Prospects for ttZ measurements

at ATLAS with the full LHC Run 2 dataset

IoP APP/HEPP Conference
Monday, 8th April 2019

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IoP HEPP committee

This talk will consider only ATLAS measurements, the latest with 2015-2016 data
arXiv:1901.03584 (Submitted to Phys. Rev. D)

I will try to answer the following questions:

- Top quark? Why do we (still) care?
  - precision measurements in the top sector
  - window to new physics
- So, what exactly did you do?
  - a quick look at the 36 fb^{-1} ttZ measurement
  - constraints on anomalous couplings and EFT
- And what's next?
  - going differential
  - full Run 2: more statistics, better systematics!
  - fun ideas for future research…

Top quark? Why do we (still) care?

Why Top still interesting?

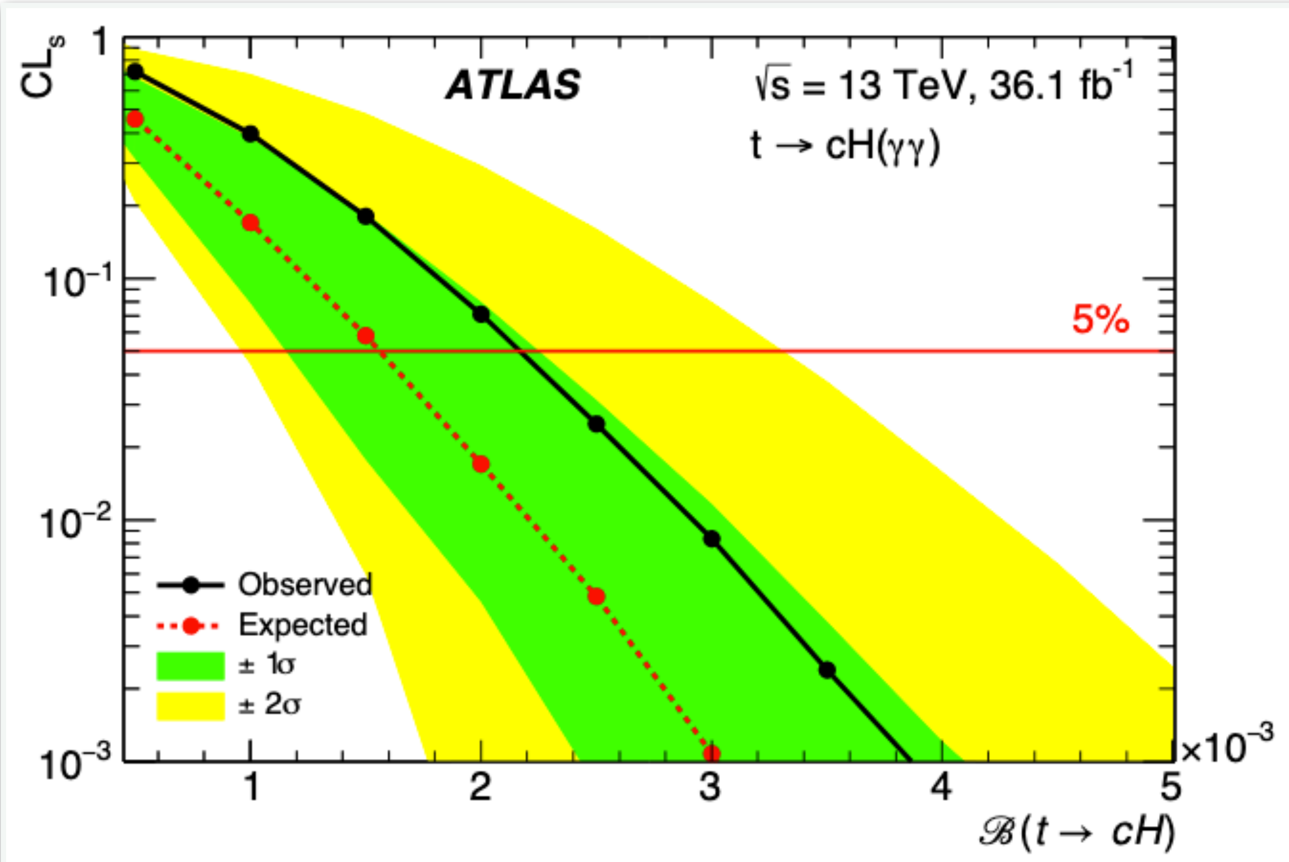
MANCHESTER 1824

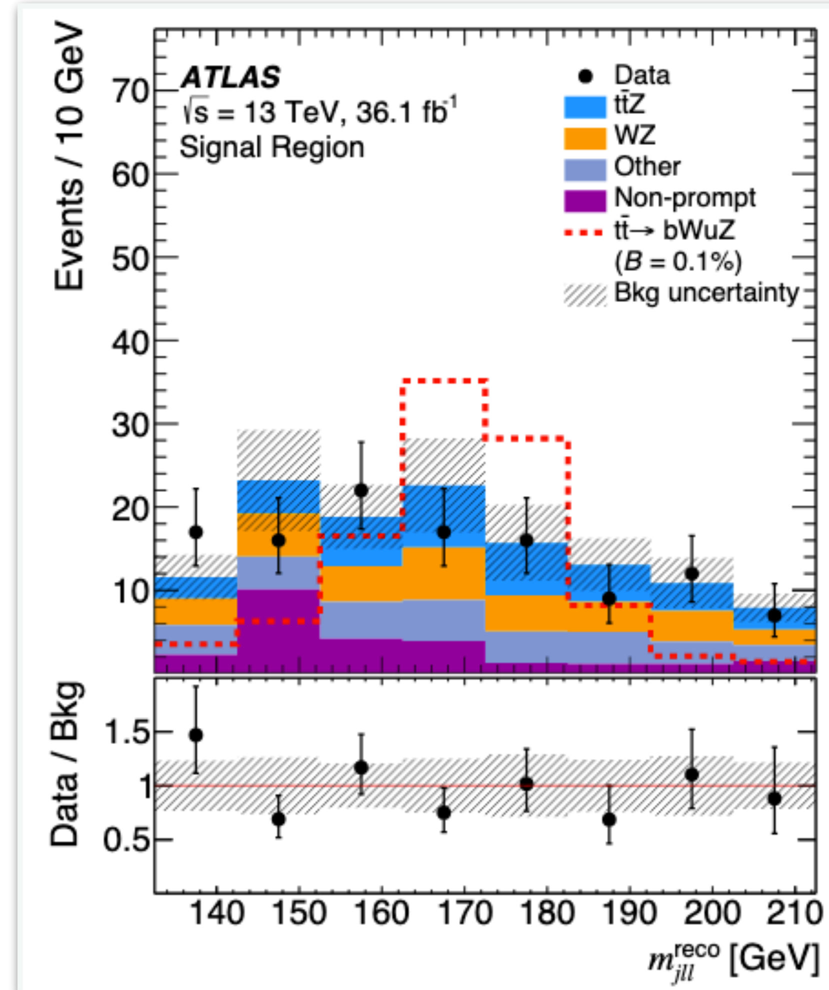
- With final Tevatron data set and the ever growing LHC data sample: top quark studies very interesting until today!
- What can we learn?
  - Is the top really the "SM top", or something else?
    → need to measure its production cross section and properties and compare with SM calculations
  - Top quark: 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

YETI'18 @IPPP

STOLEN

Precision measurements of top quark properties





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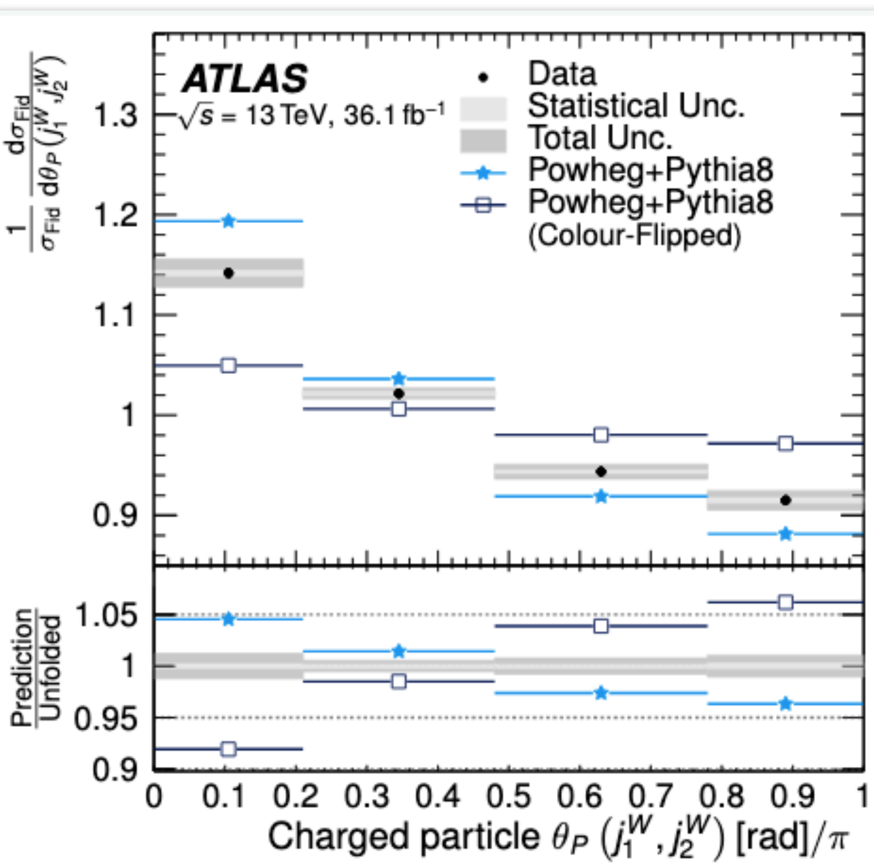
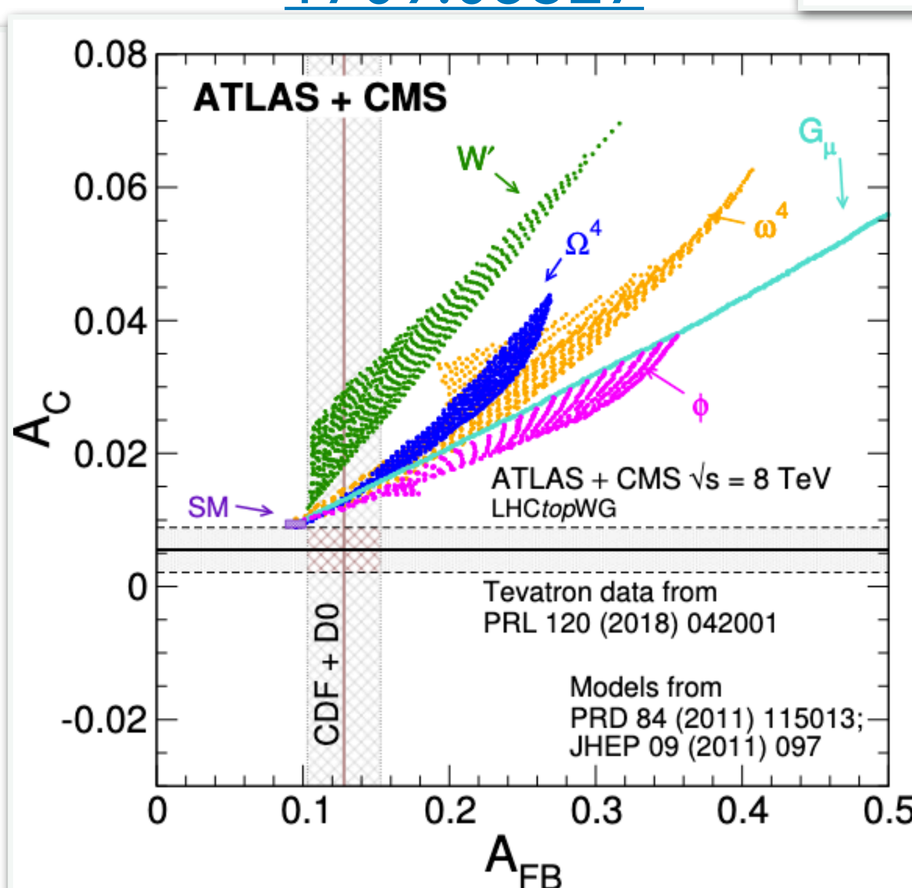
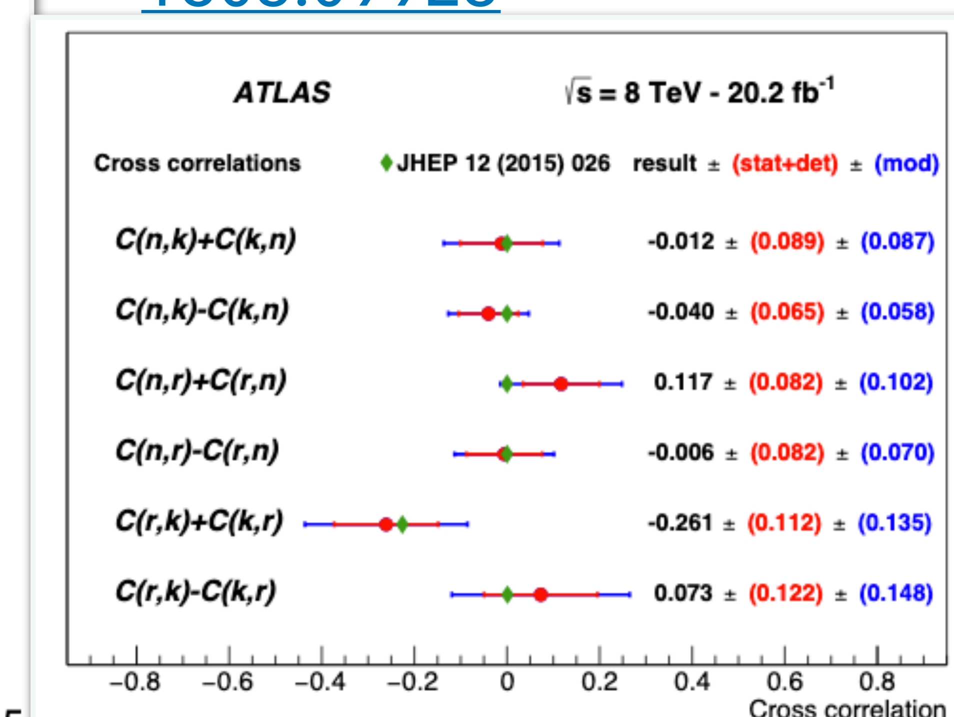
1707.01404

1709.05327

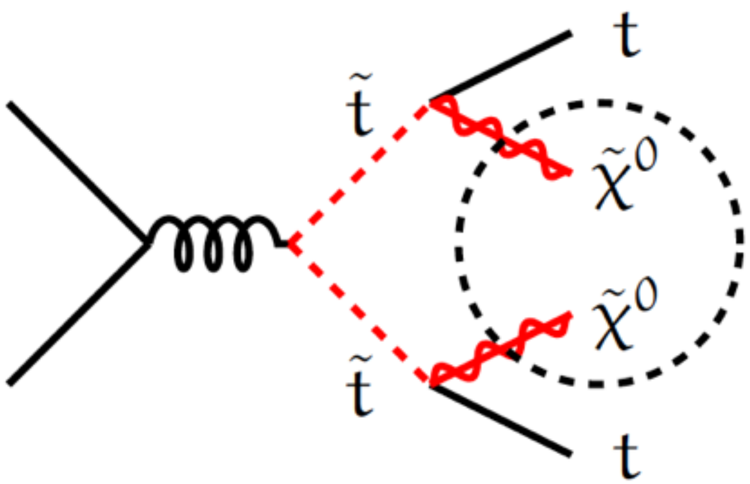
1803.09923



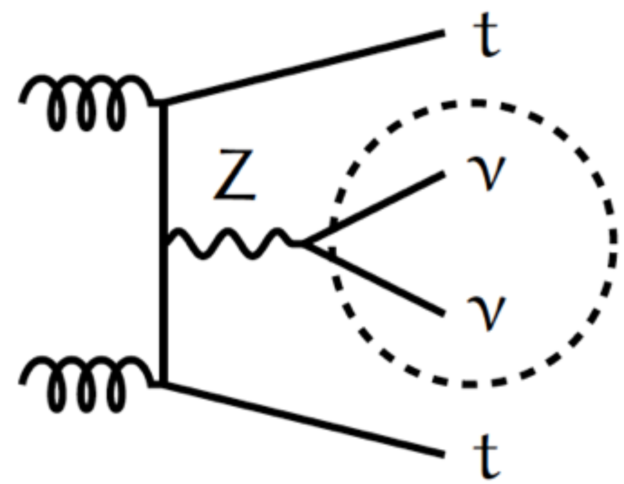




1612.07004



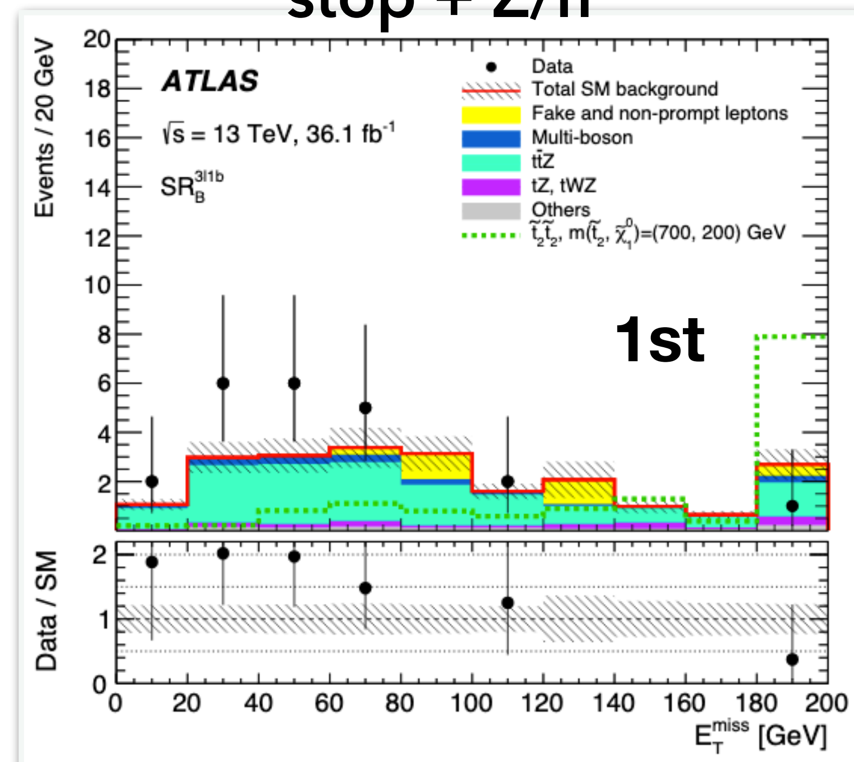
⇔



ttbar + MET (+leptons) : generic BSM signal

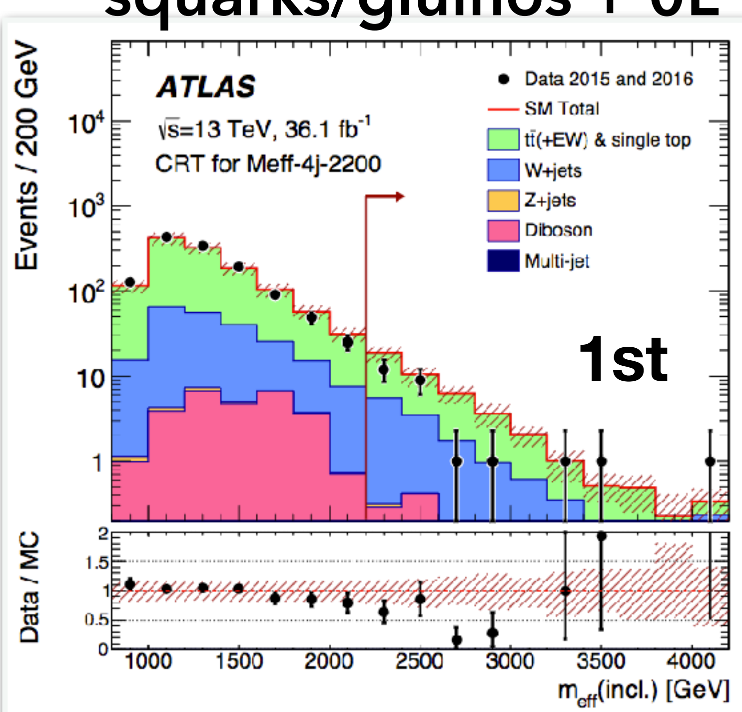
irreducible background

stop + Z/h



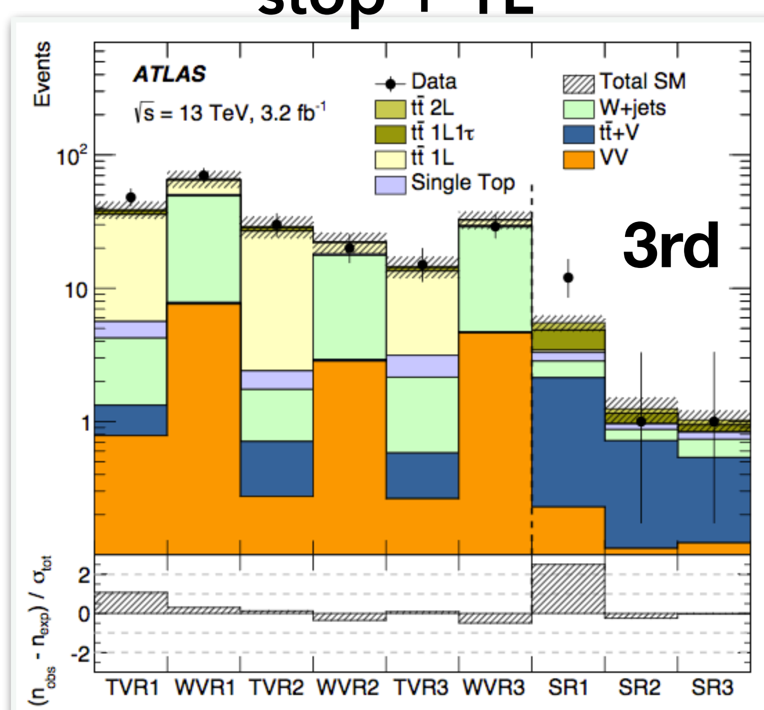
[1706.03986](https://arxiv.org/abs/1706.03986)

squarks/gluinos + 0L



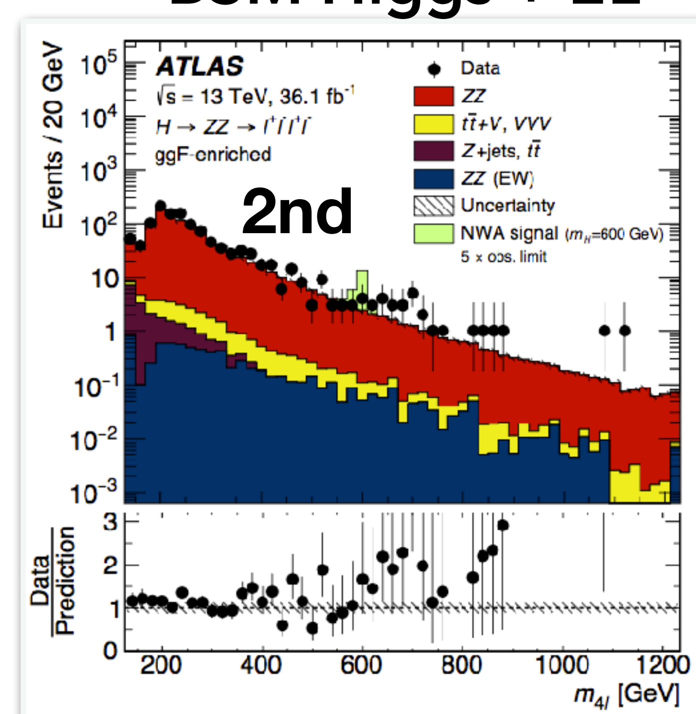
[1712.02332](https://arxiv.org/abs/1712.02332)

stop + 1L



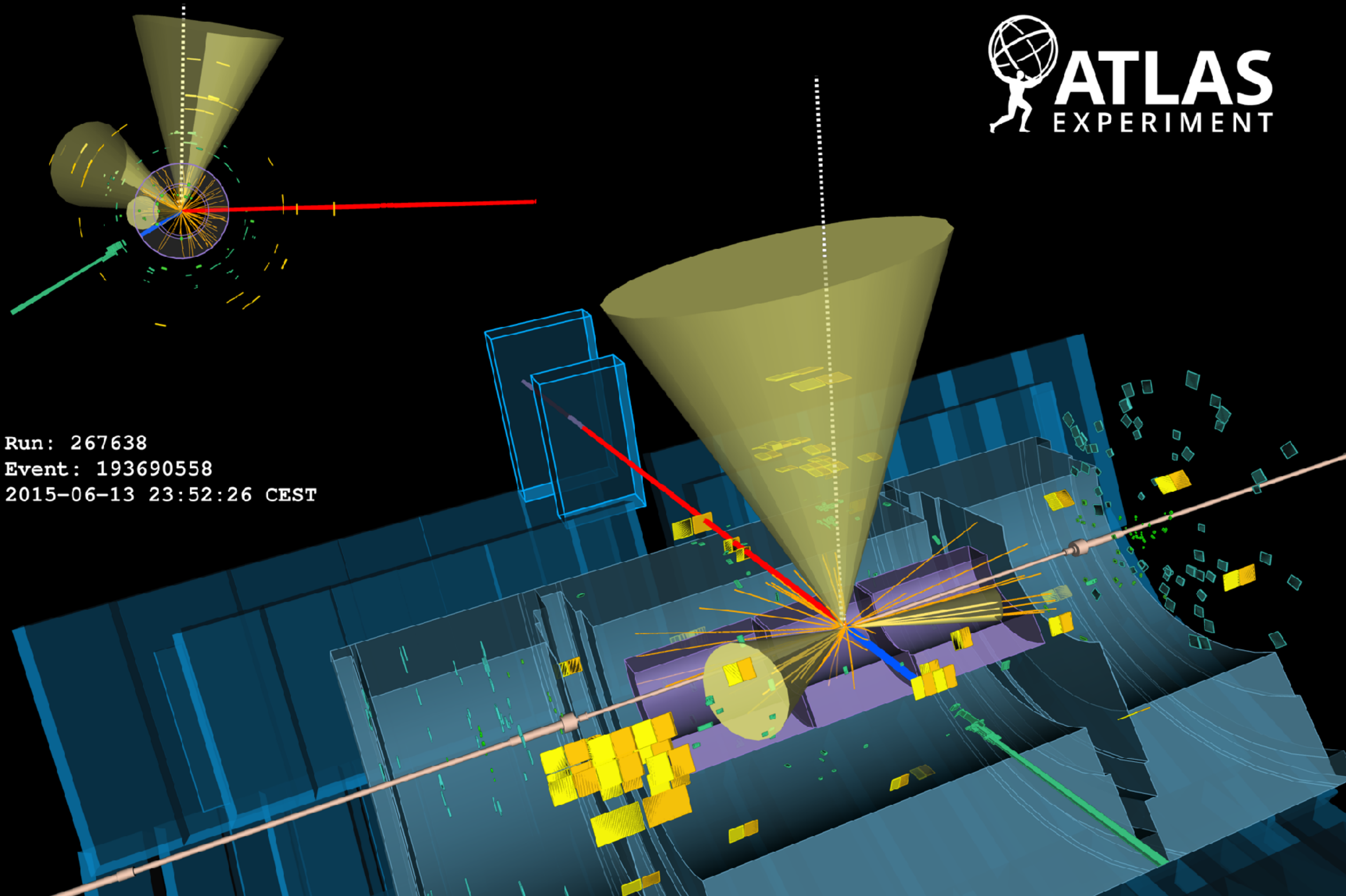
[1606.03903](https://arxiv.org/abs/1606.03903)

BSM Higgs + 2L



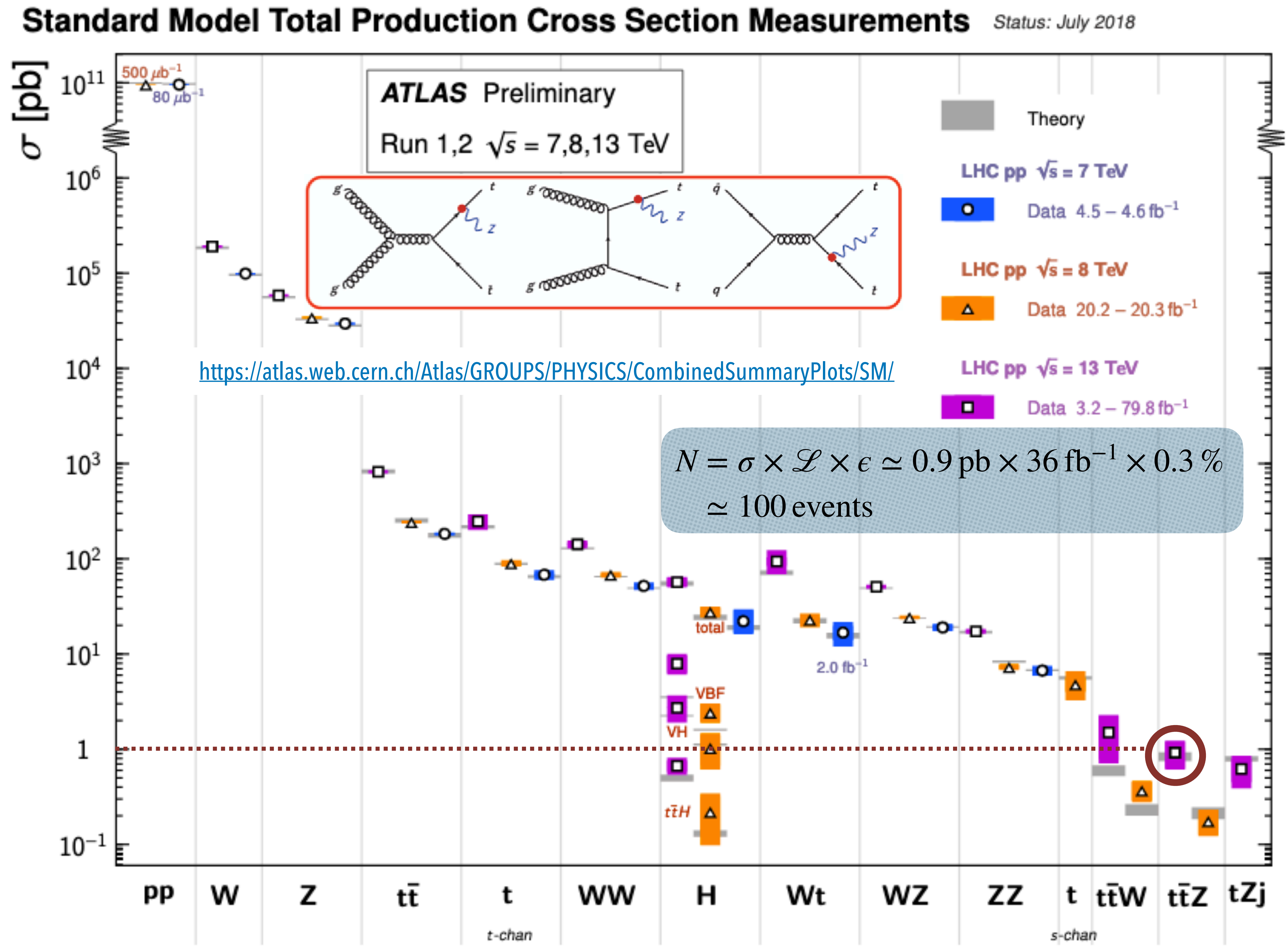
[1712.06386](https://arxiv.org/abs/1712.06386)

ATLAS EXPERIMENT



So, what exactly did you do?

Measuring the ttZ cross-section: a rare process!



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SM/

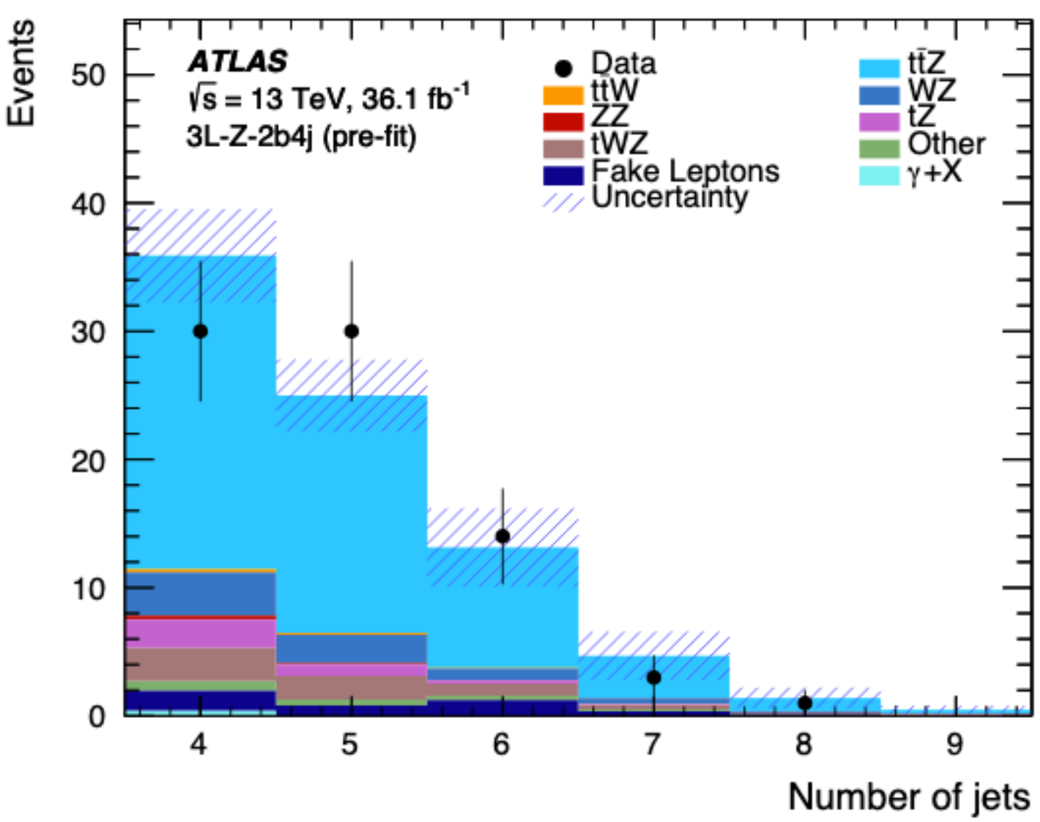
$$N = \sigma \times \mathscr{L} \times \epsilon \simeq 0.9\,\text{pb} \times 36\,\text{fb}^{-1} \times 0.3\,\%$$
$$\simeq 100\ \text{events}$$

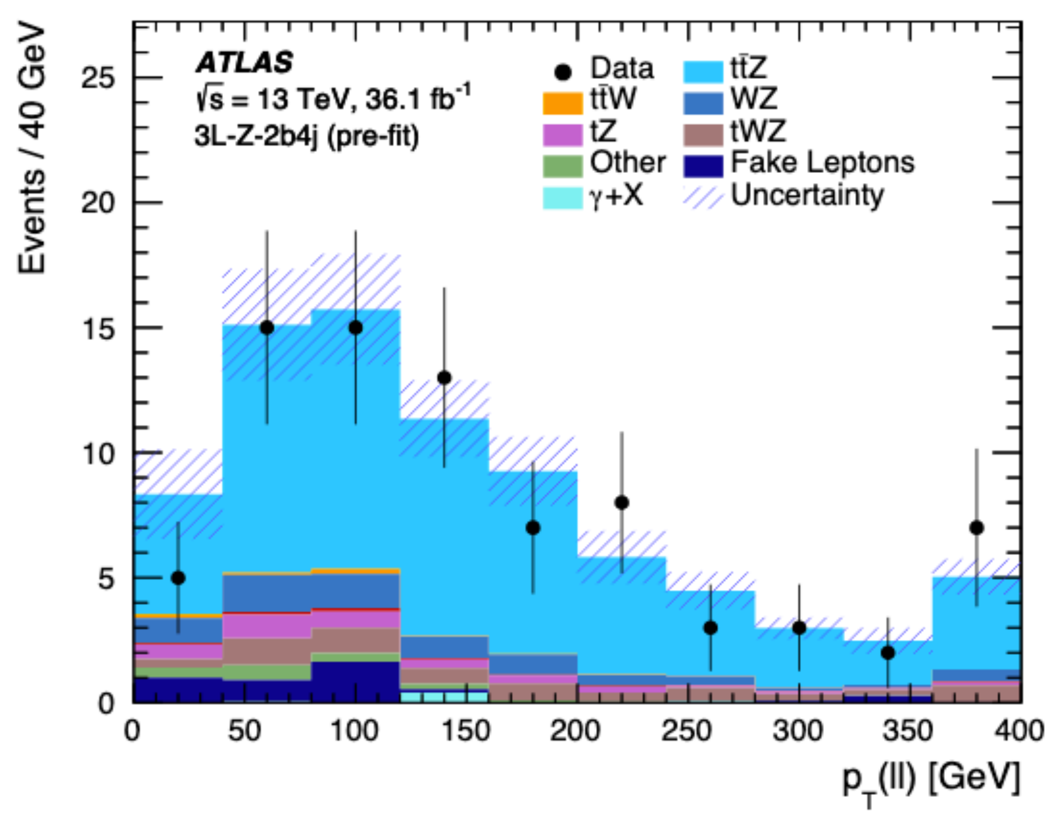
Focusing on the trilepton channel: signal regions

arXiv:1901.03584 (Submitted to Phys. Rev. D)

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

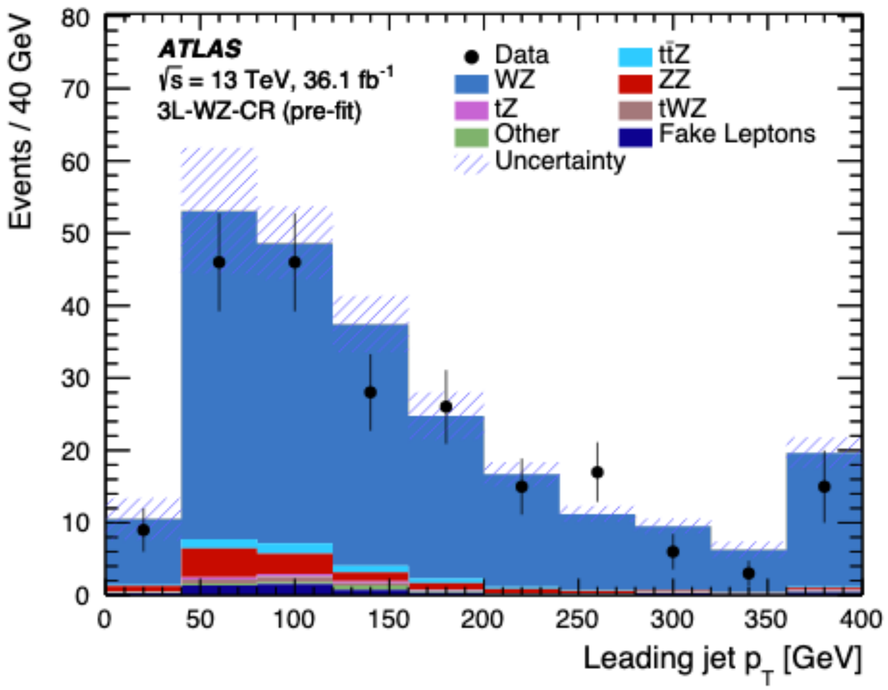
Define 3 signal regions based on (b-)jet multiplicity, and a extra one targeting off-shell Z decays and Z/γ* interference.

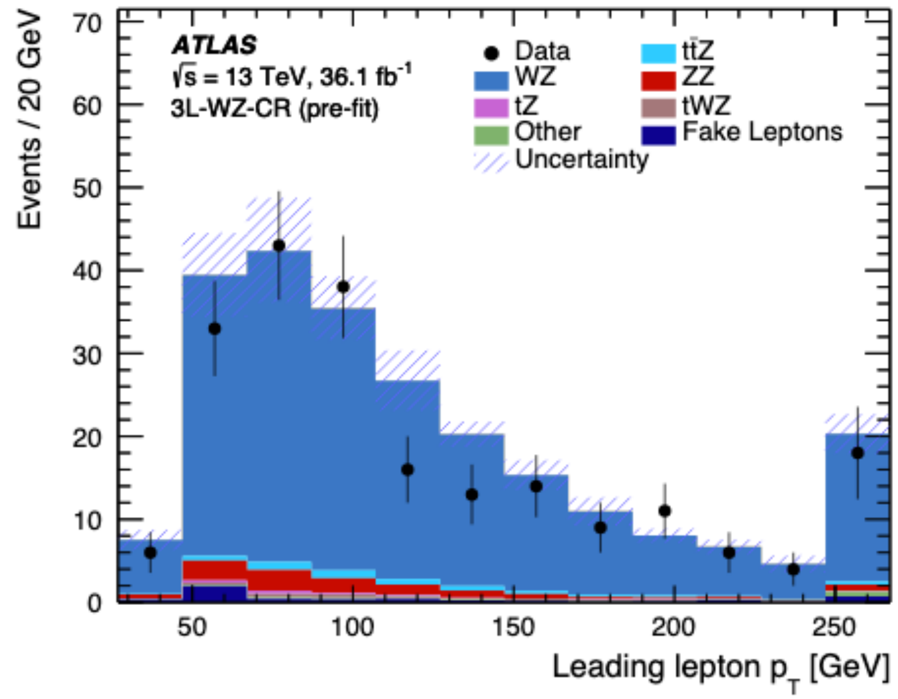




Among the backgrounds, WZ and Fakes (non-prompt leptons) require specific attention.

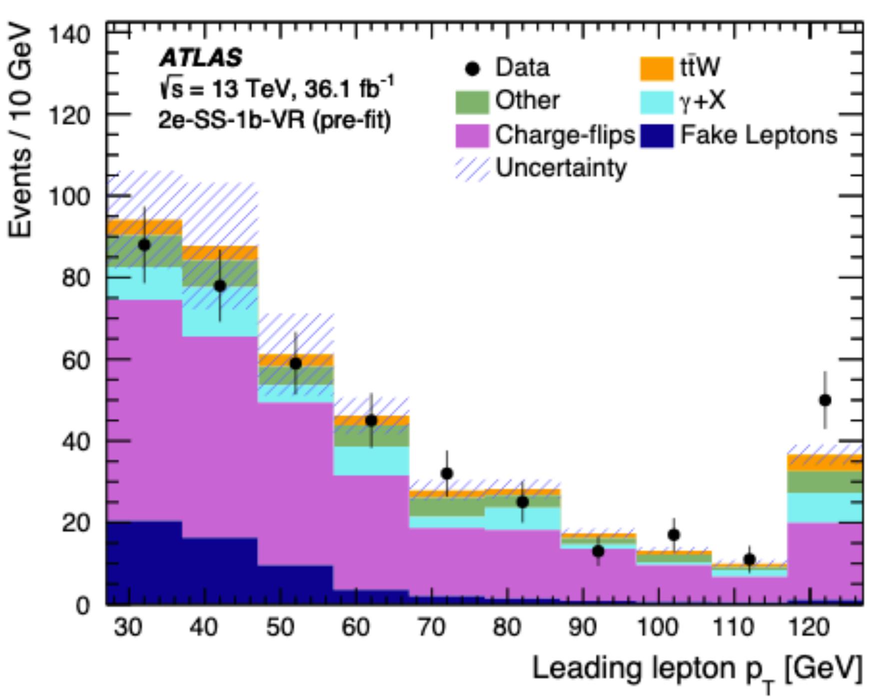
arXiv:1901.03584 (Submitted to Phys. Rev. D)

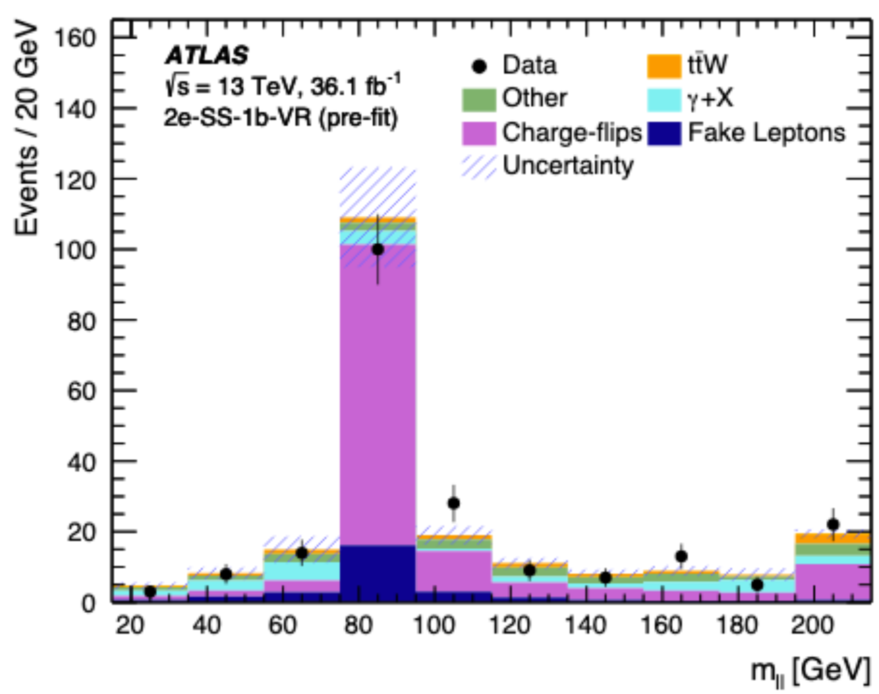




Extract **scale factor** in a WZ-enriched 0b CR:

$$\mu_{\mathrm{WZ}} = 0.93 \pm 0.07\,(\mathrm{stat.}) \pm 0.10\,(\mathrm{syst.})$$
$$= 0.93 \pm 0.12$$





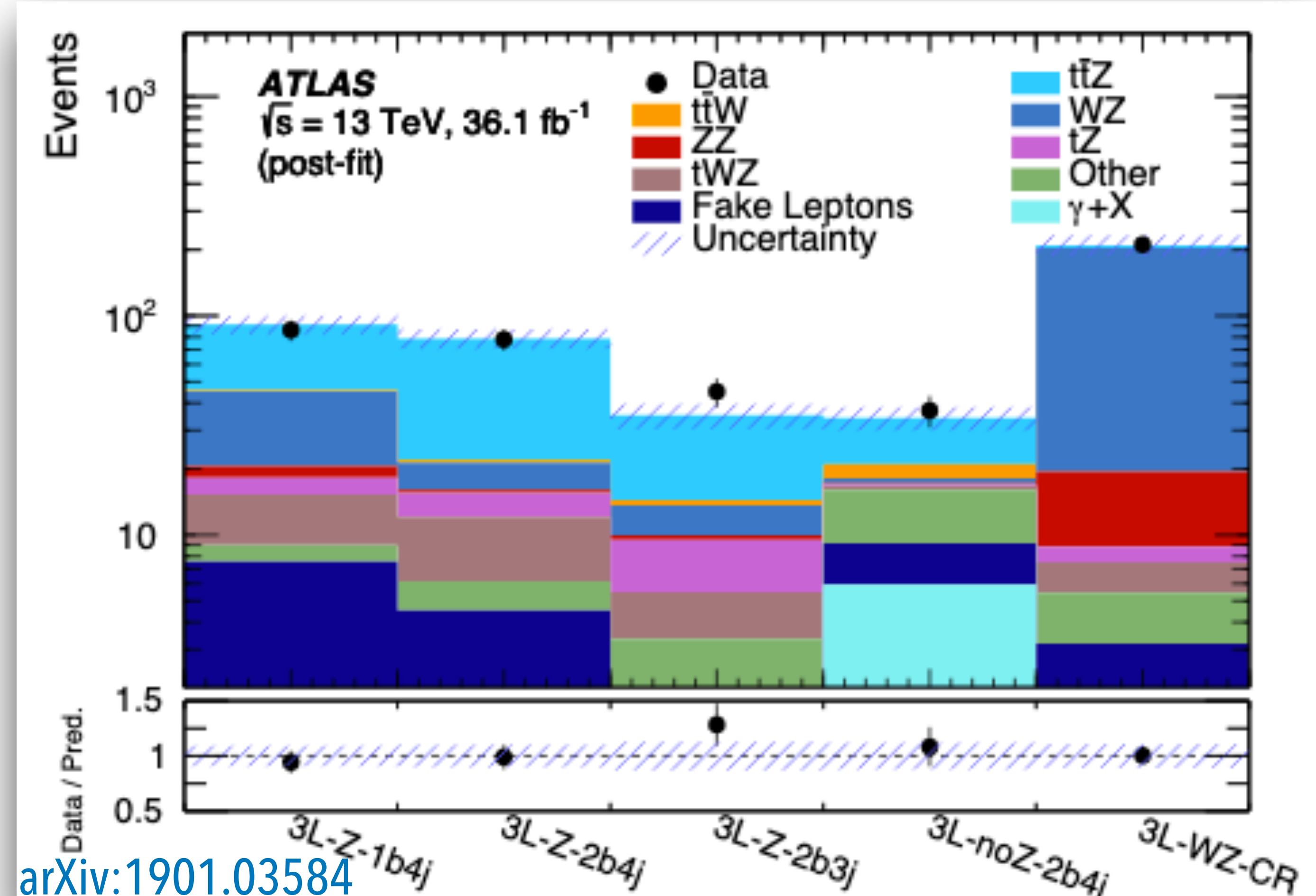
Matrix Method (1012.1792): invert the following equation to recover the number of "real" and "fake" leptons.

$$\begin{pmatrix} \langle n_T \rangle \\ \langle n_L \rangle \end{pmatrix} = \begin{pmatrix} \varepsilon_r & \varepsilon_f \\ \bar{\varepsilon}_r & \bar{\varepsilon}_f \end{pmatrix} \begin{pmatrix} n_R \\ n_F \end{pmatrix}$$

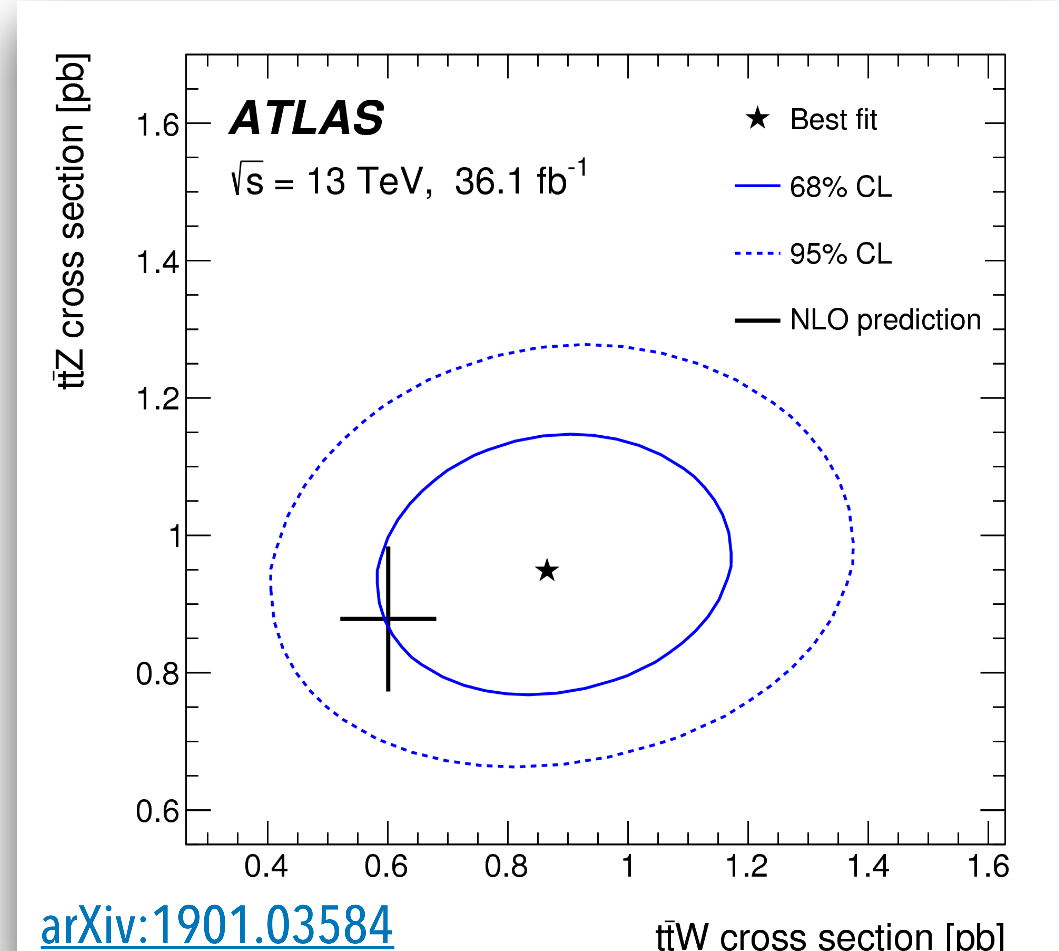
Measuring the ttZ cross-section: results at 36 fb^{-1}

Fit configuration	$\mu_{t\bar{t}Z}$	$\mu_{t\bar{t}W}$
Combined	1.08 ± 0.14	1.44 ± 0.32
2ℓ-OS	0.73 ± 0.28	-
3ℓ $t\bar{t}Z$	1.08 ± 0.18	-
2ℓ-SS and 3ℓ $t\bar{t}W$	-	1.41 ± 0.33
4ℓ	1.21 ± 0.29	-

Uncertainty	$\sigma_{t\bar{t}Z}$	$\sigma_{t\bar{t}W}$
Luminosity	2.9%	4.5%
CR and simulated sample statistics	1.8%	7.6%
JES/JER	1.9%	4.1%
Flavor tagging	4.2%	3.7%
Other object-related	3.7%	2.5%
Data-driven background normalization	2.4%	3.9%
Modeling of backgrounds from simulation	5.3%	2.6%
Background cross sections	2.3%	4.9%
Fake leptons and charge misID	1.8%	5.7%
$t\bar{t}Z$ modeling	4.9%	0.7%
$t\bar{t}W$ modeling	0.3%	8.5%
Total systematic	10.2%	16.0%
Statistical	8.4%	15.2%
Total	13.0%	22.2%



arXiv:1901.03584



arXiv:1901.03584

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

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

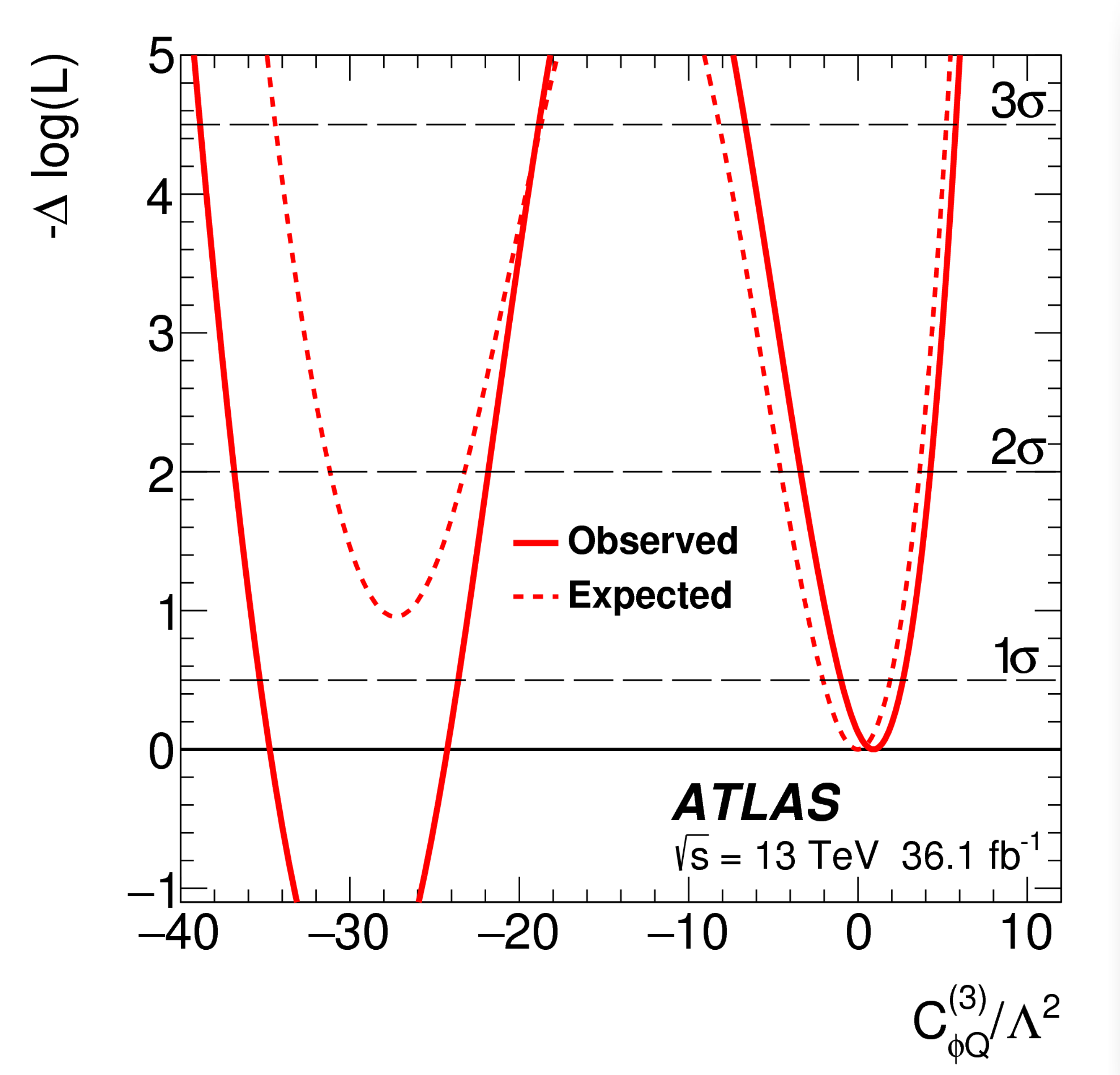
$$\mathcal{L}_{\text{D6}} \supset \frac{C_{uW}}{\Lambda^2} \left(\bar{q}\sigma^{\mu\nu}\tau^I u\right) \tilde{\varphi} W^I_{\mu\nu} + \frac{C_{uB}}{\Lambda^2} \left(\bar{q}\sigma^{\mu\nu} u\right) \tilde{\varphi} B_{\mu\nu} + \frac{C^{(3)}_{\varphi q}}{\Lambda^2} \left(\phi^\dagger \overset{\leftrightarrow}{D}{}^I_\mu \varphi\right) \left(\bar{q}\gamma^\mu \tau^I q\right)$$
$$+ \frac{C^{(1)}_{\varphi q}}{\Lambda^2} i \left(\phi^\dagger \overset{\leftrightarrow}{D}_\mu \varphi\right) \left(\bar{q}\gamma^\mu q\right) + \frac{C_{\varphi u}}{\Lambda^2} \left(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu \varphi\right) \left(\bar{u}\gamma^\mu u\right)$$

1601.08193

5 relevant dimension-6 EFT operators

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

Constraints on anomalous couplings and EFT



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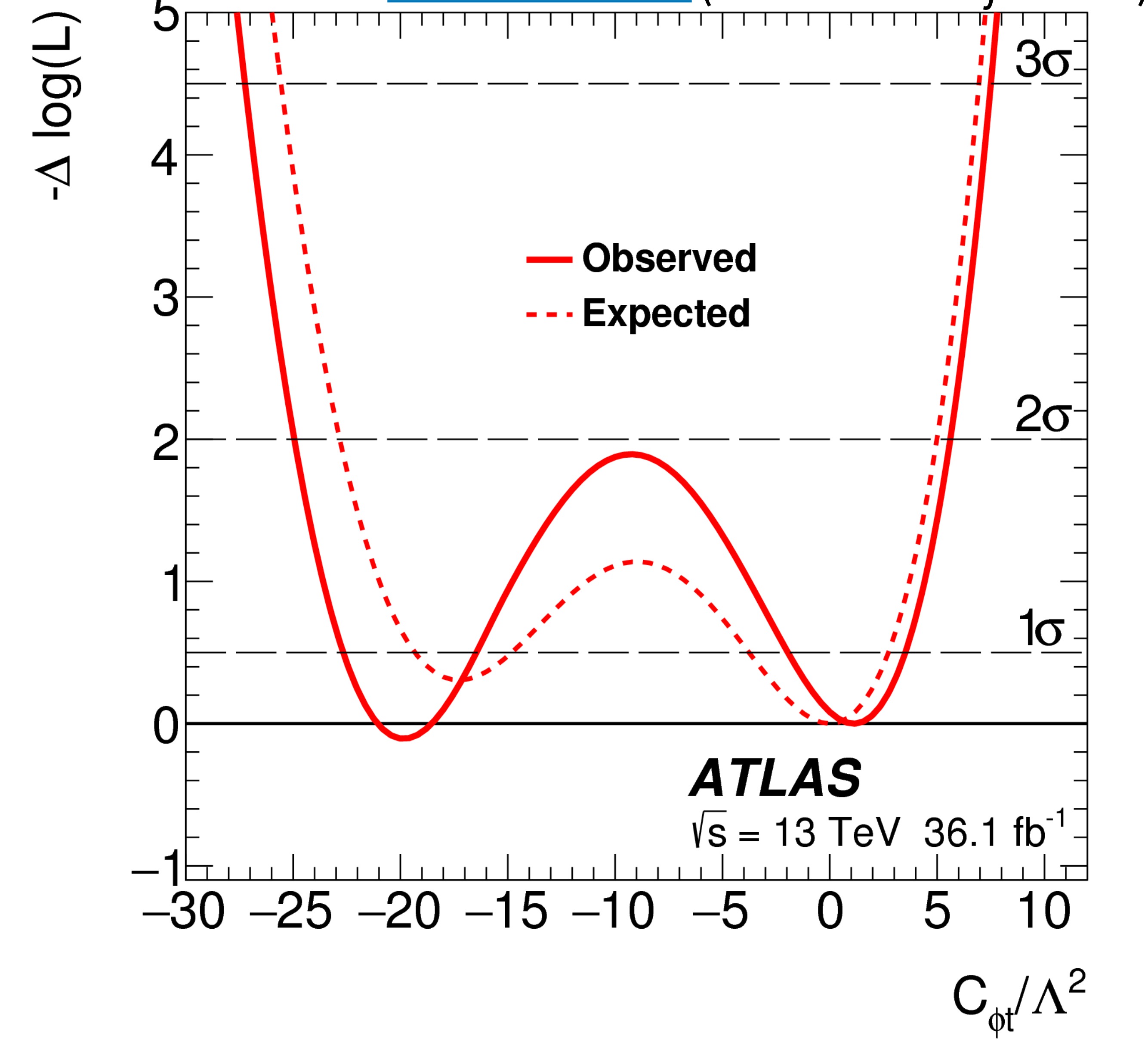
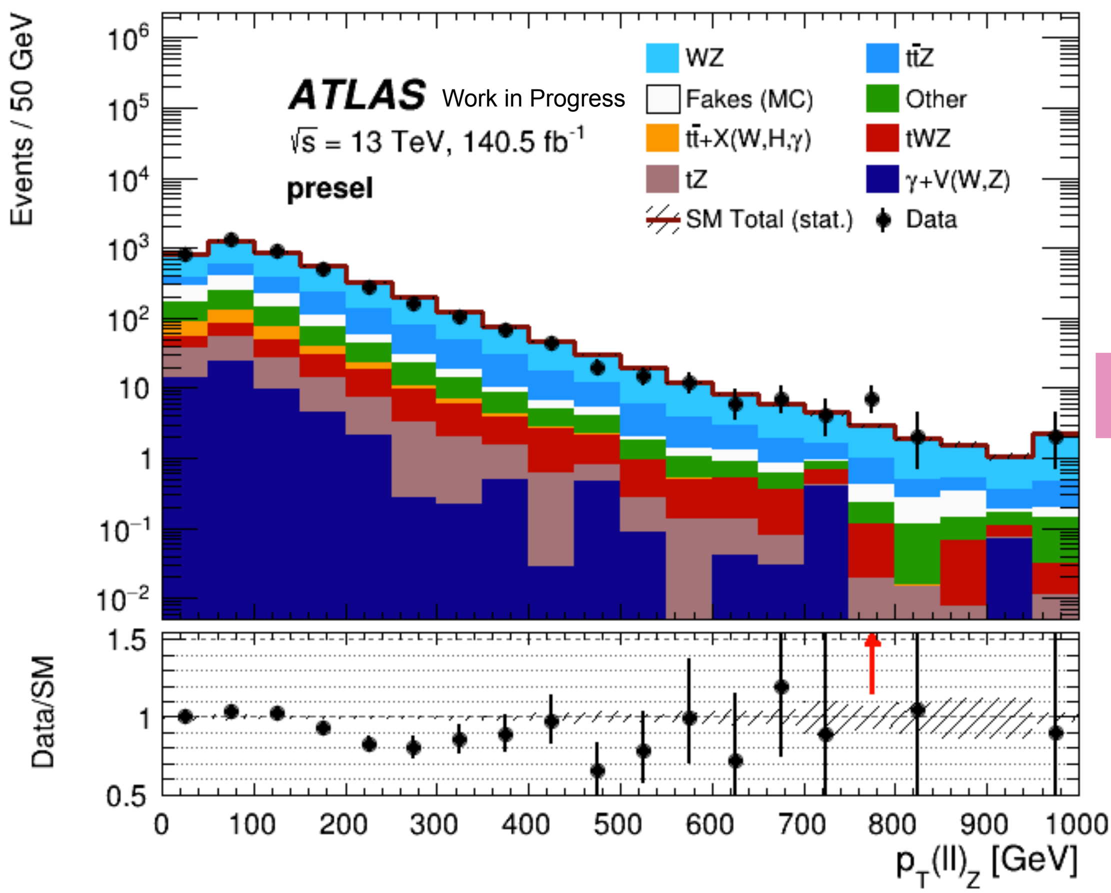


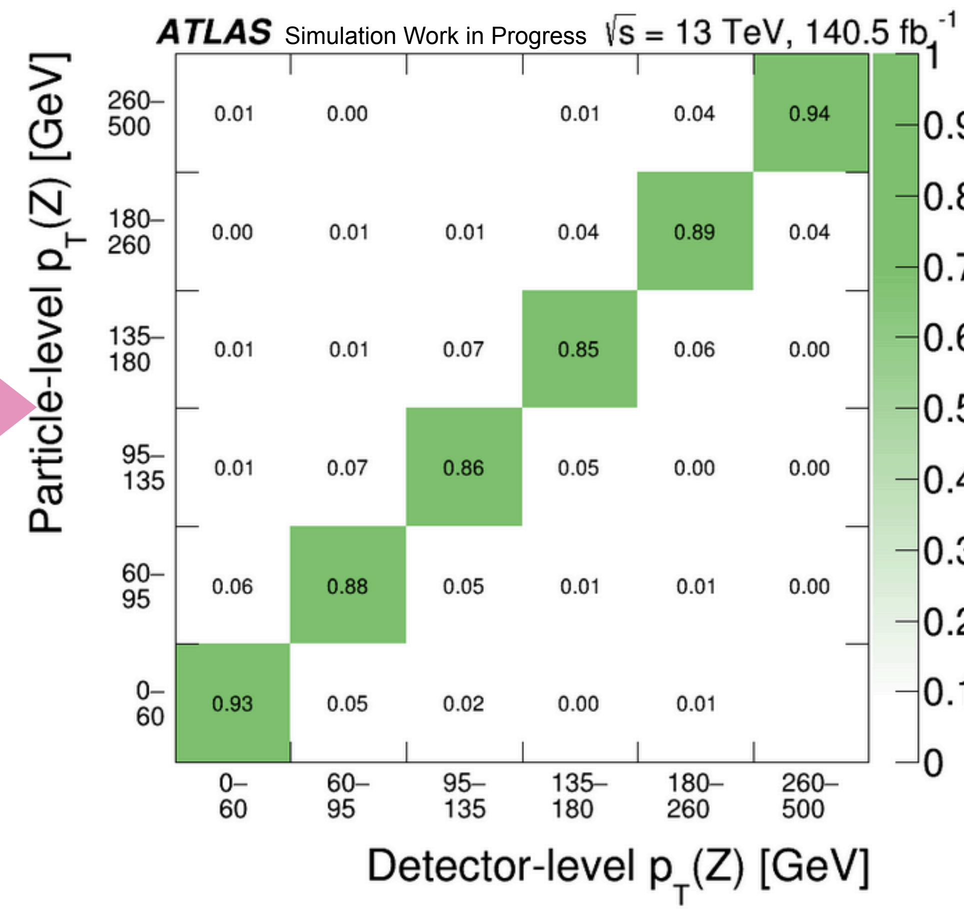
Coefficient	Expected limits at 68% and 95 % CL	Observed limits at 68% and 95 % CL	Previous constraints at 95 % CL
$(C^{(3)}_{\phi Q} - C^{(1)}_{\phi Q})/\Lambda^2$	[-2.1, 1.9], [-4.6, 3.7]	[-2.0, 2.7], [-3.4, 4.3]	[-3.4, 7.5]
$C_{\phi t}/\Lambda^2$	[-3.8, 2.8], [-23, 5.1]	[-2.0, 3.6], [-27, 5.7]	[-2.5, 7]
C_{tB}/Λ^2	[-8, 9], [-12, 13]	[-3.7, 3.7], [-7.2, 7.2]	[-16, 43]
C_{tW}/Λ^2	[-2.8, 2.8], [-4.0, 4.0]	[-2.0, 2.3], [-3.4, 3.6]	[-0.15, 1.9]

And what's next?

Going differential with the full Run 2 dataset

☞ Almost 5x more data, systematics better understood, can focus on high purity regions.

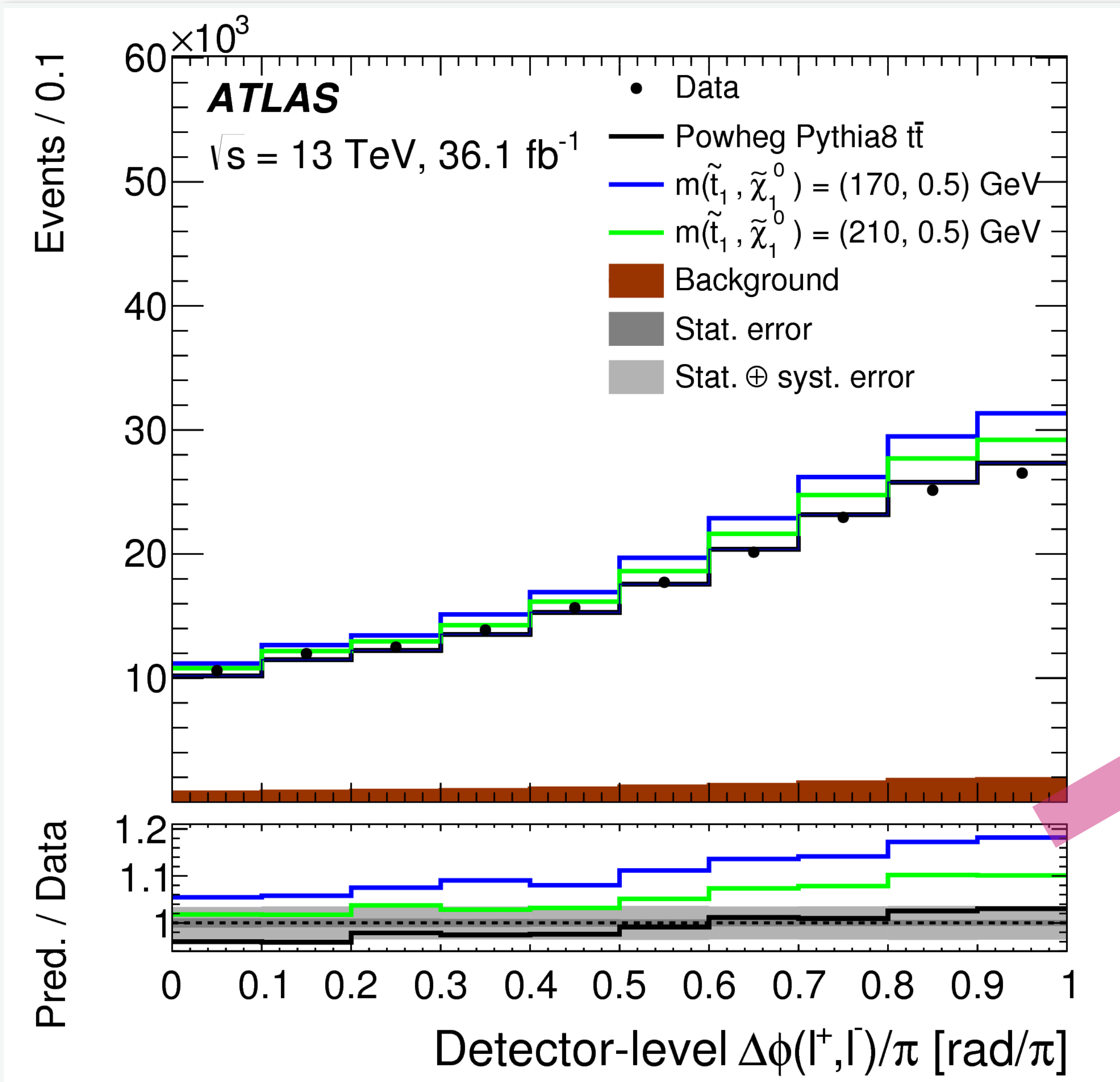


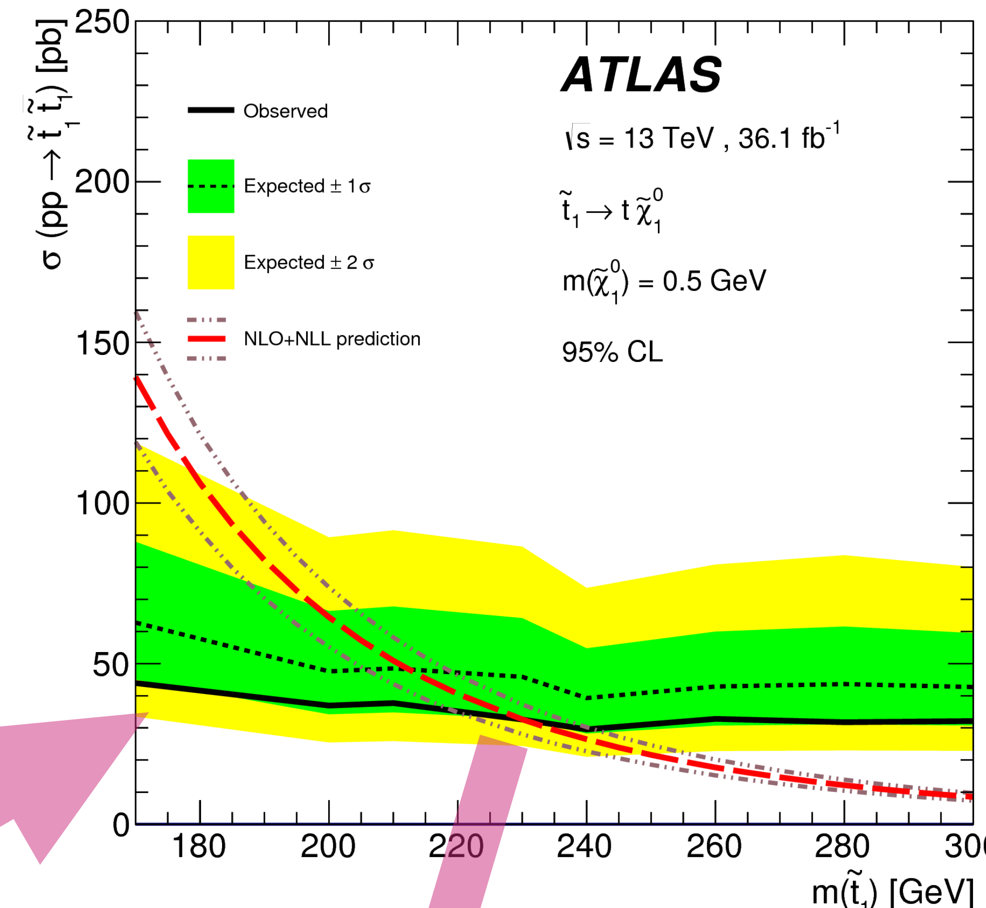


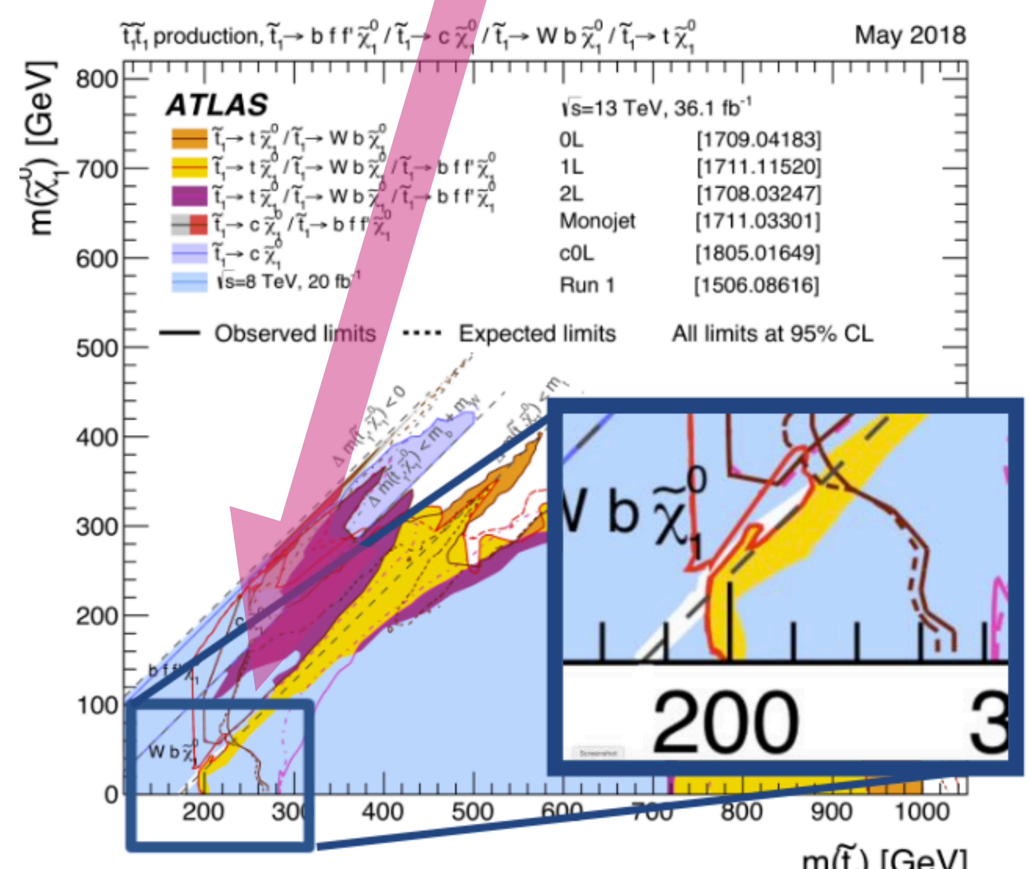
Special interest in **top reconstruction techniques**: studying jet matching algorithms, neutrino reweighting, lost jet corrections, likelihood fitting, transfer functions, b- and c-tagging…

☞ Besides being able to compare the observed shapes of ttZ-system kinematics to various generators, one could also investigate ttZ spin correlations…

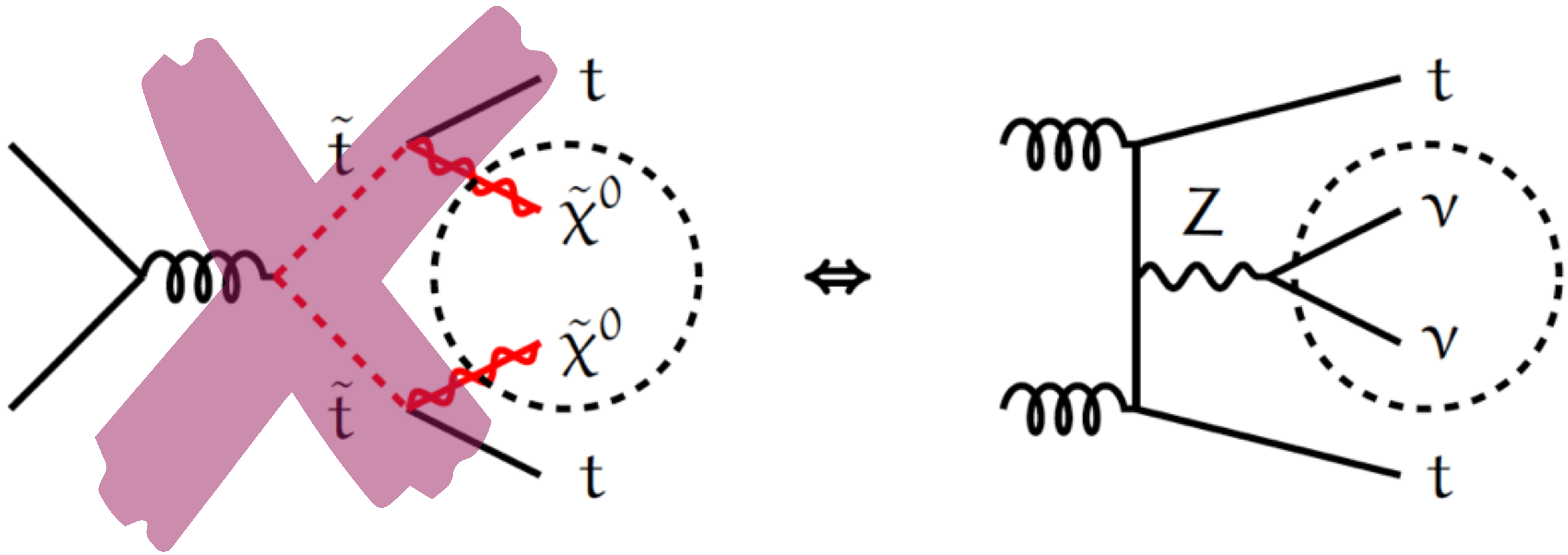
1903.07570



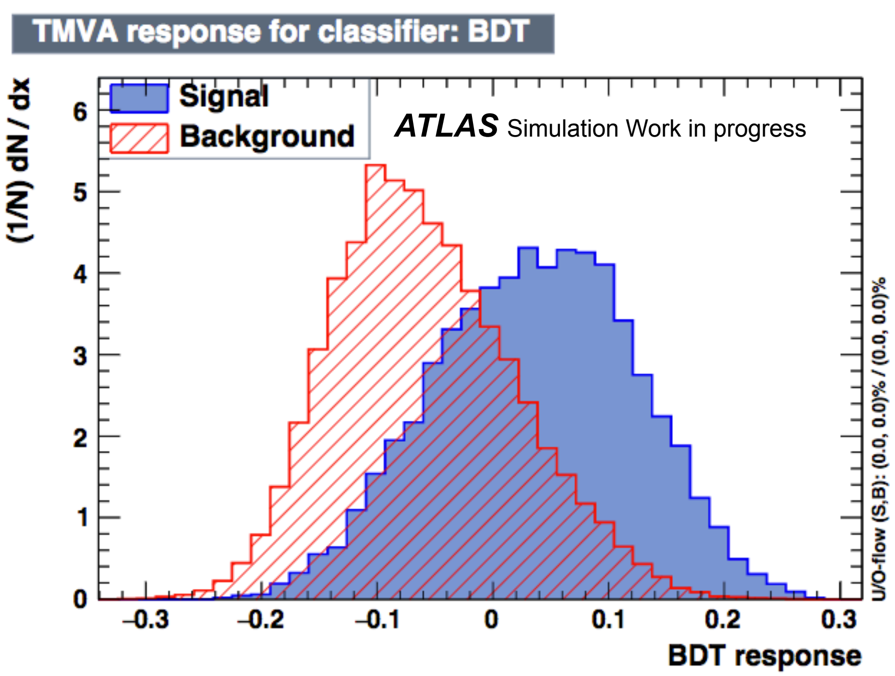




Spin correlation in dileptonic ttbar events: SM-like, or heavy mediator signature?



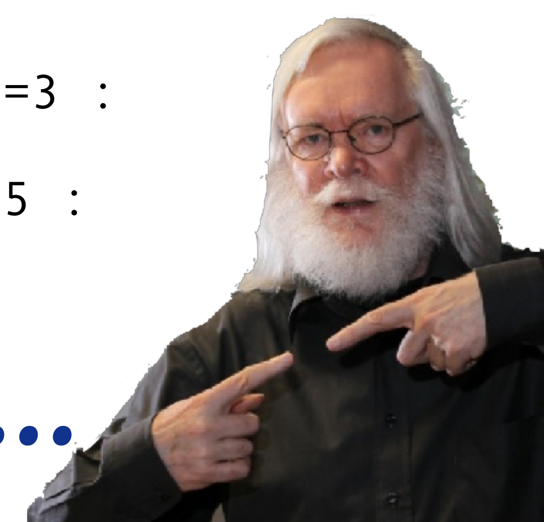
Turn null-results into SM measurements!



Very basic BDT-based proof-of-concept (there are much more interesting ML approaches one could take!):
here, discriminate ttZ(vv) against background in a loose 0L region.

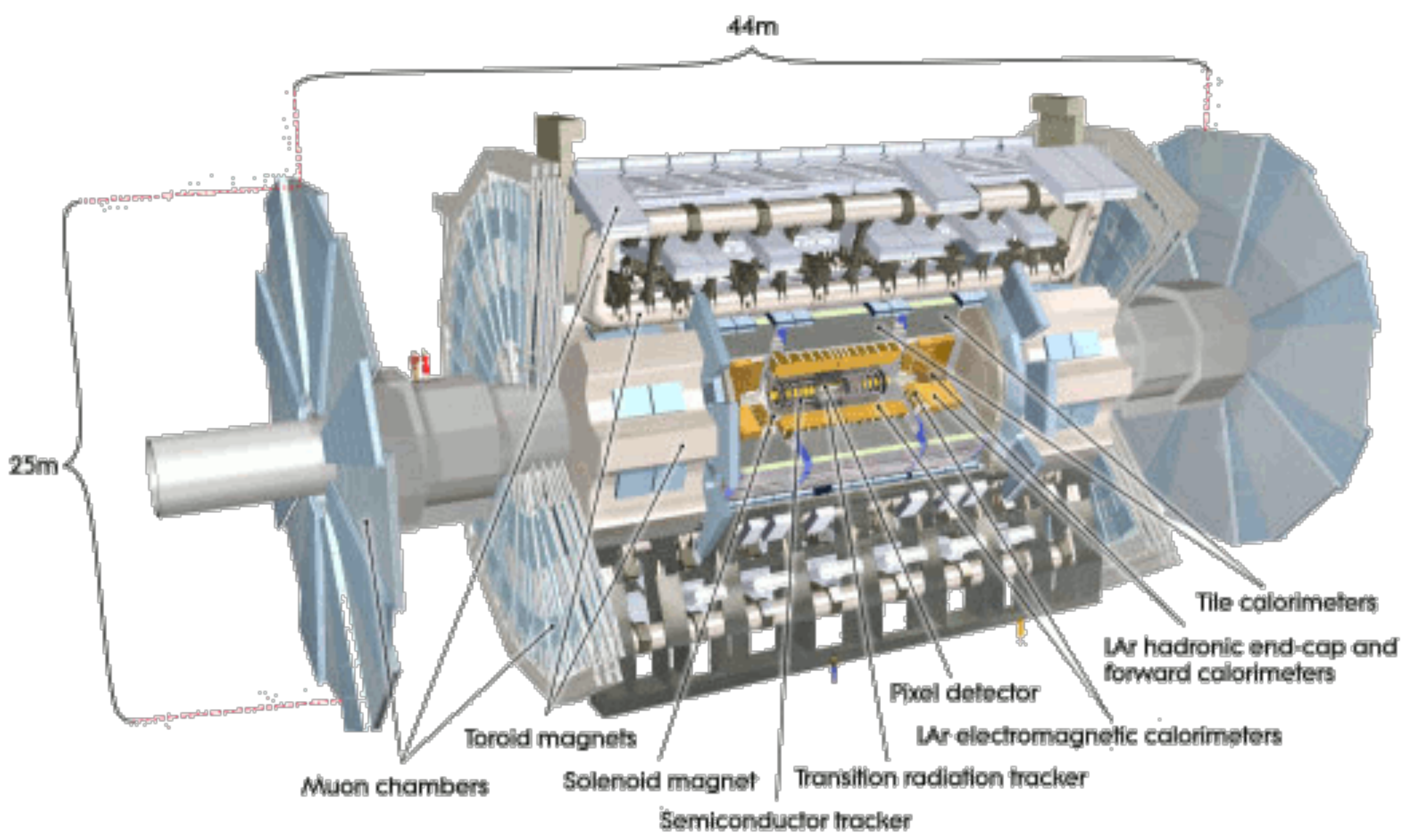
```
NTrees=850 : MinNodeSize=2.5% : MaxDepth=3 :
BoostType=AdaBoost : AdaBoostBeta=0.5 :
UseBaggedBoost : BaggedSampleFraction=0.5 :
SeparationType=GiniIndex : nCuts=20
```

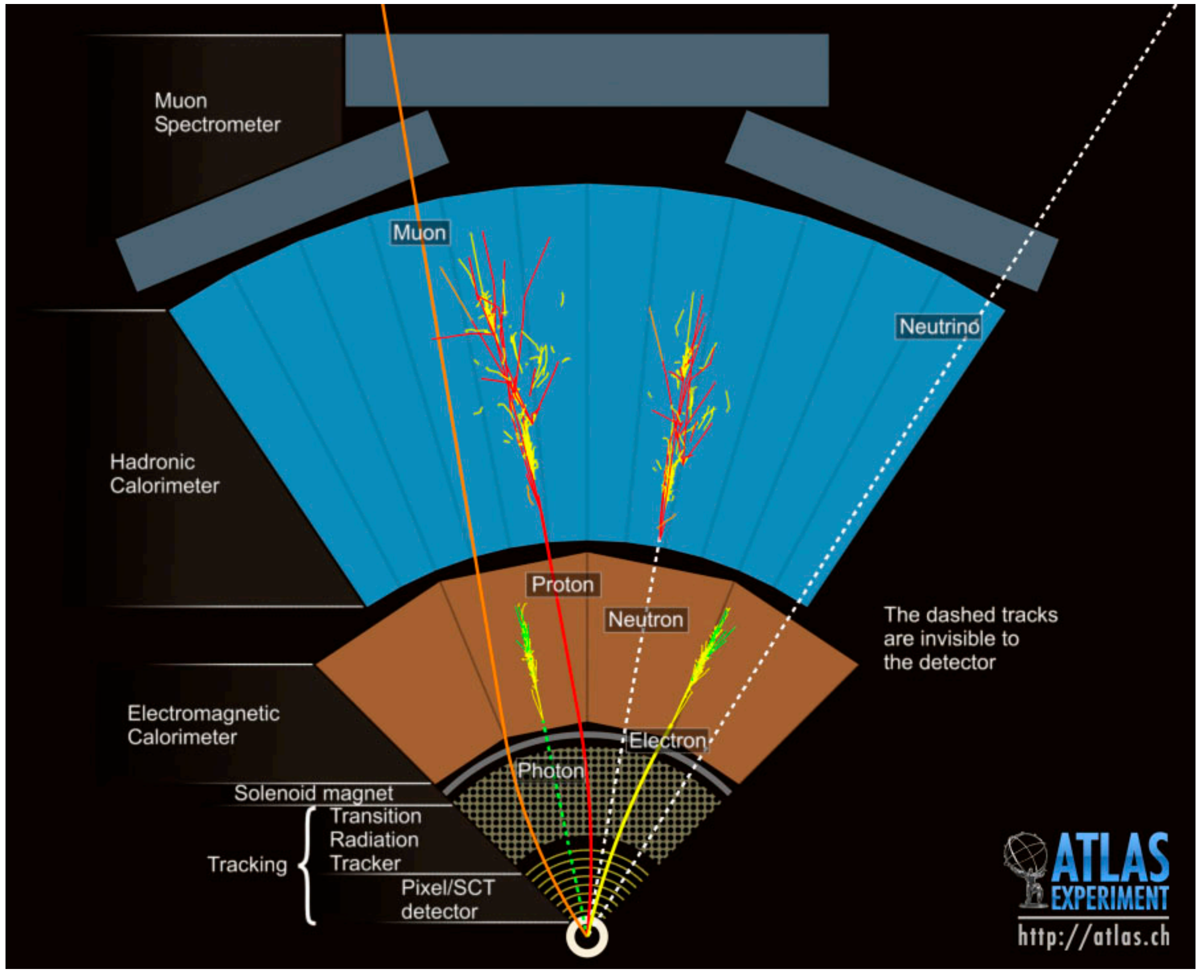
Run 2 results are coming! Stay tuned…




BACKUP

The ATLAS detector





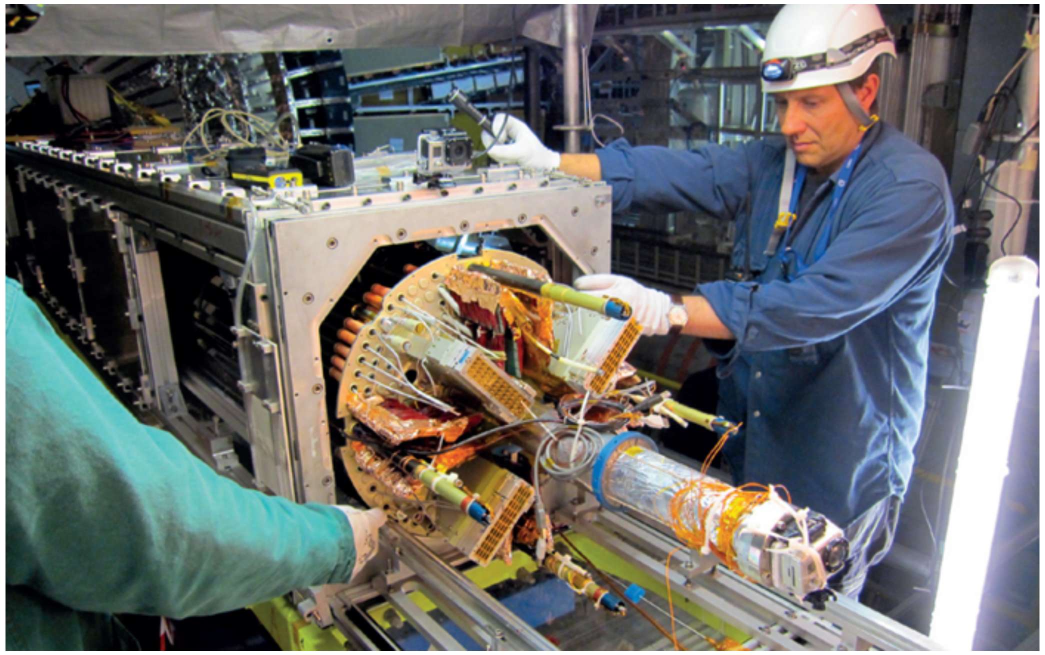
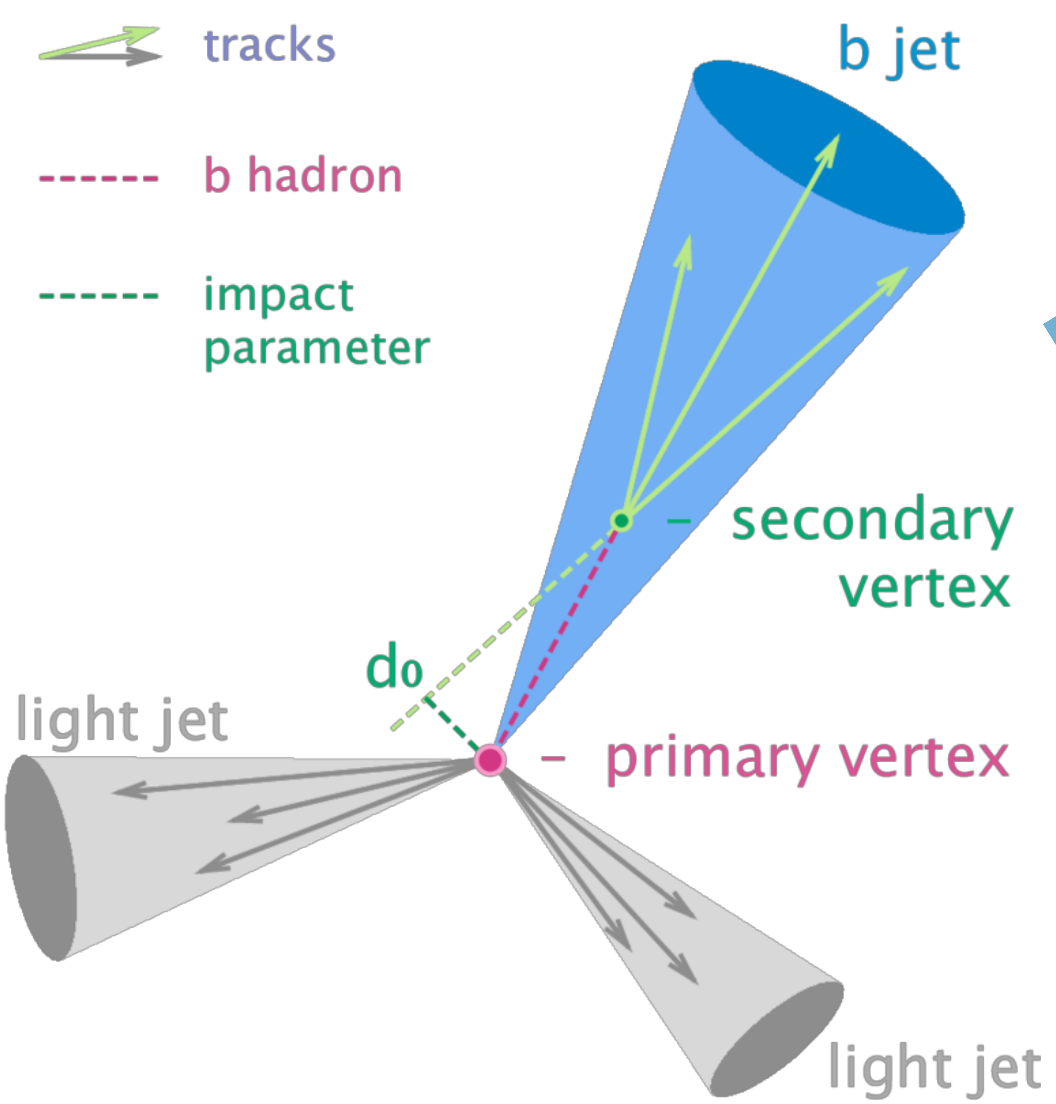
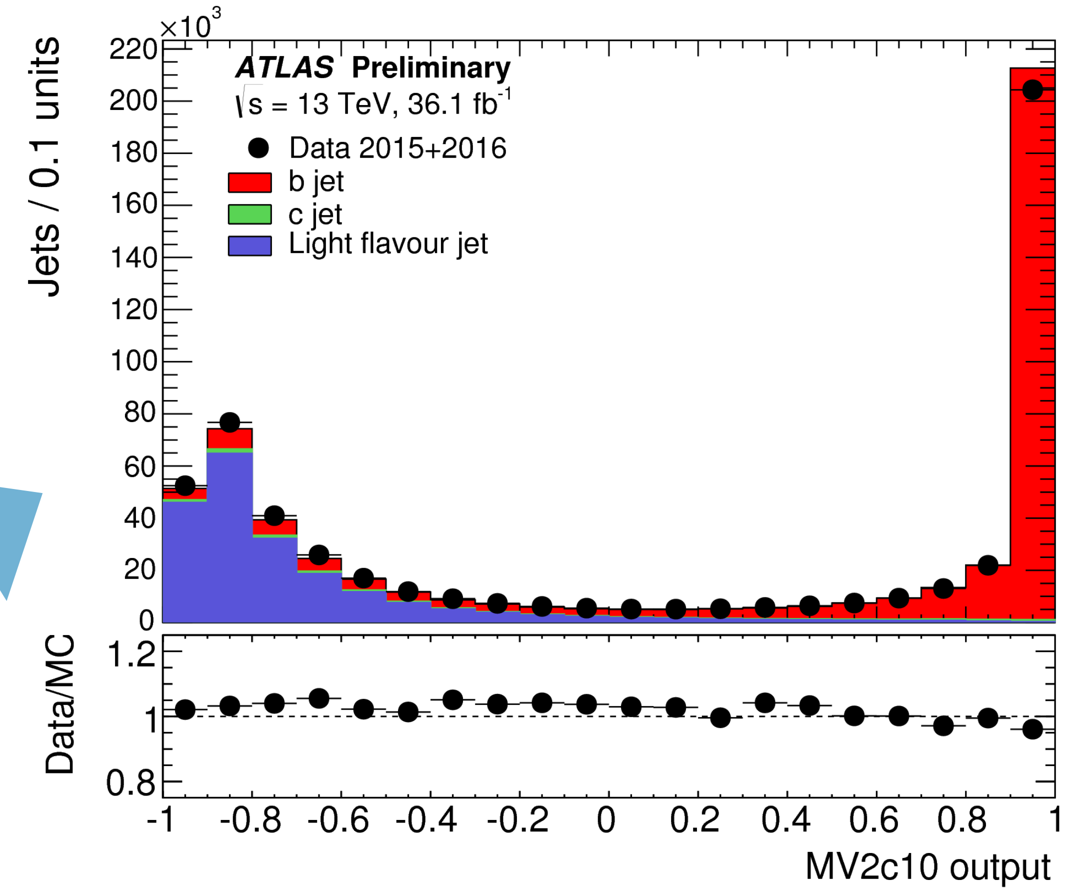
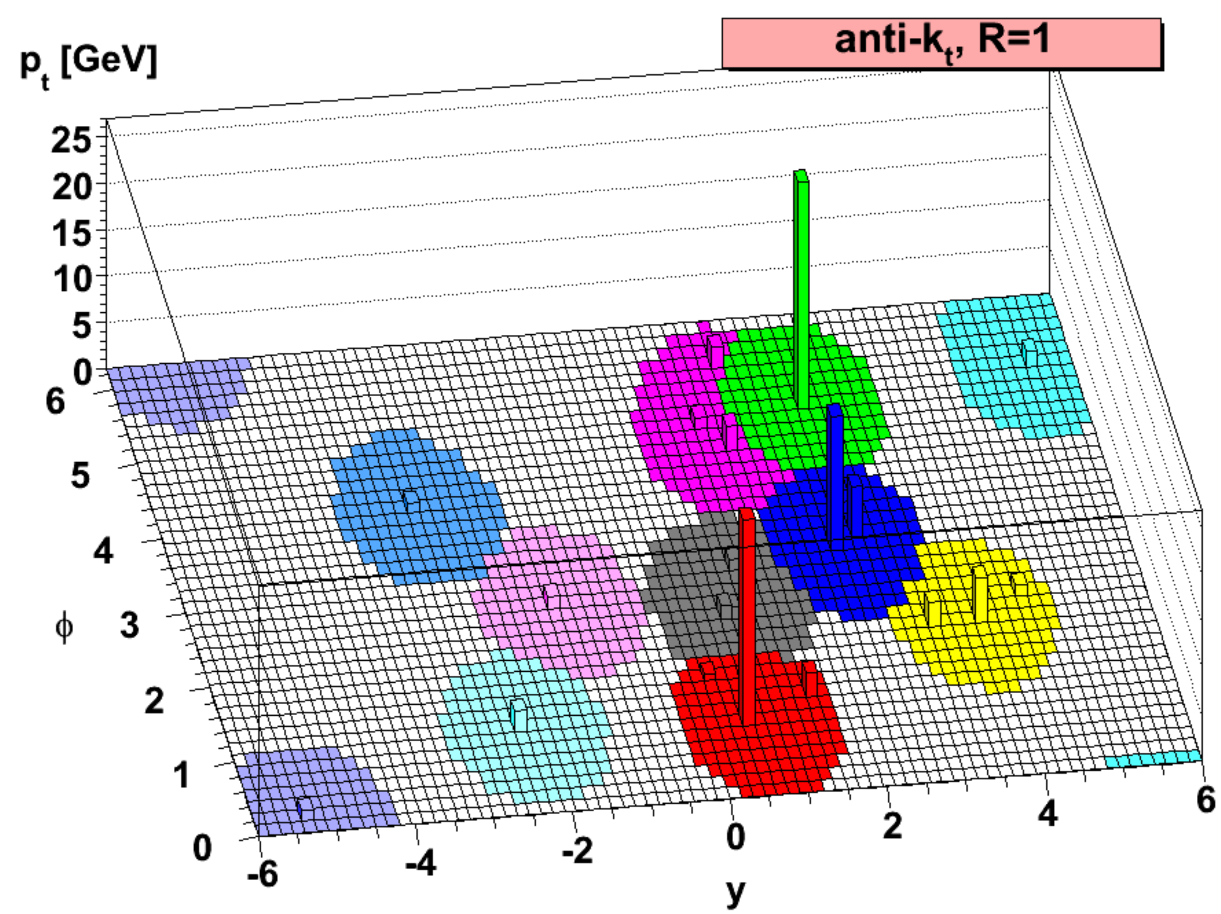


Fig. 3: Rare footage of ATLAS physicists giving birth to a **pixel detector**


tracks
b hadron
impact parameter
b jet
secondary vertex
d0
light jet
primary vertex
light jet


ATLAS Preliminary
√s = 13 TeV, 36.1 fb-1
Data 2015+2016
b jet
c jet
Light flavour jet
Jets / 0.1 units
×10^3
Data/MC
MV2c10 output


anti-kt, R=1
pt [GeV]
ϕ
y