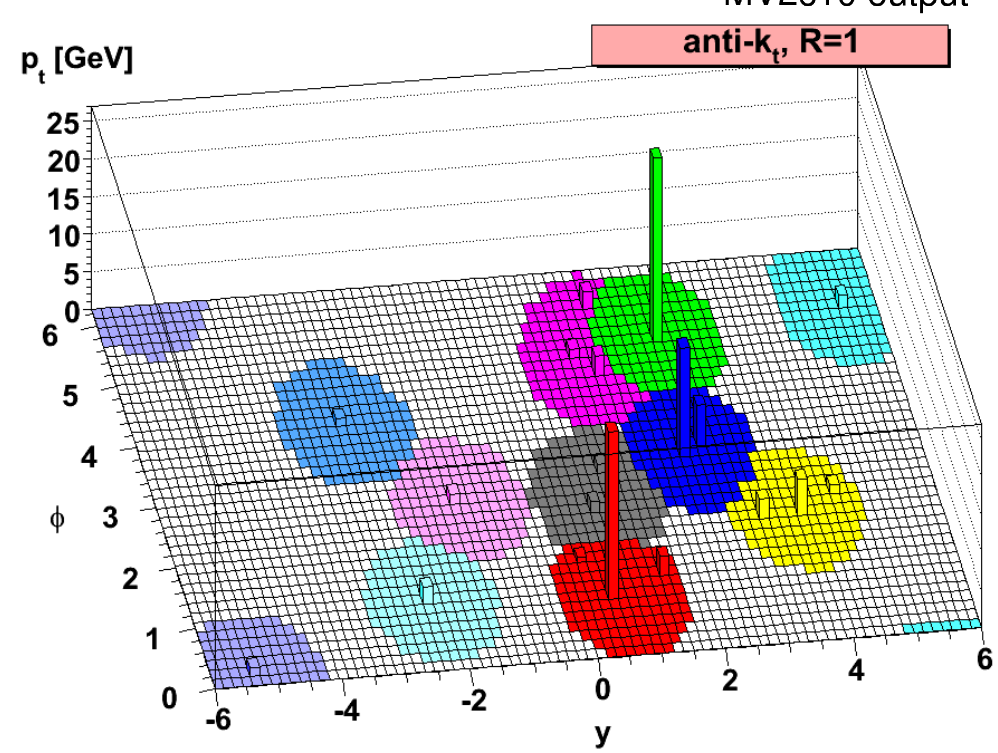


Fig. 3: Rare footage of ATLAS physicists giving birth to a **pixel detector**

Jets and b-tagging







Analysis strategy: *"cut & count"*

Signal Region definition → Control Regions: MC modelling & data-driven → Turn on data!

Process	$t\bar{t}$ decay	Boson decay	Channel	$Z \to \ell^+\ell^-$
$t\bar{t}W^{\pm}$	$(\ell^{\pm}\nu b)(q\bar{q}b)$	$\ell^{\mp}\nu$	OS dilepton	no
	$(\ell^{\pm}\nu b)(\ell^{\mp}\nu b)$	$q\bar{q}'$	OS dilepton	no
	$(\ell^{\pm}\nu b)(q\bar{q}b)$	$\ell^{\pm}\nu$	SS dilepton	no
	$(\ell^{\pm}\nu b)(\ell^{\mp}\nu b)$	$\ell^{\pm}\nu$	Trilepton	no
$t\bar{t}Z$	$(\ell^{\pm}\nu b)(\ell^{\mp}\nu b)$	$q\bar{q}$	OS dilepton	no
	$(q\bar{q}b)(q'\bar{q}'b)$	$\ell^+\ell^-$	OS dilepton	yes
	$(\ell^{\pm}\nu b)(q\bar{q}b)$	$\ell^+\ell^-$	Trilepton	yes
	$(\ell^{\pm}\nu b)(\ell^{\mp}\nu b)$	$\ell^+\ell^-$	Tetralepton	yes

Focus on high-σ regions

Same-sign dilepton ttW

exceedingly rare in the SM!

(= kills off dileptonic top pairs)

$$p_T(\ell) > 25 \text{ GeV}$$
$$E_T^{\text{miss}} > 40 \text{ GeV}$$
$$\sum_{\text{jets}} p_T > 240 \text{ GeV}$$
$$N_{\text{b-jets}} \geq 2$$

+ split by lepton flavour

Trilepton ttZ

low branching fraction but excellent S/B ratio

$$p_T(\ell) > 25, 20 \text{ GeV}$$
$$|m_{\ell\ell} - m_Z| < 10 \text{ GeV}$$
$$N_{\text{jets}} \geq 3$$
$$N_{\text{b-jets}} \geq 1$$

signal lepton

expect 2 neutrinos / a Z

1 hadronic top

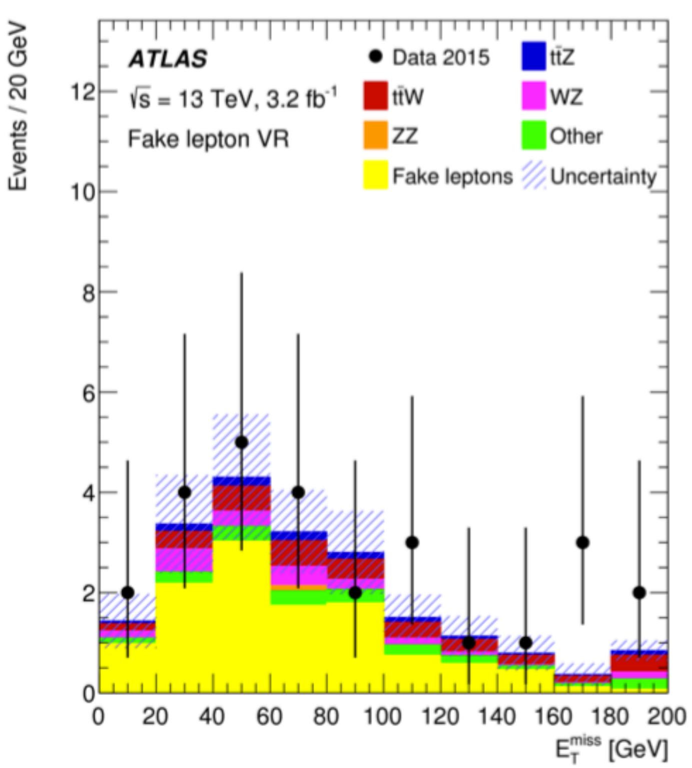
Tetralepton region is also good for EFT, but suffers from very low statistics

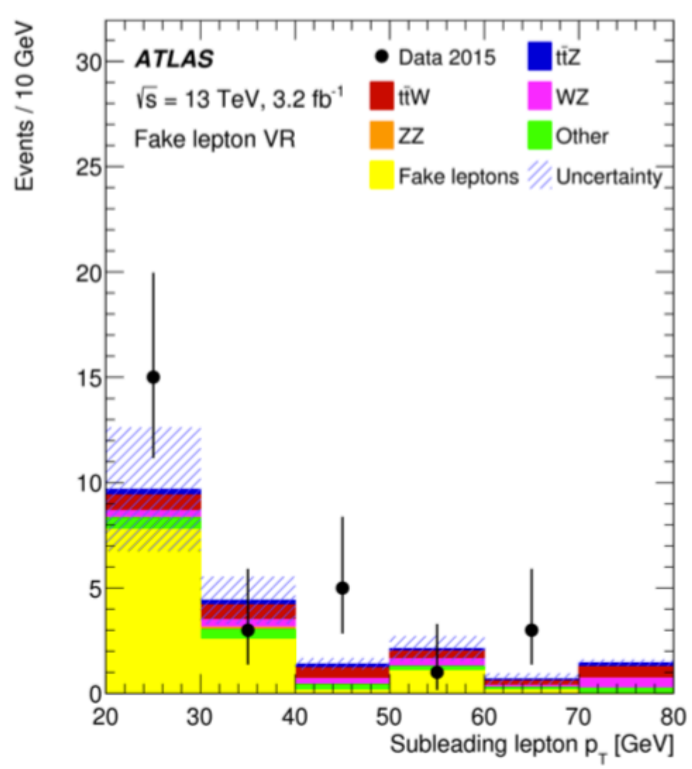
Background estimation

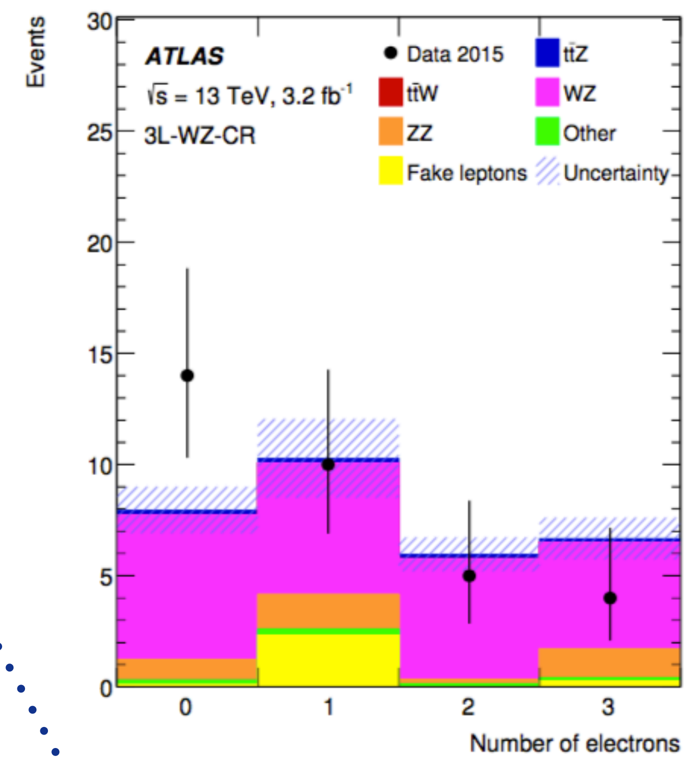
Fake leptons

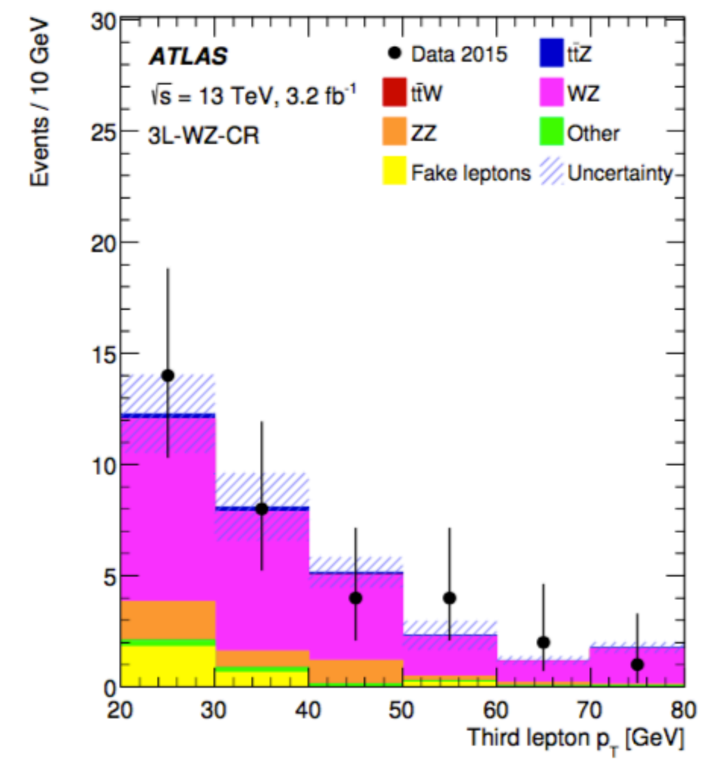
fully/semi data-driven

charge flips, jet mis-ID, photon conversion, non-prompt leptons…







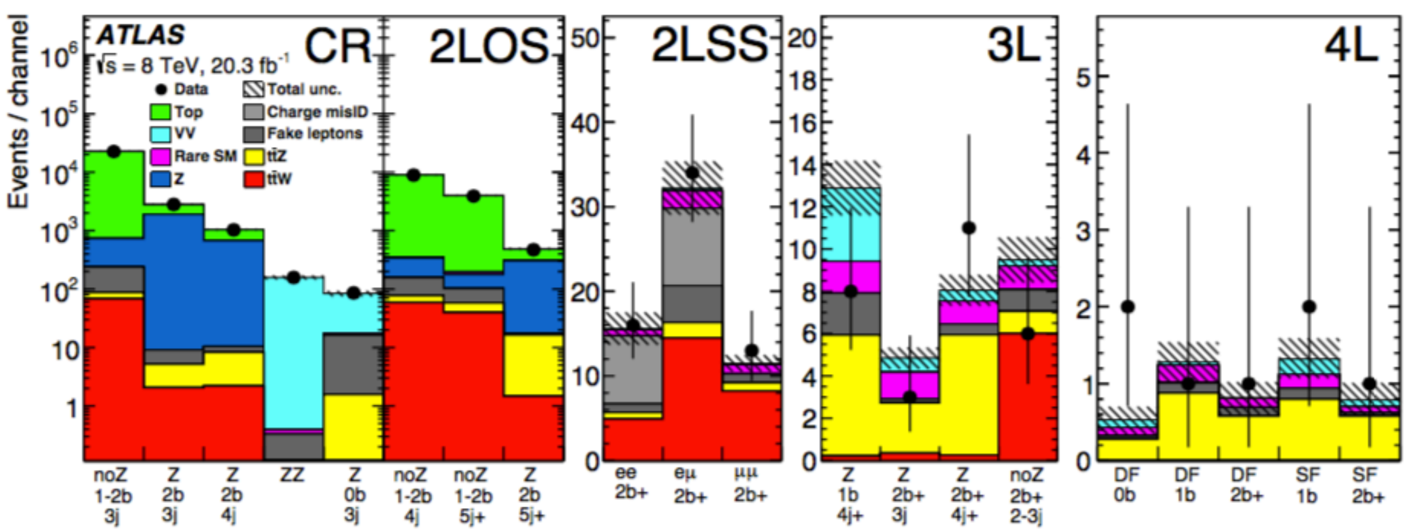


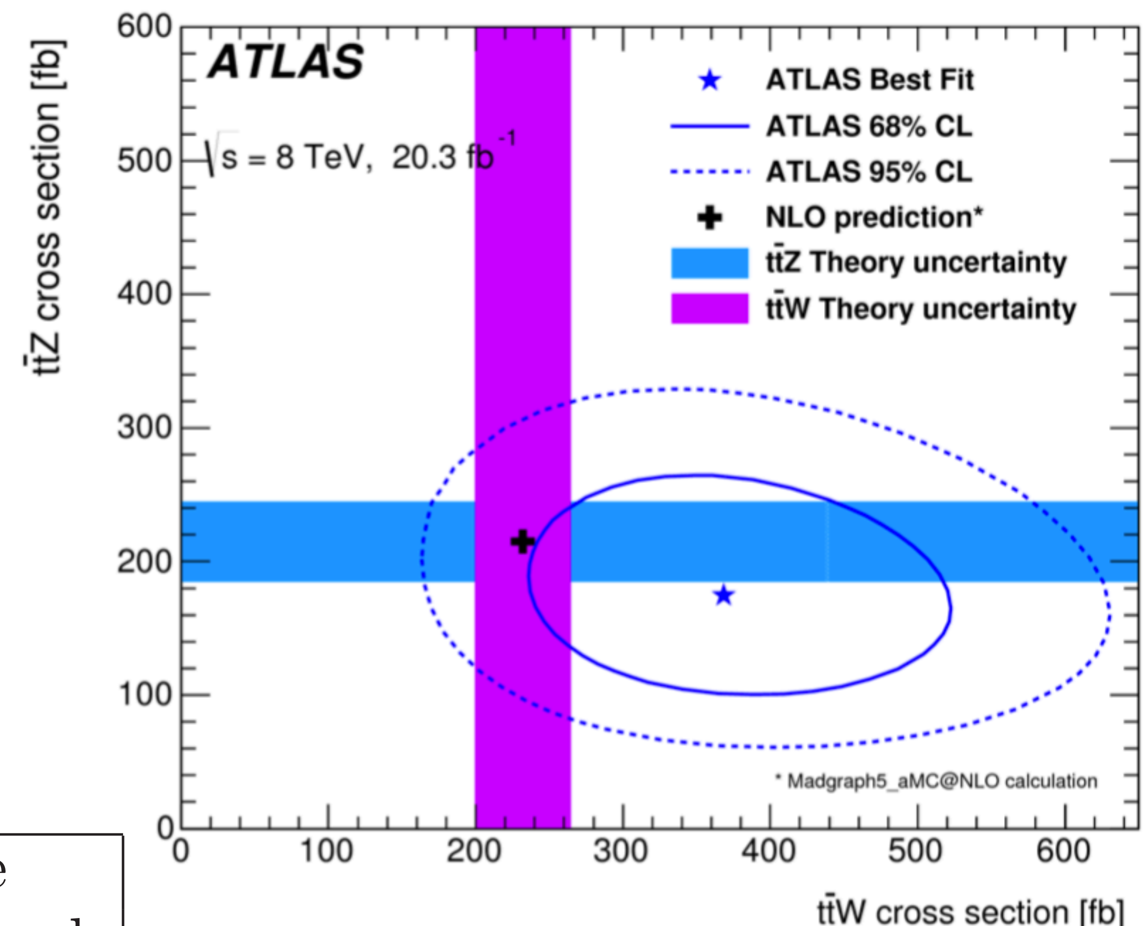
WZ+jets background

Monte Carlo estimate

scale factor derived in a control region orthogonal to the ttZ 3L SR

Results at 8 TeV



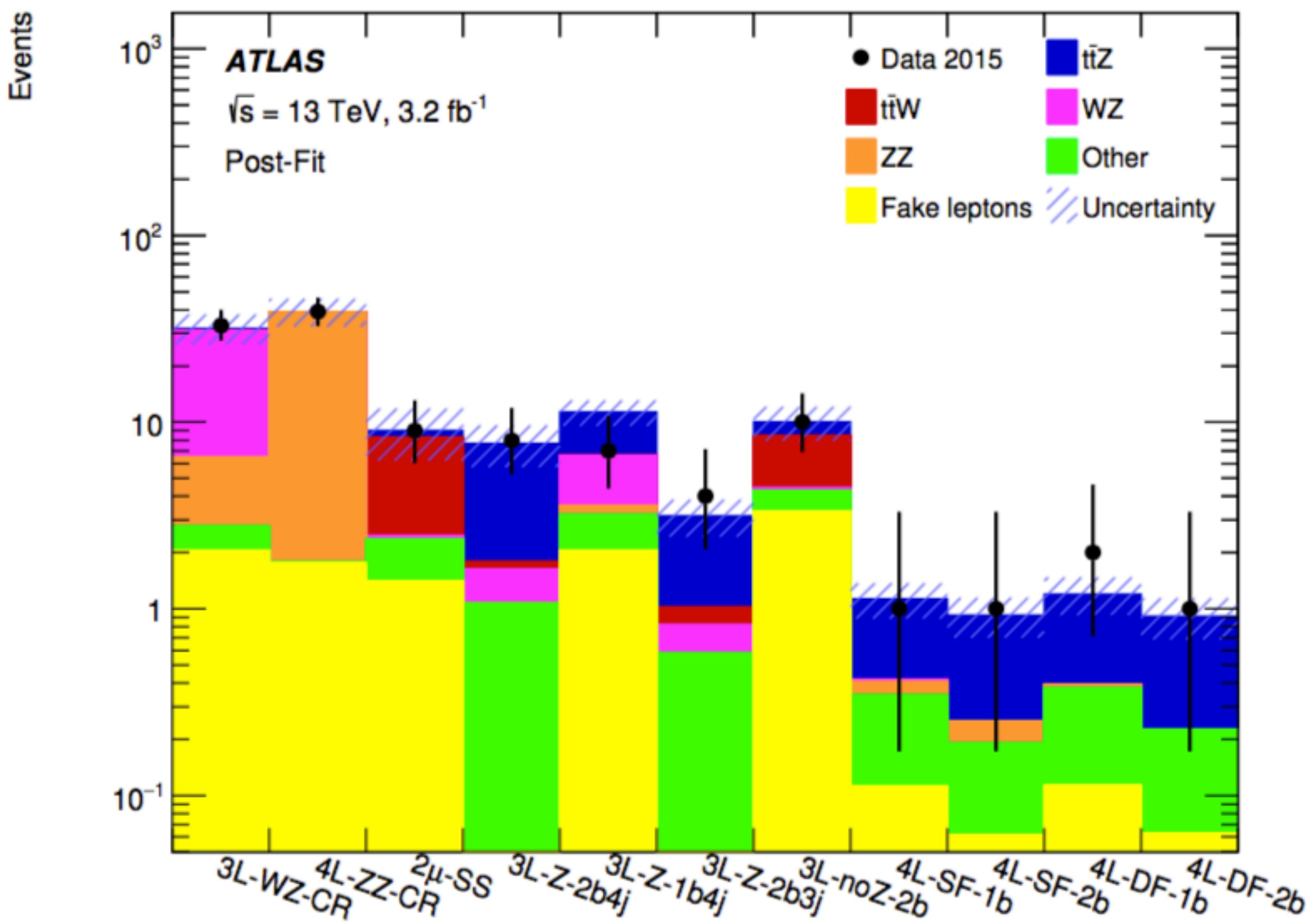


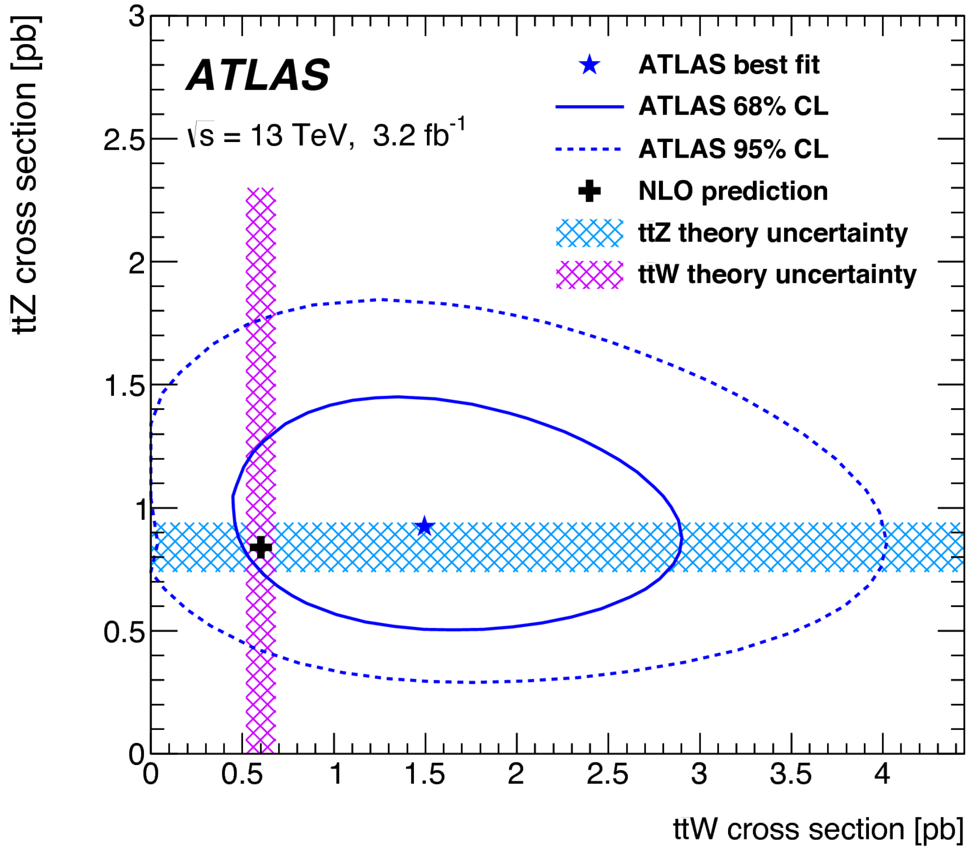
Channel	$t\bar{t}W$ significance Expected	$t\bar{t}W$ significance Observed	$t\bar{t}Z$ significance Expected	$t\bar{t}Z$ significance Observed
2ℓOS	0.4	0.1	1.4	1.1
2ℓSS	2.8	5.0	-	-
3ℓ	1.4	1.0	3.7	3.3
4ℓ	-	-	2.0	2.4
Combined	3.2	5.0	4.5	4.2

"discovery

"evidence

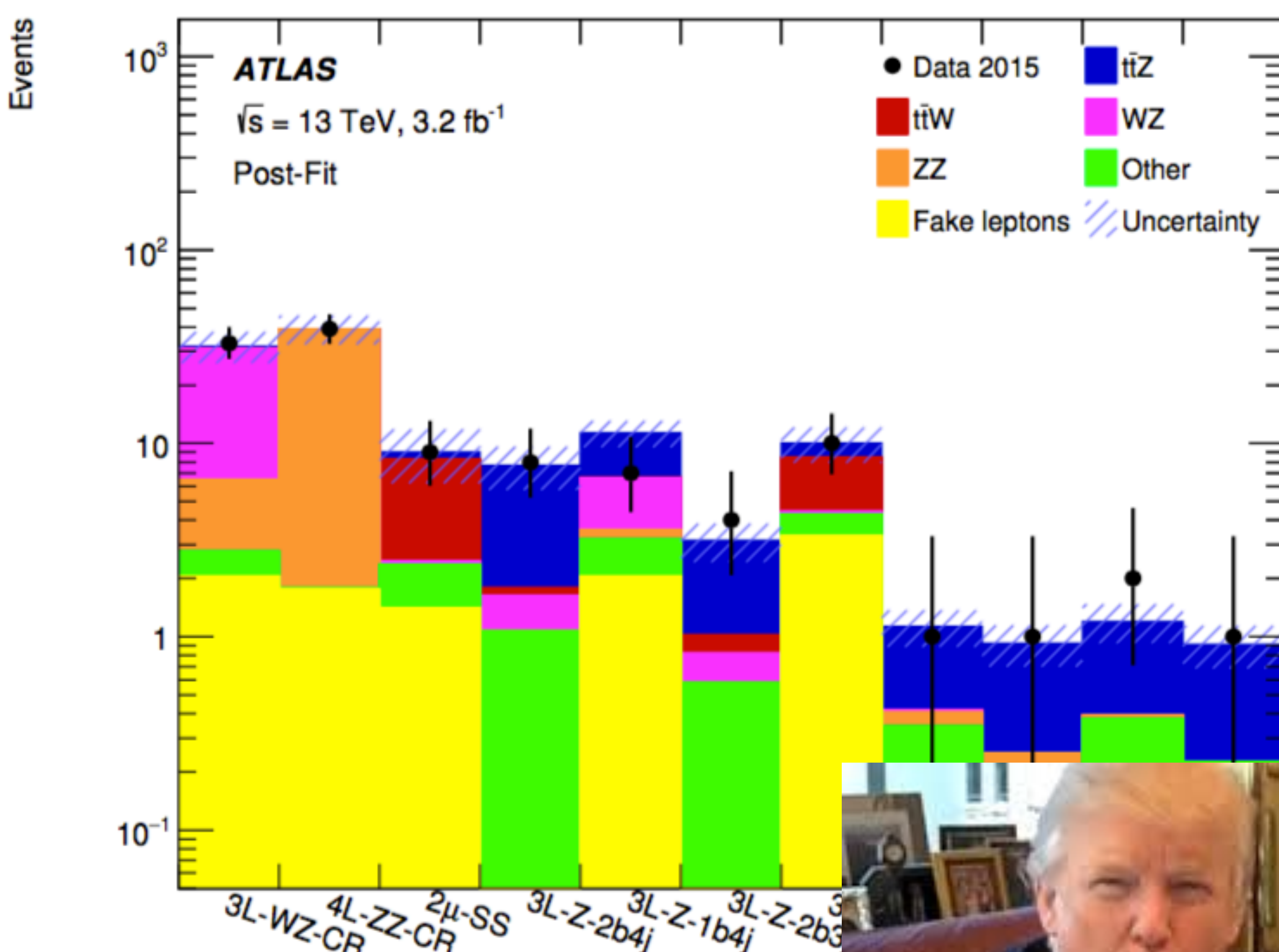
Results at 13 TeV

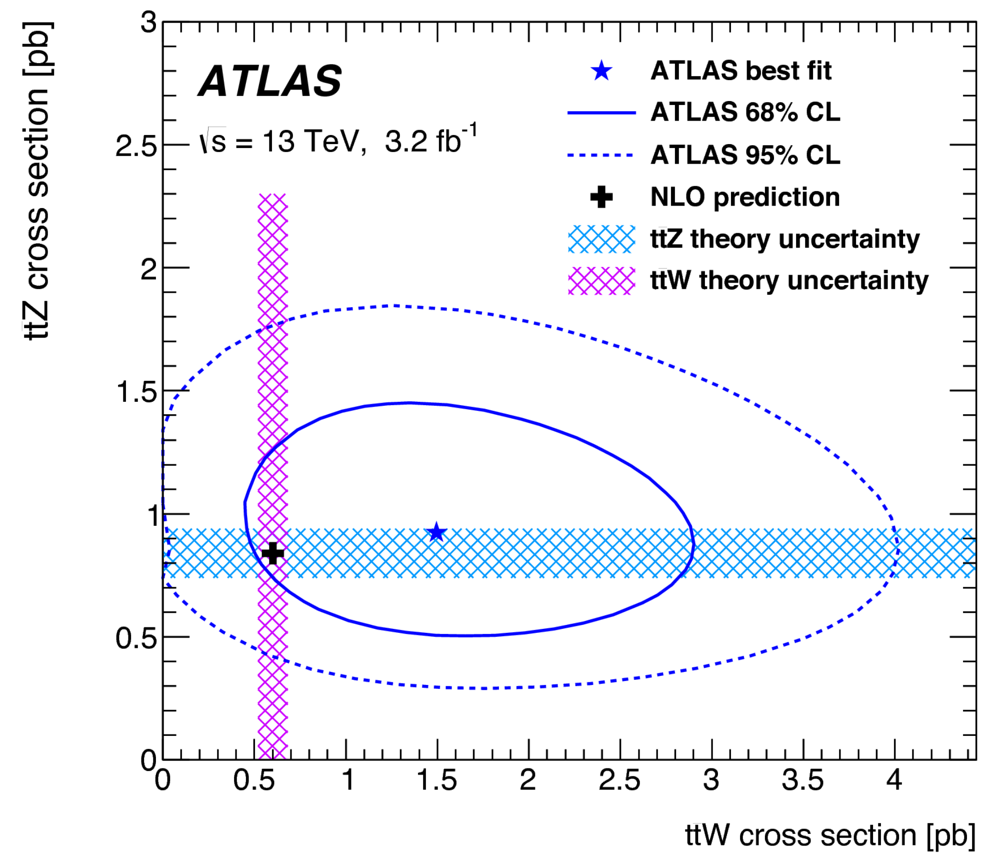




Uncertainty	$\sigma_{t\bar{t}Z}$	$\sigma_{t\bar{t}W}$
Luminosity	2.6%	3.1%
Reconstructed objects	8.3%	9.3%
Backgrounds from simulation	5.3%	3.1%
Fake leptons and charge misID	3.0%	19%
Signal modelling	2.3%	4.2%
Total systematic	11%	22%
Statistical	31%	48%
Total	32%	53%

Results at 13 TeV





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Constraints on BSM physics

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i$$

$$\sigma = \sigma_{\rm SM} + \sum_i \frac{c_i}{\Lambda^2}\sigma_i^{(1)} + \sum_{i,j} \frac{c_i c_j}{\Lambda^4}\sigma_{ij}^{(2)}$$

$$\mathcal{L}_{\rm D6} \supset \frac{C_{uW}}{\Lambda^2}\left(\bar{q}\sigma^{\mu\nu}\tau^I u\right)\tilde{\varphi}W^I_{\mu\nu} + \frac{C_{uB}}{\Lambda^2}\left(\bar{q}\sigma^{\mu\nu}u\right)\tilde{\varphi}B_{\mu\nu} + \frac{C^{(3)}_{\varphi q}}{\Lambda^2}\left(\phi^\dagger \overleftrightarrow{D}^I_\mu \varphi\right)\left(\bar{q}\gamma^\mu\tau^I q\right)$$

$$+ \frac{C^{(1)}_{\varphi q}}{\Lambda^2} i\left(\phi^\dagger \overleftrightarrow{D}_\mu \varphi\right)\left(\bar{q}\gamma^\mu q\right) + \frac{C_{\varphi u}}{\Lambda^2}\left(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi\right)\left(\bar{u}\gamma^\mu u\right)$$

1601.08193

5 relevant dimension-6 EFT operators

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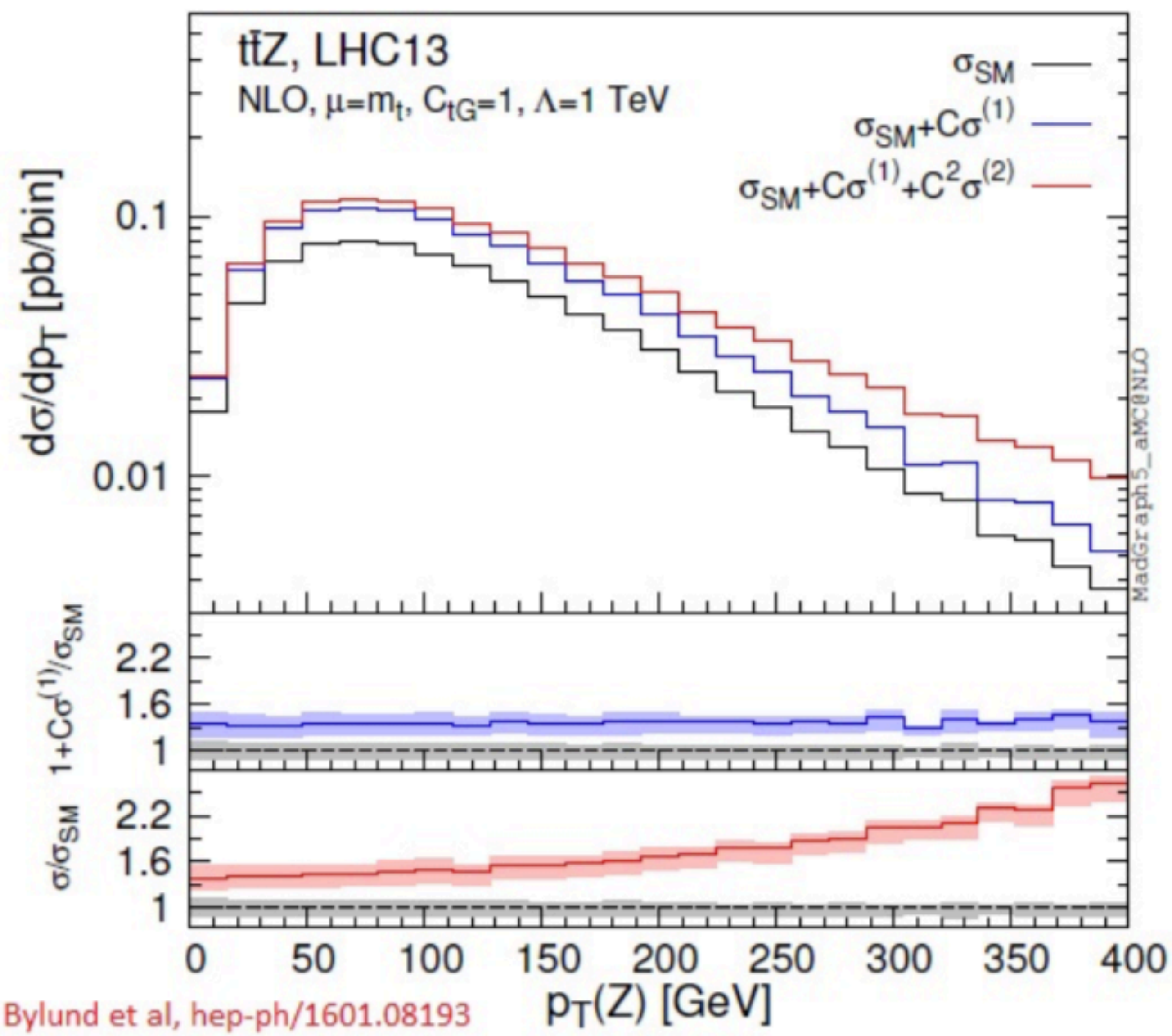
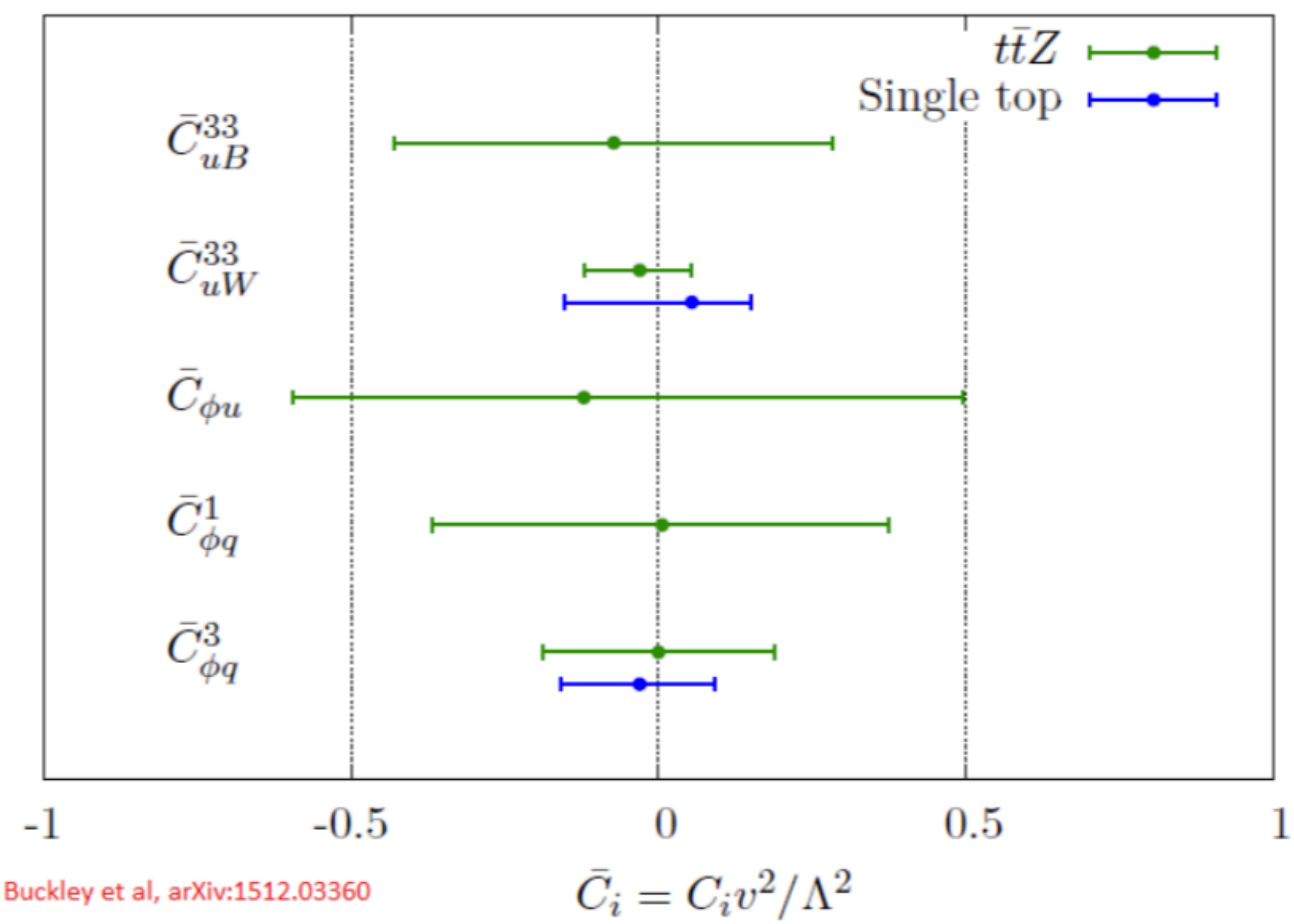
New observables from EFT

$$\mathcal{L}_{t\bar{t}Z} = e\bar{u}\left[\gamma^{\mu}\left(C_{1,V}+\gamma_5 C_{1,A}\right)+\frac{i\sigma^{\mu\nu}q_{\nu}}{m_Z}\left(C_{2,V}+i\gamma_5 C_{2,A}\right)\right]vZ_{\mu}$$



Bylund et al, hep-ph/1601.08193



Buckley et al, arXiv:1512.03360

Conclusions

Measurement of top quark pair production in association with a vector boson at ATLAS

$$\boxed{\begin{aligned} \sigma_{t\bar{t}Z} &= 0.92 \pm 0.30(\text{stat.}) \pm 0.11(\text{syst.})\ \text{pb} \\ \sigma_{t\bar{t}W} &= 1.38 \pm 0.70(\text{stat.}) \pm 0.30(\text{syst.})\ \text{pb} \end{aligned}}$$

- Good agreement with SM prediction at NLO
- 2015 + 2016 combination (36 fb^{-1}) under way
- + 2017 : differential cross-section measurement
- Full Run-2 data: large reduction of EFT coupling uncertainties
- Precision measurement and novel techniques can benefit BSM searches too

Run 2 results are coming! Stay tuned…