Recent highlights on QCD, EW and Top Physics from the LHC

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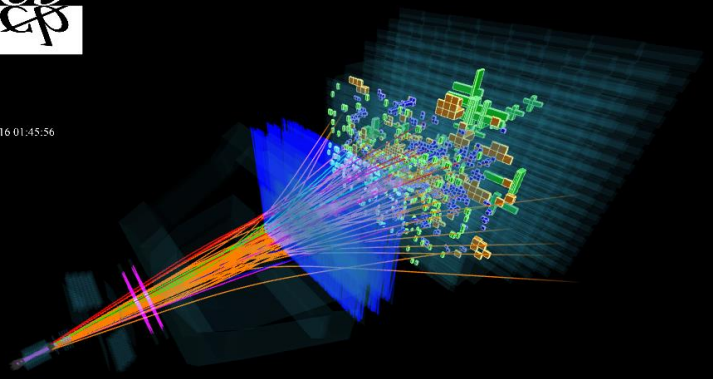
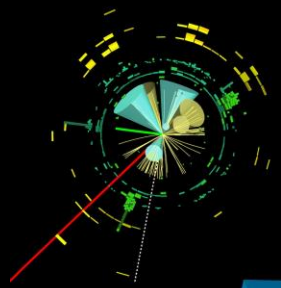
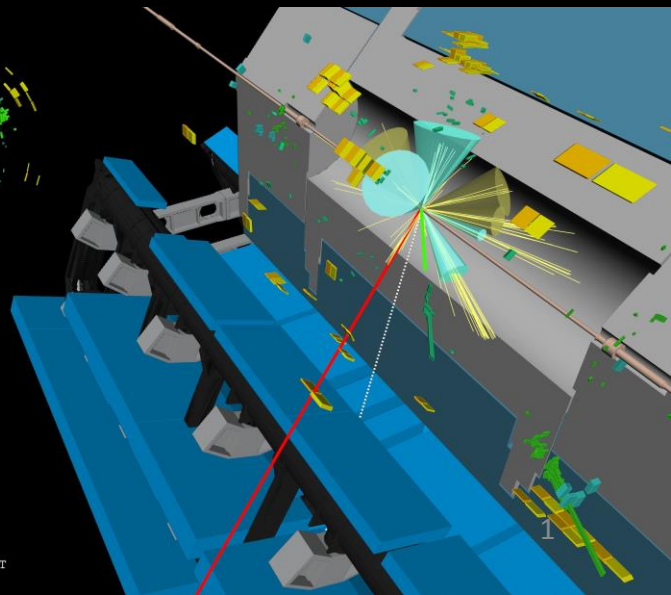






*supported by the NSF

Outline

Introduction (LHC data taking)

Recent highlights from the ATLAS, CMS, and LHCb experiments on:

Jet Production

- Inclusive jet cross-sections
- Multi-jet correlations and shapes
- Heavy flavor di-jet cross-sections
- Quark and gluon-jets
- Jet substructure (Lund Plane)
- Double Parton scattering in 4-jets

Photons

- Photon fusion with tagged proton

W,Z Production

- Inclusive W,DY production
- Z→ $\nu\bar{\nu}$ production
- W branching fractions

V+jets

- Z/γ+jets differential cross sections
- Z+c, Z+b(b)
- Double Parton scattering in Z+jets

Multi-bosons

- WZ production
- 4 leptons final states
- Wγ production
- WW+≥1 jet production
- VV production at 5.02 TeV
- EW production of VV (Zγjj and ZZjj)
- W$\gamma\gamma$ and Z$\gamma\gamma$ production
- Observation of $\gamma\gamma \to W^+W^-$
- Polarized $W^\pm W^\pm$ scattering

Top quark production

- Pair production cross-sections (at 5.02 TeV and differential)
- EW top cross-section and mass
- Associated pair production
- Rare top production (four tops)

* Disclaimer: an incomplete list of topics and recent results. Many more results exist and and will be discussed in the parallel sessions.

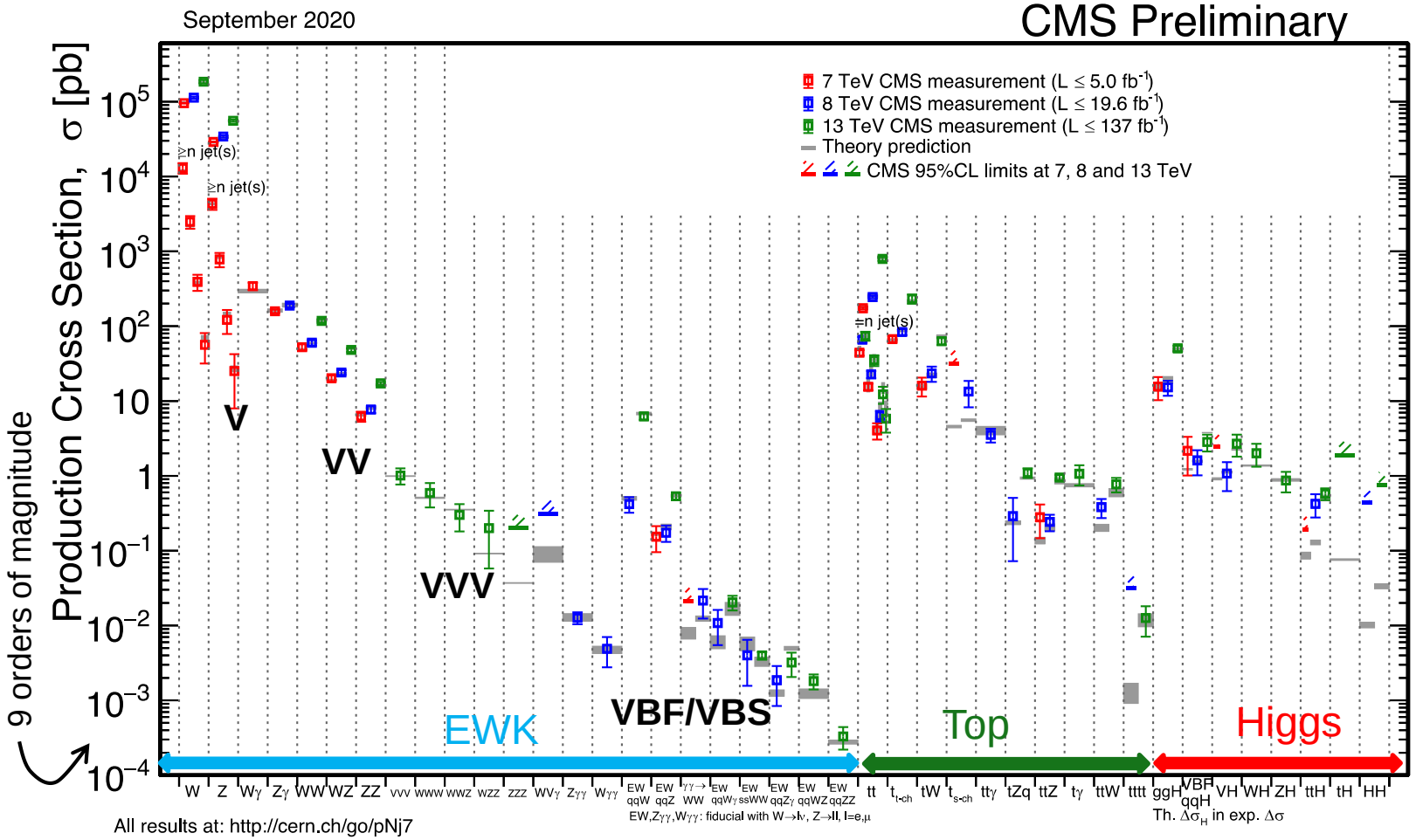
LHC data taking

LHC delivered 163 fb^{-1} of luminosity for Run 2 pp collisions, 2015-2018, at $\sqrt{s}$ = 13 TeV, concluded in Dec 2018 with a lead-proton run.
CMS, ATLAS, LHCb continue to analyze data (millions and millions of W's for precision measurements, a new paradigm for precision QCD and for looking for new physics through precision measurements).
Next collisions, Run 3, planned for 2022, at $\sqrt{s}$ = 13/14TeV .

- Run-3 luminosity goal: ~350$fb^{-1}$by 2024
- HL-LHC goal: ~3-4ab^{-1}

Standard Model physics

SM measurements at the LHC allow us to test a wide range of theory predictions with unprecedented precision. They are sensitive to, and constraint new physics contributions. They are backgrounds to all direct searches for new physics.

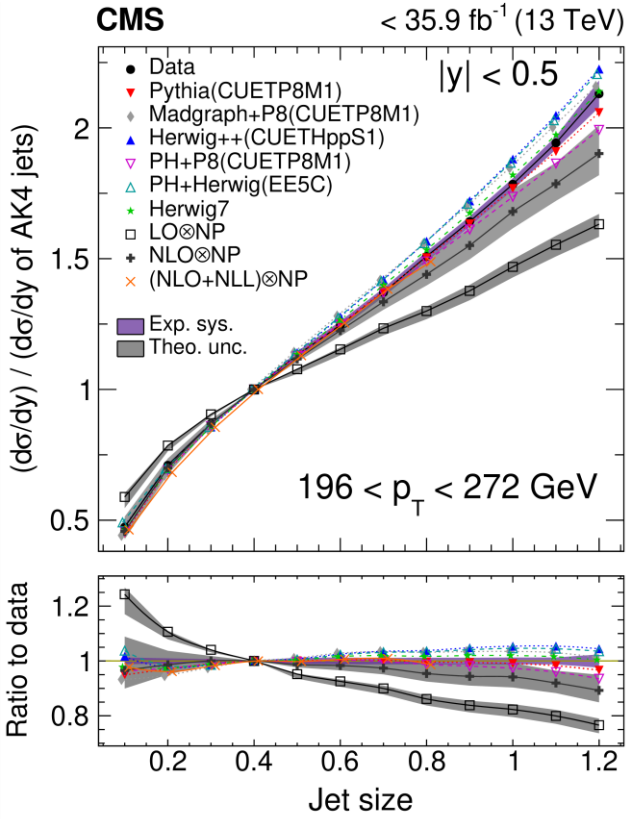


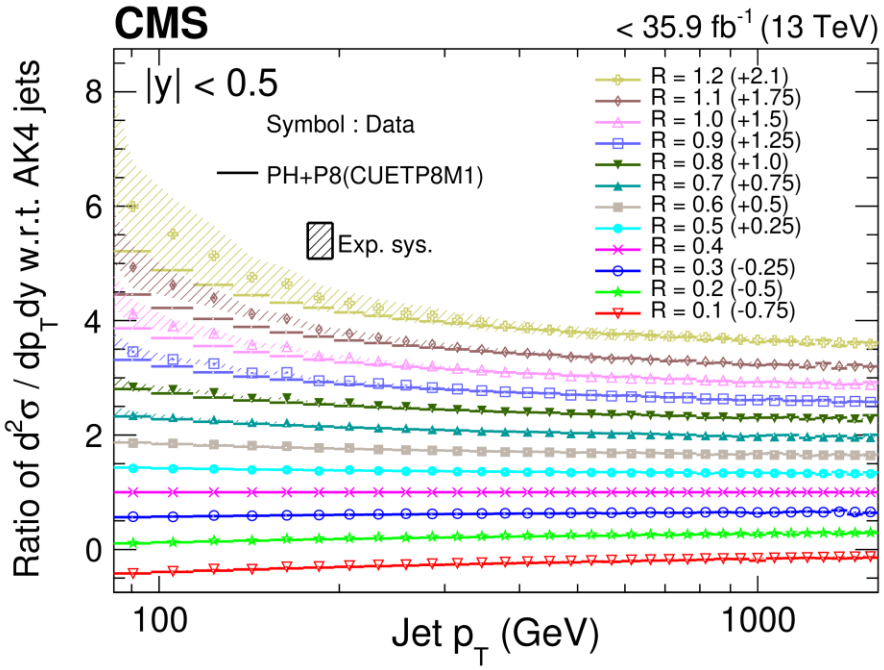
Inclusive jet cross-sections

At the LHC, double differential (p_T, y) jet cross sections are measured and compared to fixed-order calculations and MC predictions. They are sensitive to PDFs over a wide (x,Q^2) range, in particular high-x gluon and valence quark.

Here the dependence on the jet anti k_T algorithm distance parameter R (jet size in y, ϕ) is studied via ratios ⟶

JHEP 12 (2020) 082





R is sensitive to various components of the evolution of partons into jets: radiation & parton shower (PS), hadronization, underlying event (UE).

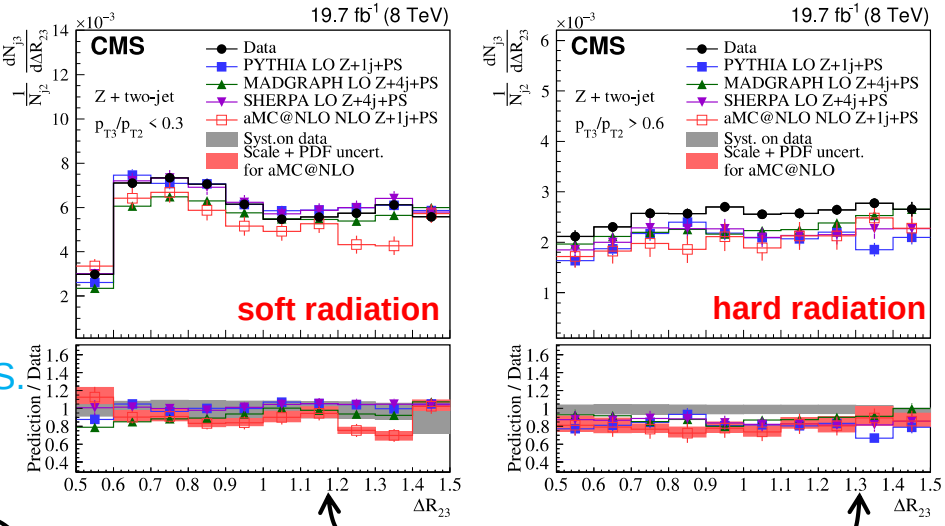
PS calculations agree well with data.
NLO corrections on fixed-order LO are needed.
Accurate modeling of non-perturbative (UE, hadronization) effects is essential.

Multi-jet correlations

Multi-jet correlations are sensitive to the modeling of radiative processes.

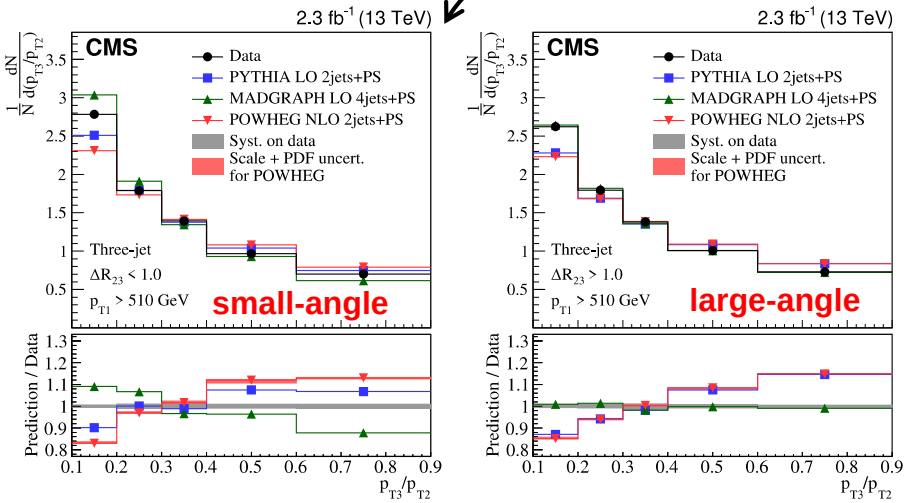
Normalized differential cross-sections in angular separation DR_{23} and p_T ratio of the two sub-leading jets in 3-jet events and Z+2 jet events are studied to probe large or small angle, soft and hard radiation.

Small-angle and soft regions are well described by PS.
Regions of large angular separation are often best described by calculations using higher-order ME.



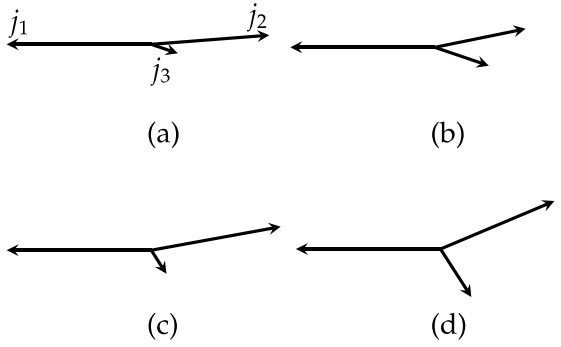
Soft radiation ($p_{T3}/p_{T2} < 0.3$)

Hard radiation ($p_{T3}/p_{T2} > 0.6$)



Collinear radiation (small-angle, $\Delta R_{23} < 1.0$)

Large-angle radiation ($\Delta R_{23} > 1.0$)

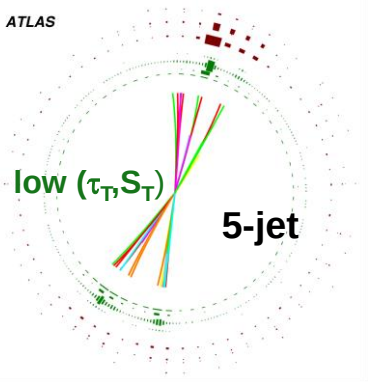


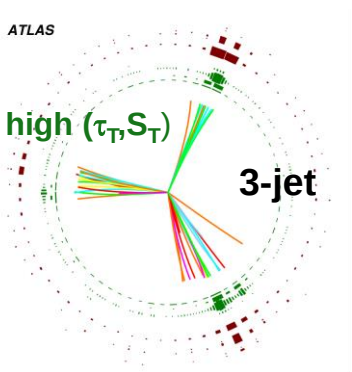
CMS-SMP-17-008, Submitted to EPJC

Multi-jet event shapes

Event shapes in multi-jet events describe the dynamics of energy flow from 2→2 processes to multi-jets events with uniformly distributed energy. Event shapes are sensitive to hard, large angle radiation, higher-orders, re-summation effects.

Normalized shape observables such as transverse thrust (τ_T), transverse sphericity (S_T) and aplanarity are studied in different regions of jet multiplicity n_{jet}, and energy scale H_{T2} (scalar sum of two leading jets p_T)

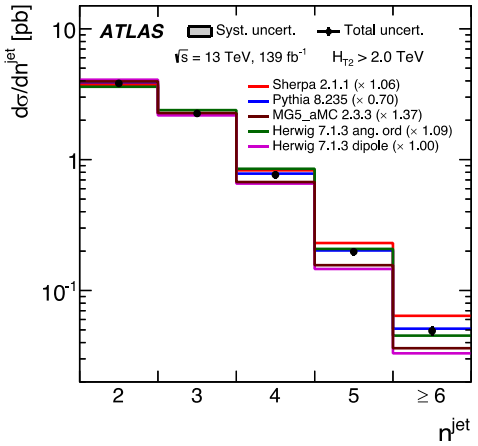


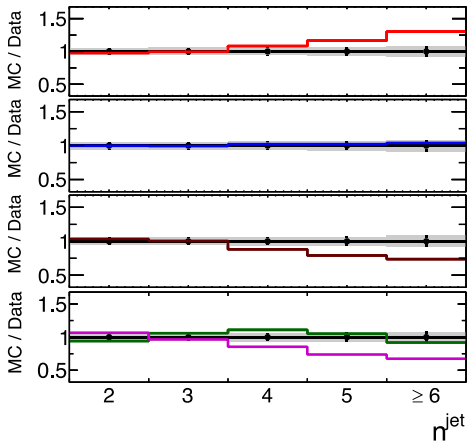


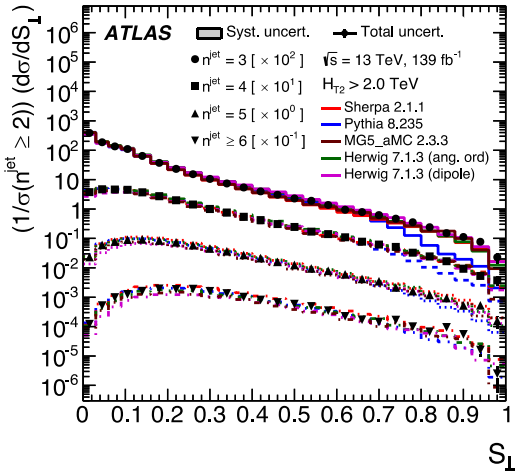
No prediction reproduces the data well in the full phase space.

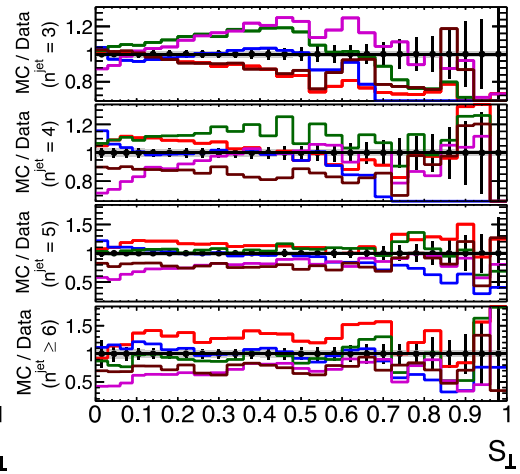
Higher-order ME better describes overall shapes.

Angle-ordered PS gives a better description than dipole PS.







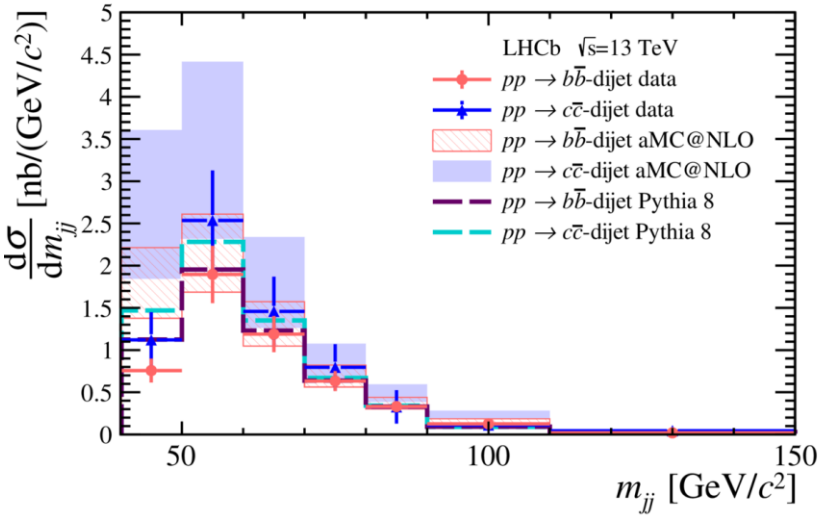


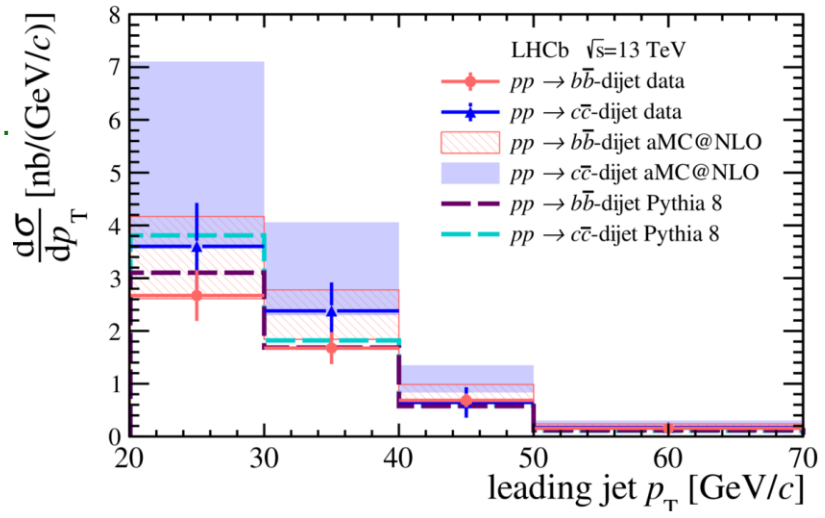
JHEP 01 (2021) 188

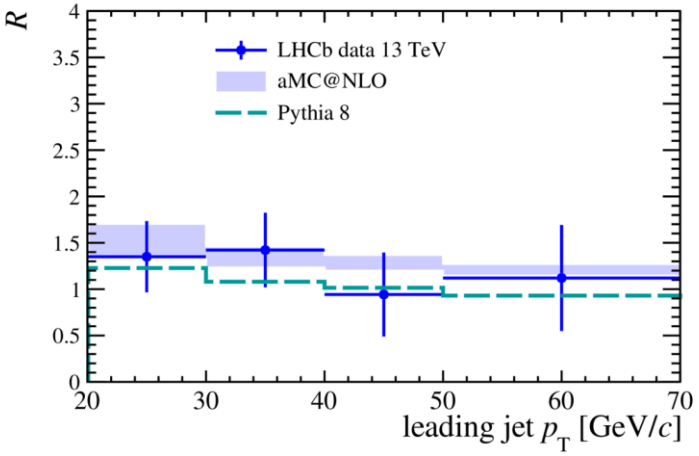
Heavy flavor dijet cross-sections

Differential $b\bar{b}$ and $c\bar{c}$ dijet cross sections are measured by LHCb in the forward region (jet p_T> 20 GeV, 2.2<$|\eta_{jet}|$<4.2), as functions of leading jet p_T and η,the rapidity difference between jets, and the dijet mass.

Heavy flavor jets are tagged using an algorithm based on the reconstruction of secondary vertices (SV). b- and c-jet are separated with BDT classifiers.







Fiducial cross-sections are measured. The ratio between $b\bar{b}$ and $c\bar{c}$ dijet cross-sections is also measured and found to be 1.37±0.27, in agreement with MG5_aMC@NLO and PYTHIA predictions.

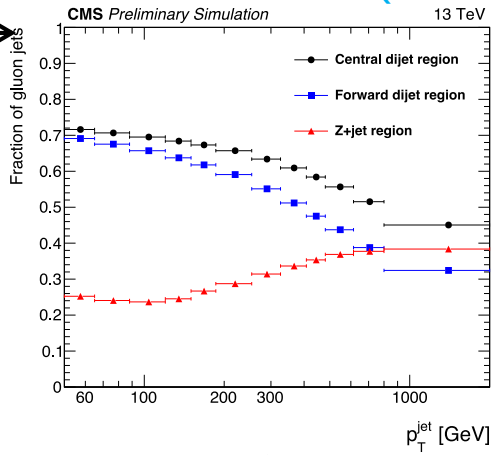
JHEP 02 (2021) 023

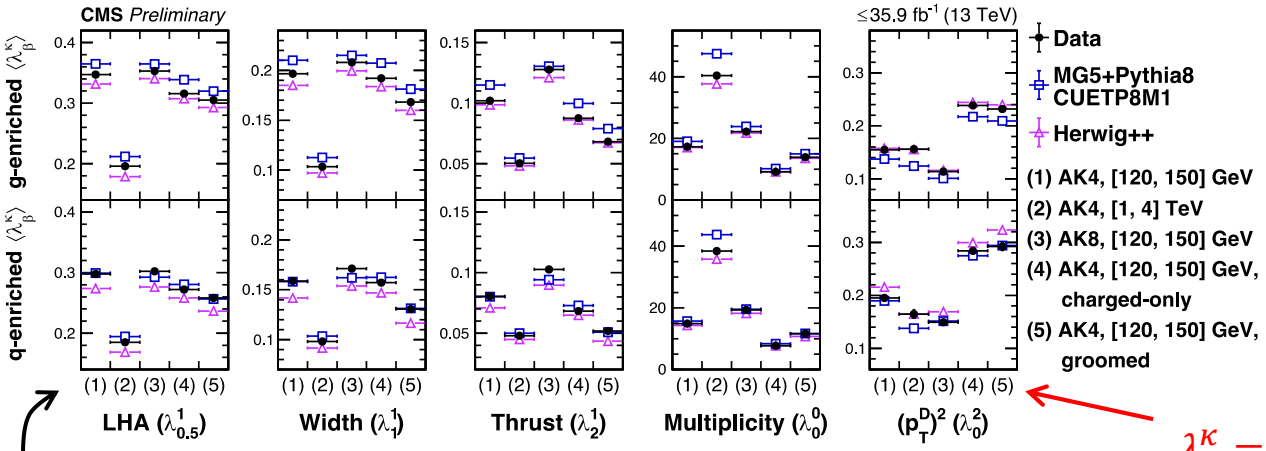
Quark- and gluon-jets

CMS-SMP-20-010

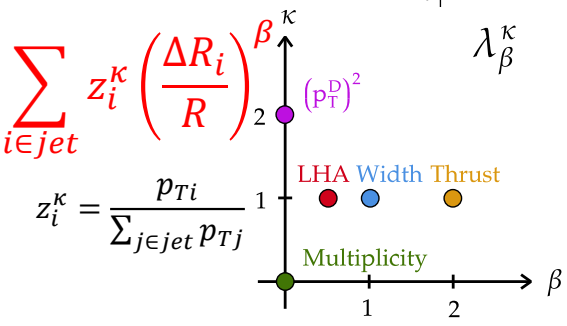
At the LHC, observables related to jet substructure are used to study the formation of jets.

Here gluon- and quark-initiated jets identified via jet substructure observables (the generalized angularities λ_β^κ) in di-jets and Z+jets events

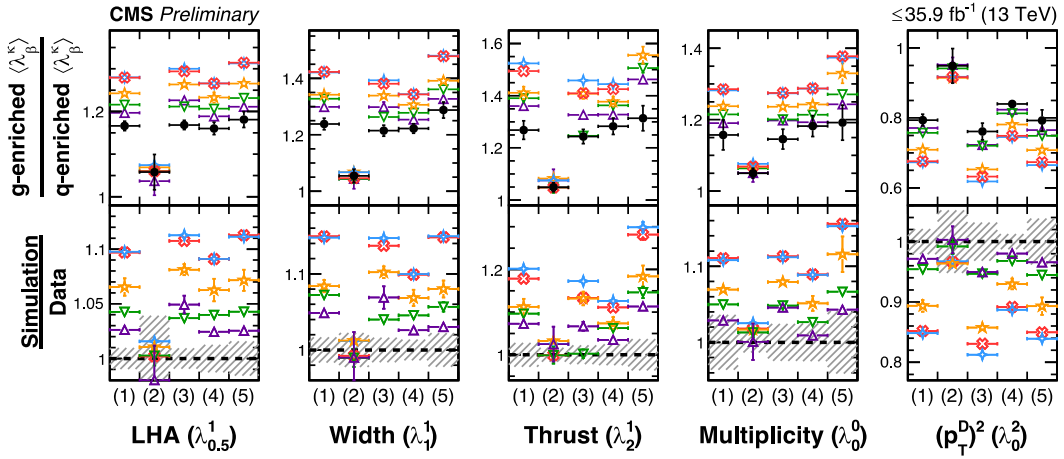




$$\lambda_\beta^\kappa = \sum_{i \in jet} z_i^\kappa \left(\frac{\Delta R_i}{R}\right)^\beta \qquad z_i^\kappa = \frac{p_{Ti}}{\sum_{j \in jet} p_{Tj}}$$



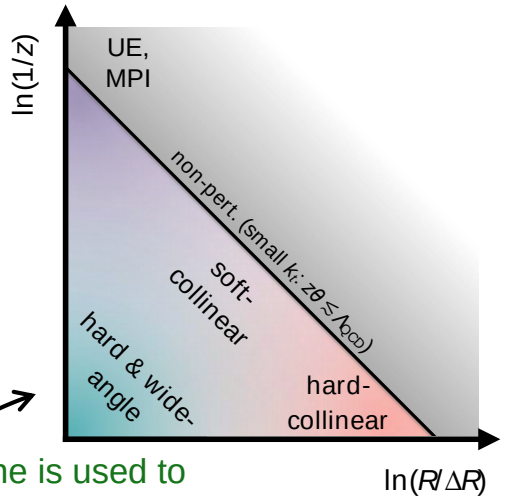
q- and g- data enveloped by MG5+PYTHIA8 and HERWIG++



q/g ratios overestimated by newer simulations and tunes, improvements needed.

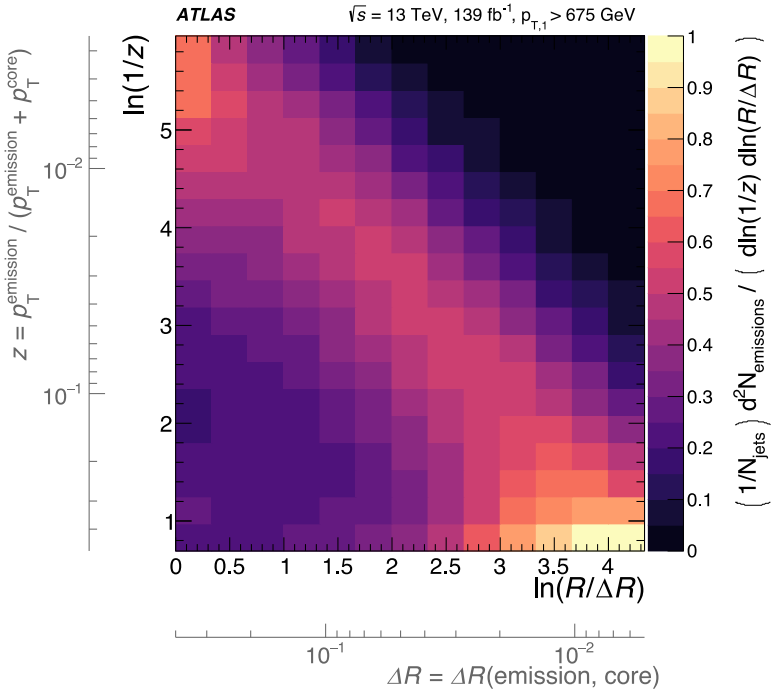
Jet substructure

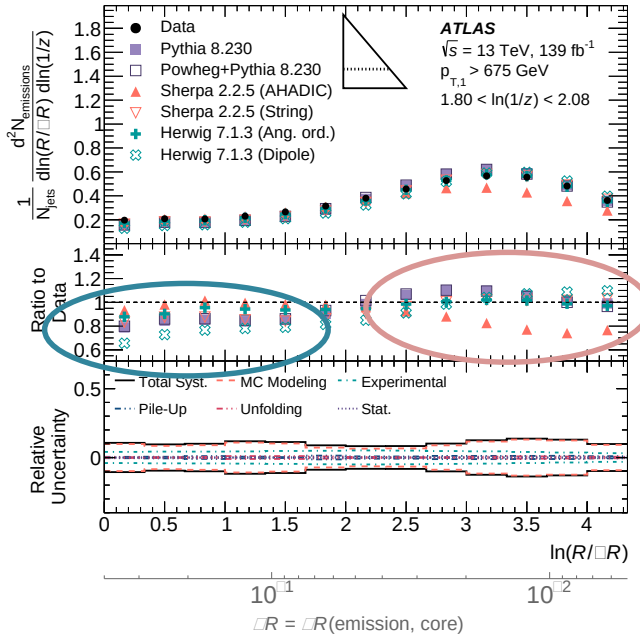
Jet formation & structure can also be studied via the Lund Jet Plane (LJP). Double differential cross-section measurements of the Lund jet plane (z, ln(R/ΔR)) in di-jet events with leading jet p_T >675 GeV and using charged tracks in z,R,ΔR for improved angular resolution. MC predictions are compared with data in LJP slices.



PRL 124 (2020) 222002

The Lund jet plane is used to characterize relative energy and angle of each emission. Different physical effects are localized in specific regions.





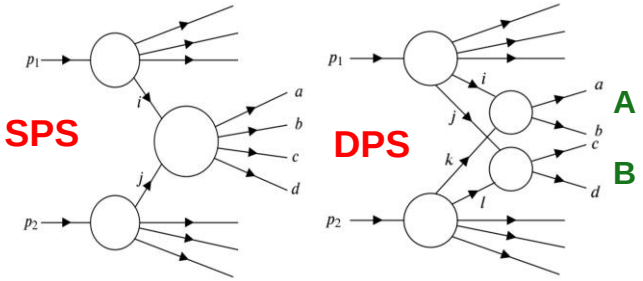
wide angle PS

collinear hadronization

No prediction reproduces the data well in the full phase space, but Herwig7.1.3 with angle-ordered PS provides the best description across most of the LJP.

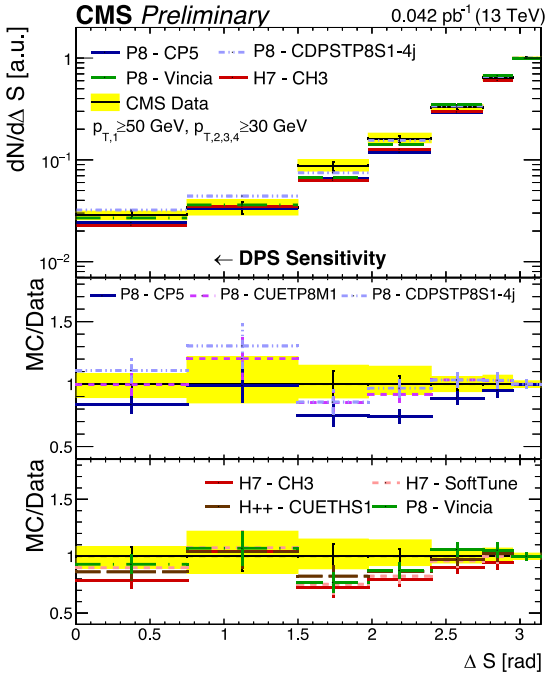
Double-Parton Scattering in jets

Inclusive 4-jet differential cross sections in p_T, η, and angular correlation observables are measured to study UE, PS, ME, and the interplay between decorrelations caused by PS and double-parton scattering (DPS).



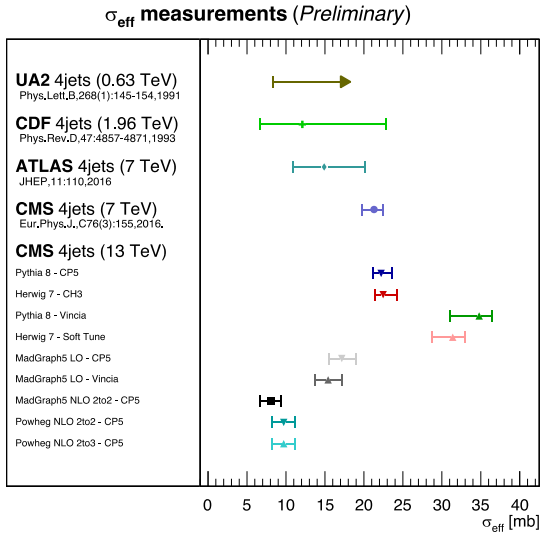
Comparison with Herwig, Pythia, and multi-jet MCs:
All LO 2→2 predictions overestimate data (low jet p_T and forward jets), improved by NLO and multi-leg ME.
Azimuthal correlations distinguish between p_T-and angle or dipole-order PS (improvement seen in latter).

$\Delta S = \arccos\left(\frac{(\vec{p_{T1}}+\vec{p_{T2}})\cdot(\vec{p_{T3}}+\vec{p_{T4}})}{|\vec{p_{T1}}+\vec{p_{T2}}||\vec{p_{T3}}+\vec{p_{T4}}|}\right)$ is the least sensitive to PS effects → used to extract σ_{DPS} and σ_{eff}



DPS contribution extracted with template fit of SPS MC distributions and DPS constructed from inclusive single-jet data events.

$$\sigma_{A,B}^{DPS} = \frac{\epsilon_{4j}\sigma_A\sigma_B}{\sigma_{eff}}\left(1-\frac{1}{2}\frac{\sigma_A}{\sigma_B}\right)$$

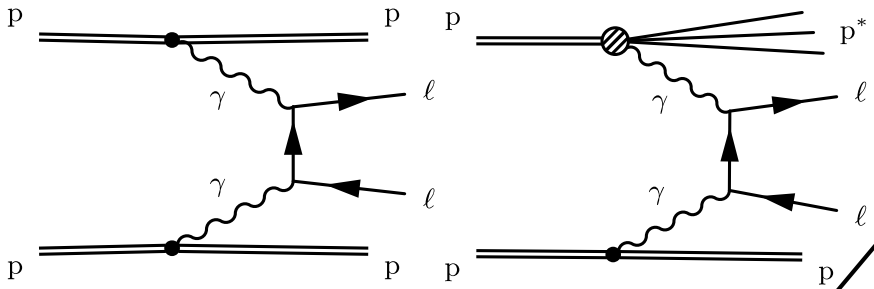


CMS-SMP-20-007

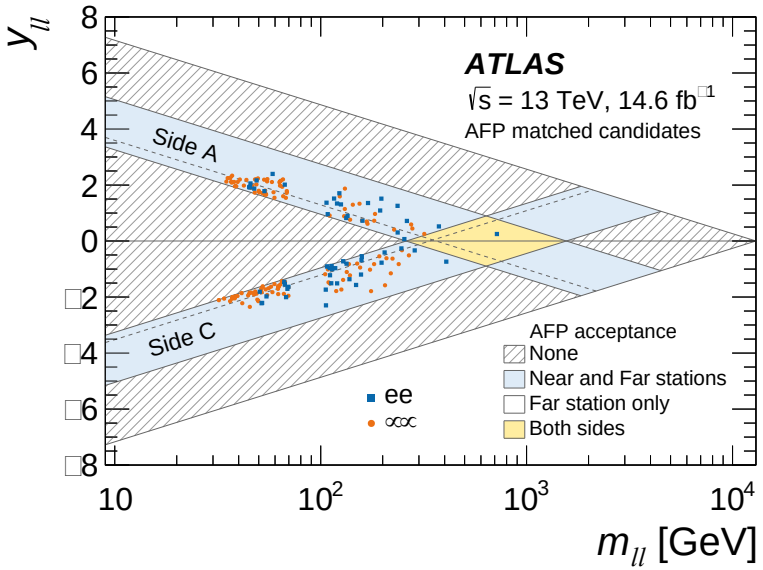
σ_{eff} which reflects the correlation among processes A and B, depends on the SPS models used for them.

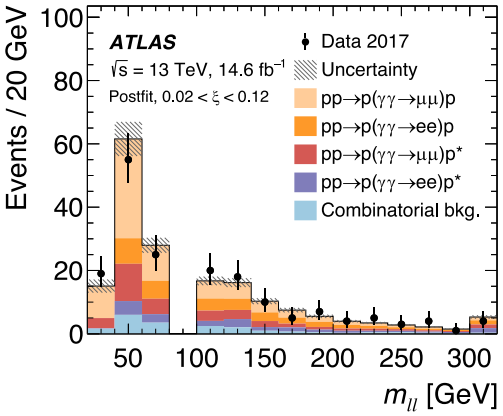
Photon-fusion with forward proton

Observation and cross-section measurement of forward proton scattering in association with lepton pairs (e^+e^-+p or $\mu^+\mu^-+p$) produced via photon fusion, with the scattered proton detected by the ATLAS Forward Proton spectrometer (AFP). Rare process at the LHC, test of QED. Proton tagging avoids large uncertainties associated with the modeling of strong interactions among scattered protons.



Exclusive and single dissociative events simulated with Herwig7 and LPAIR 4.0.
Protons tagged in AFP acceptance (at least one side). Background from pileup DY events modelled with data. Kinematic in the signal region as expected (Z boson region is vetoed).





Fiducial cross-section (in agreement with predictions):

σ_{ee+p}= 11.0±2.6(stat)±1.2(syst)±0.3(lumi) fb

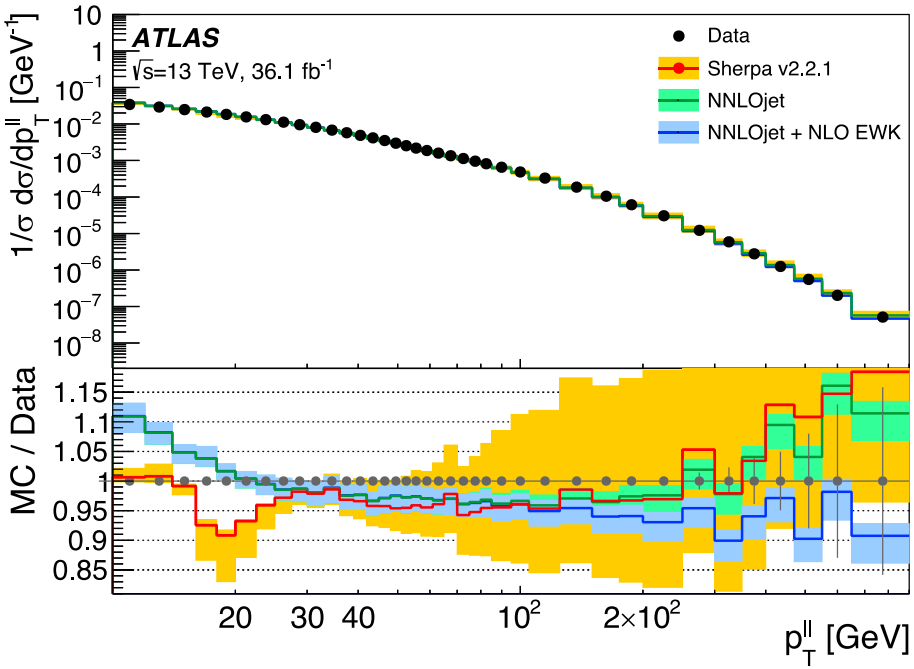
$\sigma_{\mu\mu+p}$= 7.2±1.6(stat)±0.9(syst)±0.2(lumi) fb

PRL 125 (2020) 261801

W and DY production

Sensitive to EW and QCD sectors of SM: extract fundamental parameters of EW theory (M_W, M_Z, $\sin^2\theta_W$), probe proton structure (PDF's), consistent with SM predictions at highest order corrections (NNLO QCD and NLO EW).
Clear experimental leptonic signatures. Rare decays explored.

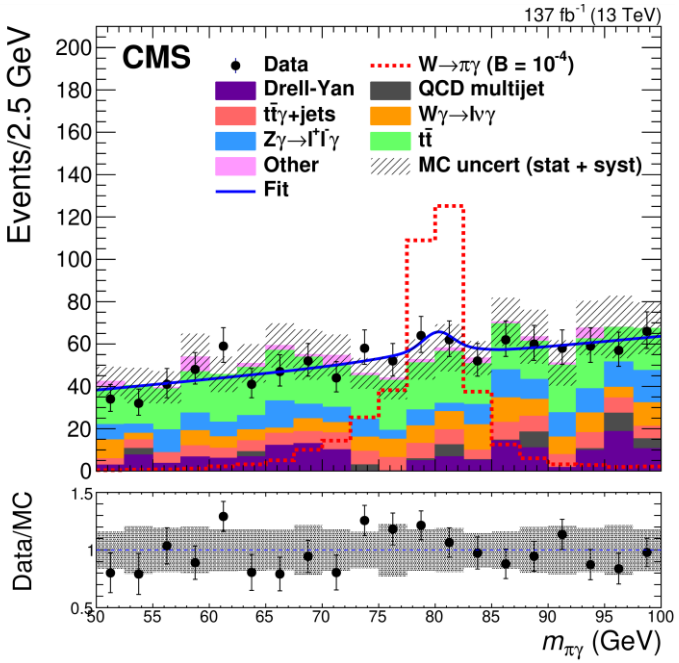
Eur. Phys. J. C 80 (2020) 616



New $p_T^{\ell\ell}$ DY differential cross-sections in regions of $m^{\ell\ell}$ in B.Bilin's talk on Thursday.

W→ πγ exclusive decay with visible final state (tracks and a photon). Uses $t\bar{t}$ events with a leptonic W decay as a tag.

CMS-SMP-20-008, Submitted to PLB



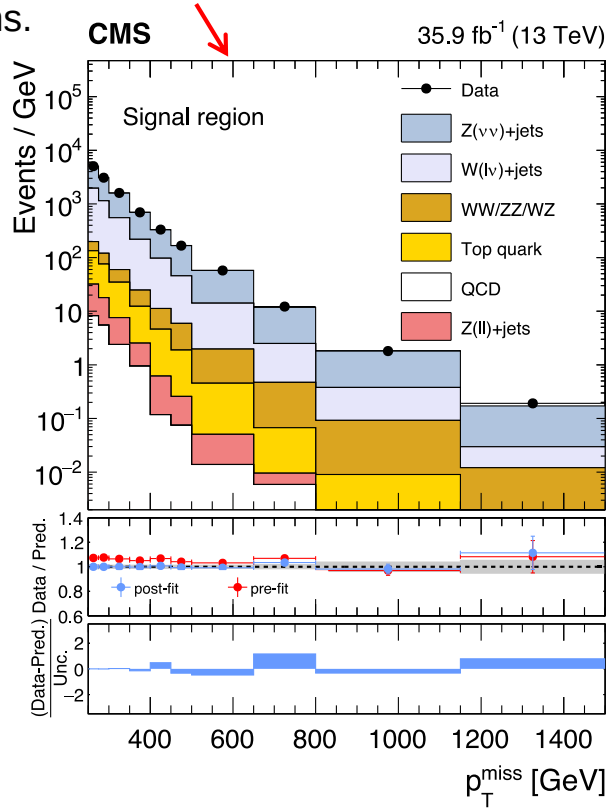
B(W→πγ) < 1.50×10^{-5} @ 95% C.L.

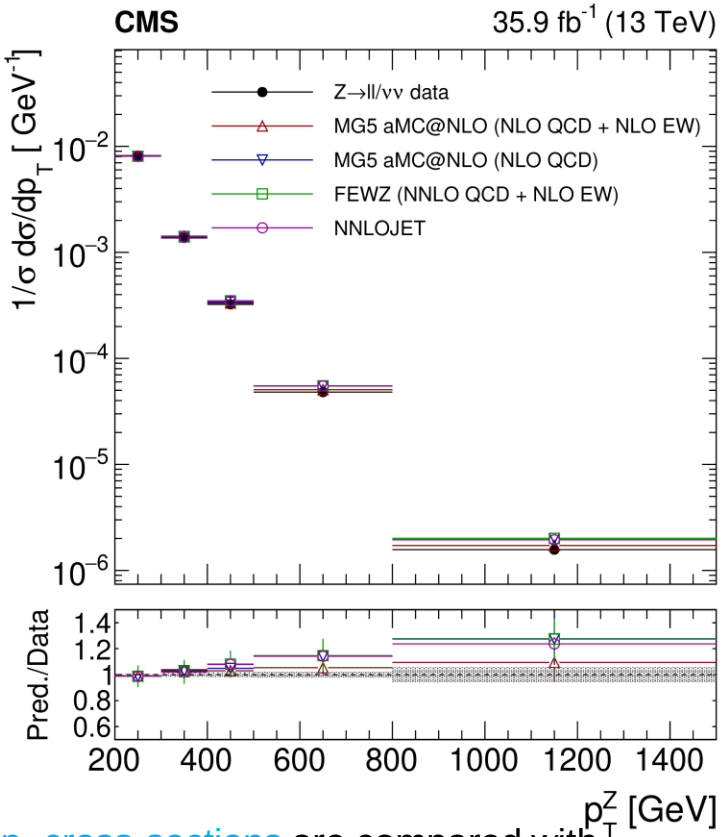
Z→ $\nu\bar{\nu}$ production

Important background to searches with invisible particles (e.g. dark matter). Its combination with charged lepton decay modes provides the most precise measurement of the differential Z p_T cross-sections at high p_T.

Signal topology: Z(→ $\nu\nu$) recoiling against an initial state radiation (ISR) jet. Lead jet p_T> 100 GeV, p_T^{miss}>150 GeV. Main background: W(→ $\ell\nu$)+jets. Signal extracted w/ fits to the p_T^{miss} distribution in signal and two control regions.

CMS-SMP-18-003, Submitted to JHEP



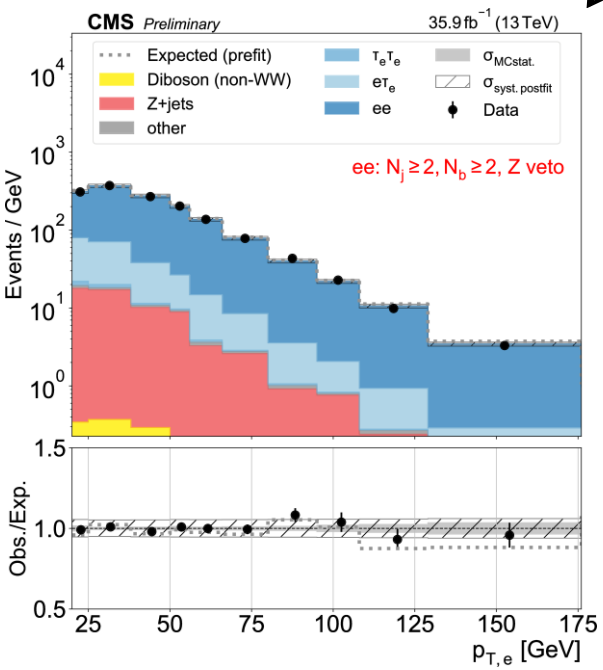


Fiducial Z p_T cross-sections are compared with MG5_aMC@NLO (QCD and EW), FEWZ and Z+1 jet at NNLO QCD and agree within uncertainties

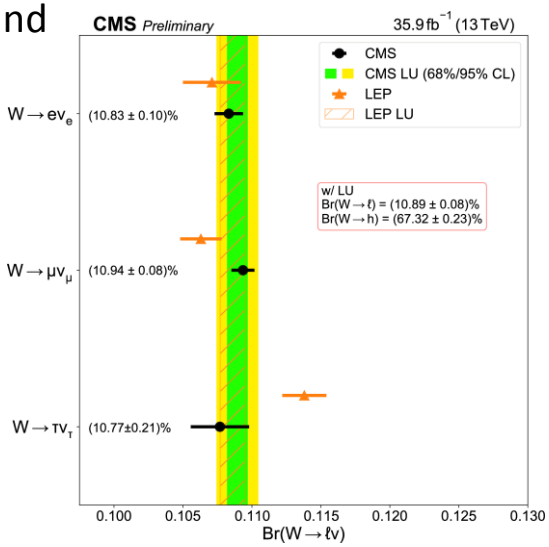
W branching fractions

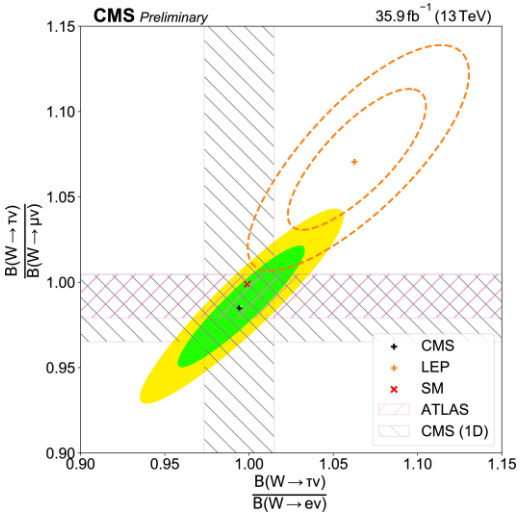
Test of lepton universality (LU). W decays from $t\bar{t}$ (also tW and WW). Decay channels categorized by lepton flavor (e, μ, hadronic τ), N_{jets} and $N_{b\ tags}$. Background processes: VV (non WW), Z+jets, multi-jet QCD. Trailing lepton p_T discriminates prompt decays to e, μ from decays of a τ lepton.

A binned likelihood is constructed combining all selection categories and category-specific observables.



Leptonic branching fractions are measured and hadronic branching fractions are reported w/ or w/o assuming LU.



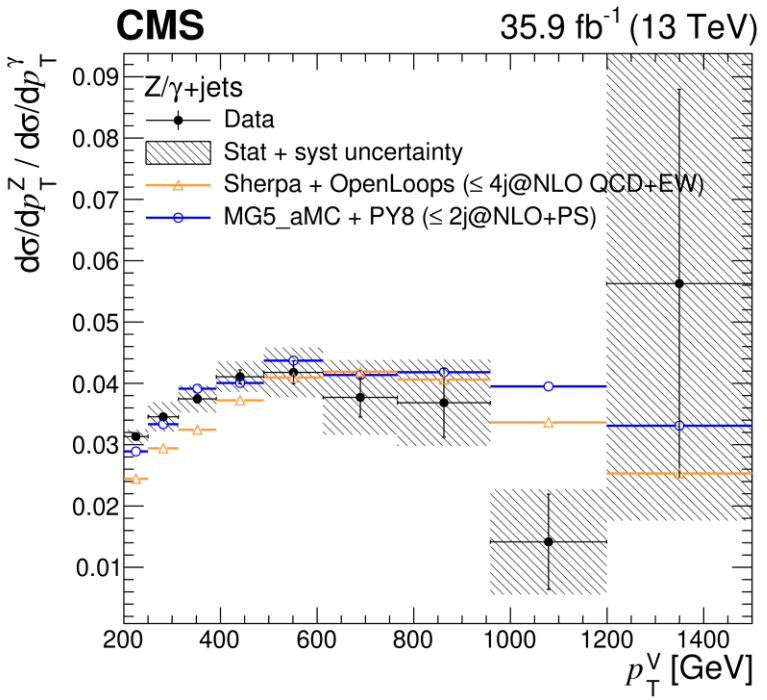


Results consistent with LU (and ATLAS Rτ/μ result), exceeding LEP's precision. From the leptonic/hadronic ratios, three SM quantities are derived (with certain assumptions): the sum square of elements in the first two rows of the CKM matrix $\sum|V_{ij}|^2 = 1.989 \pm 0.021$, $|V_{cs}| = 0.969 \pm 0.011$, and $\alpha_S(m_W) = 0.094 \pm 0.033$.

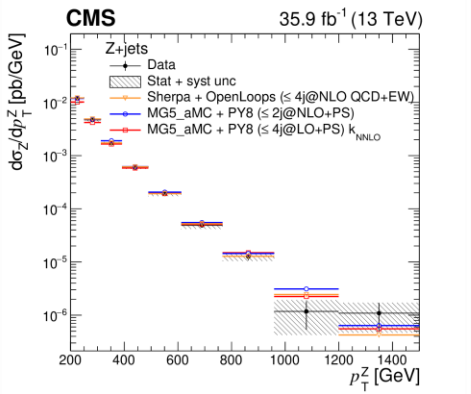
CMS-SMP-18-011

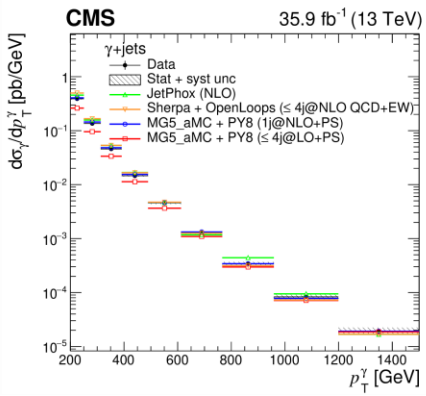
Z/γ+jets

Z/γ ratio is sensitive to higher order EW corrections at high p_T. The measurement requires lead jet p_T>100 GeV and photon p_T>200 GeV, testing bosons p_T up to 1.5 TeV. It is also provides input for the modelling of background in searches.

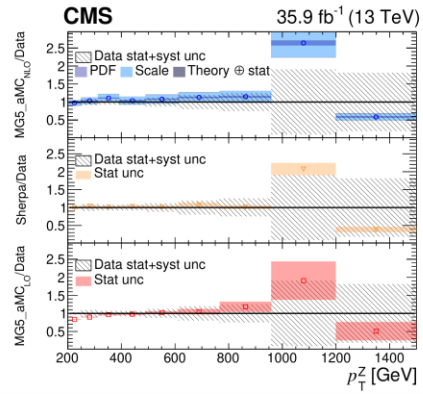


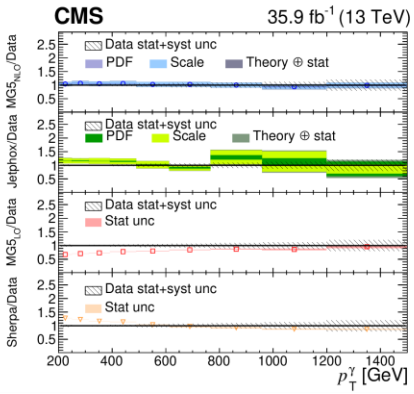
CMS-SMP-19-010, Submitted to JHEP

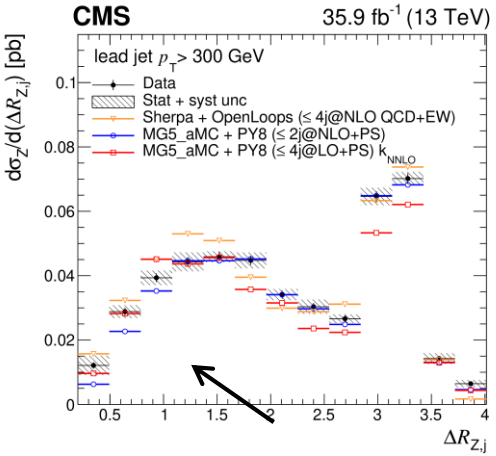




Z and γ+jets differential cross sections are compared to MC predictions at LO and NLO (QCD and EW) → good agreement.



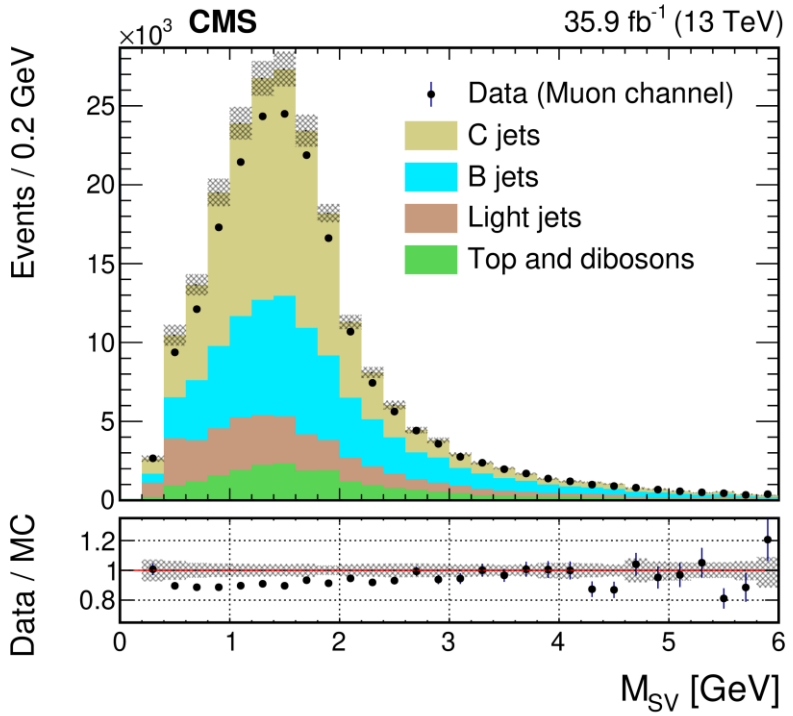


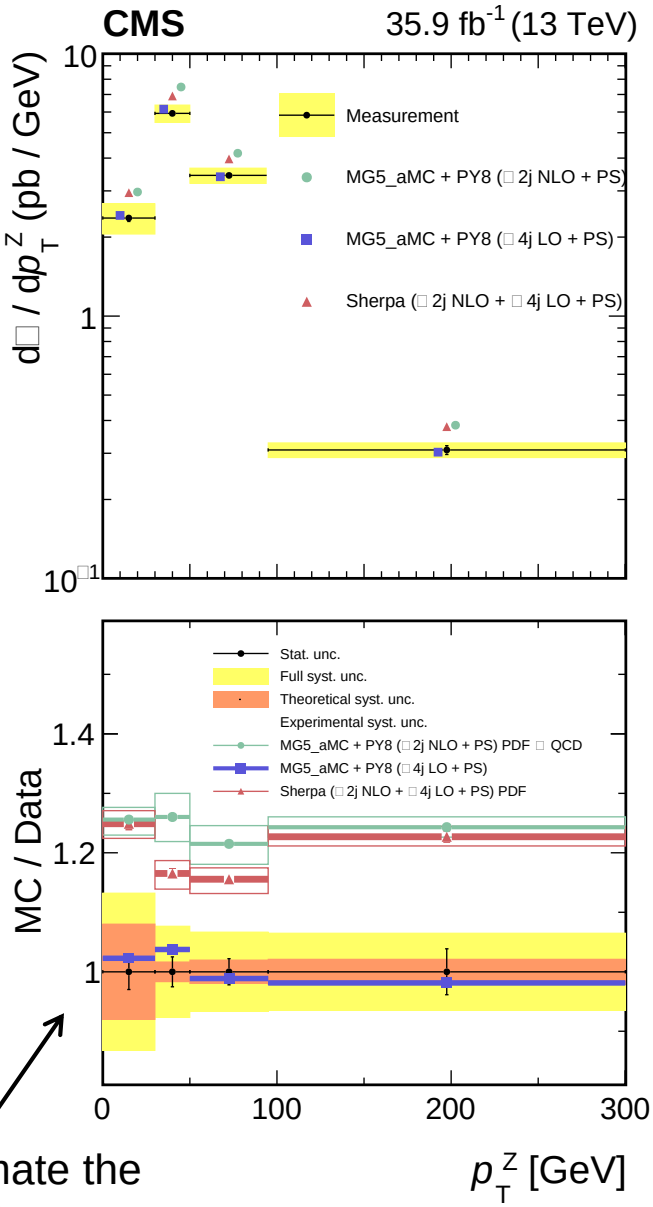


The topology of collinear emission of a Z boson is studied for the first time.

Z+c production

Z+c: sensitive to charm content: perturbative and NP (i.e. intrinsic charm), Test modelling of Z+HF in BSM searches. Extract Z+c components with fit to the invariant mass of tracks M_{SV} associated with secondary vertex.





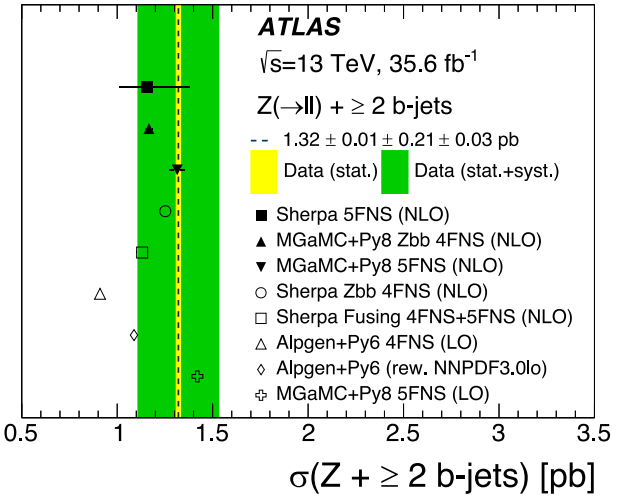
CMS-SMP-19-011, Accepted by JHEP

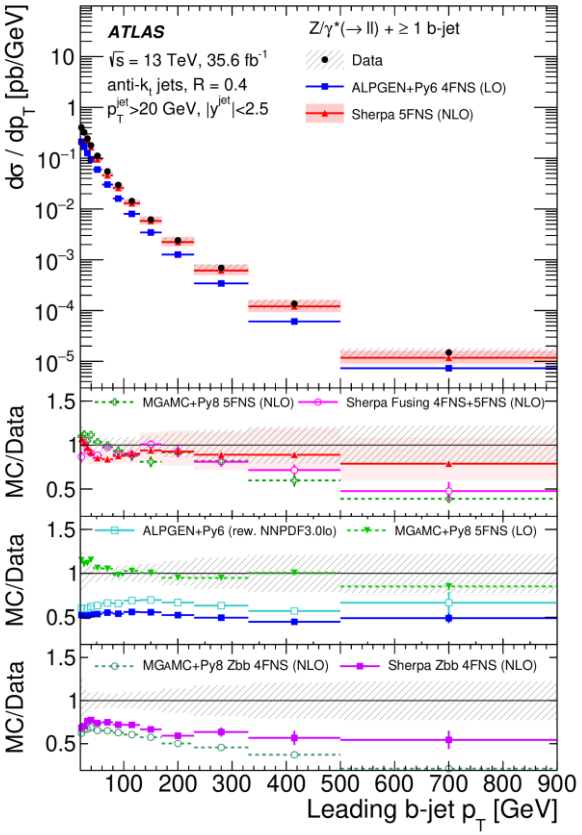
MG5_aMC@NLO and SHERPA at NLO overestimate the cross section, PDFs overestimate charm content?

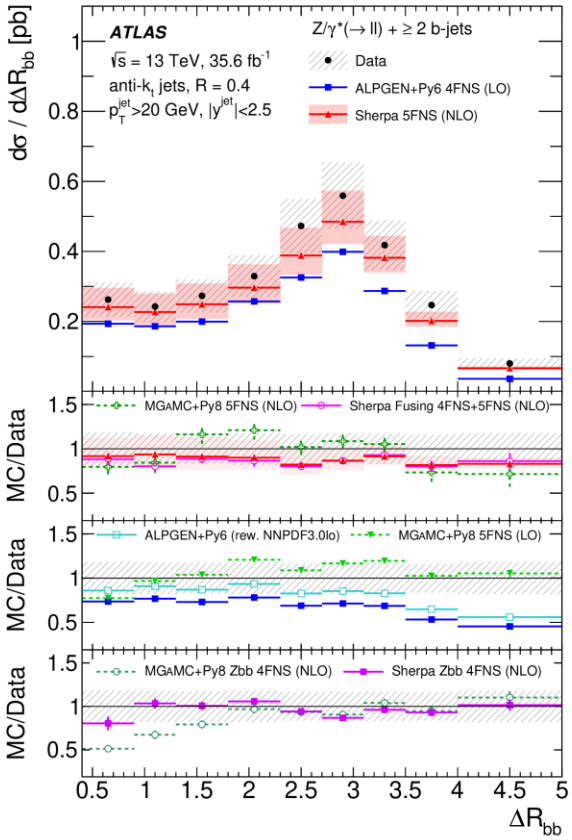
Z+b(b) production

Z+b(b): sensitive to gluon splitting, can probe b-quark PDF, provides input on flavor number scheme approaches, background to BSM searches. Z+b(b) component extracted from fit to flavor-sensitive distributions constructed from b-tagging output variables.

Fiducial and differential cross sections vs. Z and b-jet kinematics and angular separations → best agreement with 5-flavor scheme (5FNS) at NLO.



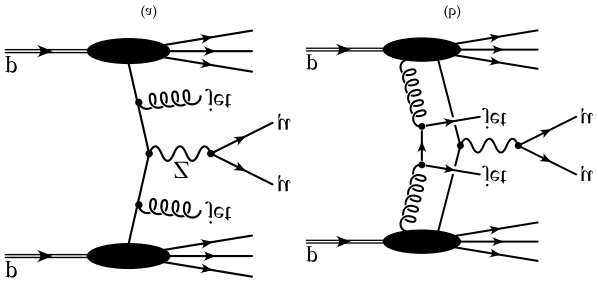


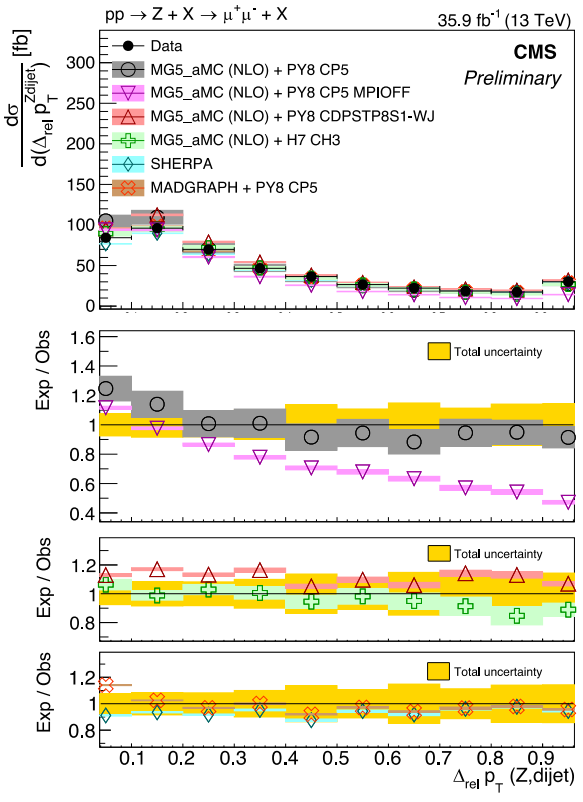


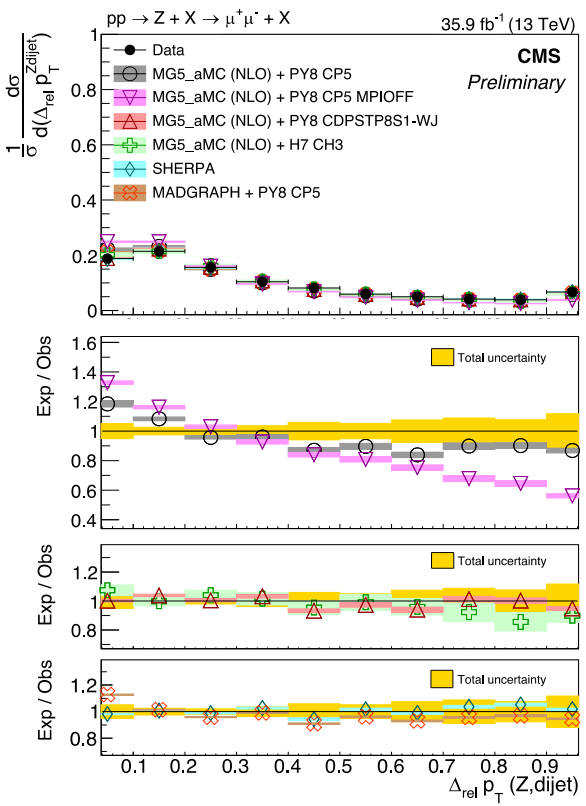
JHEP 07 (2020) 44

DPS in Z+jets

Differential and normalized cross sections of Z + ≥ 1 jet, and Z + ≥ 2 jets in relative p_T imbalance and azimuthal separation of the Z boson and the lead jet or dijet system. Such variables can help distinguish double-parton scattering (DPS) from SPS (jets are expected to balance each other in DPS but not SPS)







MG5_aMC + PYTHIA 8 with DPS specific tune CDPSTP8S1-WJ overestimates cross-sections by 10-15% but describes shapes.

MG5_aMC + PYTHIA 8 with CP5 describes the cross-sections w/some exceptions. Other MPI and hadronization models, i.e. SHERPA and MG5_aMC + HERWIG7, also describe data. Measurements are significantly sensitive to MPI.

CMS-SMP-20-009

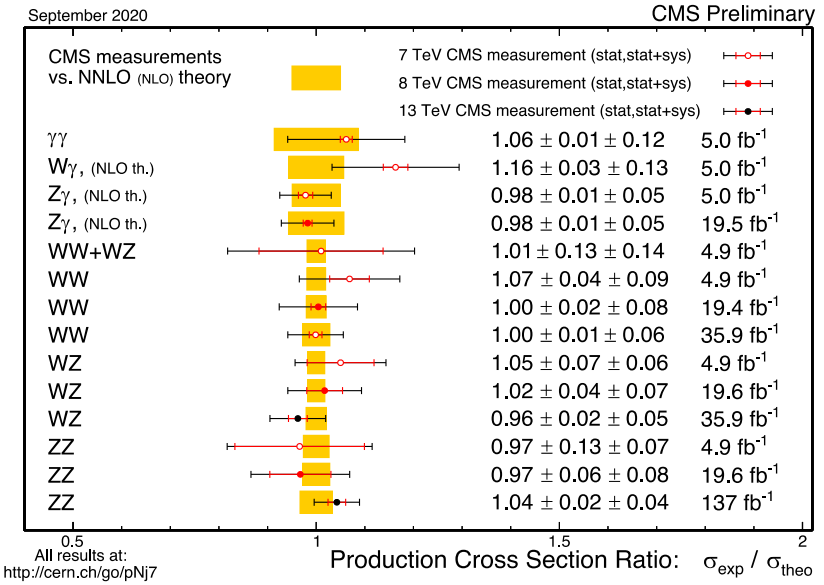
Multi-boson production

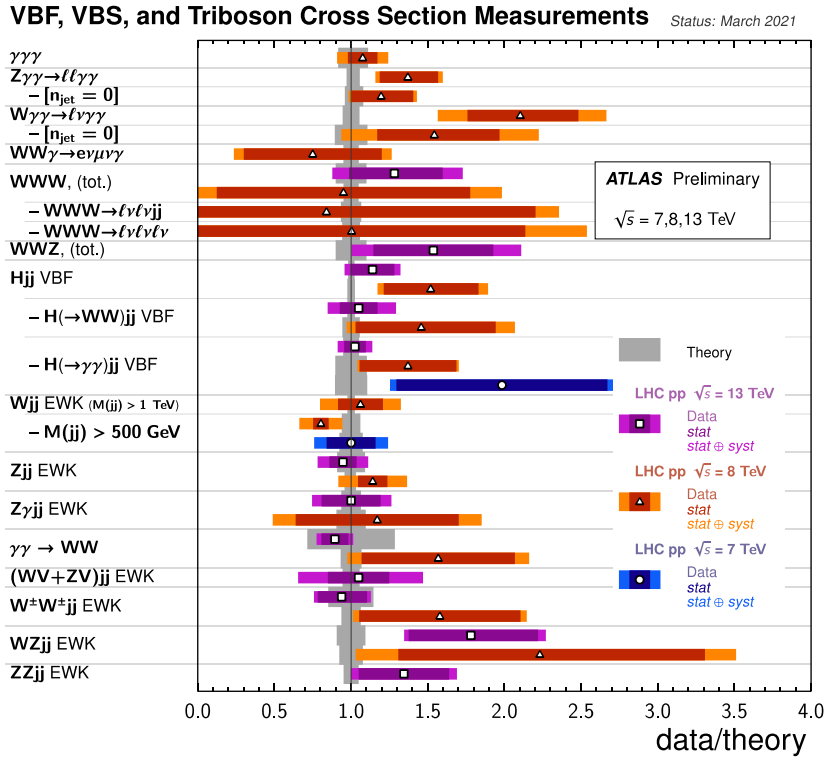
Backgrounds to Higgs and searches, sensitive to higher order corrections.
Tests of the SM EW gauge structure.

Anomalous vector boson couplings:
new physics at higher scales leading to modified couplings → probe for σ increase.
aTGC constrained w/ inclusive VV and EW Vjj.
aQGC constrained w/ EW VVjj and VVV.

$$L_{\mathrm{EFT}} = L_{\mathrm{SM}} + \sum_i \frac{\bar{C}_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_i \frac{\bar{C}_i^{(8)}}{\Lambda^4}\mathcal{O}_i^{(8)} + \dots$$

Many recent 13 TeV results in good agreement with SM. Inclusive di-boson cross section measurements dominated by systematic uncertainties, but we are now increasingly sensitive to rare processes, tri-bosons and vector boson scattering (VBS)

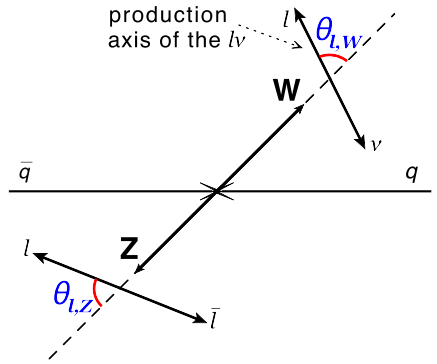


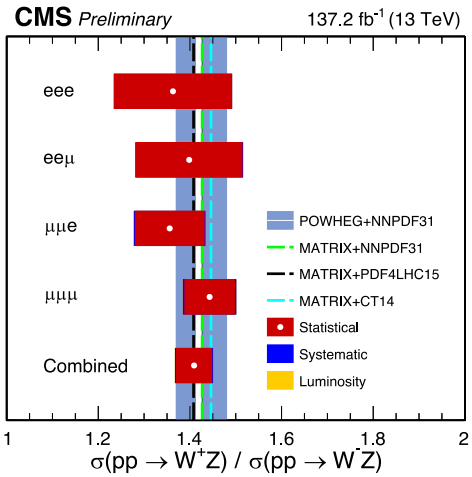


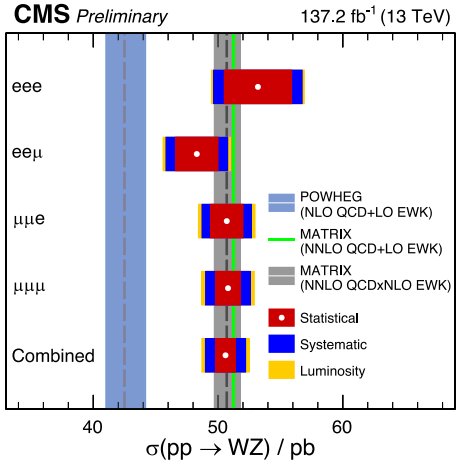
WZ production

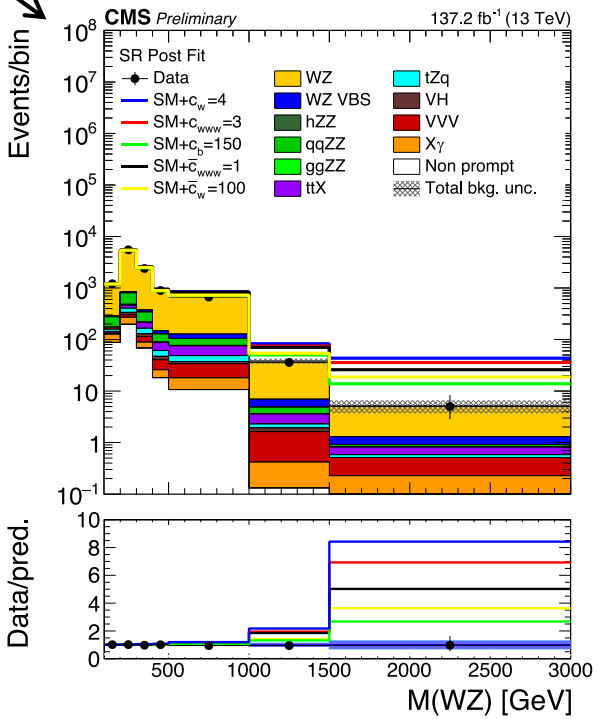
CMS-SMP-20-014

WZ with leptonic final states (e and μ): new 13 TeV results include inclusive total and differential cross-sections, charge asymmetry, search for aTGCs, polarization

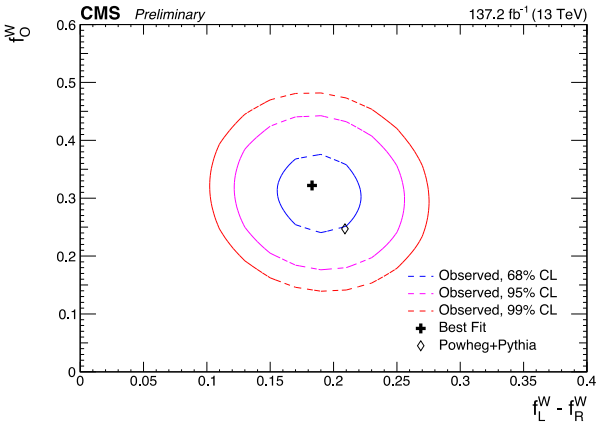








First observation of longitudinally polarized W's in WZ: using lepton angular distributions and template fits to $q_\ell \cos\theta_{\ell,W(Z)}$ →5.6σ obs (4.3σ exp).



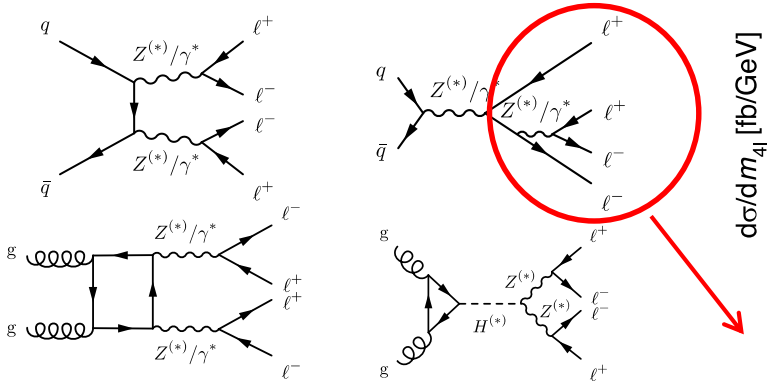
Most stringent constraints in WZ on dim-6 operators (including CP violating ones)

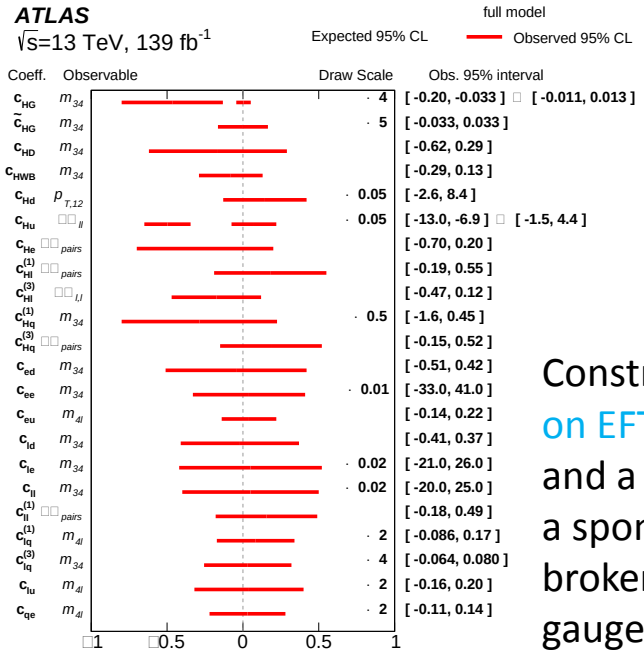
Parameter	95% CI, Exp. (TeV^{-2})	95% CI, Obs. (TeV^{-2})	Best fit, Obs. (TeV^{-2})
c_w/Λ^2	$[-2.05, 1.27]$	$[-2.52, 0.33]$	-1.34
c_{www}/Λ^2	$[-1.27, 1.33]$	$[-1.04, 1.19]$	0.15
c_b/Λ^2	$[-86.0, 125.0]$	$[-42.7, 113.0]$	43.6
$\tilde{c}_{www}/\Lambda^2$	$[-0.76, 0.65]$	$[-0.62, 0.53]$	-0.03
$\tilde{c}_w/\Lambda^2$	$[-46.1, 46.1]$	$[-45.9, 45.9]$	0.0

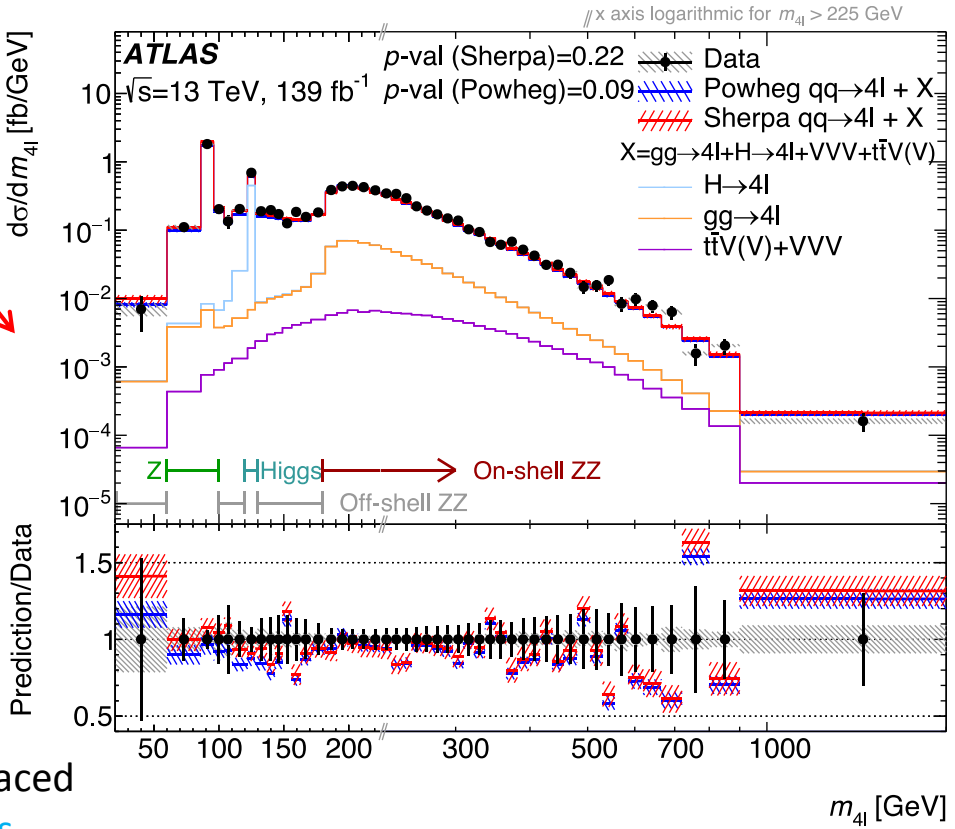
Total inclusive cross-section best agreement with MATRIX NNLO QCD + NLO EW

4 leptons final state

Measurements of four-lepton differential and integrated fiducial cross-sections in events with two same-flavor, opposite-charge electron or muon pair. Final state has contributions from ZZ, Z, H, VVV, and $t\bar{t}V$.







Constraints are placed on EFT parameters and a model based on a spontaneously broken Baryon-Lepton gauge symmetry.

Most precise measurement of $Z \to 4\ell$ branching fraction to date: $(4.41 \pm 0.30) \times 10^{-6}$

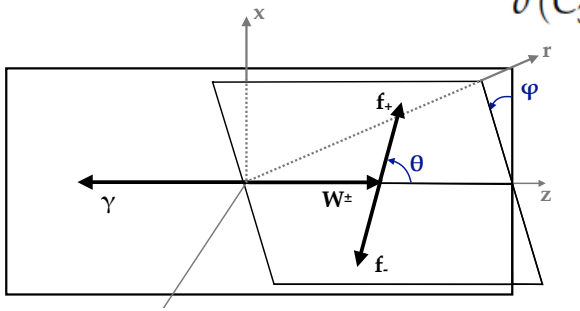
arXiv:2103.01918. Submitted to JHEP

Wγ production

Measurements of (double-)differential cross-sections in photon p_T and angular observables set constraints on anomalous WWγ couplings via novel EFT techniques (interference resurrection arXiv:1708.07823) →enhanced sensitivity to SM dim-6 interference operators.

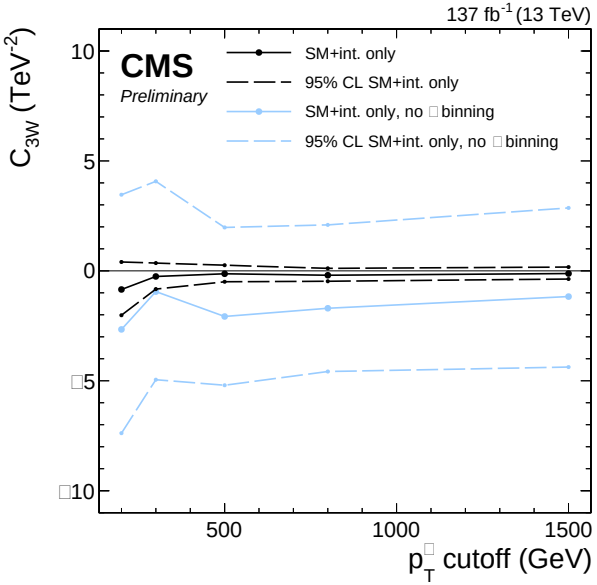
$$\mathcal{L}_{\text{EFT}} = \mathcal{L}_{\text{SM}} + \sum_i C_i^{(6)} \mathcal{O}_i^{(6)} + \sum_i C_i^{(8)} \mathcal{O}_i^{(8)} + \cdots, \quad \mathcal{O}_{3W} = \epsilon^{ijk} W_\mu^{iv} W_\nu^{j\rho} W_\rho^{k\mu}$$

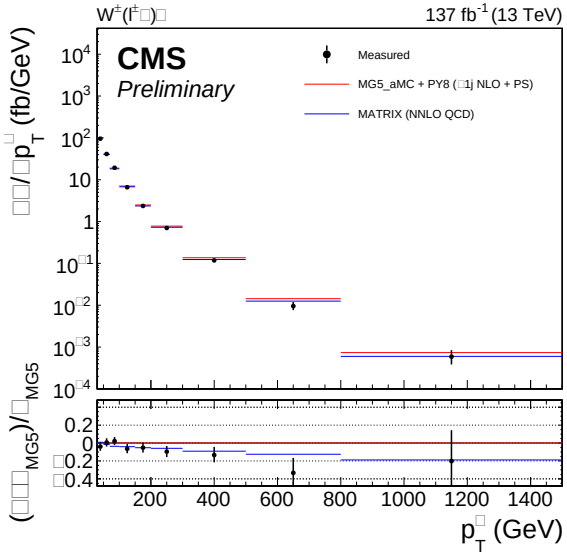
$$\sigma(C_{3W}) = \sigma_{\text{SM}} + C_{3W}\sigma_{\text{int}} + C_{3W}^2 \sigma_{\text{BSM}}$$

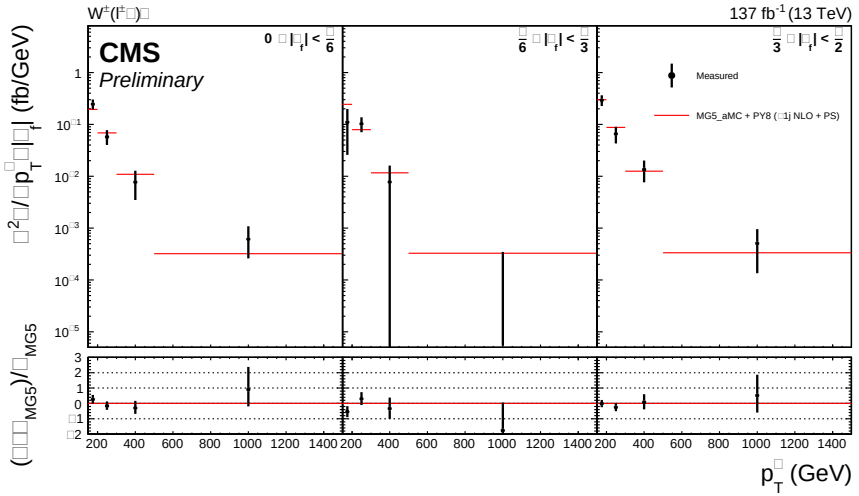


Interference effect of $\mathcal{O}_{3W}$ and SM on cross-section

Sensitivity on c_{3W} improved by use of angular variables



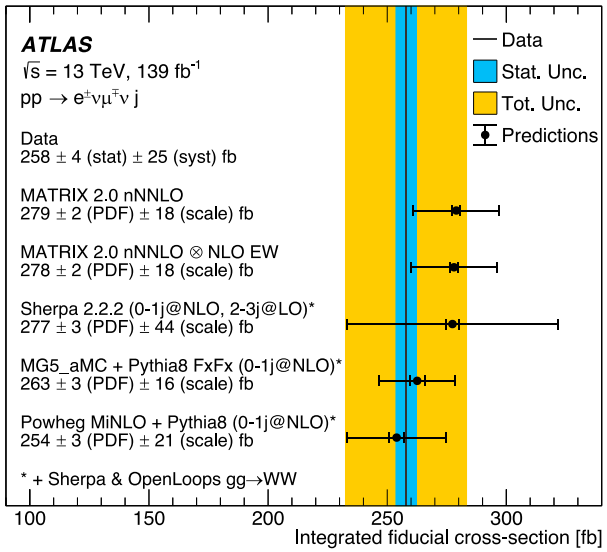


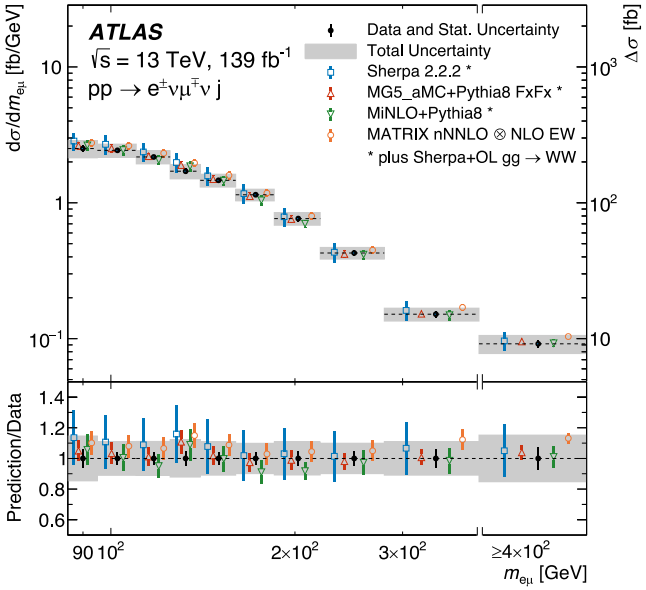


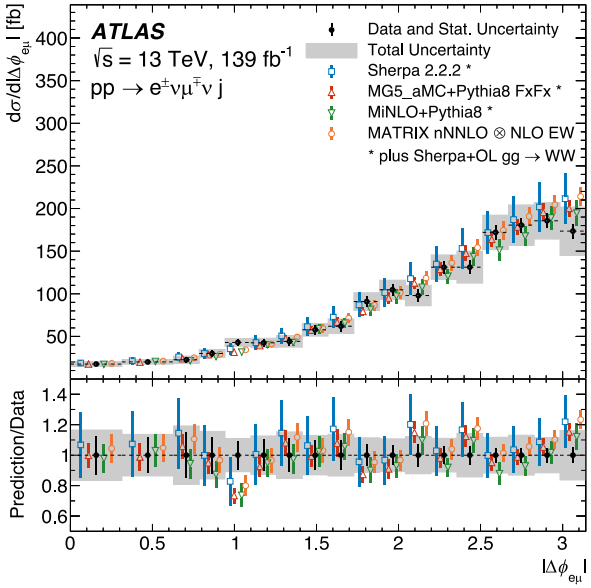
CMS-SMP-20-005

WW+≥1 jet production

Precise total fiducial and differential measurements of cross-sections in several leptonic and jet kinematic observables. Constraints on aTGC couplings are obtained in a phase space where interference between the SM amplitude and the anomalous amplitude is enhanced (by a hard cut on jet p_T> 200 GeV).







Good agreement with predictions in all distributions. Precise measurement of WW with jets (~10% uncertainty) in a previously unexplored event topology.

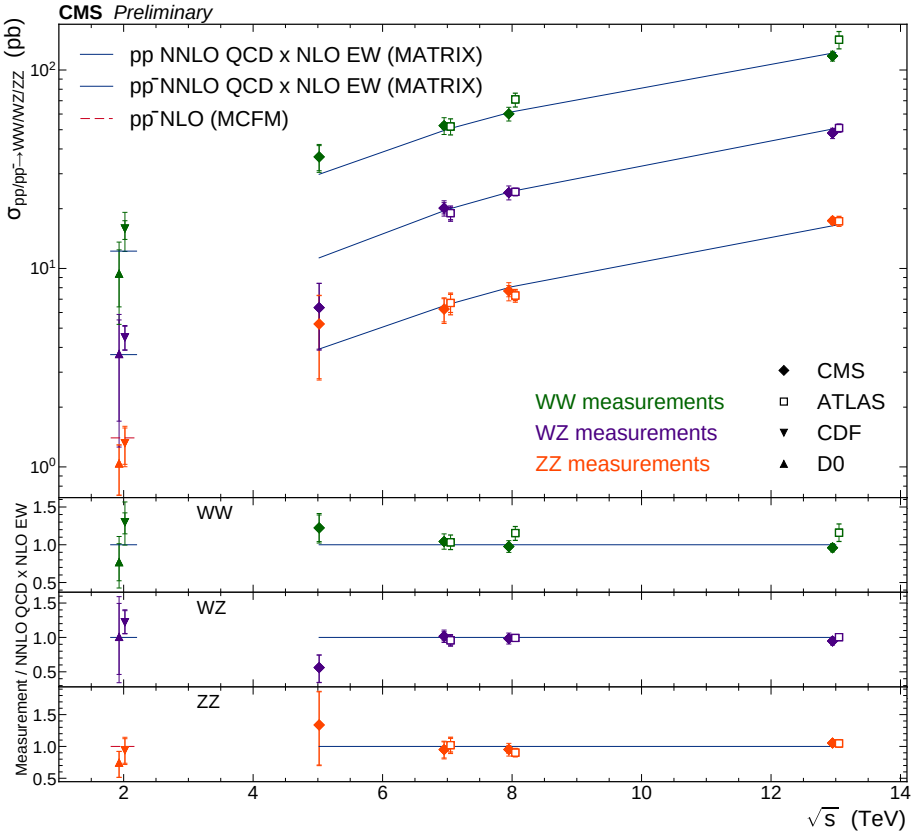
arXiv:2103.10319, Submitted to JHEP

VV production at 5.02 TeV

First measurements of total WW, WZ, and ZZ cross-sections at 5.02 TeV.
Use special low pileup run with integrated luminosity of 304 pb^{-1} and leptonic (e and μ) final states.

Process	Estimation	Total cross section [pb]
WW	MATRIX	$29.8\ ^{+0.7}_{-0.6}(\text{scale})$
	Measured	$36.5^{+5.5}_{-5.1}(\text{stat})^{+2.6}_{-2.5}(\text{syst})$
WZ	MATRIX	$11.3\ ^{+0.2}_{-0.2}(\text{scale})$
	Measured	$6.4^{+2.4}_{-2.1}(\text{stat})^{+0.5}_{-0.3}(\text{syst})$
ZZ	MATRIX	$3.9\ ^{+0.1}_{-0.1}(\text{scale})$
	Measured	$5.3^{+2.5}_{-2.0}(\text{stat})^{+0.5}_{-0.4}(\text{syst})$

Measured cross-sections are in agreement with NNLO QCD + NLO EW predictions from MATRIX

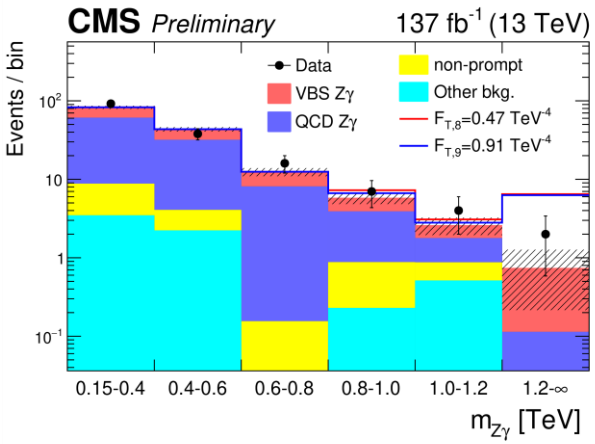


CMS-SMP-20-012

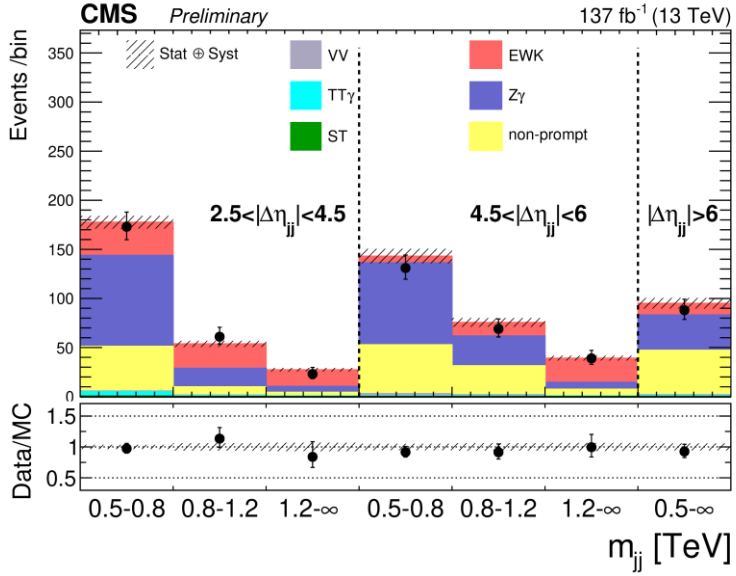
EW production of Zγjj and ZZjj

Vector Boson Scattering (VBS): Probes EWSB. 2 forward jets separated in rapidity, with low hadronic activity in between. Many new results for VVjj, increasingly more precise.

CMS-SMP-20-016



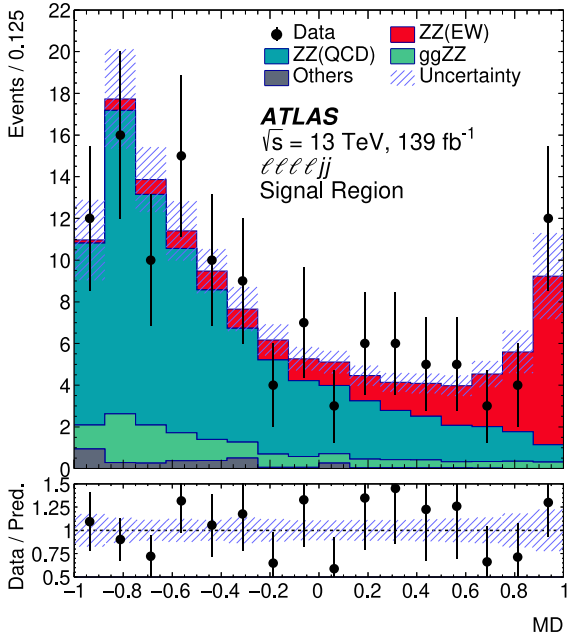
Zγjj



Zγjj (CMS): Observed significance much greater than 5σ. Stringent limits on dim-8 aQGCs from fits to $m_{Z\gamma}$ mass.

ZZjj(ATLAS) Observation with 5.5σ

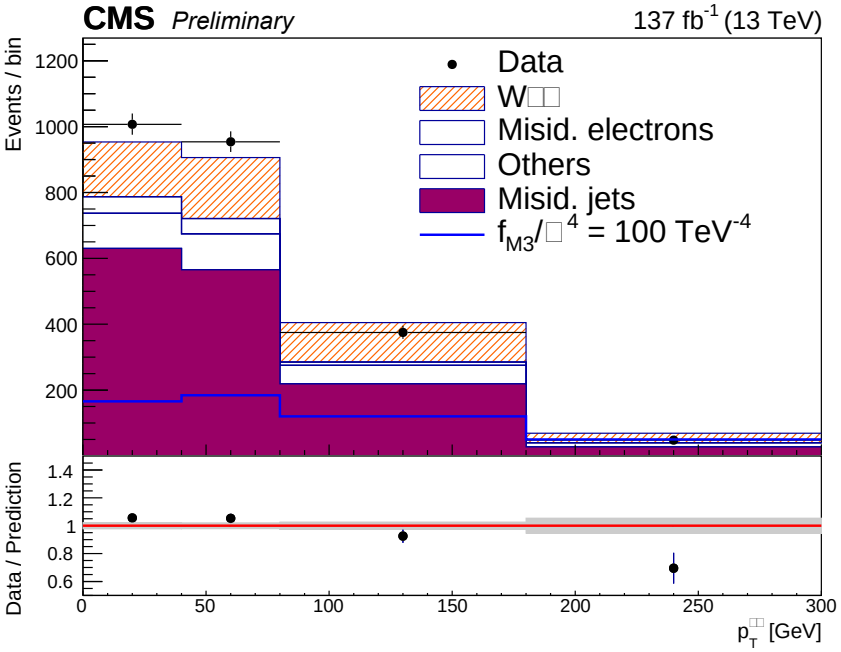
ZZjj

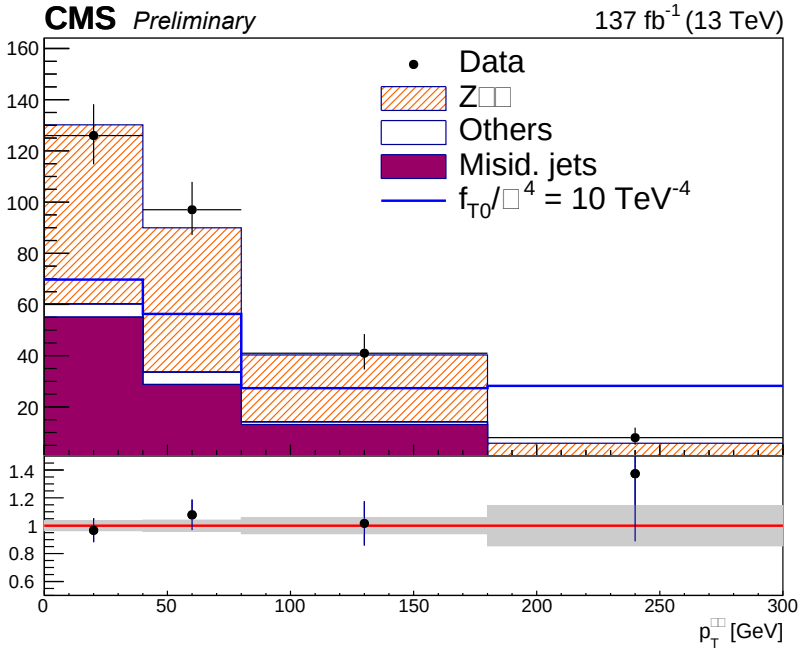


arXiv:2004.10612, Submitted to NPHYS

Wγγ and Zγγ production

First measurement of Vγγ production at 13 TeV. Leptonic W, Z decays. Rare process, sensitive to new physics.





CMS-SMP-19-013

$\sigma(W\gamma\gamma) = 13.63\ ^{+1.93}_{-1.89}\ (\text{stat.})\ ^{+4.04}_{-4.02}\ (\text{syst.}) \pm 0.08\ (\text{PDF+scale})$ fb

$\sigma(Z\gamma\gamma) = 5.41\ ^{+0.58}_{-0.55}\ (\text{stat.})\ ^{+0.64}_{-0.70}\ (\text{syst.}) \pm 0.06\ (\text{PDF+scale})$ fb

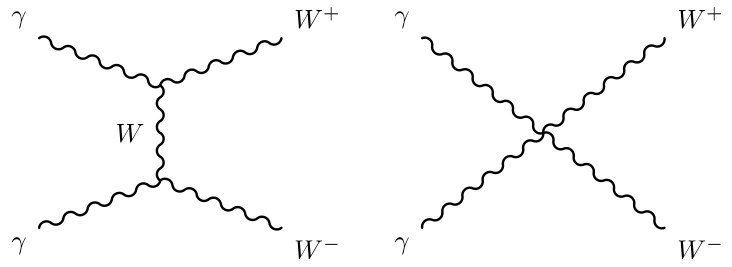
Observed 3.1σ(4.5σ exp) Wγγ and 4.8σ(5.8σ exp) Zγγ signals.

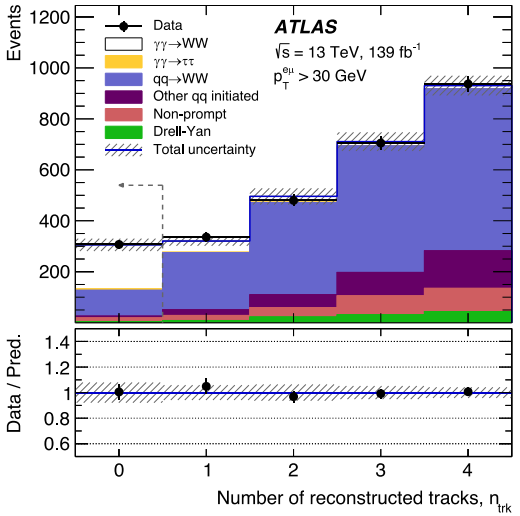
Cross-sections measured in agreement with NLO predictions.

Constraints on dim-8 aQGCs are set from fits to $p_T^{\gamma\gamma}$.

Observation of $\gamma\gamma \to W^+W^-$

First observation of photon-induced production of W boson pairs. Process occurring through tri-linear and quartic gauge couplings. Measurement of cross-section tests gauge structure of SM.



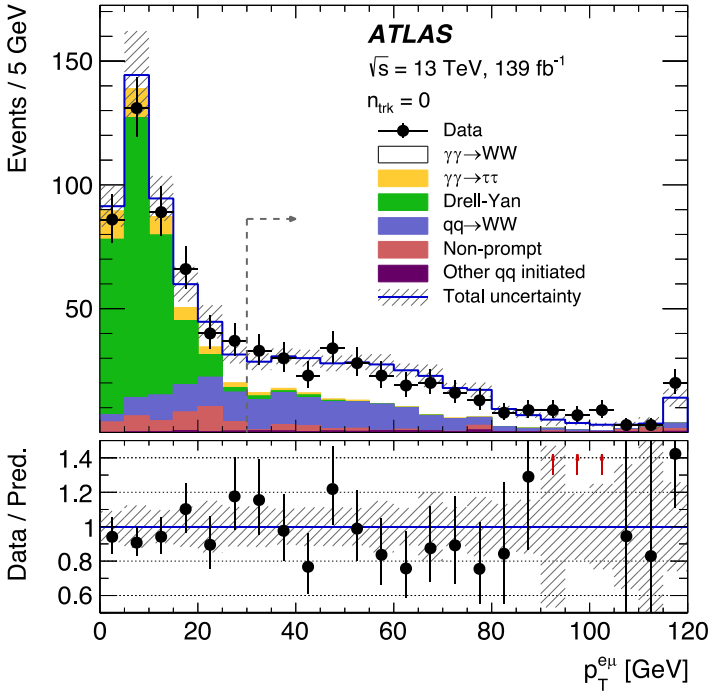


Final state of opposite sign eμ. No additional tracks in the vicinity of the interaction vertex, modelling of hadronic background from same flavor DY.

Observed significance 8.4σ(6.7σ exp)

σ_{meas}= 3.13 ± 0.31(stat.) ± 0.28 (syst) fb

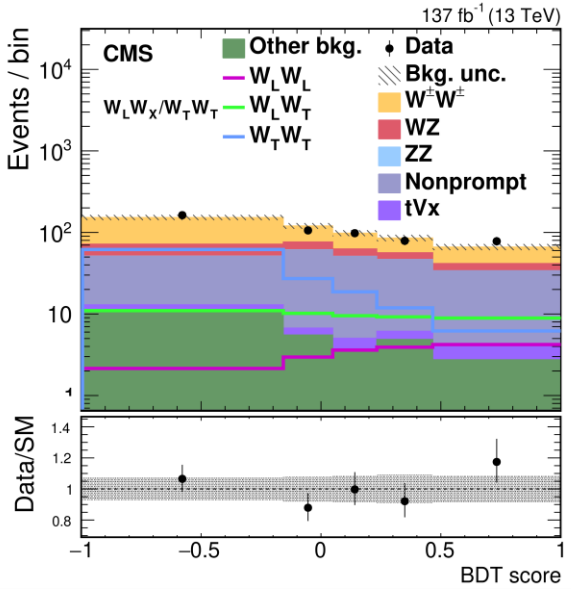
Result in agreement with theory prediction. It might serve as input to EFT interpretations.



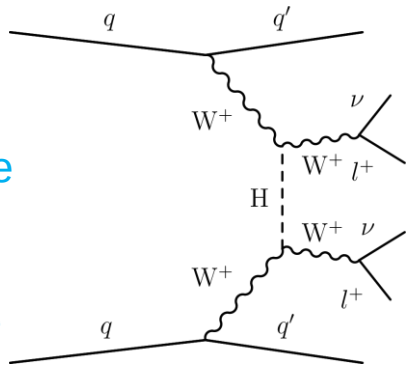
Phys. Lett. B 816 (2021) 136190

Polarized $W^{\pm}W^{\pm}$ scattering

First measurement of production cross sections for polarized same-sign WW scattering. Unitarity of the tree-level amplitude of the scattering of longitudinally polarized gauge bosons at high energies is restored in the SM by the Higgs boson.



Kinematic differences are exploited via BDTs to separate VBS from non-VBS and disentangle the various scattering processes.



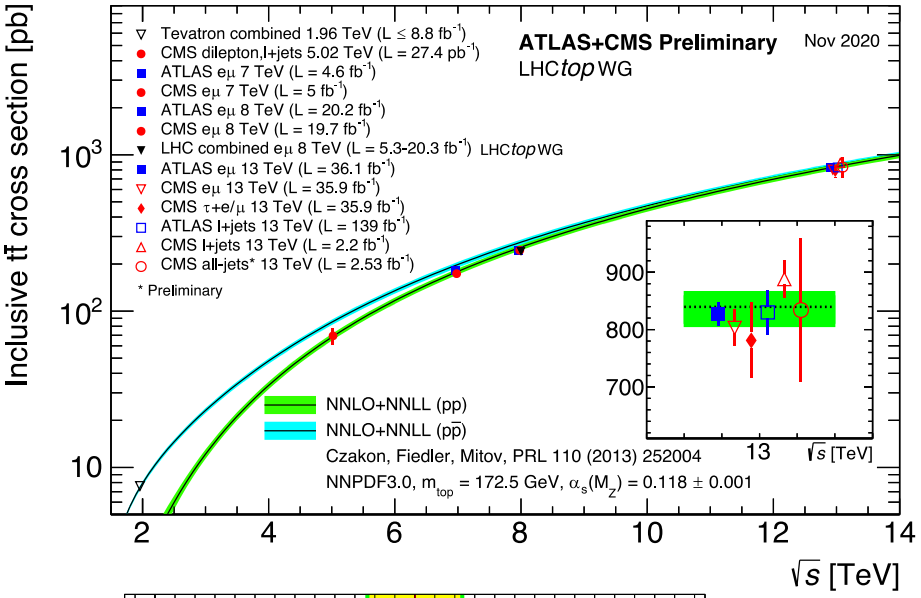
Phys. Lett. B 812 (2020) 136018

Process	$\sigma\,\mathcal{B}$ (fb)	Theoretical prediction (fb)
$W_L^{\pm}W_L^{\pm}$	$0.32^{+0.42}_{-0.40}$	0.44 ± 0.05
$W_X^{\pm}W_T^{\pm}$	$3.06^{+0.51}_{-0.48}$	3.13 ± 0.35
$W_L^{\pm}W_X^{\pm}$	$1.20^{+0.56}_{-0.53}$	1.63 ± 0.18
$W_T^{\pm}W_T^{\pm}$	$2.11^{+0.49}_{-0.47}$	1.94 ± 0.21

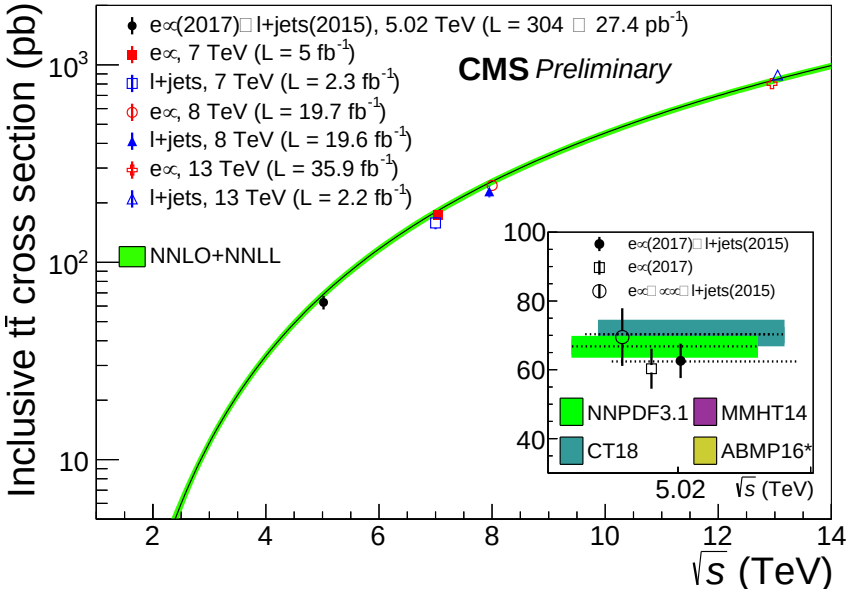
EW production of the $W^{\pm}W^{\pm}$ boson pairs with at least one W_L (W_LW_X) is measured with 2.3σ (3.1σ exp) significance.

Top Pair production

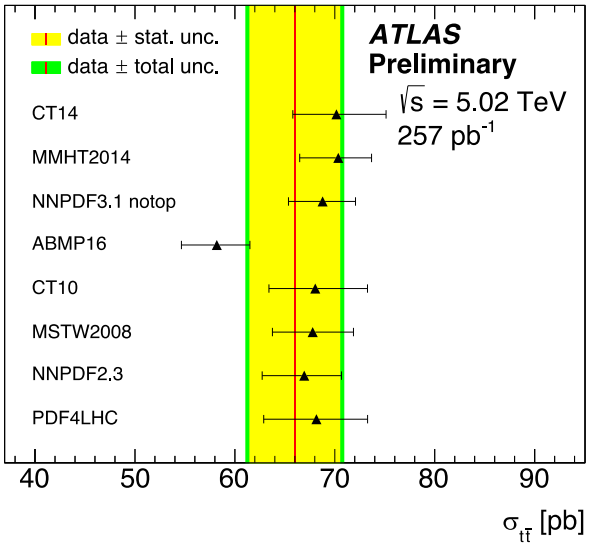
LHC as a Top factory: precision physics! Pair production results in excellent agreement with NNLO+NNLL theory ⟶



New σ_{tt} cross section results at 5.02 TeV:



CMS-TOP-20-004



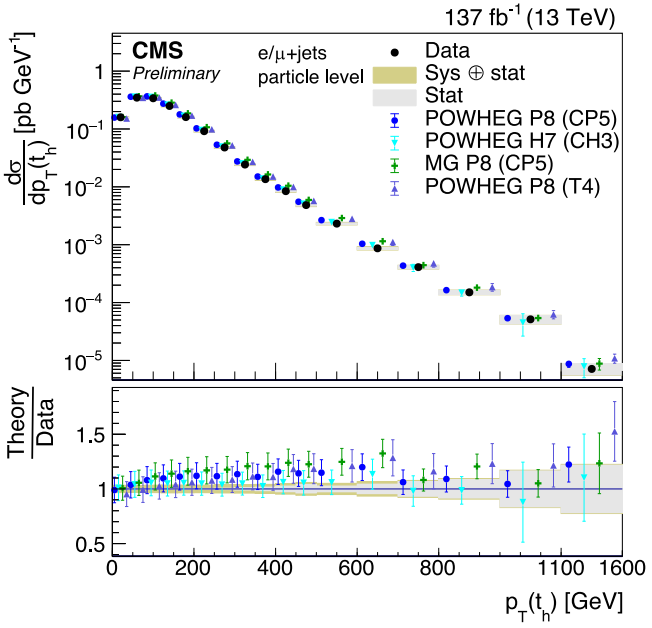
ATLAS-CONF-2021-003

$\sigma(tt)_{CMS}$= 62.6 ± 4.1(stat.) ± 3.0(syst.+lumi) pb

$\sigma(tt)_{ATLAS}$= 66.0 ±4.5(stat.) ±1.6(syst.) ±1.2(lumi) ±0.2(beam) pb

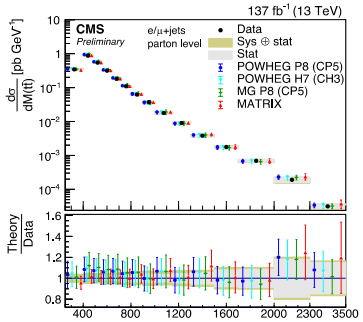
Differential σ_{tt} cross-sections

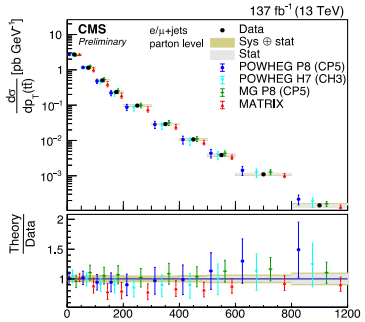
High precision, most comprehensive set of measurements of single and double differential σ_{tt} at 13 TeV: for the first time, combined fit of resolved and boosted in ℓ+jets (e and μ)

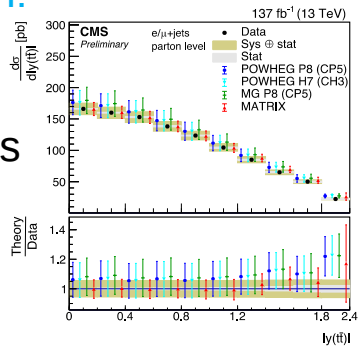


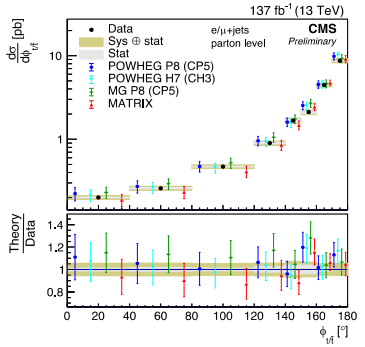
[CMS-TOP-20-001]

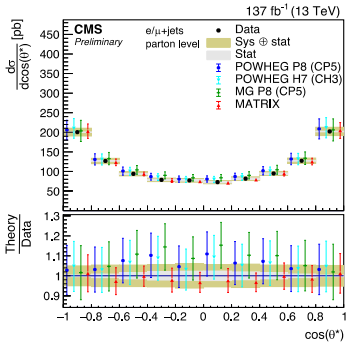
Inclusive cross section:
σ_{tot}= 791 ± 25 pb
most precise measurement in ℓ+jets











Most differential distributions compatible with predictions of POWHEG +PYTHIA, POWHEG +HERWIG, and MG5_aMC@NLO +PYTHIA.

Parton-level cross sections compared to MATRIX at NNLO QCD (w/ significantly smaller theory uncertainty).

A softer top quark p_T spectrum is observed in comparison to most of the NLO predictions.

EW Top production, σ_t and mass

EW Single top quark measured σ in agreement with NLO+NNLL predictions.
Most recent measurement: σ_{tW} in semi-leptonic decay: 89 ± 4(stat.) ± 12(syst) pb

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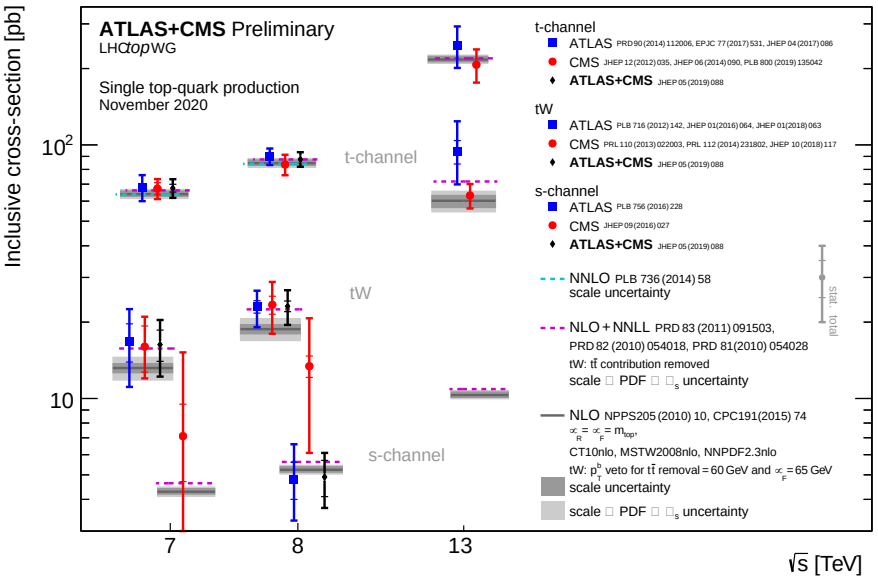
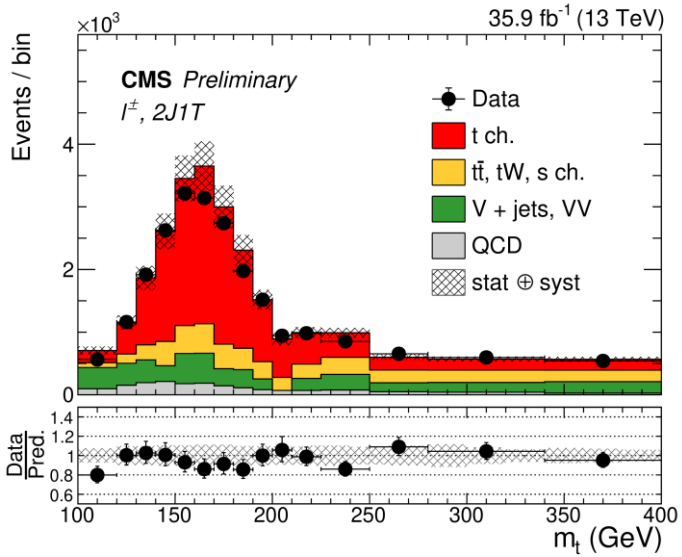
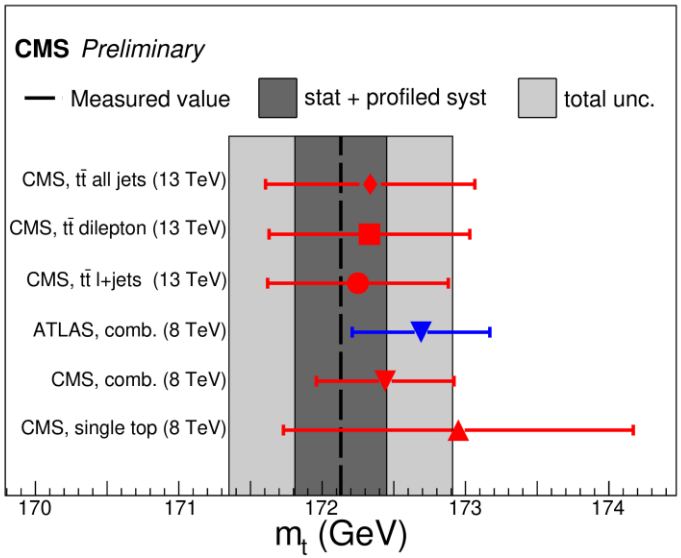


Measurement of m_{top} in single top events (e, μ, and exactly 2 jets of which 1 b-jet).
Multivariate techniques (BDTs) are used to increase signal purity.
Top and anti-top mass are also measured separately (test of CPT invariance).

$m_{top}=172.13^{+0.76}_{-0.77}$ GeV. Separate top/anti-top masses consistent with CPT invariance





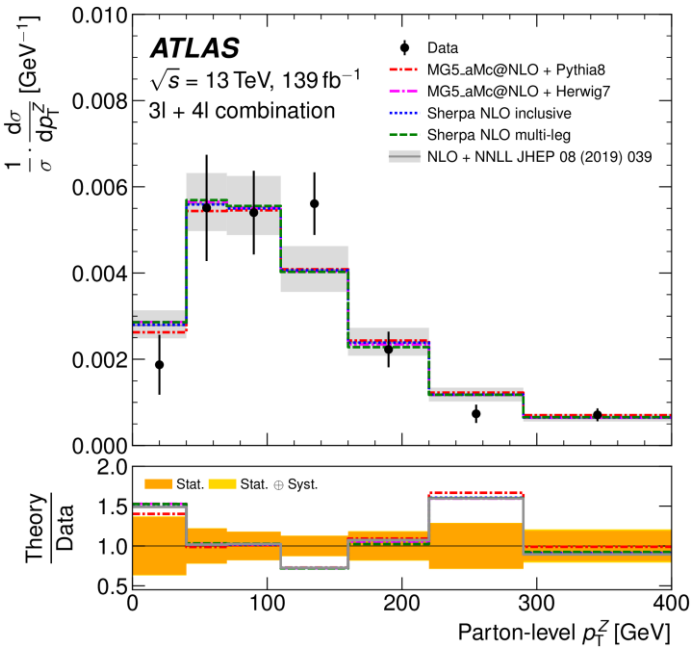
CMS-TOP-19-009

Associated production ttX

Associated production ttX provides a direct probe into top quark couplings, which can be modified in BSM models. The measurements are reaching a greater precision, with more EFT interpretations

ttZ: inclusive and differential measurements in the 3 and 4 leptons decay channel, in agreement with predictions.

σ_{ttZ}=0.99 ± 0.05(stat.) ± 0.08(syst) pb



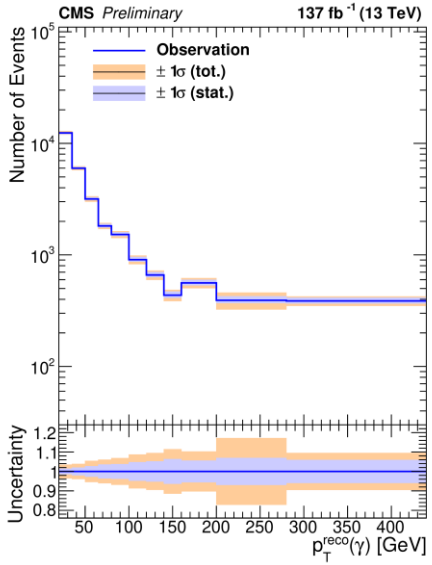
arXiv:2103.12603, Submitted to EPJC

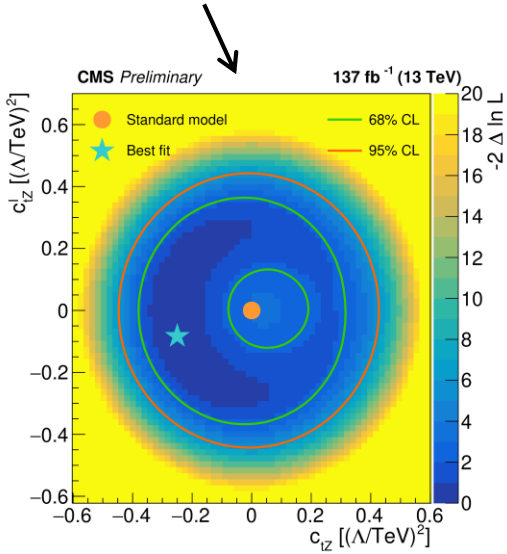
ttγ: events with a lepton (e or μ), ≥3 jets and one isolated γ (ISR, or from top, or its decay products). Likelihood fits in several signal and control regions. Fiducial cross-section measured in agreement with predictions:

$\sigma_{tt\gamma}$=800 ± 46(stat.) ± 7(syst) fb

CMS-TOP-18-010

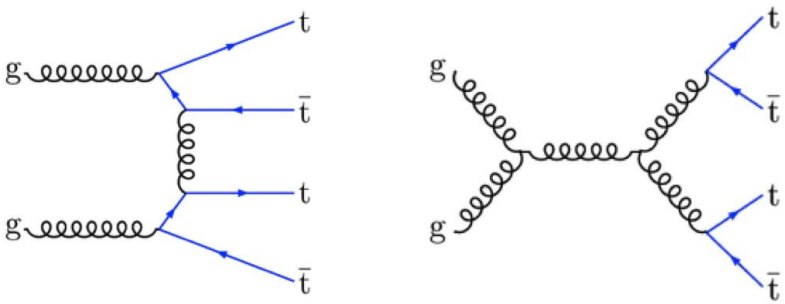
Absolute and normalized differential cross sections in $p_T(\gamma)$, $|\eta(\gamma)|$, $\Delta R(\ell,\gamma)$ are measured and interpreted with SMEFT. Strongest constraints on c_{tZ} and c^{I}_{tZ}

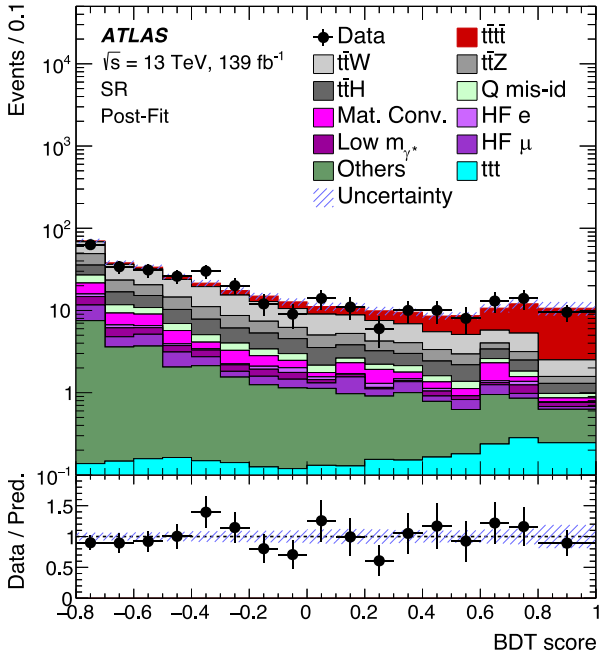


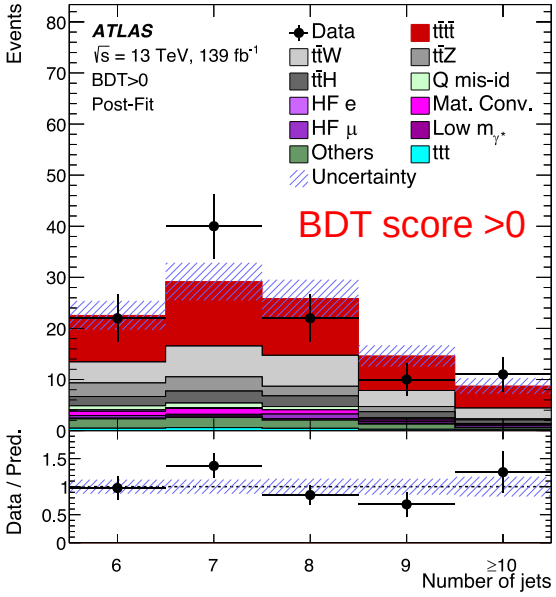


Rare Top processes, 4 tops

$t\bar{t}t\bar{t}$: very rare production! Sensitive to new physics (e.g. high mass scalars), Top Yukawa coupling. Most recent search selects events with one or two opposite sign leptons, high jet and b-jet multiplicities (main background is tt+jets). The signal is extracted via profile likelihood fit of the BDT score distribution, sensitivity is improved by combining channels.







The signal is extracted with a significance of 4.7σ (2.6σ exp). The cross section is compatible with SM predictions.

$\sigma_{tttt}=26^{+17}_{-15}$ fb

Eur. Phys. J. C 80 (2020) 1085

ATLAS-CONF-2021-013

Conclusions

Broad range of Standard Model Electroweak, QCD, and Top quark physics results with 8 TeV, and 13 TeV data from the LHC experiments, deepen and challenge our understanding of Electroweak interactions and their theoretical modeling.

Era of precision physics: Increasingly more precise and complex SM measurements now dominate on dedicate direct searches in probing for new physics.

The full set of ATLAS, CMS, and LHCb results is available at
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/WebHome#PhysicsGroups
http://cms-results.web.cern.ch/cms-results/public-results/publications/
https://lhcbproject.web.cern.ch/lhcbproject/Publications/p/Summary_all.html
and many are discussed in detail in the parallel sessions.

Thank you!

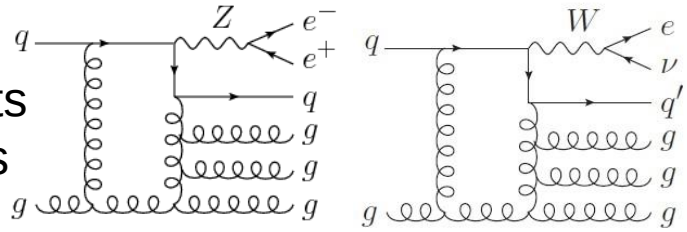
Photo credits: CERN

Back up slides

V(Z,W,γ)+jets

Z, W, and γ + light jets differential cross sections:

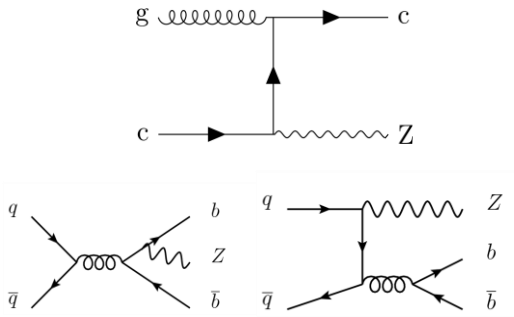
- tests of pQCD and non perturbative (NP) effects
- sensitive to higher order (QCD and EW) effects
- backgrounds to BSM searches.
- inputs to u/d/gluon PDFs



Measured cross-sections are compared to multi-leg LO, NLO(+PS) MCs, and to NLO and NNLO fixed-order theoretical calculations.

Z, W, and γ + heavy flavor (HF) jets differential cross sections:

- tests of pQCD and NP. Sensitive to higher order effects and details of the production mechanism.
- sensitive to the modelling of PDFs:
  - ✓ strange quark PDF and asymmetries in $s - \bar{s}$: W+c
  - ✓ charm quark PDF (and intrinsic charm): Z+c and γ+c
  - ✓ bottom quark PDF: Z+b(b) and γ+b
- background processes to BSM searches.

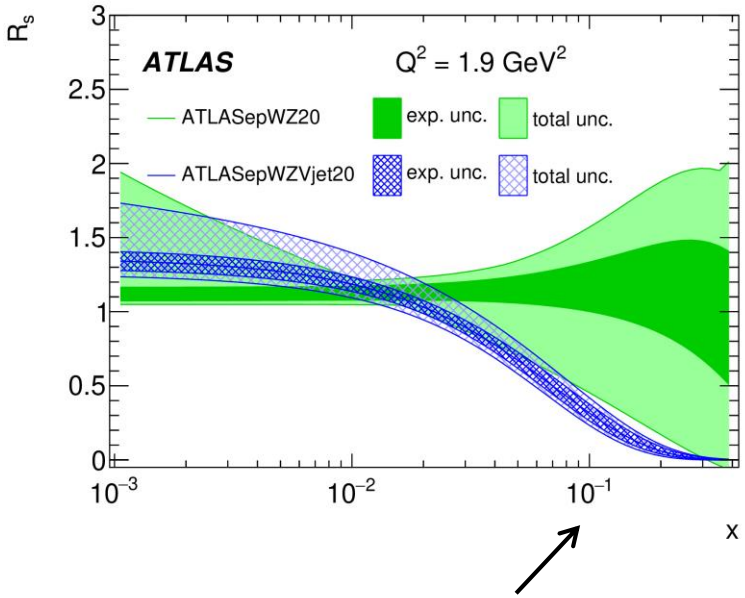


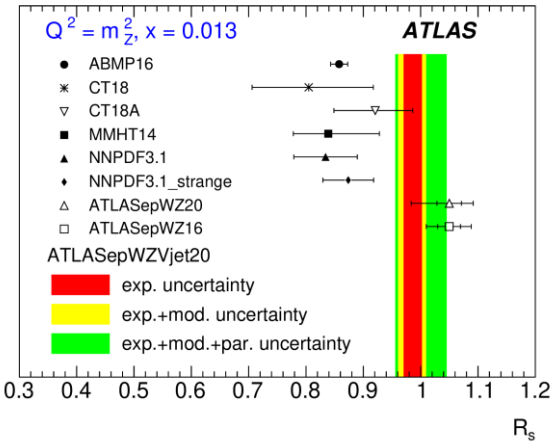
Use HF jet tagging and bottom/charm separation. Higher backgrounds than V+light jets. Model uncertainties include flavor scheme (FS), quark masses, gluon splitting.

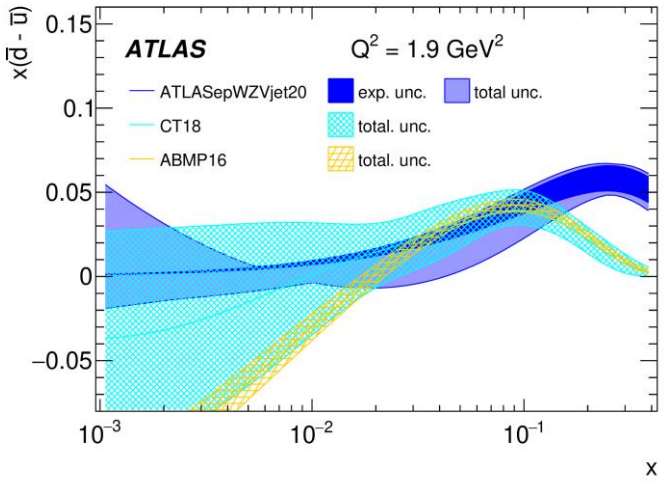
HF jet tagging: c-/b-taggers, semileptonic hadron decays, exclusive hadrons reconstruction.

V(Z,W)+jets constraints on PDFs

Proton parton distribution function - ATLASepWZVjet20 - produced in NNLO QCD analysis by ATLAS using differential measurements of W^+ and W^-+jets and Z+jets at 8 TeV, in addition to previously used 7 TeV W/Z differential measurements from ATLAS and HERA DIS data.







Adding V+jets improves determination of sea-quark densities at high-x. Sea-quark density at low-x consistent with results in previous ATLAS PDF fits.

arXiv:2101.05095, Submitted to JHEP