Recent EW and TOP measurements at ATLAS and CMS

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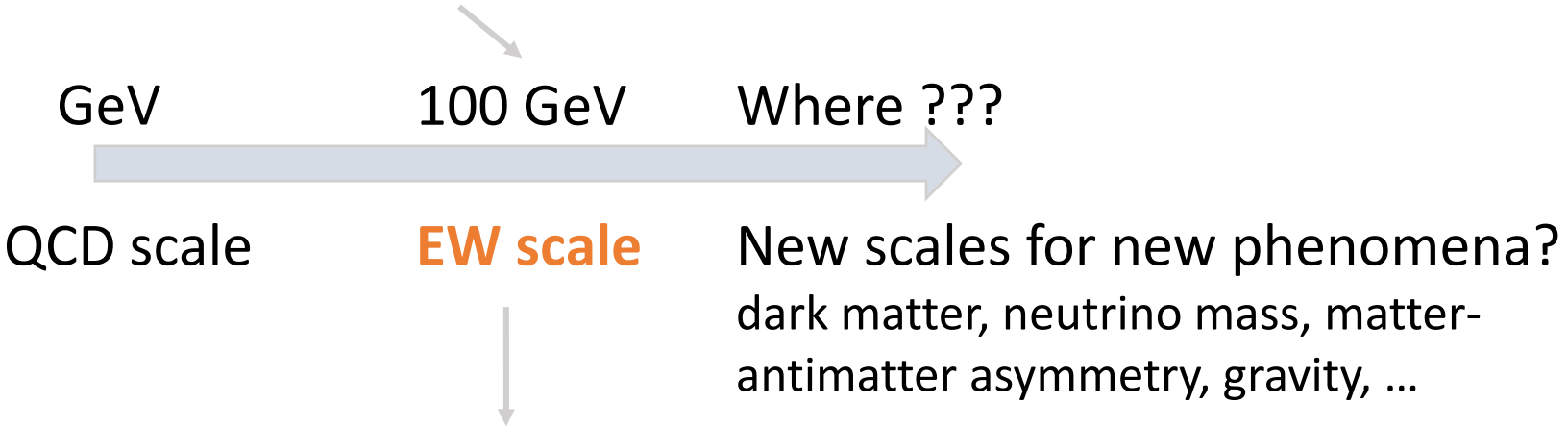
For ATLAS and CMS collaborations

La Thuile 2021 - Les Rencontres de Physique de la Vallée d'Aoste

Overview

- Story about **heavy part** of the Standard Model (SM)

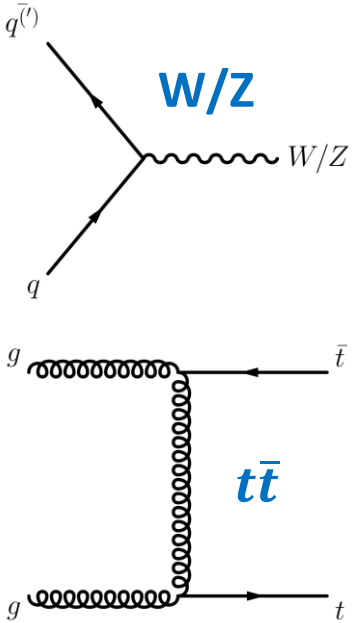


- Precise measurements of **vector bosons**, **top quark** at the LHC
  - ✓ ***Unprecedented scrutiny of the SM***, model parameters, particle properties, Gauge structures, rare processes, differential phase spaces, and QCD effects (PDF etc.)
  - ✓ ***Close interplay with Higgs physics***, leading Higgs couplings
  - ✓ ***Sensitivity to new physics*** *(*unique signatures, indirect search for loop effects, anomalous couplings)

Processes and Physics

nb pb fb

Cross-section orders at the LHC and example diagrams



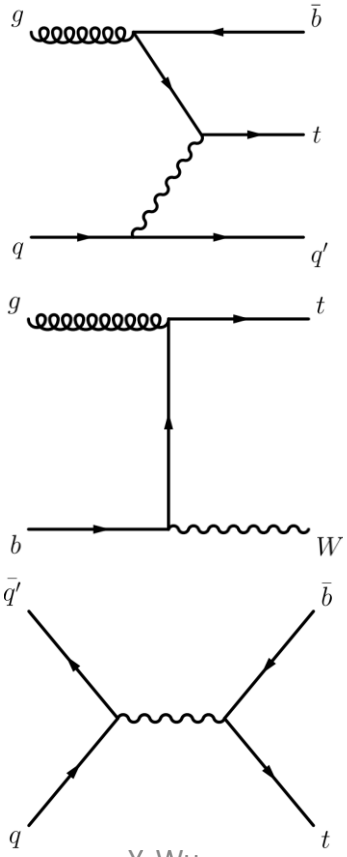
Precision regime

SM parameters (W/Z/top masses, Weinberg angle)

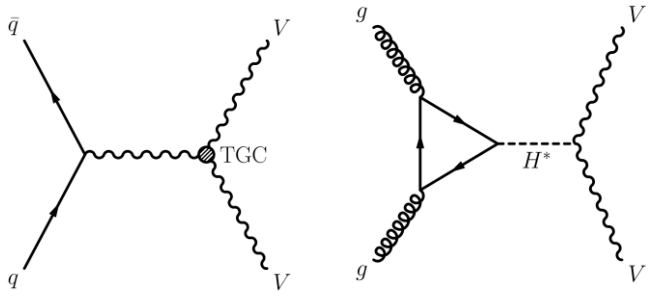
Top-quark/W/Z properties

Standard candle for many physics studies

single-top



diboson



Measurement regime

CKM $|V_{tb}|$

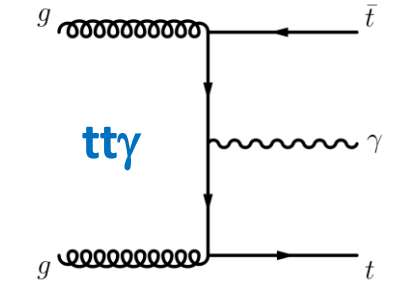
Non-abelian gauge structure

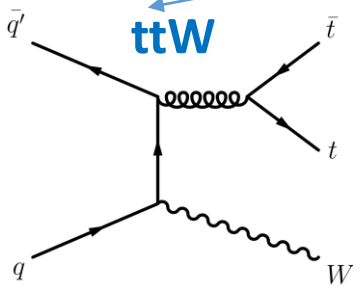
Sensitivity and diversity to probe anomalous couplings

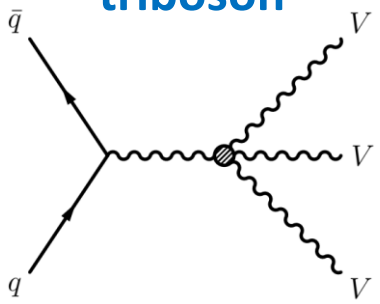
Processes and Physics

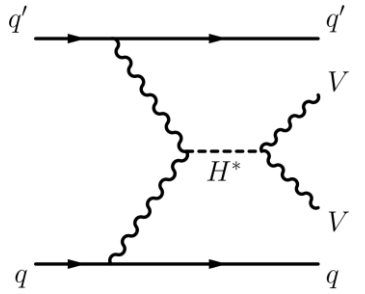
nb pb fb

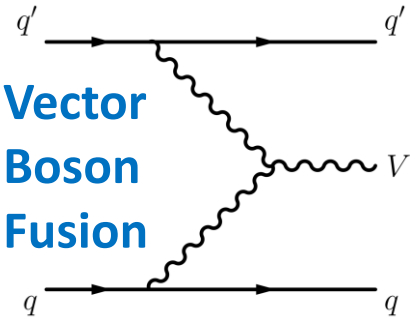
Cross-section orders at the LHC and example diagrams

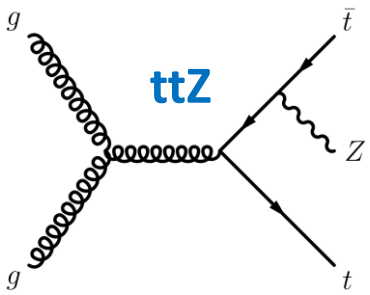


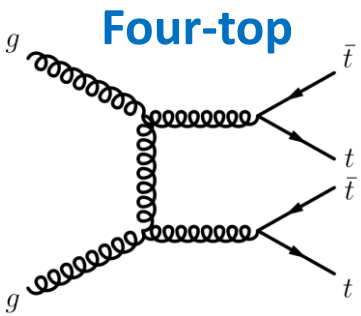


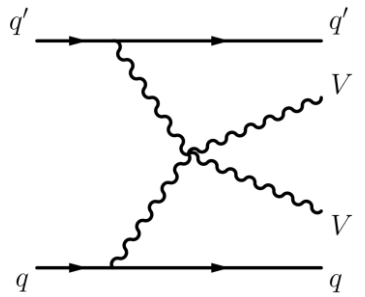








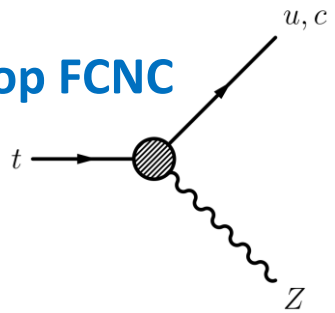




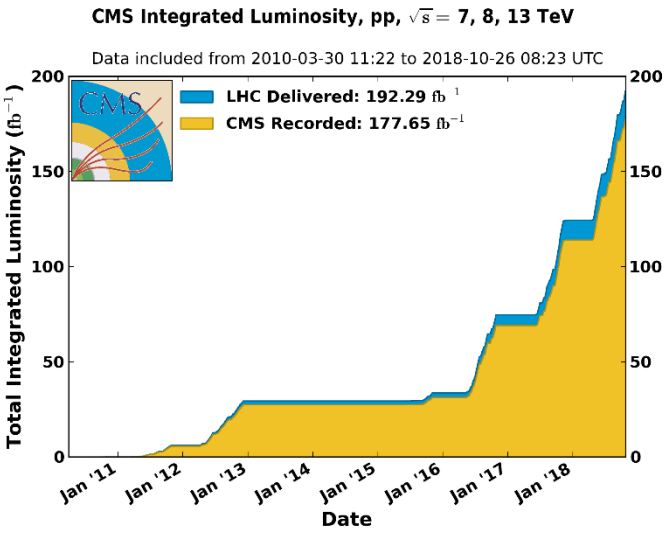
Measurement and exploration regime

Rare to very rare processes, sensitivity in three/four-body anomalous couplings, new physics

Close connection with Higgs mechanism



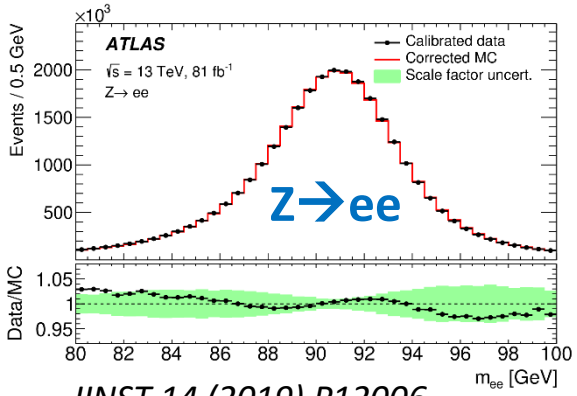
The data taking and processing



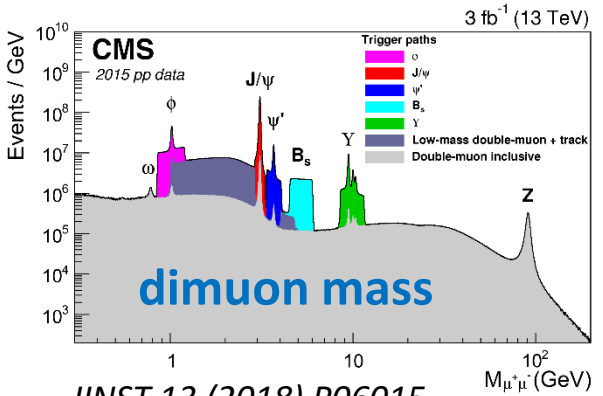
Tremendous efforts from LHC, detector teams to make the data collection smooth

Physics successes owing to precise understanding of e, μ, jets, E_T^{miss}, and tagging of heavy-flavor jets

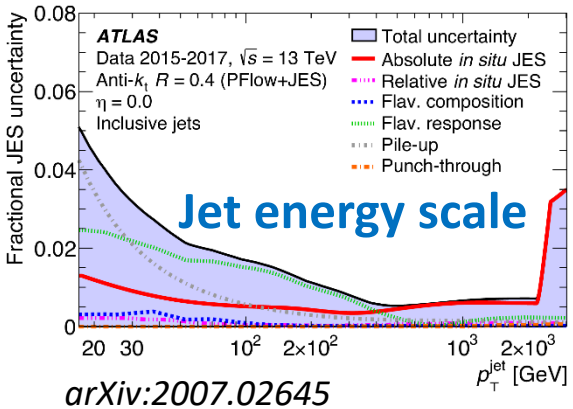
"percentage" precision achieved in many



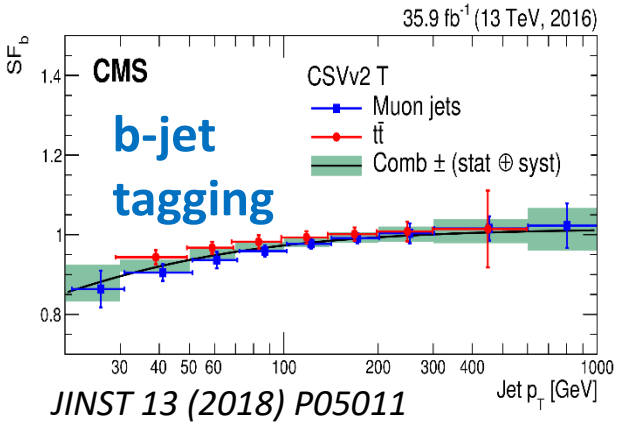
JINST 14 (2019) P12006



JINST 13 (2018) P06015



arXiv:2007.02645



JINST 13 (2018) P05011

Where we are

More: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/
http://cms-results.web.cern.ch/cms-results/public-results/publications/

Precision

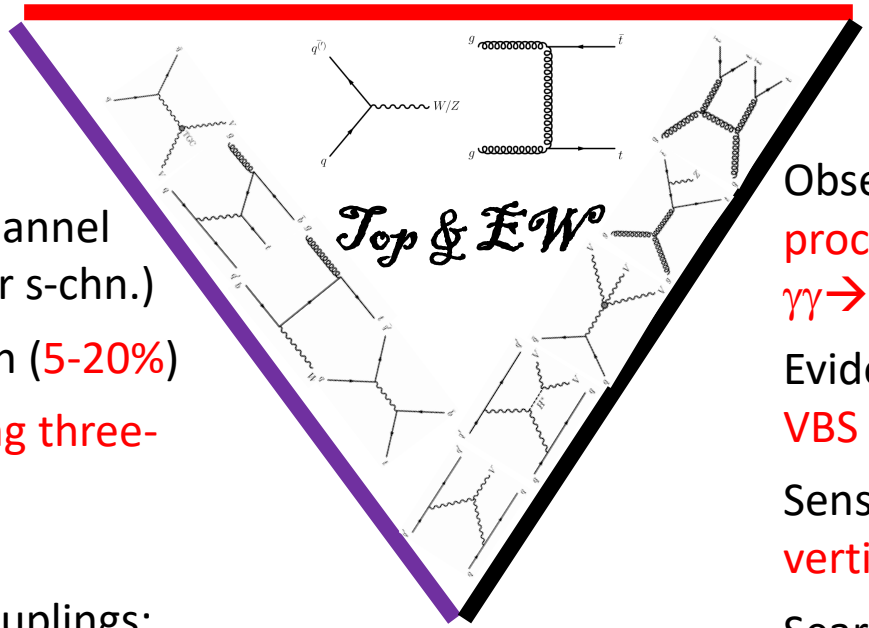
Top mass precision (< 0.5 GeV) - new record

W mass (19 MeV), $sin^2\theta_{eff}$ (1.5‰) approaching records

2-3% unc. for W/Z/$t\bar{t}$ inclusive σ, focus on multi-dim. differential

Lepton universality τ-μ (1%) - new record

Charge, forward-backward asymmetries, polarization, spin-correlation



Measurement

Diboson σ precision (5%)

Single top σ precision (t-channel 7%, Wt – 10%, evidence for s-chn.)

VBF V, tt+γ/W/Z σ precision (5-20%)

Record precision in studying three-body vertices

→ high energy behavior of anomalous triple-boson couplings; CKM $|V_{tb}|$ (5%)

Exploration

Observation of rare VBS processes (WW, WZ, ZZ, Wγ), γγ→WW, tZq, tri-bosons

Evidence for rare four-top, VBS Zγ processes

Sensitivity in four-body vertices

Searched for rare decays, top FCNCs

The news

Fruitful year (2020) for cultivating heavy particles, despite of the difficulties …

Disclaimer: selection of topics, details with biases

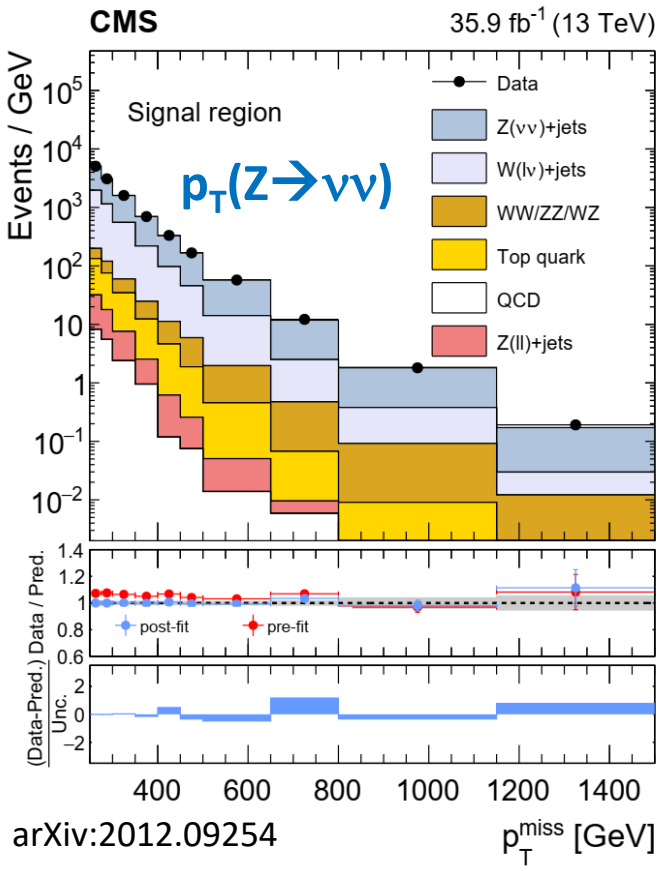
Topic	Results - ATLAS, CMS, ATLAS+CMS
Single boson	Z to νν, W property
$t\bar{t}$ σ measurement	Hadronic, Lepton+jets, 5 TeV, High-pT
$t\bar{t}$ as precision tool	τ–μ universality, b fragmentation, W polarization, Yukawa, CP violation, extra jets (l/b, c)
Diboson, VBF	VBF Z, four-lepton, WW, Wγ, ZZ
Single top	Wt σ, Wt σ, CKM
VVV, VBS	VBS ZZ, γγ→WW, γγ→ll, VBS Wγ, VBS Zγ, VBS ZZ, VVV, VBS WZ, VBS $W^{\pm}W^{\pm}$
Rare top	ttγ, ttZ, tqZ, four-top, EFT

(Quick) walkthrough of those new/important results in the following, slight emphasis with ★ for a limited number of selected results

Precision (Single-V, $t\bar{t}$)

Single-boson

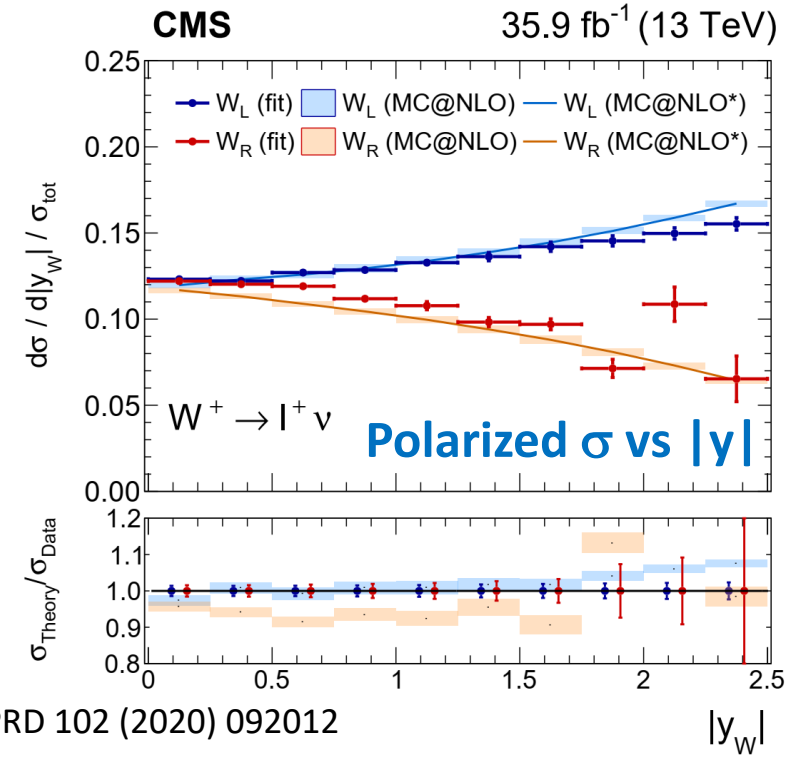
Make invisible Z visible



arXiv:2012.09254

$\sigma(Z\to\nu\nu)$ as precise as 5%, better than ee/$\mu\mu$ at TeV

W polarization → PDF → Precision physics

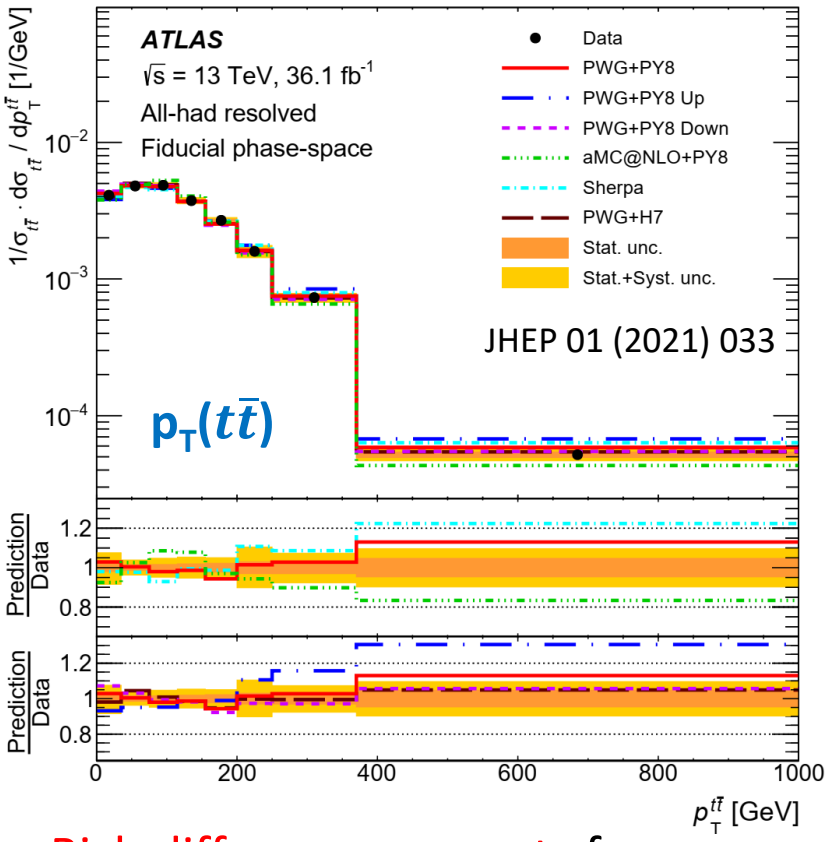


PRD 102 (2020) 092012

Fit lepton kinematics to separate helicities, percent precision on diff. σ, down to 70% PDF constraints by fitting polarized σ with NLO QCD, NNPDF

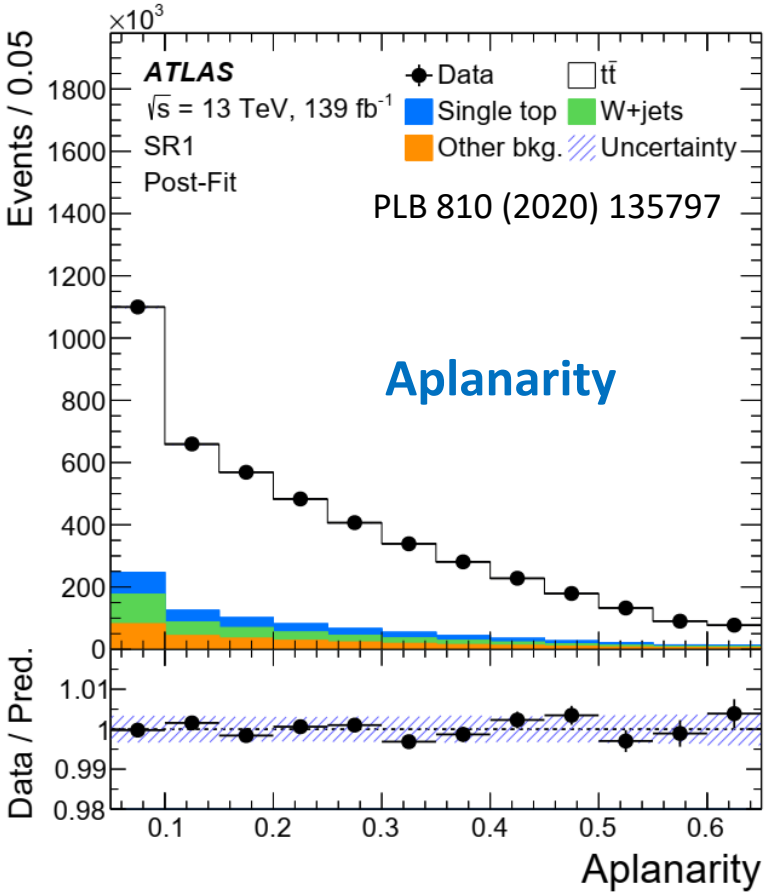
Multifold $t\bar{t}$ measurements

Strength with ($t\bar{t}$→) six jets



Rich diff. measurements for kinematic modelling, probe intermediate $t\bar{t}$ physics scale

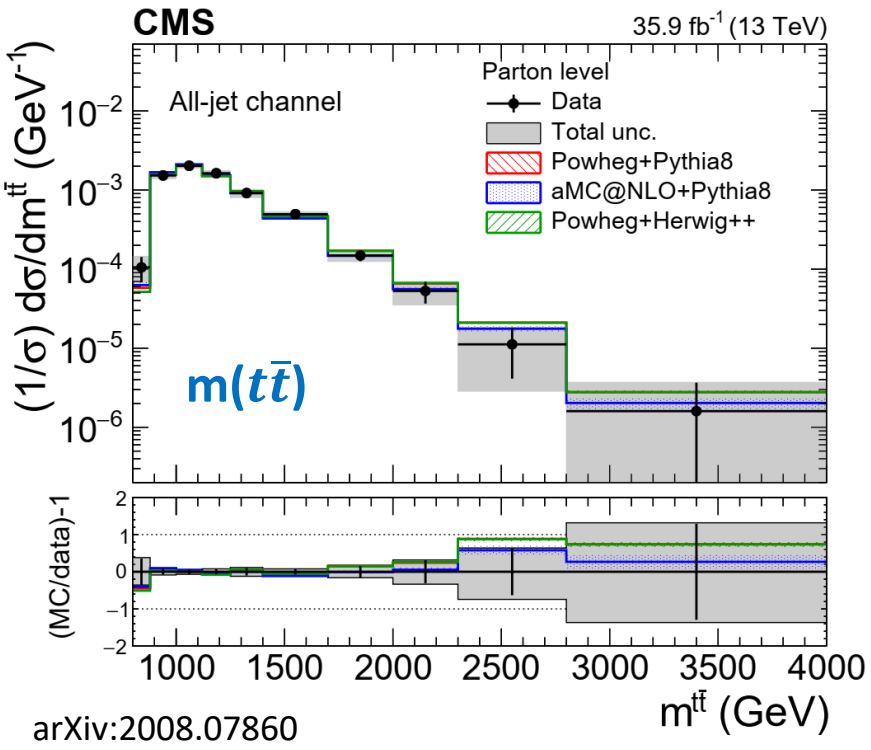
Precision with lepton and jets



4% inclusive σ error via kinematic fits, closer to dilepton channel precision

Multifold $t\bar{t}$ measurements

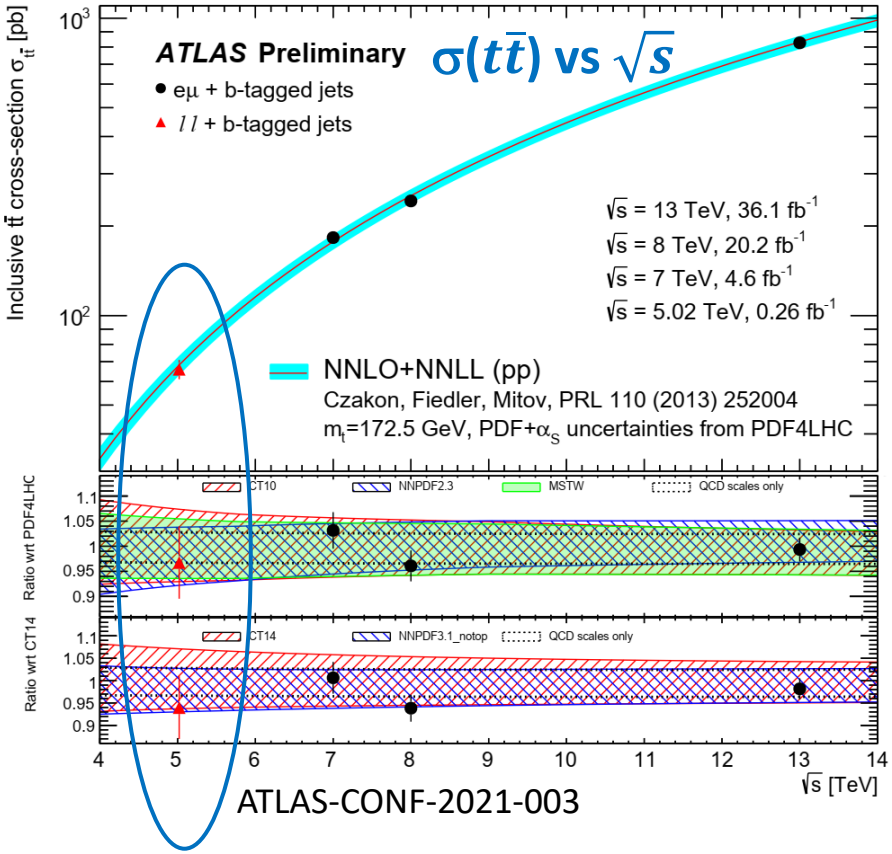
Reach high with merged jets



arXiv:2008.07860

Diff. measurements probe highest $t\bar{t}$ physics scale, up to 4 TeV, include both all jets and lepton + jet

Precision at Different $\sqrt{s}$

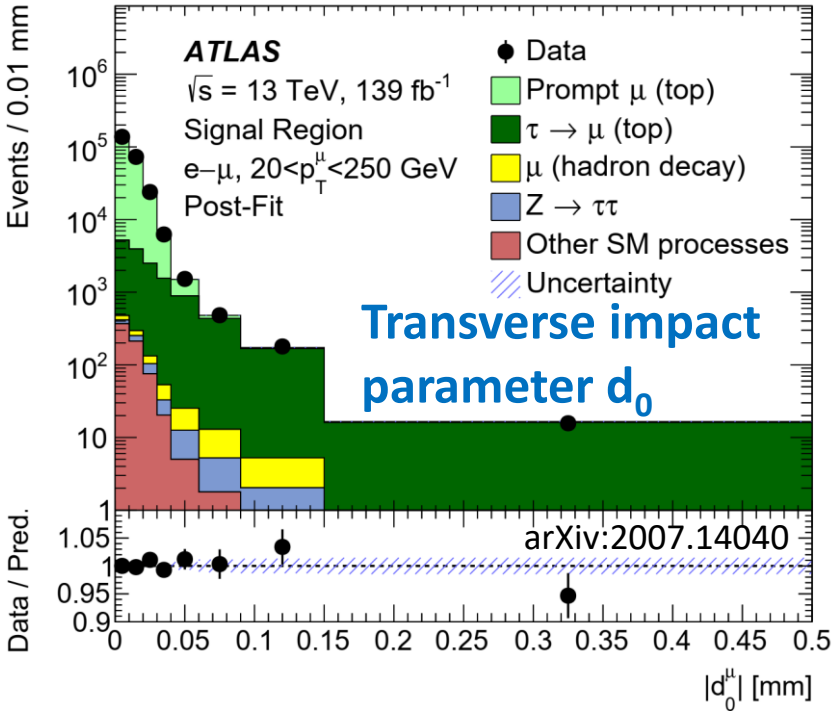


ATLAS-CONF-2021-003

σ Precision at 5 TeV reaches 7.5%, consistent and complementary w.r.t. other $\sqrt{s}$ measurements

Utilize $t\bar{t}$ precision

lepton universality meets standard candle and novelty ★

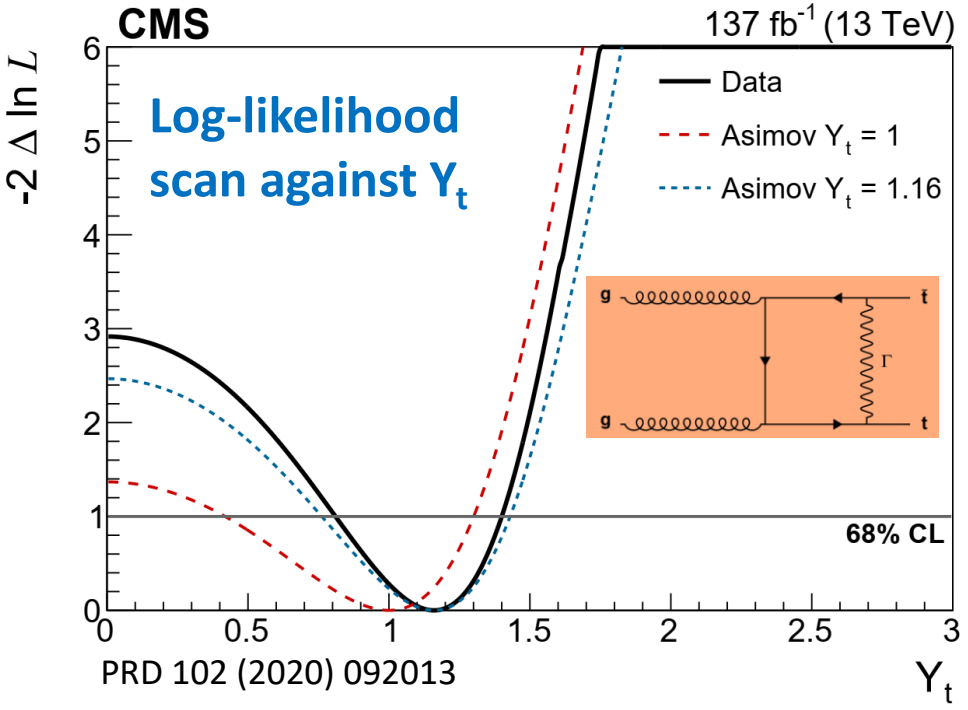


Fit d_0 to separate μ and τ→μ from Ws

➔ R(τ/μ)=0.992 with 1% precision

Record precision surpassing LEP (was 2% error, 2.7σ away from unity)

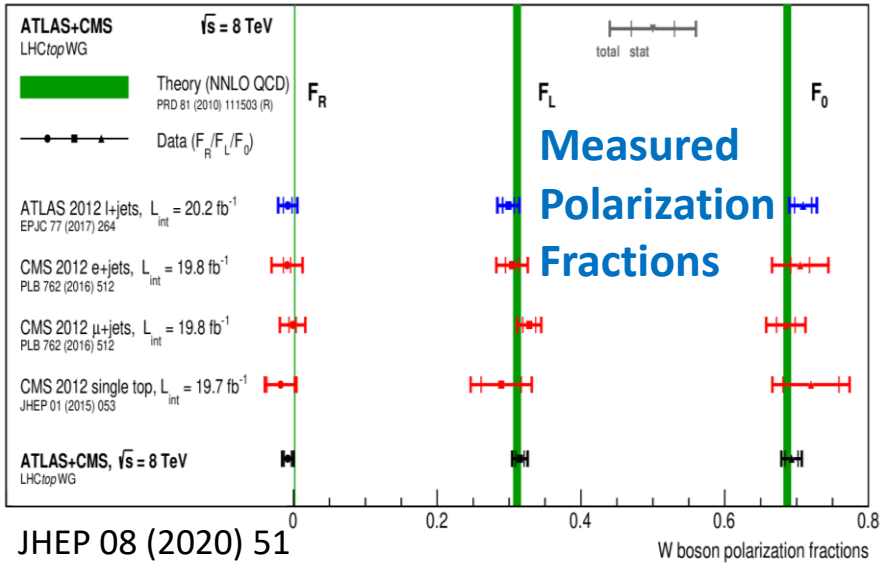
Probe top Yukawa coupling Y_t via loop effects in $t\bar{t}$→dilepton ★



Proxy of m($t\bar{t}$) and Δy($t\bar{t}$) fitted to extract $Y_t = 1.16^{+0.24}_{-0.35}$, new complementarity to on-shell Higgs studies

Utilize $t\bar{t}$ precision

Polarized Ws deepen insights into tWb weak interaction

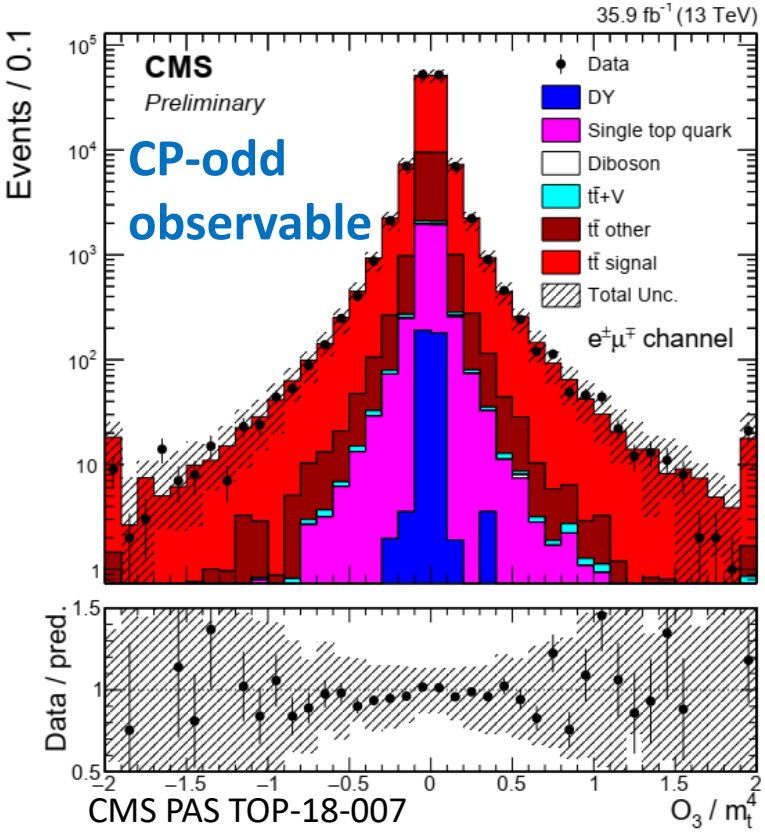


JHEP 08 (2020) 51

Combine 8 TeV measurements from both experiments, record precision (2% in F_0)

Interpreted as constraints in anomalous couplings, EFT coefficients

Probe CP violation in Top via final state observables

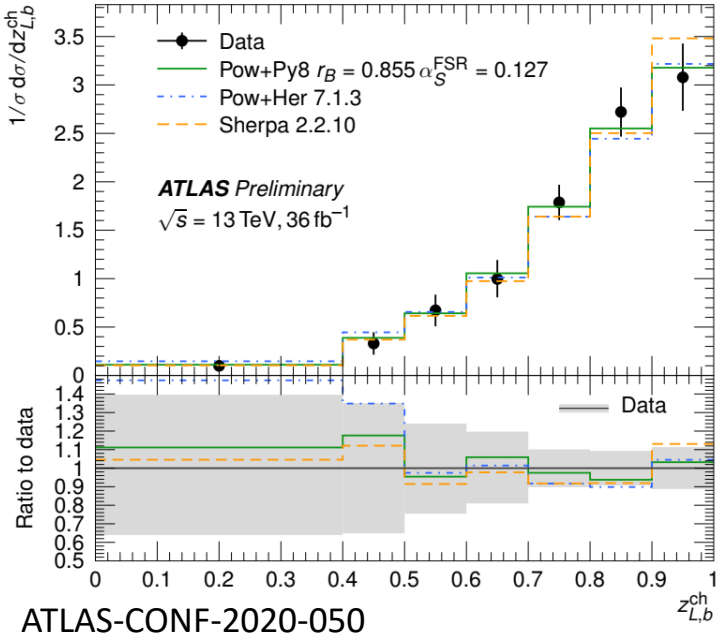


No sign of CP violation observed with per-mille precision, constraint on chromoelectric dipole moment

Utilize $t\bar{t}$ precision

Ideal sample to study b-jet fragmentation

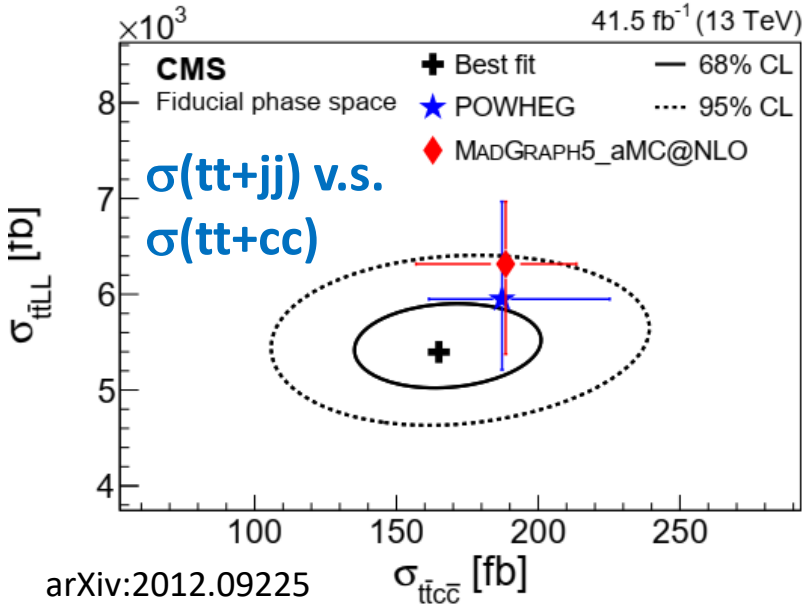
b-hadron/b-jet momentum frac.



ATLAS-CONF-2020-050

Multiple sensitive variables unfolded, complementary to e^+e^- measurements

Extremity test of QCD and Importance to Higgs physics with $t\bar{t}$ and jets



arXiv:2012.09225

$t\bar{t}$+cc measured for the first time with dilepton, key is success tagging of all jet flavors

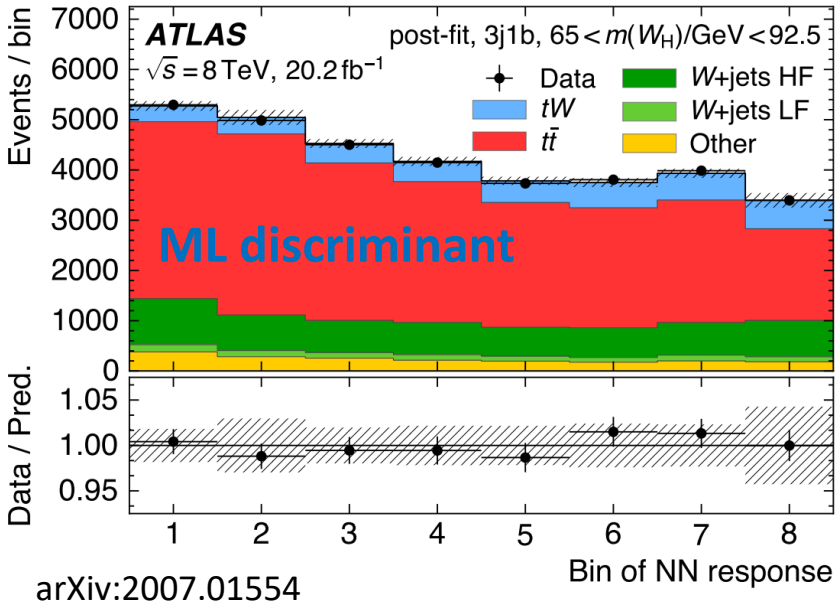
$t\bar{t}$+jj/bb was measured with record precision 10%

JHEP 07 (2020) 125

Measurement (Single-top, VV, VBF V)

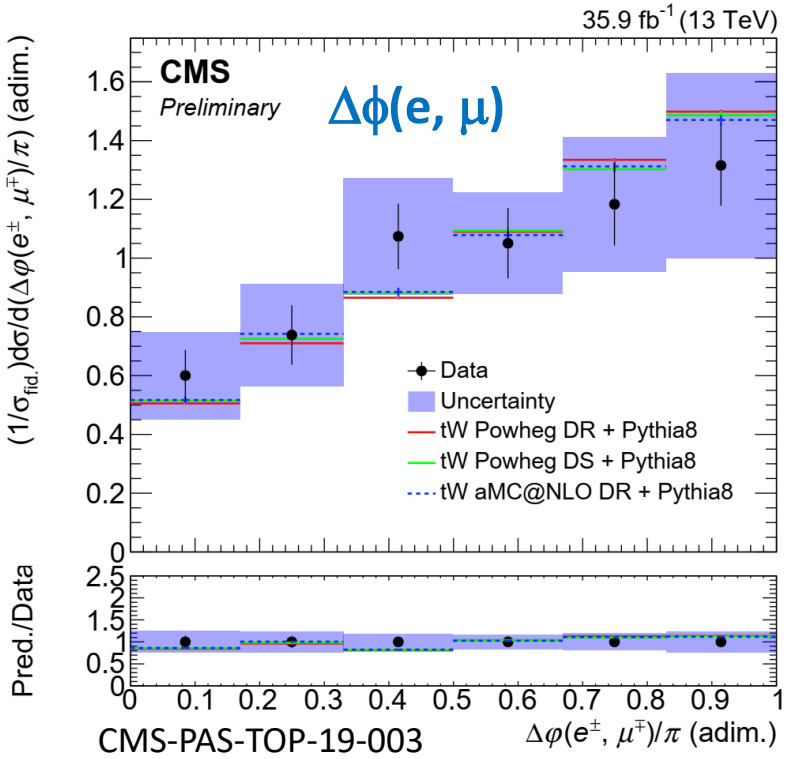
Single-top

Probe Wt with complication (final states) and machine learning



Careful study of 8 TeV data yields a first measurement in **lepton + 3 jets** events: 4.5 σ evidence

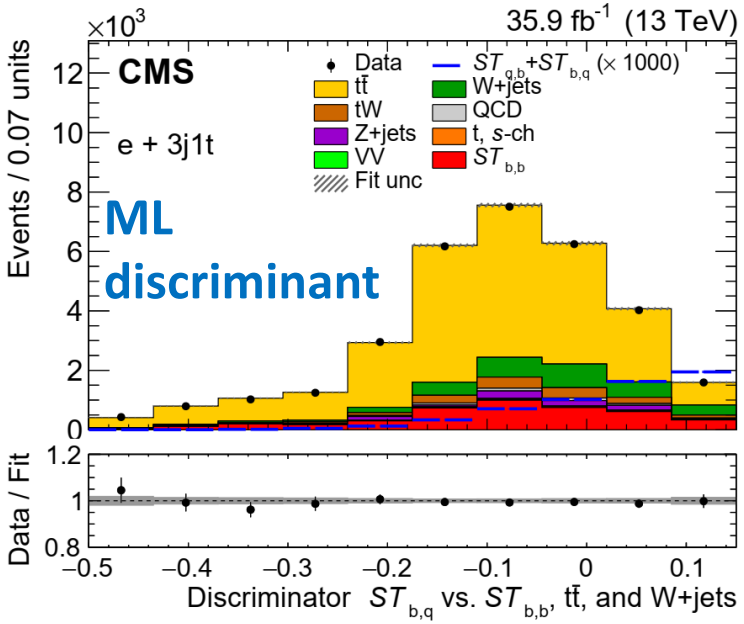
Probe Wt with relative cleanness and differentially



Measured sensitive kinematic information with **dileptons**, 20% precision many regions

(Top to) Boson and jets

Direct probe of CKM top elements in both production and decay (t-chn.)



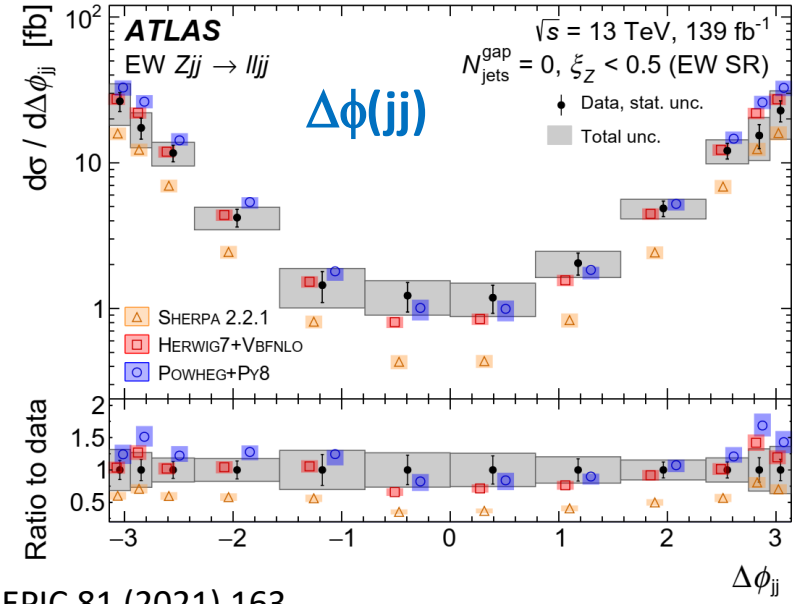
PLB 808 (2020) 135609

Best single-top results via a simultaneous probe of $|V_{tb}|$, $|V_{td}|$, $|V_{ts}|$

If not assume unitarity: $|V_{tb}| = 0.988 \pm 0.051$

$|V_{td}|^2 + |V_{ts}|^2 = 0.06 \pm 0.06$

Test Gauge structures with high scale and precision (**VBF Z**)



EPJC 81 (2021) 163

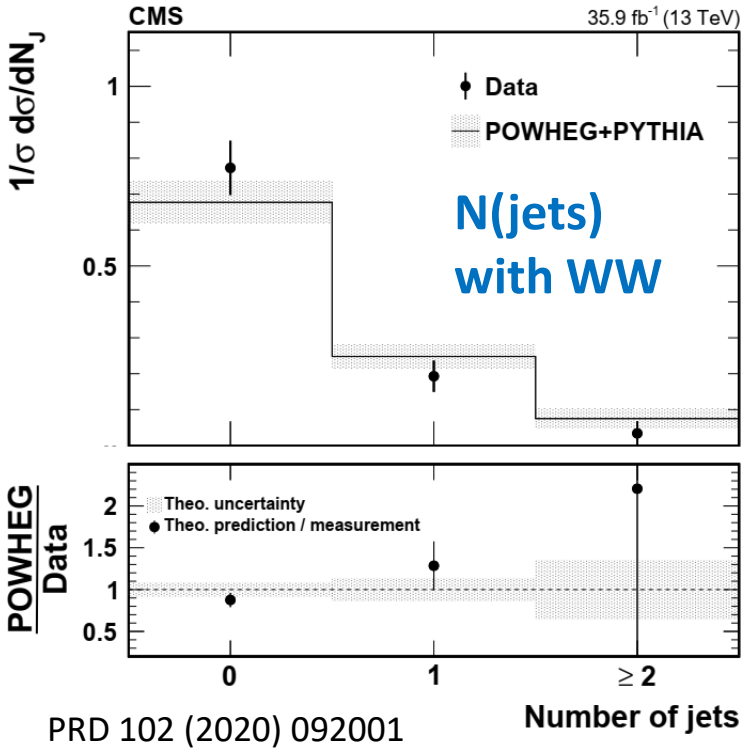
Inclusive σ precision 15% and diff. σ

Record constraints of the interference of SM and dim-6 EFT coefficients

Diboson

"Gauge" the charged diboson production:

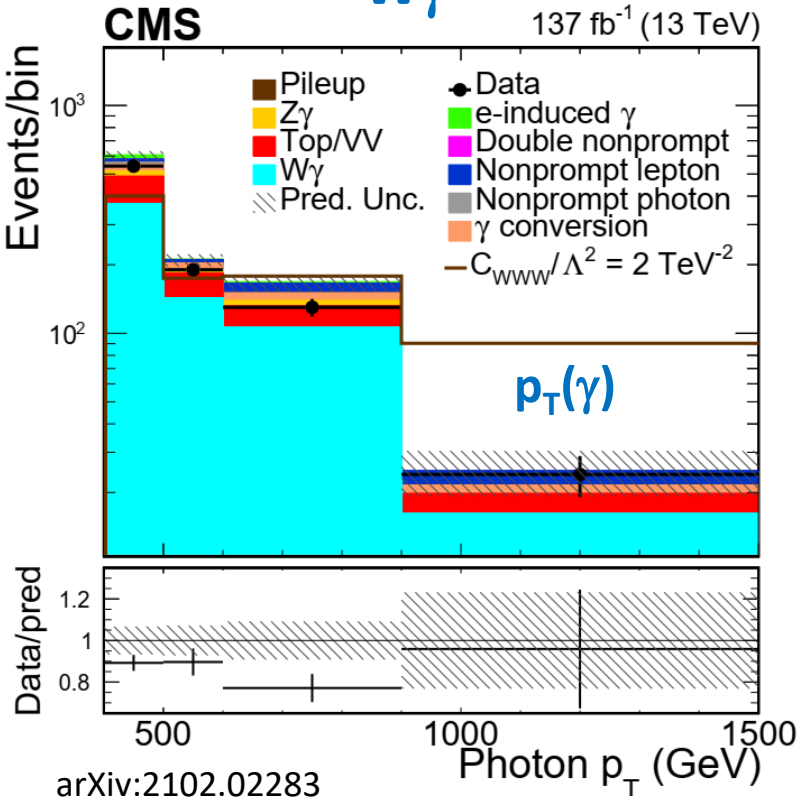
WW



PRD 102 (2020) 092001

More on P. Manteca's YSF talk

Wγ



arXiv:2102.02283

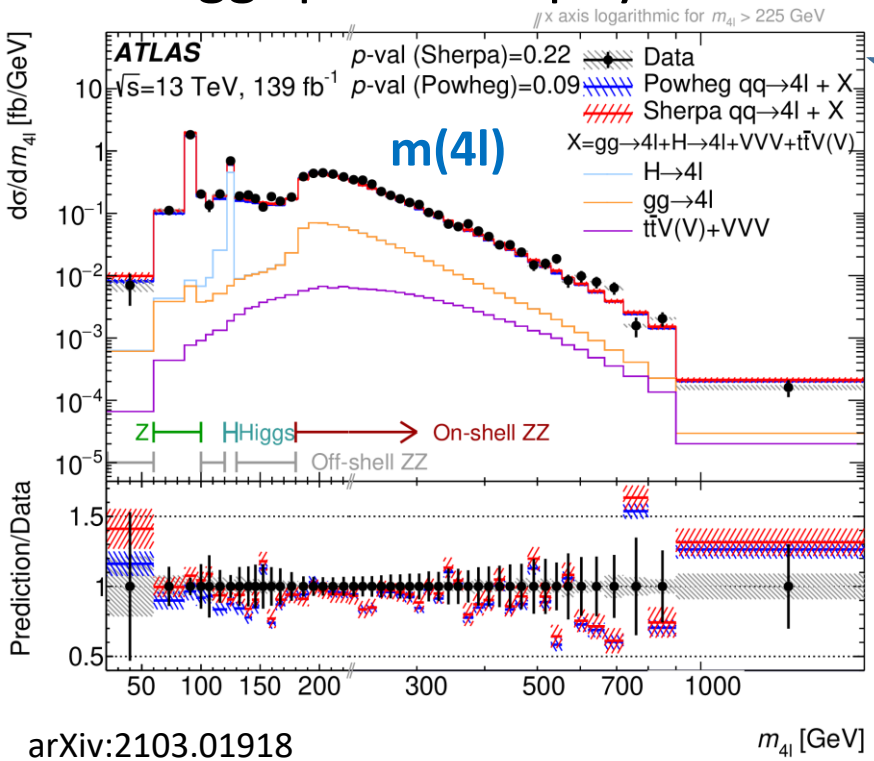
Strength in diff. σ, advances in jet multiplicity

First 13 TeV measurement

Inclusive σ precise as 5%, strong constraints on anomalous couplings

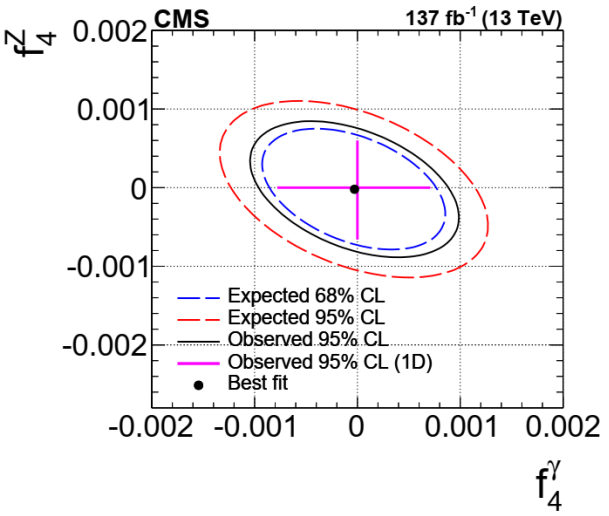
Diboson

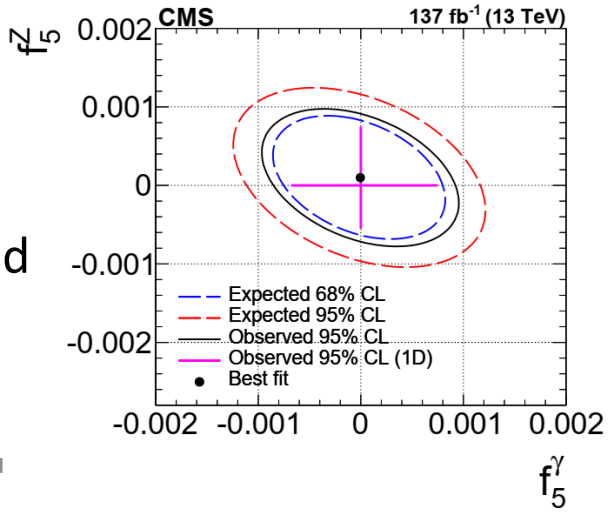
Probe rare neutral Gauge interactions, and essential for Higgs precision physics: **ZZ to 4 leptons**



arXiv:2103.01918

arXiv:2009.01186





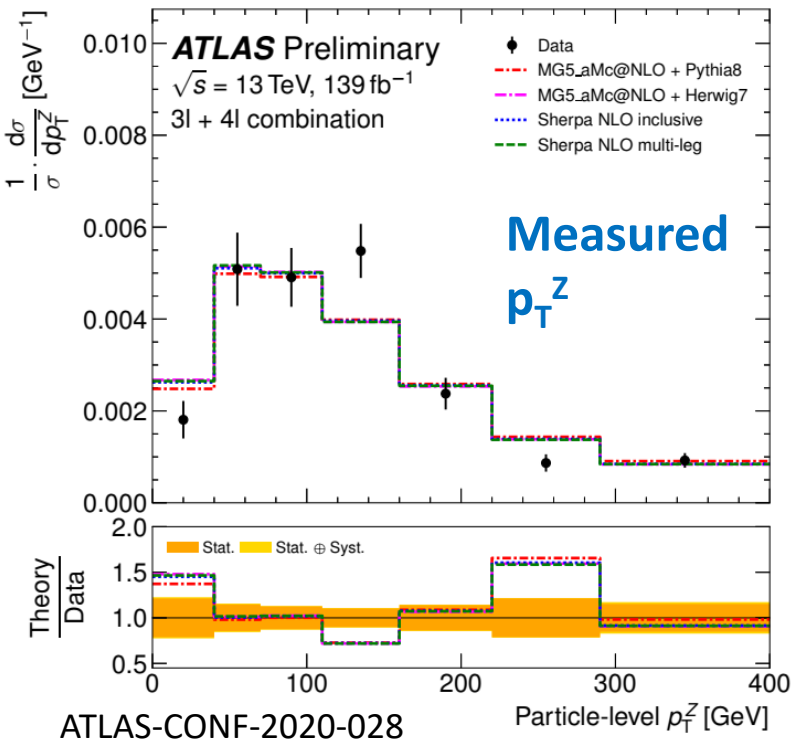
Per-mille constraints on neutral boson couplings

Record precision lineshape 10-1000 GeV and multi-dim. diff σ, and record constraints on neutral gauge couplings

Exploration (ttX, four-top, VVV, VBS VV, $\gamma\gamma \rightarrow XX$)

Top and Boson

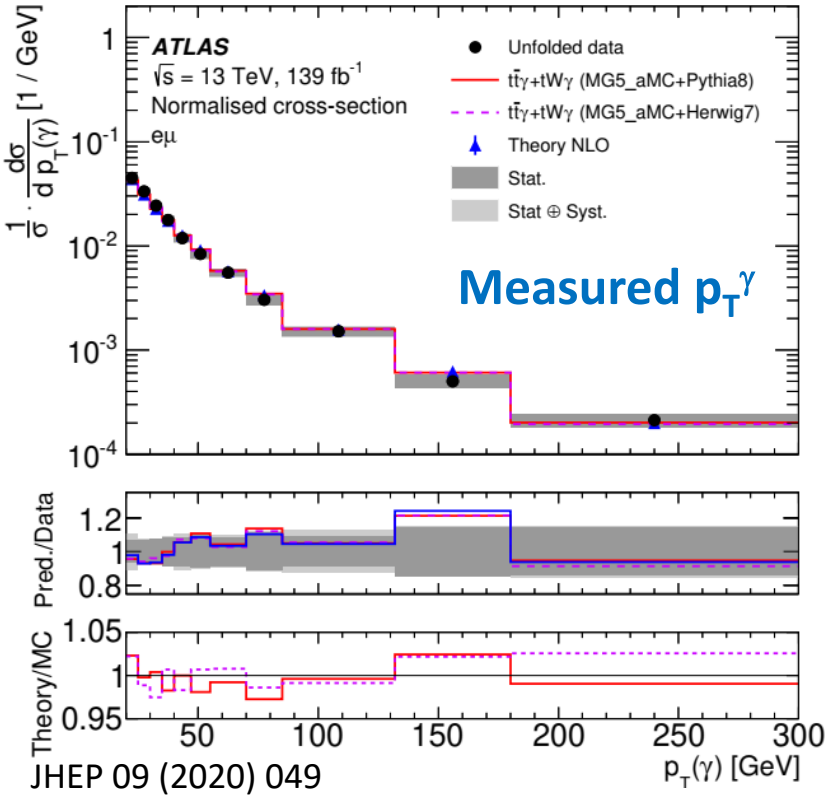
Probe neutral t-Z coupling via $t\bar{t}$+Z



ATLAS-CONF-2020-028

Inclusive σ record 10% precision with 3 or 4 lepton events; various diff. σ reported

Probe neutral t-γ coupling via $t\bar{t}$+γ

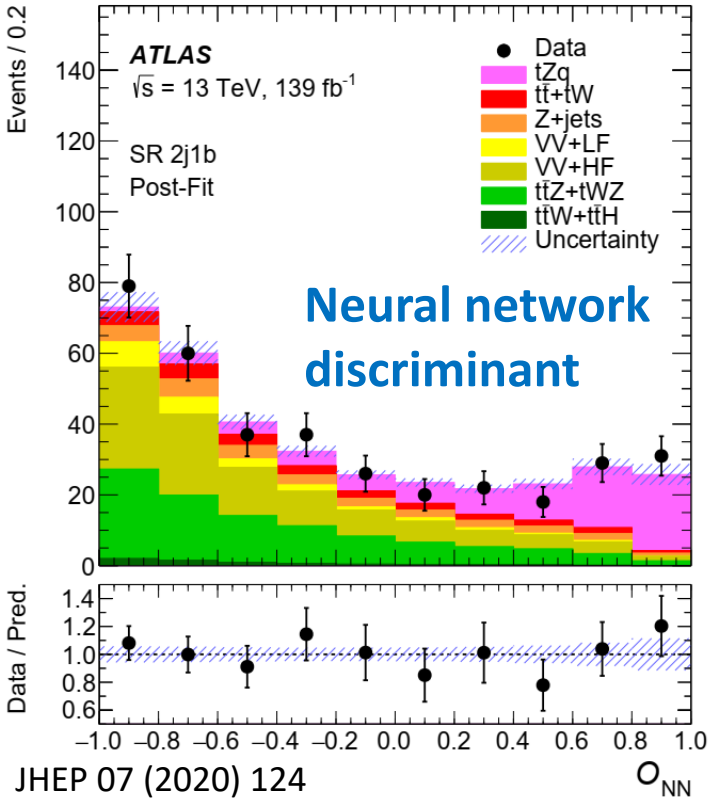


JHEP 09 (2020) 049

Inclusive σ record 7% precision with eμγ events, diff. σ reported

Top and Boson

Probe t-V coupling via *tZq*



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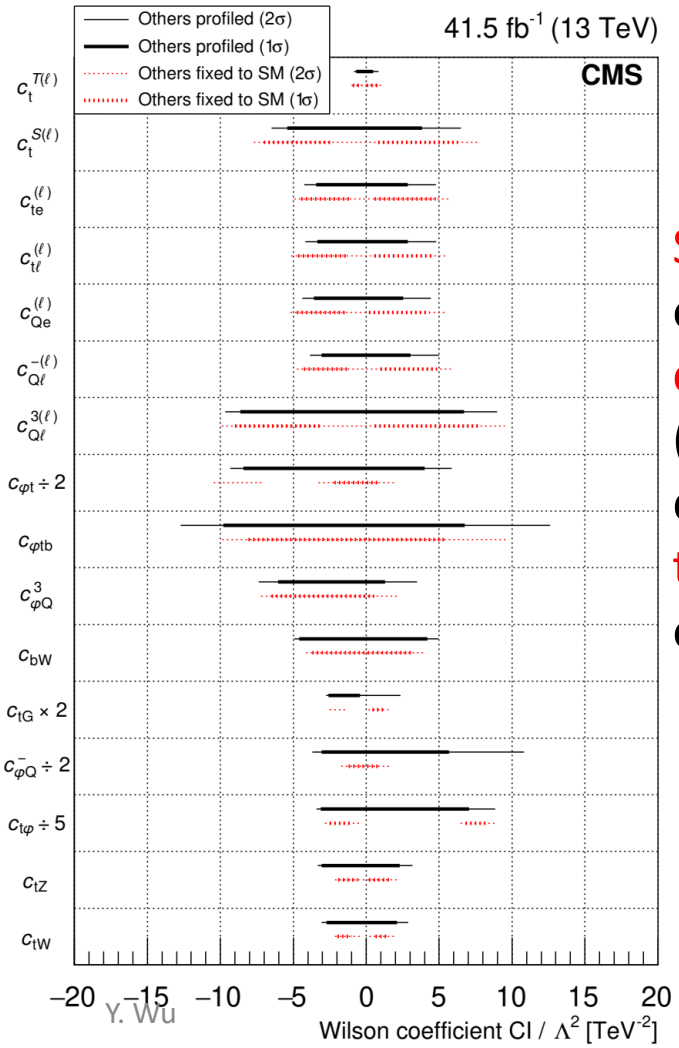
Utilize 3-lepton + jets events, first observation in ATLAS, total σ uncertainty 14%

Sensitive probe into anomalous couplings with top + boson production



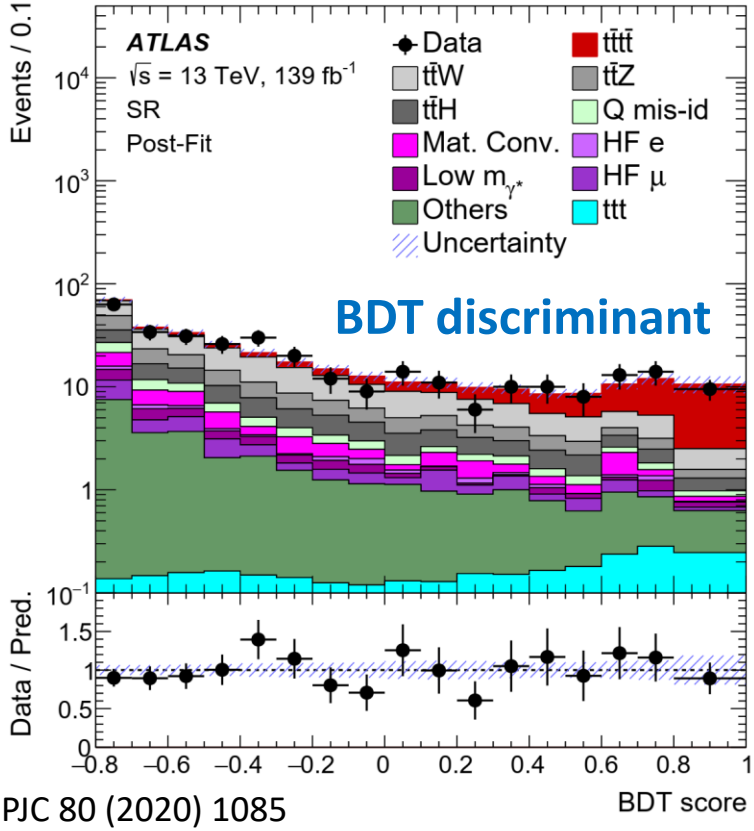
Simultaneous fit of 16 relevant EFT coefficients (Warsaw basis dim-6) using ttZ, ttW, tHq, tZq, ttH events

arXiv:2012.04120

Interval of EFT coefficients

Rare is many

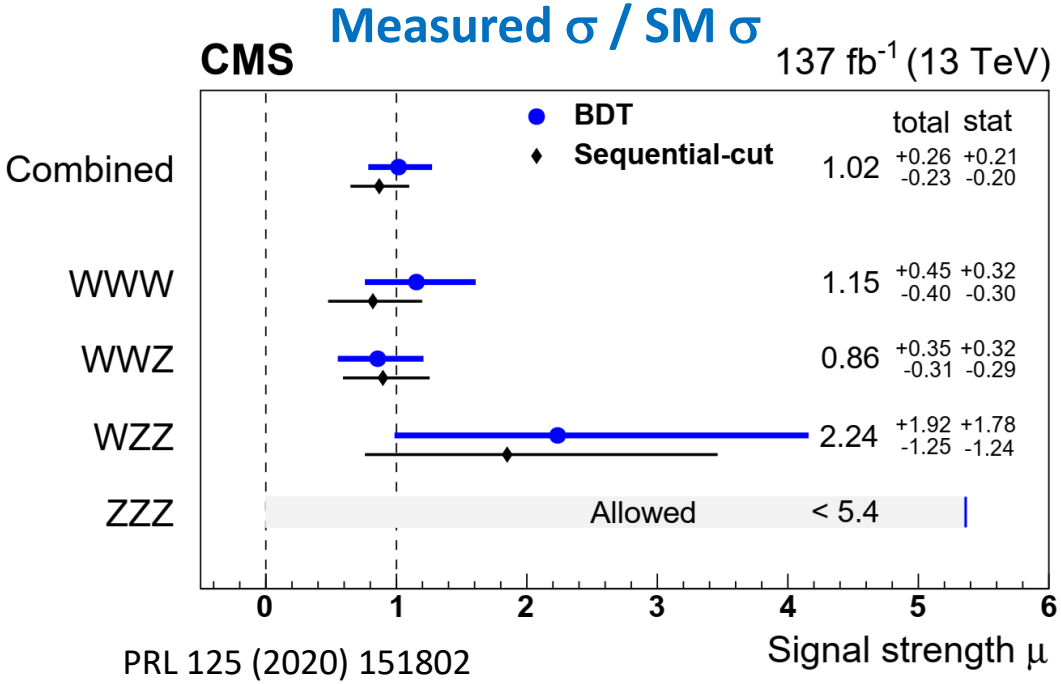
Four-top extreme in QCD, yet sensitive to Higgs, new physics



EPJC 80 (2020) 1085

Same-sign dilepton or three lepton events lead to a first evidence (4.3 σ)

Triple weak (bosons), yet matter for Higgs, Gauge structures



PRL 125 (2020) 151802

Enhance sensitivity via simultaneous fit in same-sign 2-lepton, 3-/4-lepton events, lead to a first observation (5.7 σ)

Vector boson scattering

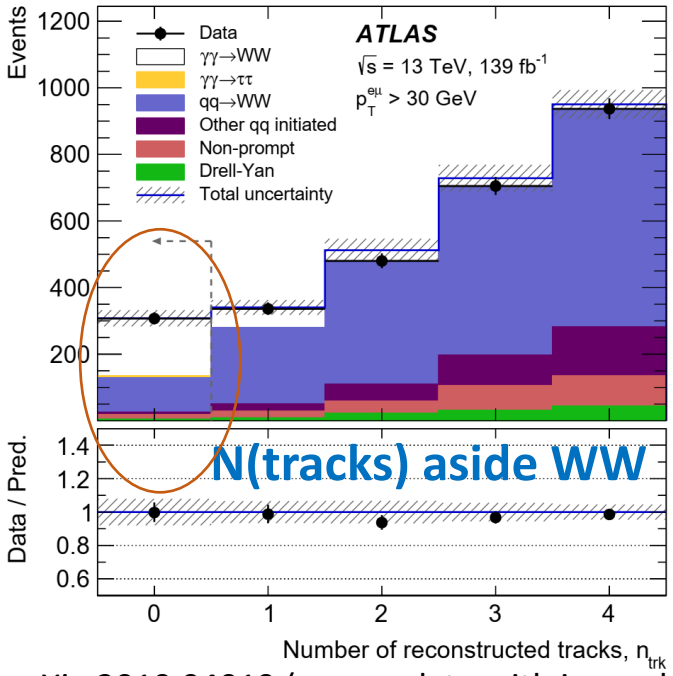
See also PRL 125 (2020) 261801 for $\gamma\gamma \rightarrow$ dilepton with forward proton scattering

Rare, unique EW process, sensitive to Gauge, Higgs and new physics

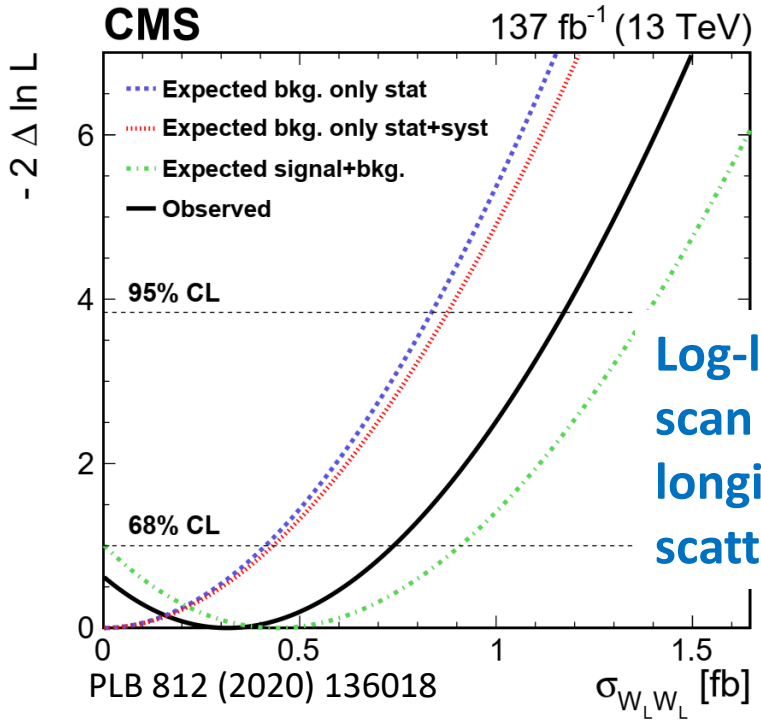
VBS WW

$\gamma\gamma$ collision helps reveal electroweak structure

Same-sign dilepton offers good S/B



arXiv:2010.04019 (may update with journal ref.)



Large lumi. meets soft QCD meets $\gamma\gamma$ meets WW ➔ first observation of $\gamma\gamma \rightarrow$ WW scattering

First attempt to disclose the "key" longitudinal scattering, ~ 0.5 σ

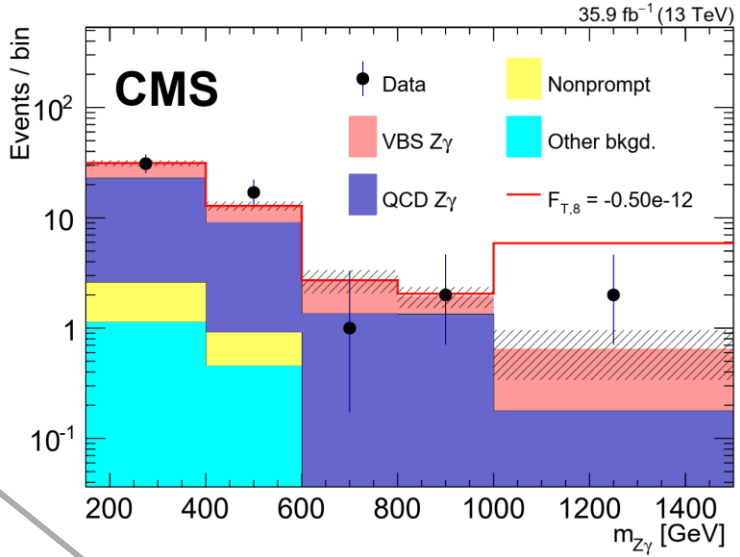
Vector boson scattering

Observation mode

VBS Zγ

VBS WZ

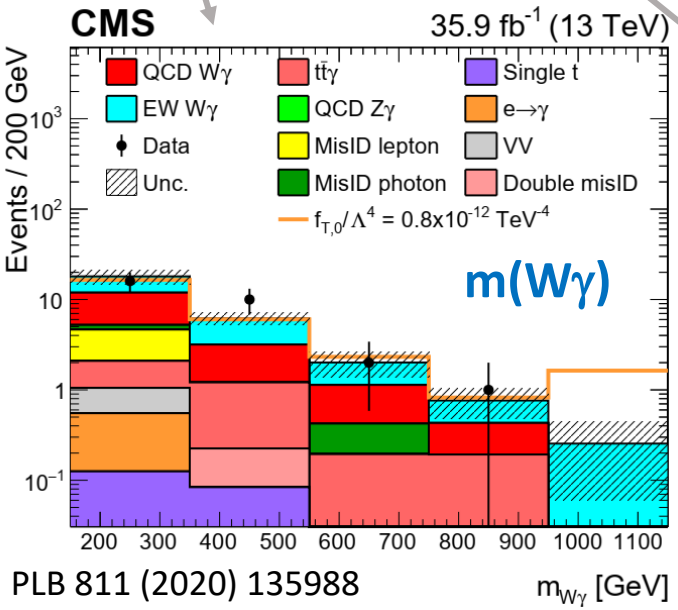
VBS Wγ



m(Zγ)

A first evidence (3.9σ), probe quartic-boson couplings

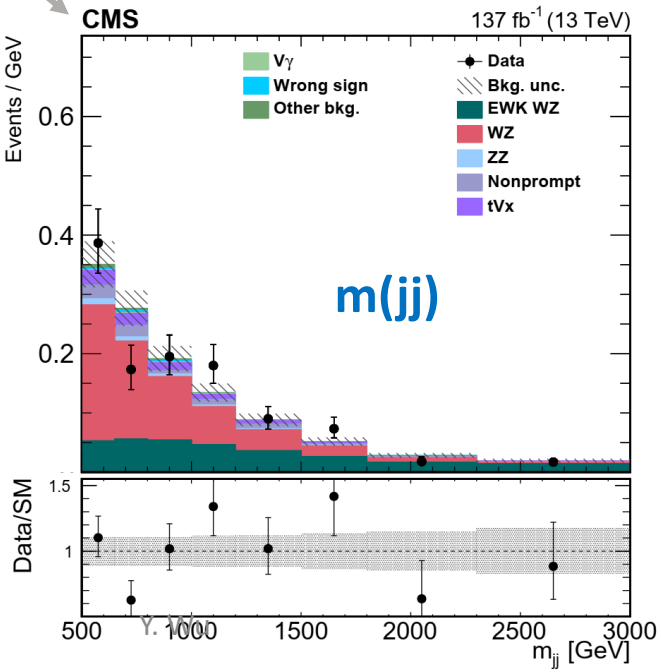
JHEP 06 (2020) 076



m(Wγ)

PLB 811 (2020) 135988

A first observation (5.3σ) combined with 8 TeV



m(jj)

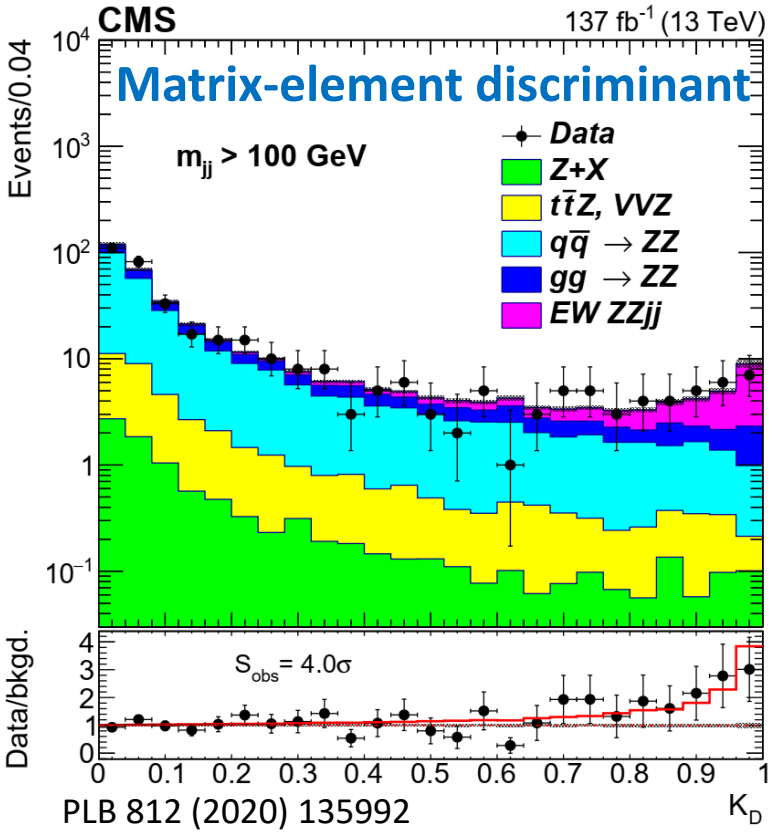
CMS observation of VBS WZ (6.8σ)

Differential σ for same-sign WW and WZ plus jj

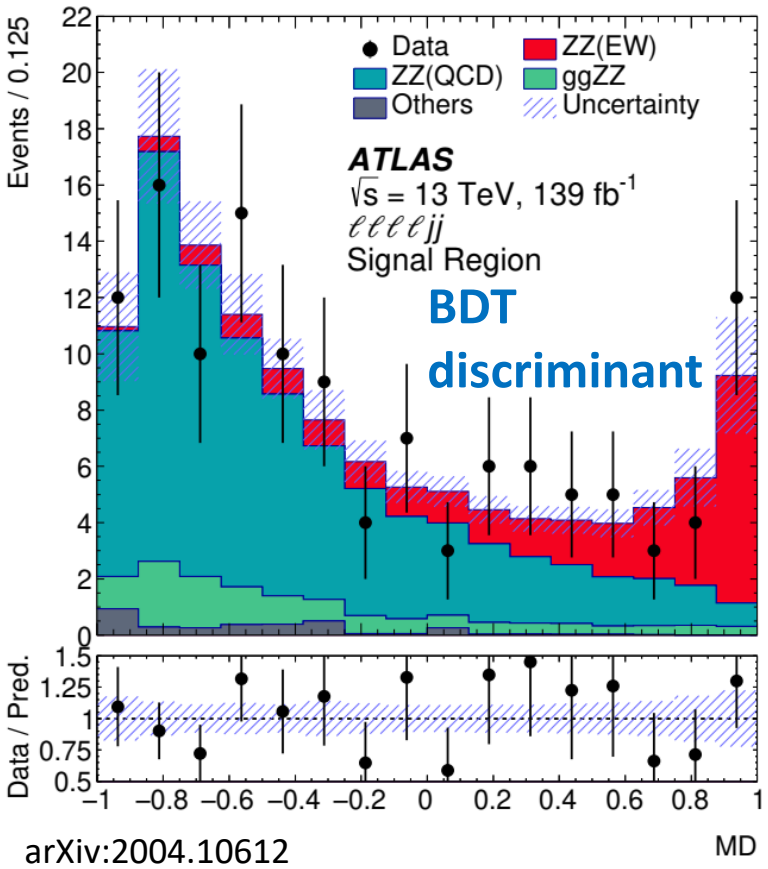
PLB 809 (2020) 135710

Rarest VBS to conclude

Successful probe of rare VBS ZZ process, O(0.1) fb fiducial σ



Study of 4-lepton events leads to evidence (4σ), report constraints to quartic-boson couplings



Study of 4-lepton and ll+E_T^{miss} events leads to observation (5.5σ)

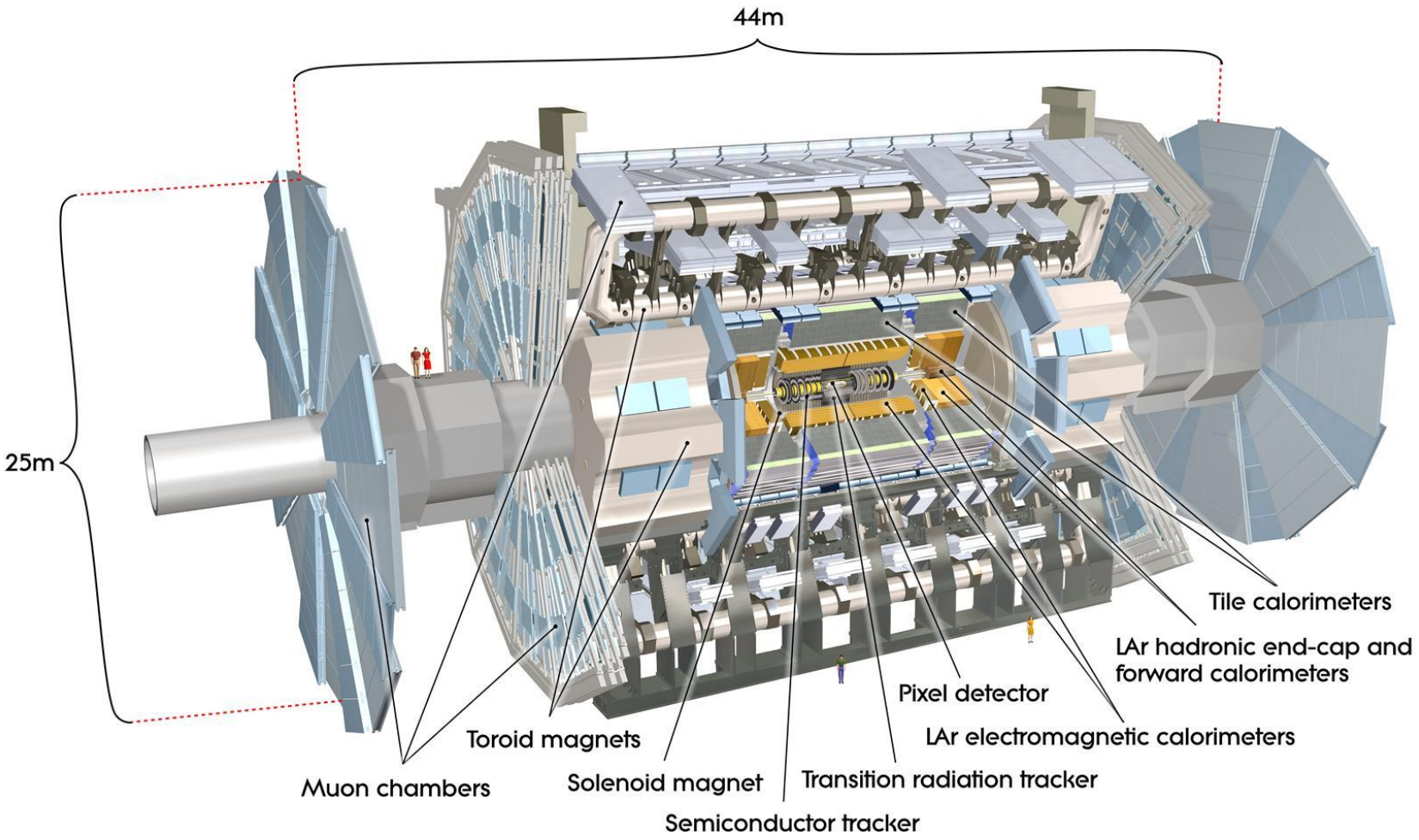
More on J. Li's YSF talk

Summary

- Discussed various recent results in the electroweak and top physics sector, from ATLAS and CMS
- Large dataset, detailed work, and deployment of novel methods leads to unprecedented precision in both traditional and exploration channels
- Interplay between previously isolated studies are more seen, yielding interesting results
- Interpretation of measurements becomes more pursued, e.g., in the EFT framework
- Further results with full Run-II dataset are yet to come
- While Run-III data will come in a while and wouldn't give an immediate boost, thoughts on overlooked corners still with Run-II might be still interesting …

Thank you for your attention!

ATLAS Detector



CMS Detector