Measurements Of Top Production And Properties At The LHC

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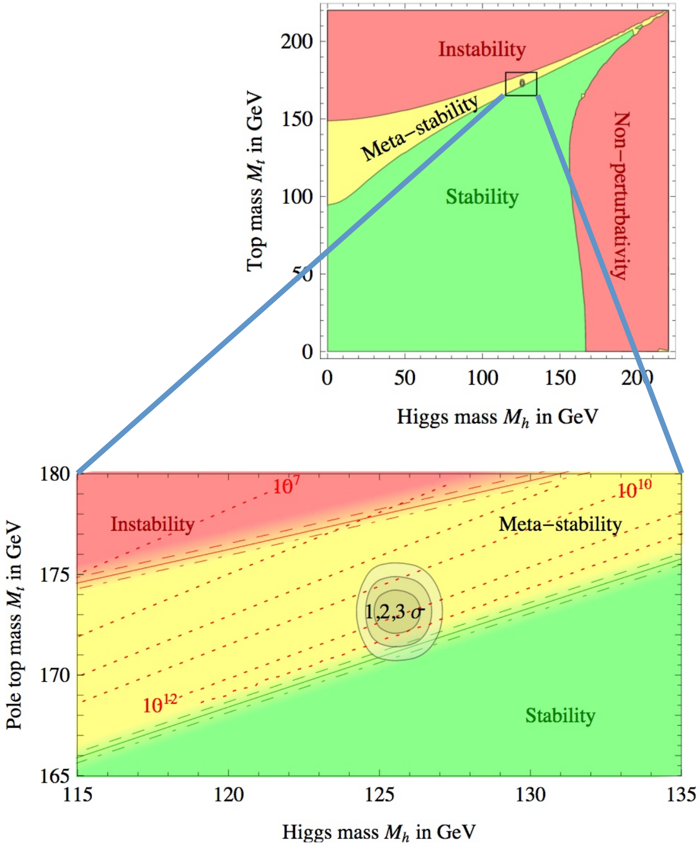
On behalf of ATLAS and CMS collaborations

Les Rencontres de Physique de la Vallée d'Aoste, La Thuile 2019

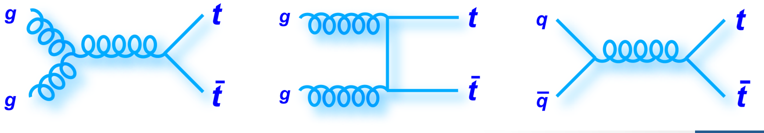
Why Is The Top-Quark So Interesting

arXiv:1205.6497

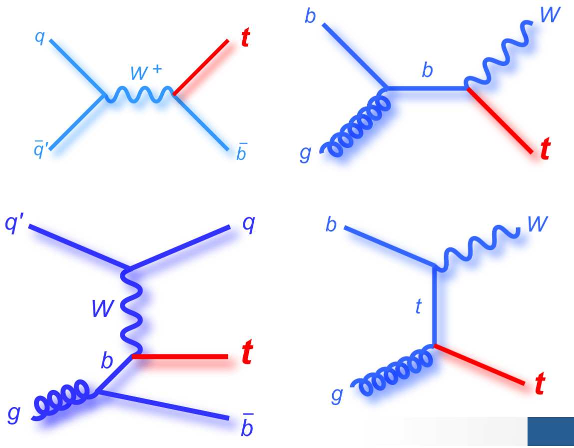
- Top-quark is 40 times heavier than the b (doublet)
  - Same mass scale as gauge bosons: Connection to EWSB?
  - Top Yukawa is almost exactly 1: coincidence?
  - Meta-stability of SM: valid up to Planck Scale
  - Mass would need to be tested precisely at e^+e^- colliders
- Heaviest SM particle and produced abundantly
  - Cross-section between 0.2 and 0.8 nb
  - Important background to BSM searches
  - May couple to New Physics
- Top decays before hadronisation (lifetime < Λ_{QCD})
  - Study the properties of the pseudo-bare quark
- With the full Run-2 datasets, more than 10^8 top pairs have been produced. Statistic is often not the limiting factor. Time for precision in the systematics!!!



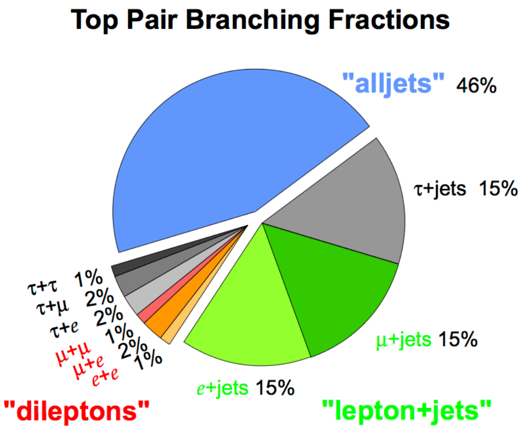
Top Production And Decay



- Top pair production at the LHC governed by strong interaction
  - Gluon-gluon fusion (~90% at 13 TeV)
  - Quark-antiquark annihilation (10% at 13 TeV)



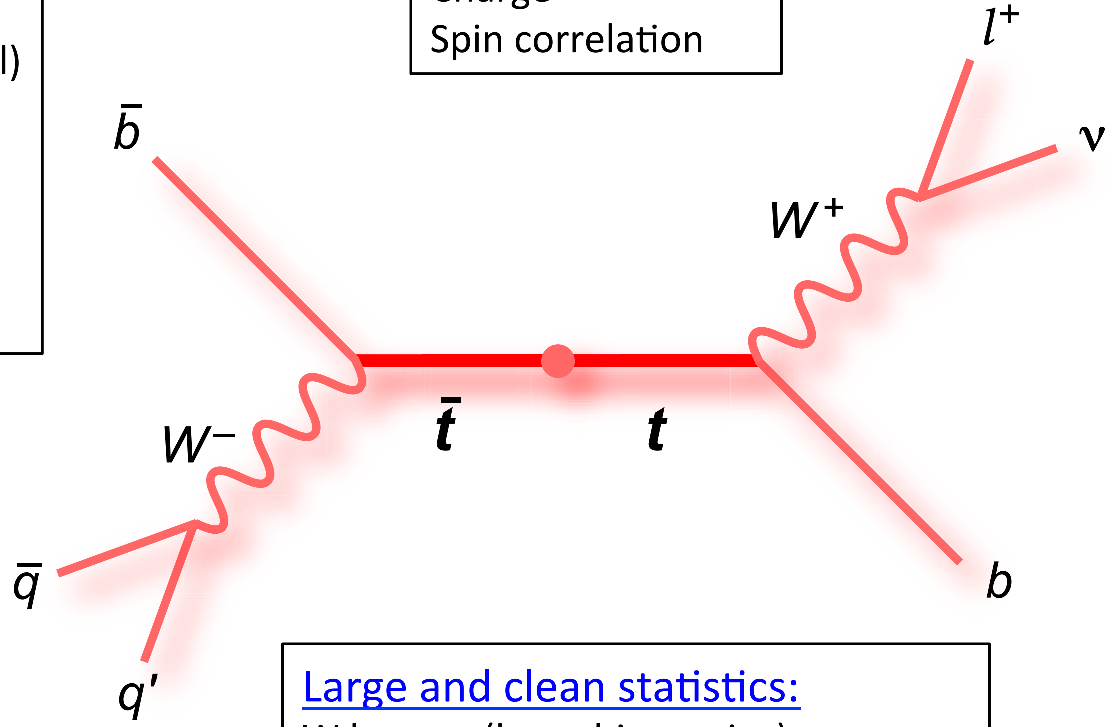
- Single top production via EW interaction:
  - Exchange of a virtual W boson in the s and t channels
  - Production in association with a real W boson
- Decays (electrons and muons only)
  - **Dilepton [4%]** cleanest signature, but lower statistics
  - **Lepton+jets [30%]** Compromise between statistics and background contamination
  - **All hadronic [45%]** higher statistics but large uncertainty due to multijet background. Easy kinematic reconstruction; all decay particles measured



Top-Quark Physics

Intrinsic:
Mass
Width
Charge
Spin correlation

Production:
Cross sections (inclusive, differential)
Charge asymmetry
Production through new particles
Top polarization
Color flow
In association with EW bosons



Decay:
W-helicity
Branching fraction
Anomalous couplings
Dead Cone

Large and clean statistics:
W bosons (branching ratios)
b-quarks (fragmentation, rare decay)

Results Presented Today

- **ATLAS**
  - tt+bb 1811.12113
  - Spin corr. TOP_2018_027
  - Top mass comb 1810.01772
  - tt Wt interf 1806.04667
  - More details in public page

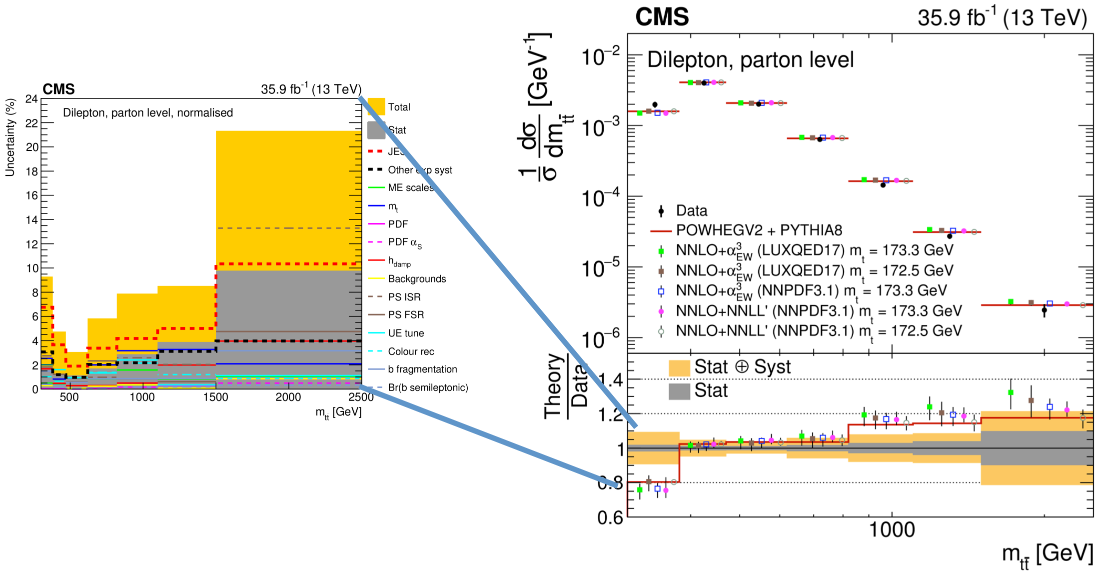
- **CMS**
  - σ_{tt}, m_{top}, α_s 1812.10505
  - σ_{tt}, m_{top}, α_s, PDF CMS_PAS_TOP_18_004
  - Pola,spin corr CMS_PAS_TOP_18_006
  - Top mass L+jets CR 1805.01428
  - Top mass comb 1812.10534
  - Diff XS, CMDM, AC 1811.06625
  - Top-yukawa CMS_PAS_TOP_17_004
  - More details in public page

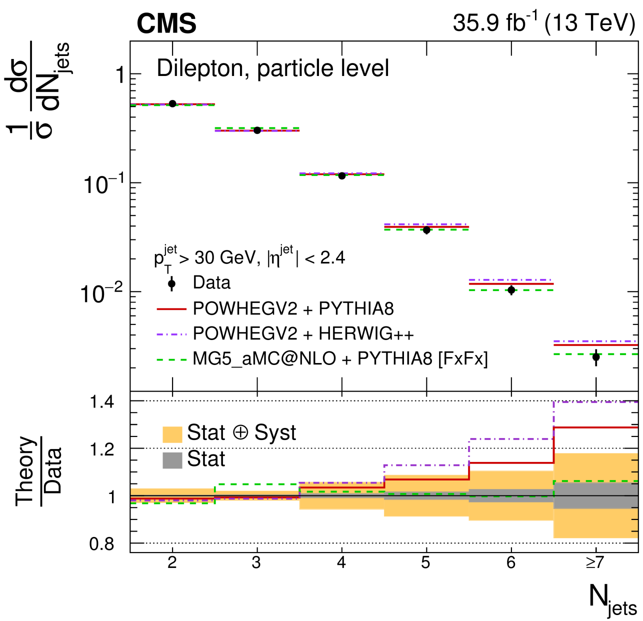
- **Combination**
  - V_{tb} 1902.07158 single top

Top Production

Differential Cross-Section

[1811.06625]





- Analysis
  - Diff. cross sections presented as functions of numerous observables related to tt production and decay
  - Significant disagreement between the data and NLO MC simulation is observed for p_T(top), p_T(l), p_T(b), p_T(tt), p_T(ll), p_T(bb), m_{tt}, m_{ll}, m_{bb}
  - Jet multiplicity distribution not very well described by all of the MC predictions (except maybe MG5_aMC@NLO +Pyhtia8 [FxFx])

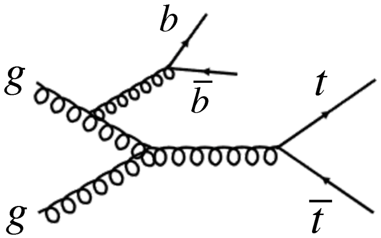
tt+bb Production 1/2

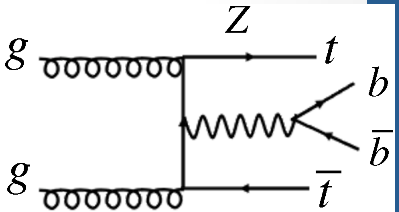
1811.12113

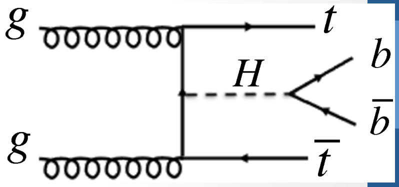
- Motivations
  - Predictions for tt+HF affected by large uncertainties due to non-negligible b-quark mass
  - Very important background for ttH $H \rightarrow bb$ production

- Measure
  - Inclusive cross-sections of the production of top pairs with 3 and 4 b-jets
  - Differential cross-sections as a function of global event and b-jet properties

- Differential cross-sections presented
  - Events with ≥3/4 b-jets
  - Events l+jets or in the eμ channel
  - As a function of H_T , H_{Thad} , p_T of b-jets, b-jet multiplicity, ΔR_{bb} , m_{bb} and $p_{T,bb}$





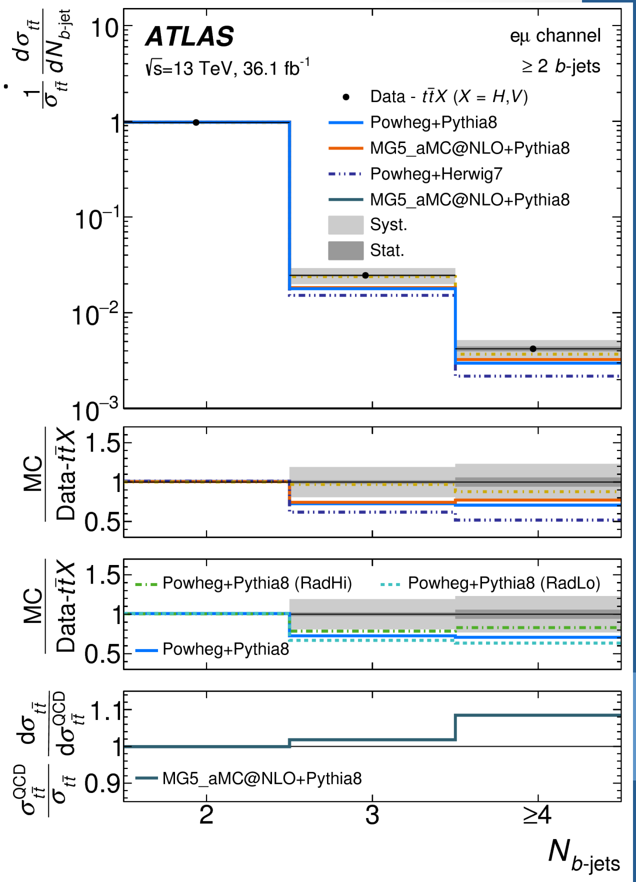


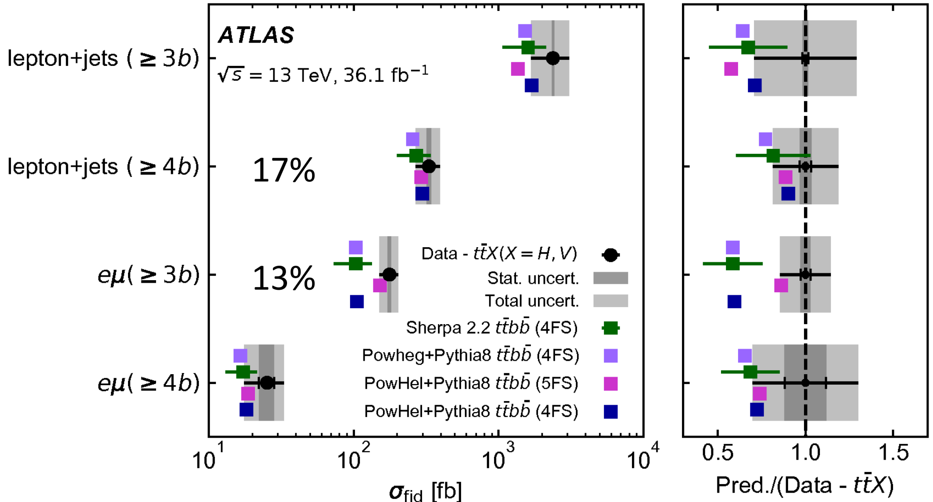
- *No attempt to identify the origin of the b-jets*

tt+bb Production 2/2

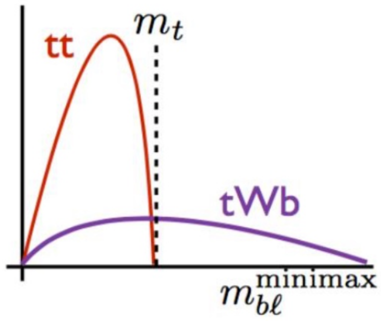
1811.12113

- Final particle level measurement in fiducial phase space
  - Precision limited by stat, generator, jet energy scale and reso. uncert.
  - Comparisons with NLO+PS predictions employing 4 and 5-flavor schemes, produced using the tt and $ttbb$ matrix elements
  - Higher cross section measured than predictions
  - Predictions where additional *b*-jets are produced by PS predicts too few events with more *b*-jets than those produced in top decays

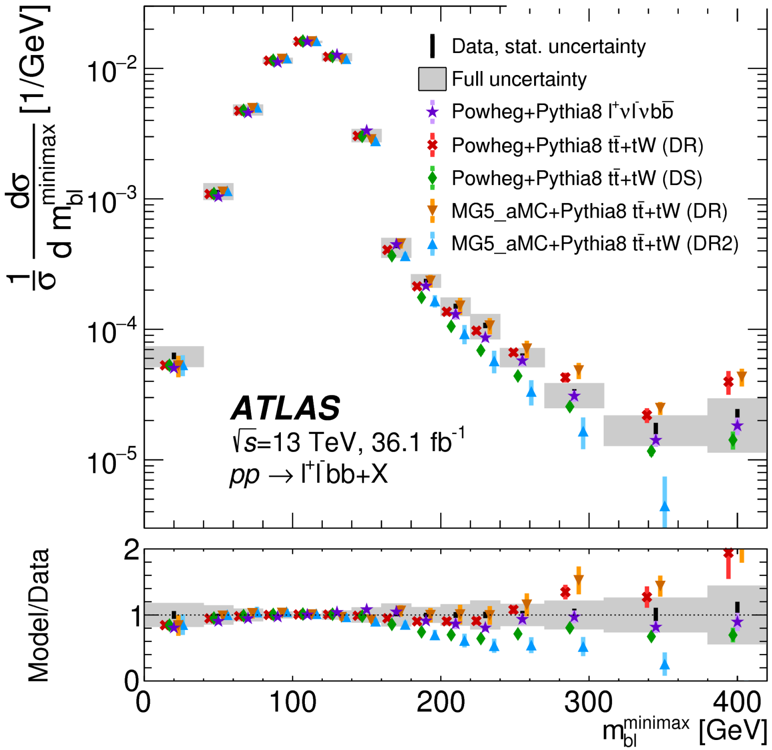




Interference Wt And tt [1806.04667]

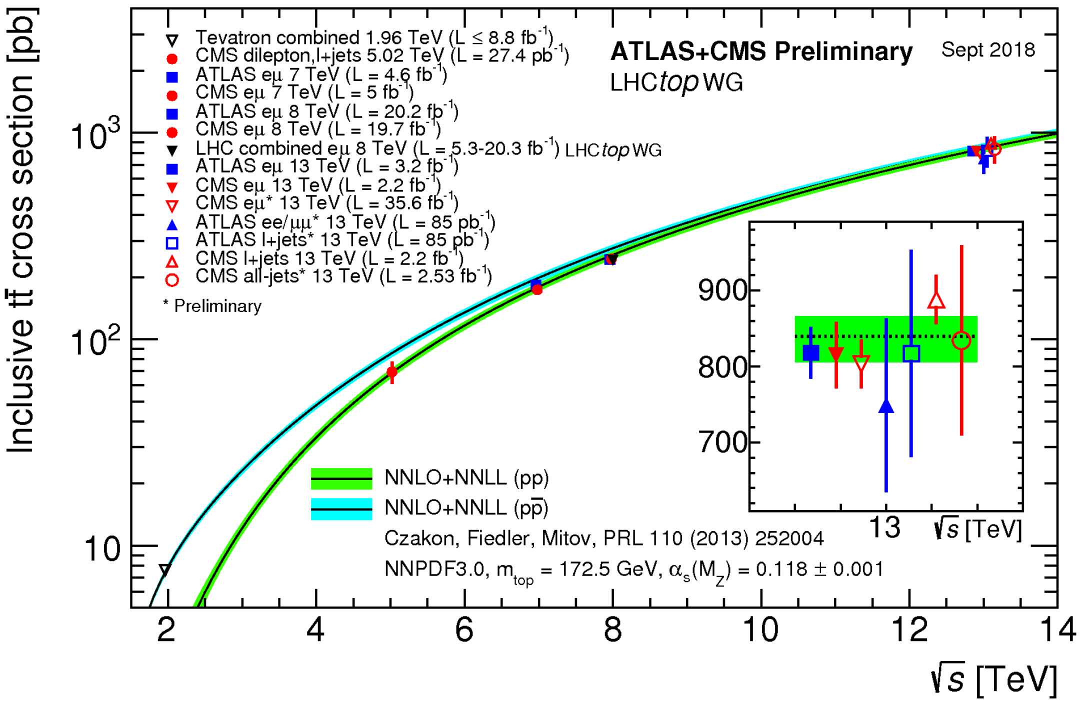


- [tW diagrams beyond the leading order interfere with tt]
  - Size of the interference dependent on the phase space
  - Both process are factorized in standard calculations (NWA)
  - Very important for searches
- [Different methods to handle the interference at NLO]
  - Diagram Removal (DR) and Diagram subtraction (DS)
  - $WbWb$ -> $lvblvb$ in PowHeg Res **bb4l**: interference automatically handled
- [Analysis/results]
  - $m_{lb}{}^{minimax}$ sensitive to the tt/tWb interference
  - The bulk well described by all the predictions
  - Good agreement for **bb4l** in the full range
  - Mis-modelling in the tails by MG5_aMC+Pythia8 predictions with opposite behavior
  - PowHeg+Pythia8 DS and DR diverge in tails



Top Quark Pair Cross Section Summary

- Large variety of measurements by ATLAS and CMS in different decay channels
- Good agreement of all inclusive measurements with SM predictions
- Not the same story differentially
- Experimental uncertainties already comparable with theoretical ones
- Measurements in eμ and lepton+jets channels are the most precise
- Overall comparable precision between the two experiments
- All summary plots here



Top Properties

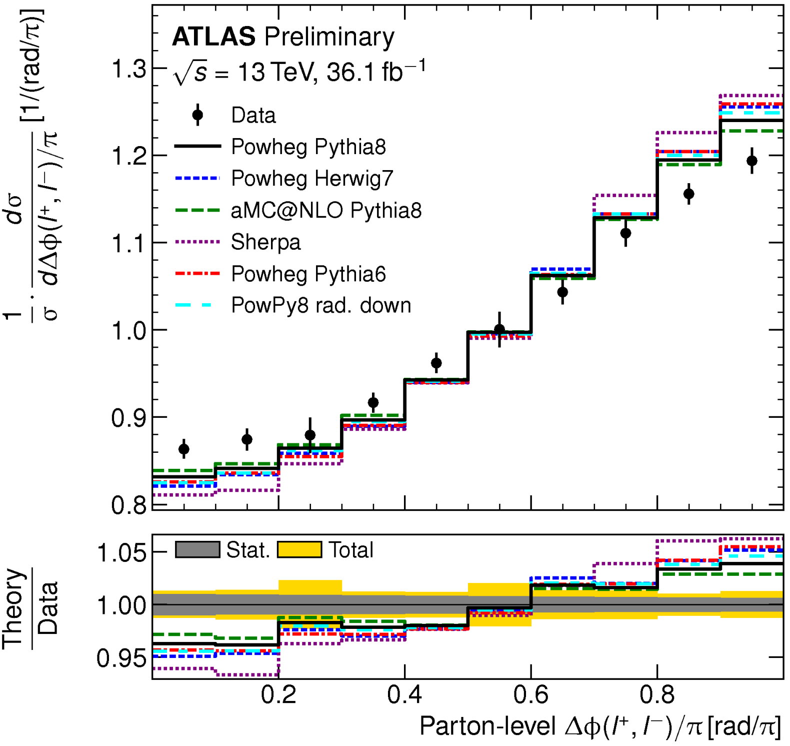
Spin Correlations

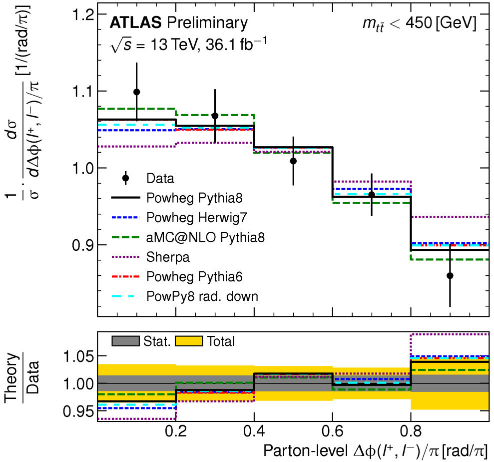
- Top quark lifetime 3 10^{-25} sec – decays as a bare quark, does not hadronise
  - Top spin information transferred to decay products, not 'corrupted' by QCD
  - Expect negligible pola. in SM, but correlation between top/anti-top spins
  - Charged leptons from W decays carry almost the full available information

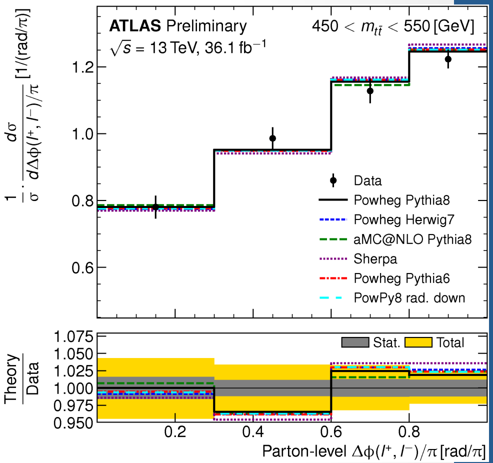
- 'Classical' spin observable: azimuthal $\Delta\phi$(ll) in di-leptonic top-pair events
  - Already used at Run-1 to establish spin correlations at level predicted by SM
  - With Run-2 data sample, can start to look differentially in bins of m_{tt} system (ATLAS) and spin density matrix (CMS, also ATLAS 8 TeV)
    - Both implies reconstruction of the top-pair kinematics

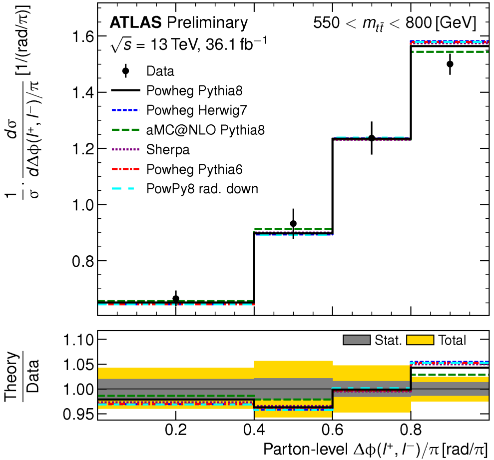
Spin Correlations Results

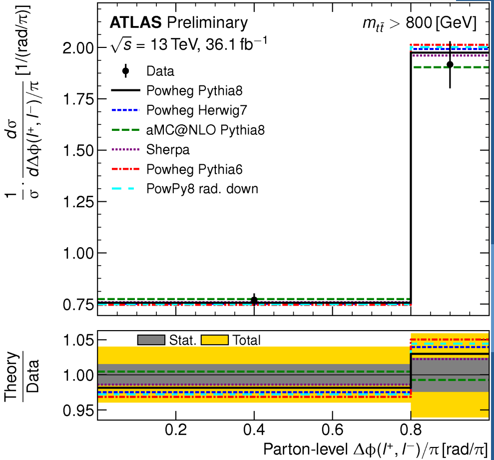
2018-027











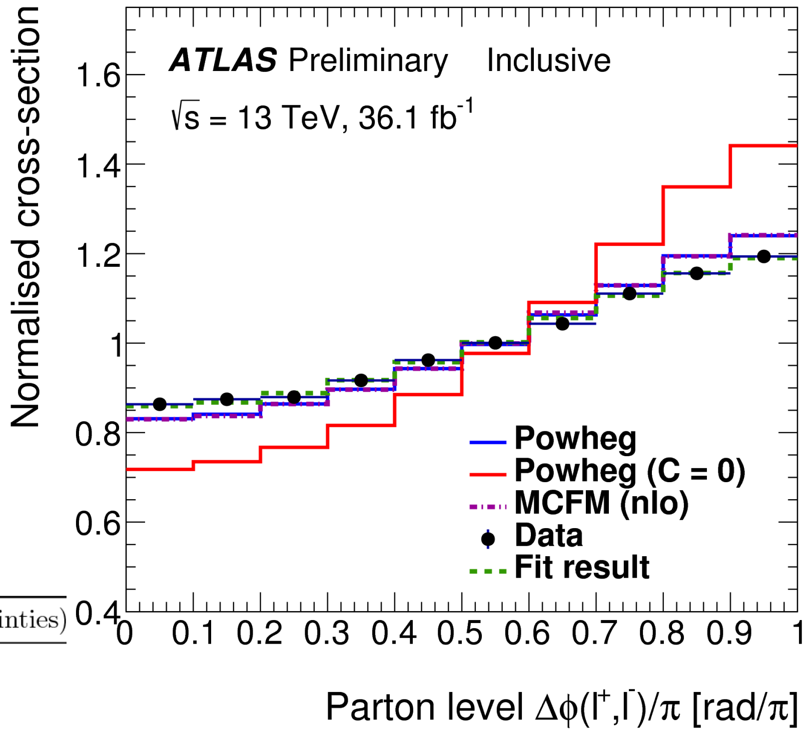
Spin Correlations Interpretation 2018-027

- Fit the inclusive $\Delta\phi$ distribution to templates
  - MC with SM-like spin correlation ON/OFF
  - Steeper distribution with OFF (C=0)

$$n_i = f_{\mathrm{SM}} \cdot n_{\mathrm{spin}} + (1 - f_{\mathrm{SM}}) \cdot n_{\mathrm{nospin}}$$

- f_{SM}=1 for 'SM-like' spin correlation, 0 for none
- Obtain f_{SM}=1.250 ±0.026 (stat) ±0.063 (syst)
  - f_{SM} is 3.2 σ above 1, when including QCD scale and PDF uncertainties on templates
  - f_{SM} also above 1 in m_{tt} bins, lower significance

Region	f_{SM}	Significance (incl. theory uncertainties)
$m_{t\bar{t}} < 450$ GeV	$1.11 \pm 0.04 \pm 0.13$	0.85 (0.84)
$450 < m_{t\bar{t}} < 550$ GeV	$1.17 \pm 0.09 \pm 0.14$	1.00 (0.91)
$550 < m_{t\bar{t}} < 800$ GeV	$1.60 \pm 0.24 \pm 0.35$	1.43 (1.37)
$m_{t\bar{t}} > 800$ GeV	$2.2 \pm 1.8 \pm 2.3$	0.41 (0.40)
inclusive	$1.250 \pm 0.026 \pm 0.063$	3.70 (3.20)

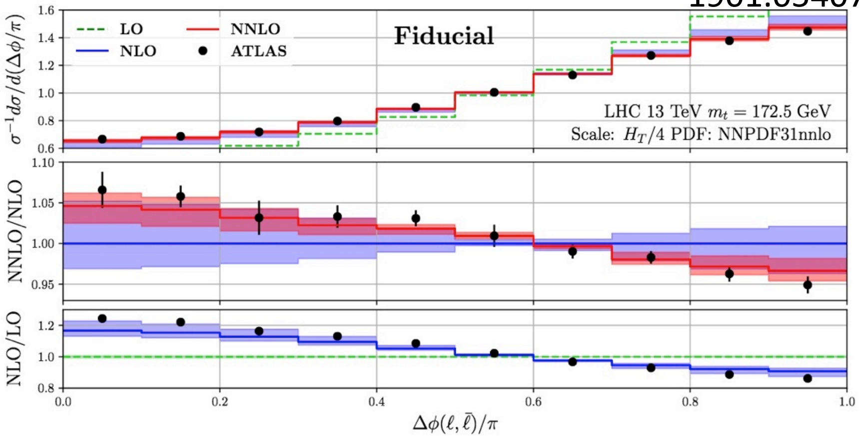


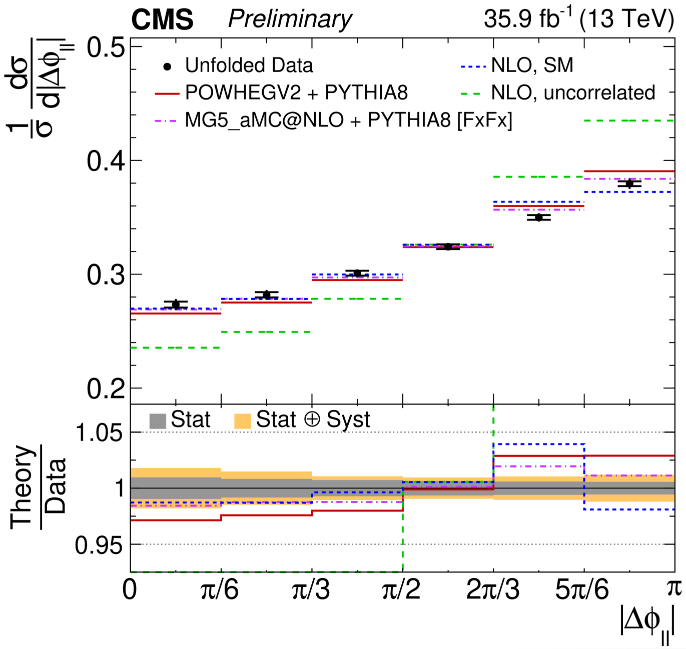
Spin Correlation results

CMS_PAS_TOP_18_006

- Slightly smaller discrepancy observed as ATLAS
- Too much spin correlation wrt. Prediction?
  - Robust against variation of generator for templates
  - Inclusion of NLO top decays
  - Recent work 1901.05407 (Behring et al) suggests NNLO corrections are important

1901.05407



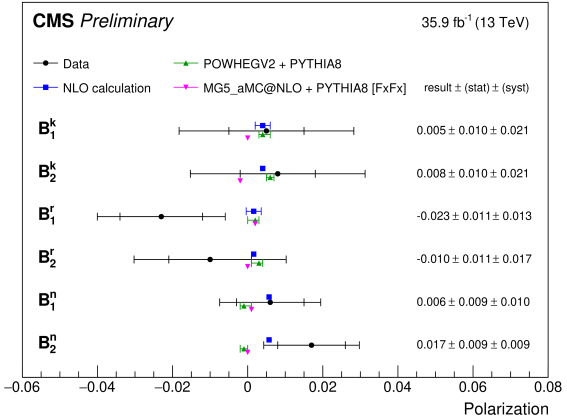


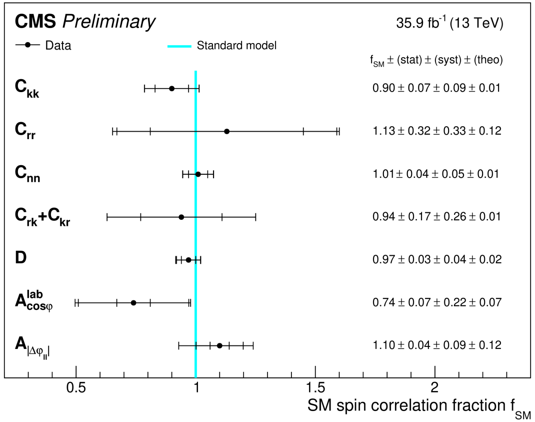
CMS_PAS_TOP_18_006

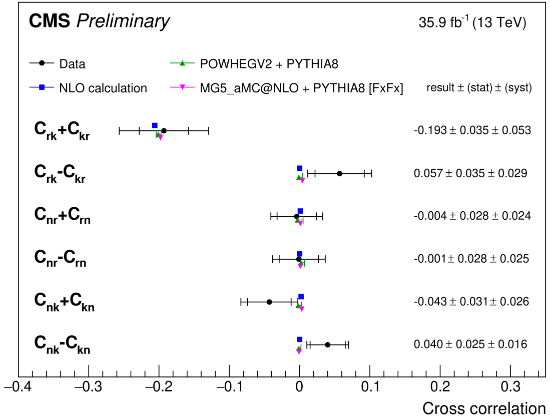
Spin Density Matrix

- Measures all 15 coefficients of the spin density matrix
  - First time done at 13 TeV
  - Compatible with SM

$$\frac{1}{\sigma}\frac{\mathrm{d}^2\sigma}{\mathrm{d}\cos\theta_+^a\,\mathrm{d}\cos\theta_-^b} = \frac{1}{4}\left(1 + B_+^a\cos\theta_+^a + B_-^b\cos\theta_-^b - C(a,b)\cos\theta_+^a\cos\theta_-^b\right),$$





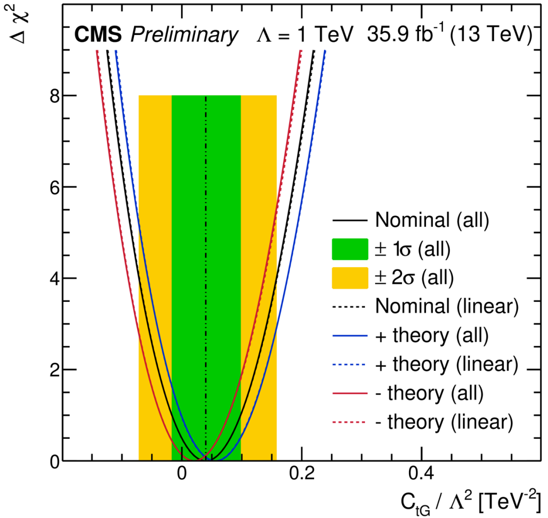


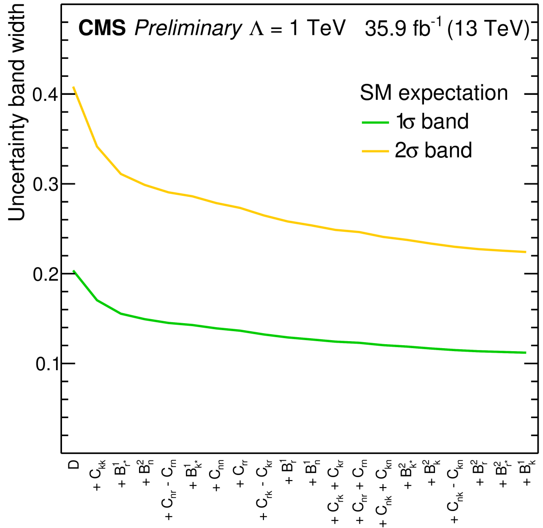
Additional Measurements

CMS_PAS_TOP_18_006

- Constraining Chromomagnetic dipole moment (CMDM) of the top
  - Strongest direct constraint to date
  - Factor 2 improvement w.r.t best result to date
  - More interpretations and Rivet data on release of the paper

$-0.07 < C_{tG}/\Lambda^2 < 0.16\,\mathrm{TeV}^{-2}$



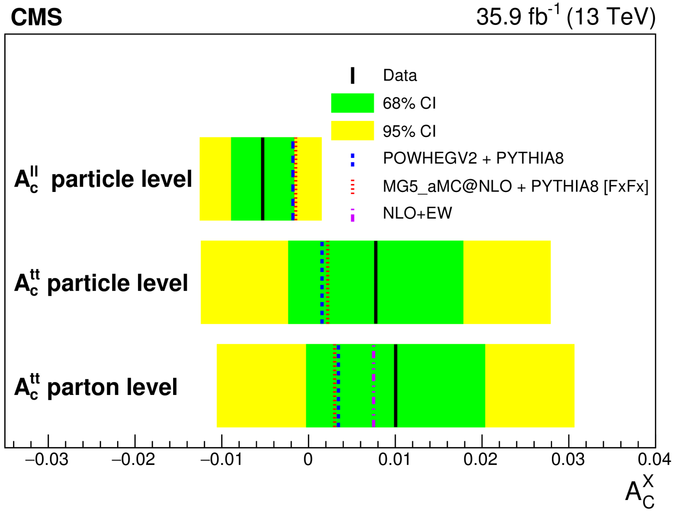


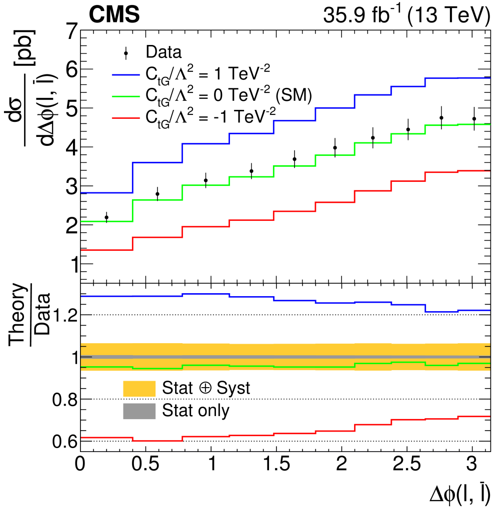
A_C, A_{lep} And Top-Chromo

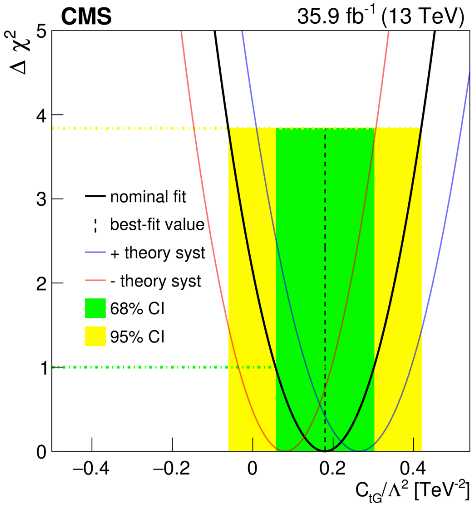
[1811.06625]

- Additional measurements form dilepton XS analysis:
  - The tt and leptonic charge asymmetries are measured at 13 TeV for the first time
  - Particle-level diff. cross section as a function of $\Delta\varphi$(l,l) is used to constrain the top quark chromo-magnetic dipole moment at NLO using an EFT
  - Very sensitive to new physics
  - Found to be in agreement with SM predictions

$-0.06 < C_{tG}/\Lambda^2 < 0.41 \text{TeV}^{-2}$



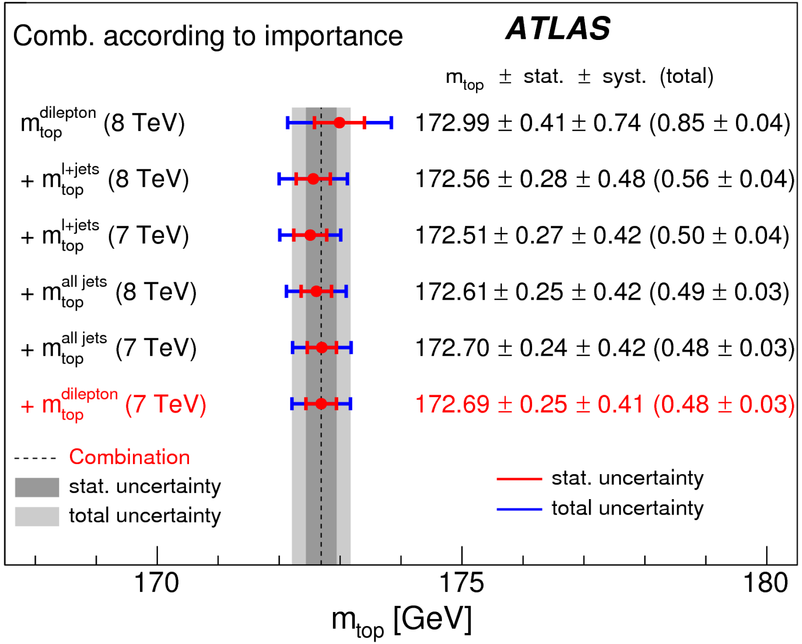




Top Mass Combination

1810.01772

- Combine l+jets, dilepton all-jets at 8 and 7 TeV
- Analyses optimised to maximise combination gain



	m_{top} [GeV]
Results	172.69
Statistics	0.25
Method	0.06
Signal Monte Carlo generator	0.12
Hadronization	0.00
Initial- and final-state QCD radiation	0.07
Underlying event	0.03
Colour reconnection	0.08
Parton distribution function	0.05
Background normalization	0.02
W/Z+jets shape	0.06
Fake leptons shape	0.03
Data-driven all-jets background	0.03
Jet energy scale	0.22
Relative b-to-light-jet energy scale	0.17
Jet energy resolution	0.09
Jet reconstruction efficiency	0.03
Jet vertex fraction	0.05
b-tagging	0.17
Leptons	0.08
Missing transverse momentum	0.04
Pile-up	0.06
Trigger	0.01
Fast vs. full simulation	0.01
Total systematic uncertainty	0.41 ± 0.03
Total	0.48 ± 0.03

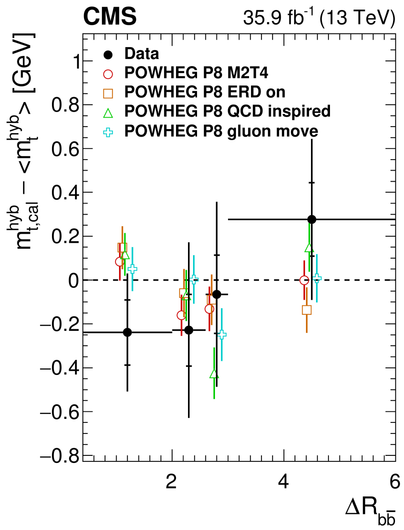
1805.01428

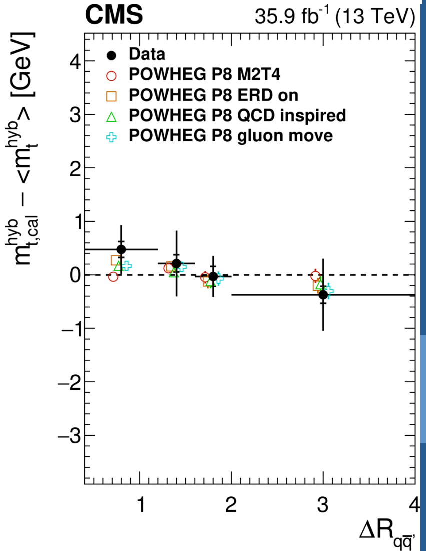
Top Mass L+jets CR Models

- New color reconnection models all with "early resonance decays" (ERD)
  - Default setup
  - String formation beyond leading color ("QCD inspired") [JHEP **1508** (2015) 003]
  - Gluons can be moved to another string ("gluon move") [JHEP **1411** (2014) 043]

- Results
  - No significant discrepancy observed in any differential measurement
  - More data might help to exclude models
  - Dedicated CR studies needed to reduce the uncertainty associated to CR
  - Theory input necessary to judge which models are meaningful

Model	χ^2 probability							
	$p_T^{t,had}$	$m_{t\bar{t}}$	$p_T^{t\bar{t}}$	N_{jets}	$p_T^{b,had}$	$\lvert\eta^{b,had}\rvert$	$\Delta R_{b\bar{b}}$	$\Delta R_{q\bar{q}'}$
POWHEG P8 M2T4	0.68	0.93	0.90	0.71	0.98	0.61	0.59	0.68
MG5 P8 [FxFx] M2T4	0.93	0.80	0.85	0.90	0.72	0.26	0.66	0.97
MG5 P8 [MLM] M1	0.49	0.79	0.99	0.39	0.97	0.16	0.68	0.57
POWHEG H++ EE5C	0.07	5×10^{-14}	0.53	0.73	2×10^{-4}	0.55	0.36	8×10^{-6}
POWHEG P8 ERD on	0.75	0.99	0.83	0.53	0.95	0.64	0.37	0.96
POWHEG P8 QCD inspired	0.80	0.93	0.94	0.66	0.99	0.71	0.48	0.89
POWHEG P8 gluon move	0.87	0.93	0.93	0.71	0.93	0.51	0.57	0.92



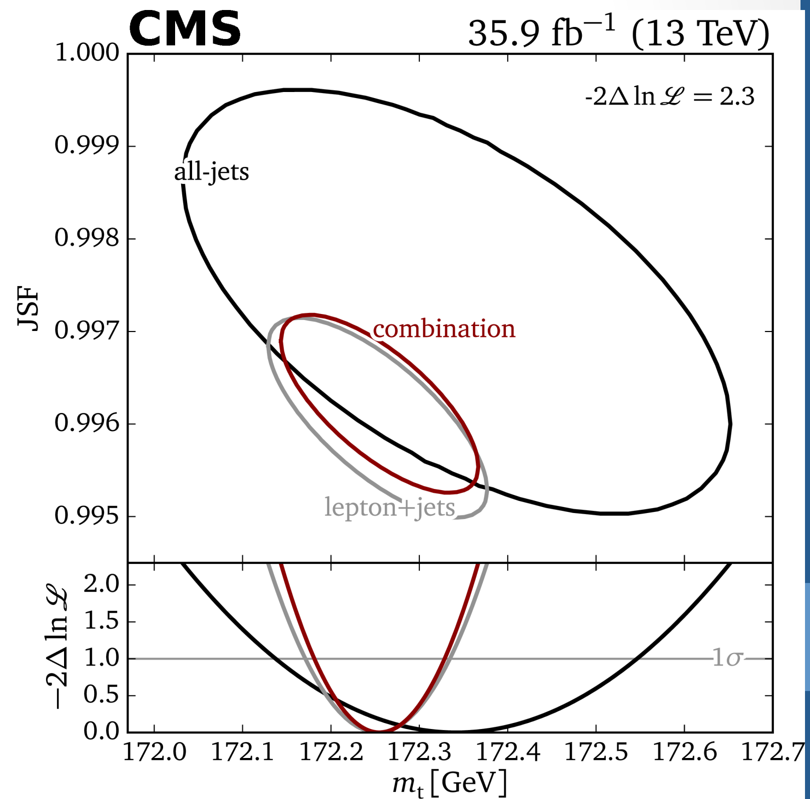


Top Mass L+jets all had comb

[1812.10534]

	δm_t^{hyb} [GeV]		
	all-jets	ℓ+jets	combination
Experimental uncertainties			
Method calibration	0.06	0.05	0.03
JEC (quad. sum)	0.15	0.18	0.17
– Intercalibration	−0.04	+0.04	+0.04
– MPFInSitu	+0.08	+0.07	+0.07
– Uncorrelated	+0.12	+0.16	+0.15
Jet energy resolution	−0.04	−0.12	−0.10
b tagging	0.02	0.03	0.02
Pileup	−0.04	−0.05	−0.05
All-jets background	0.07	–	0.01
All-jets trigger	+0.02	–	+0.01
ℓ+jets background	–	+0.02	−0.01
Modeling uncertainties			
JEC flavor (linear sum)	−0.34	−0.39	−0.37
– light quarks (uds)	+0.07	+0.06	+0.07
– charm	+0.02	+0.01	+0.02
– bottom	−0.29	−0.32	−0.31
– gluon	−0.13	−0.15	−0.15
b jet modeling (quad. sum)	0.09	0.12	0.06
– b frag. Bowler–Lund	−0.07	−0.05	−0.05
– b frag. Peterson	−0.05	+0.04	−0.02
– semileptonic b hadron decays	−0.03	+0.10	−0.04
PDF	0.01	0.02	0.01
Ren. and fact. scales	0.04	0.01	0.01
ME/PS matching	+0.24	−0.07	+0.07
ME generator	–	+0.20	+0.21
ISR PS scale	+0.14	+0.07	+0.07
FSR PS scale	+0.18	+0.13	+0.12
Top quark p_T	+0.03	−0.01	−0.01
Underlying event	+0.17	−0.07	−0.06
Early resonance decays	+0.24	−0.07	−0.07
CR modeling (max. shift)	−0.36	+0.31	+0.33
– "gluon move" (ERD on)	+0.32	+0.31	+0.33
– "QCD inspired" (ERD on)	−0.36	−0.13	−0.14
Total systematic	0.70	0.62	0.61
Statistical (expected)	0.20	0.08	0.07
Total (expected)	0.72	0.63	0.61

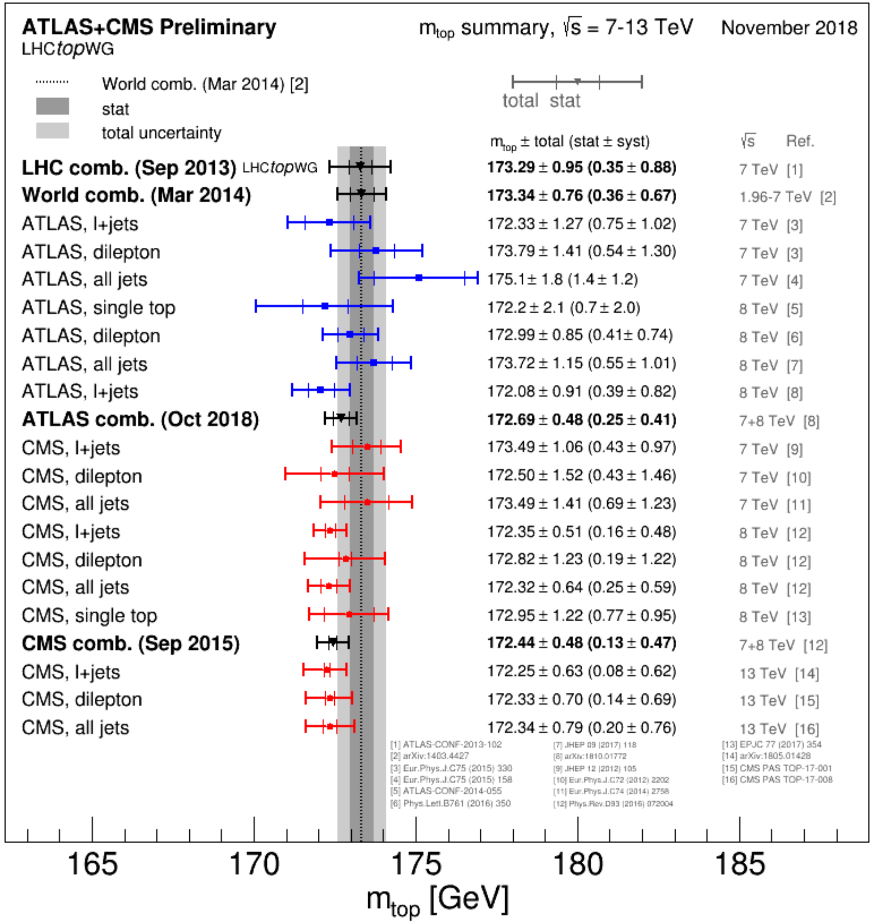
Simultaneous fit to L+jets and all had



LHC top physic results 14/03/19

Top Mass Summary

- Measurements in all decay channel at 13TeV
- Also various indirect measurements with tighter relation to theory (not ‘MC mass’) from
  - Total top-pair cross-section
  - Top-pair + jet
  - Lepton differential distributions
- Typically fitted to dedicated theory predictions at NLO or NNLO
- Compatible results, but insufficient precision to compete with direct measurements
- Active theoretical development



Simultaneous determination of m_{top}, α_s, PDFs

- Calculations of tt production depend on:
  - Strong coupling α_S
  - Top quark mass
  - Gluon (quark) PDF in the proton

- Measurements of σ_{tt} can be used to constrain these parameters
  - m_t provides a hard scale ⇒ ultimate probe of pQCD (NLO, aNNLO, NNLO)
  - Produced mainly via gg ⇒ constrain gluon PDF at high x
  - Production sensitive to α_s and m_t(pole)
  - May provide insight into possible new physics
  - Need to go 3D to constraint m_{top}, α_S and PDFs

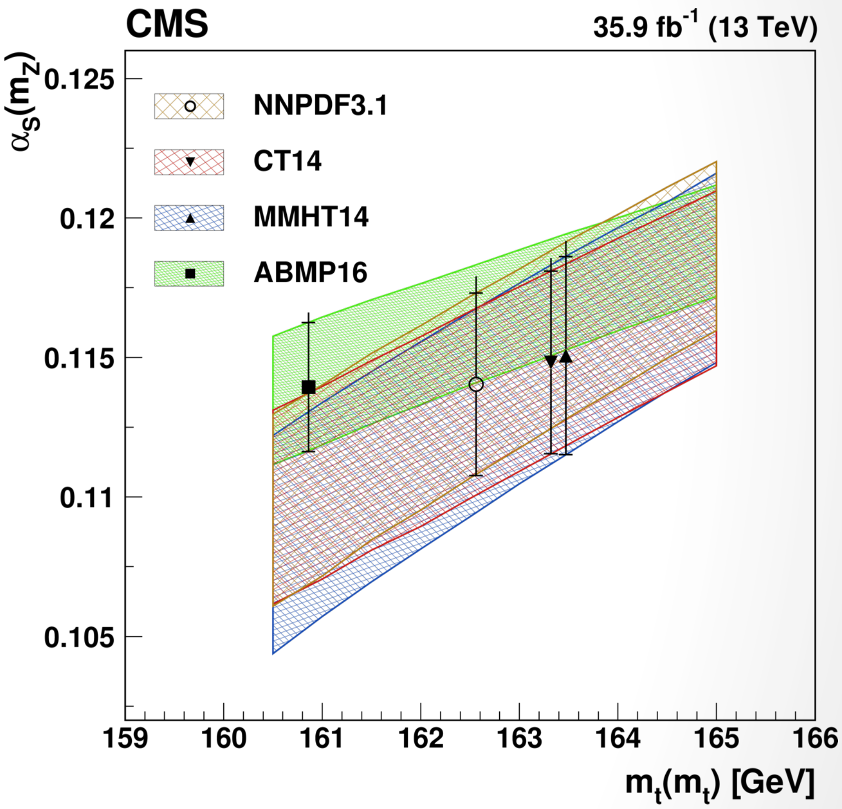
m_{top}, α_s from inclusive σ_{tt}

1812.10505

- α_S and m_t cannot be determined simultaneously
- $\Rightarrow$ m_t fixed to native value of PDF

- Uncertainties
  - Experimental: from σ_{tt} measurement
  - PDF: from eigenvectors
  - Independent μ_r, μ_f variations by factor 2

- Results
  - Dependence of extracted α_S vs m_t investigated → linear
  - Somehow flatter in case of ABMP16
  - α_S and m_t correlated, need to go 3D

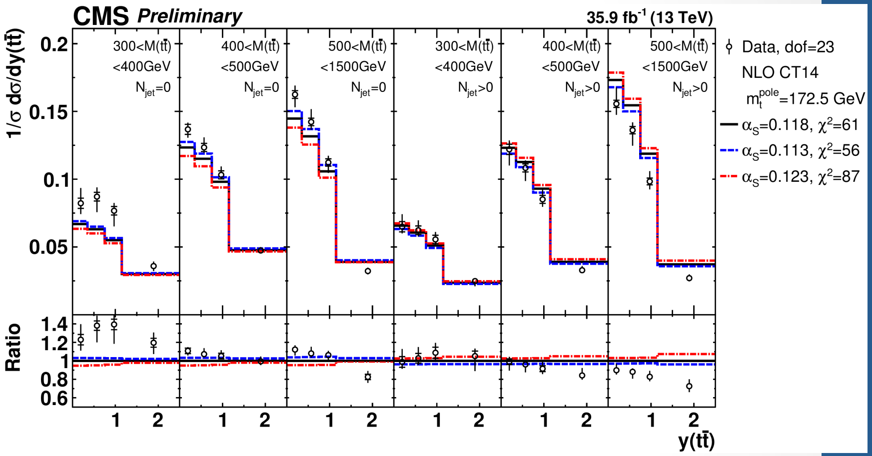


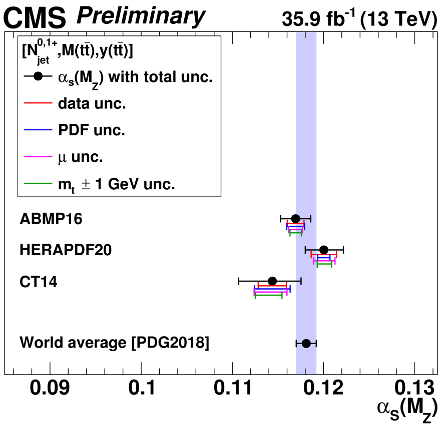
[CMS_PAS_TOP_18_004]

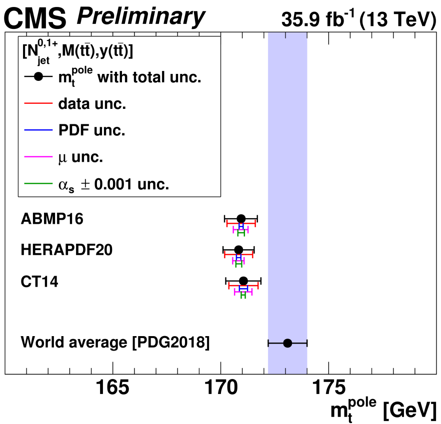
m_{top}, α_s, PDFs from diff σ_{tt} 1/2

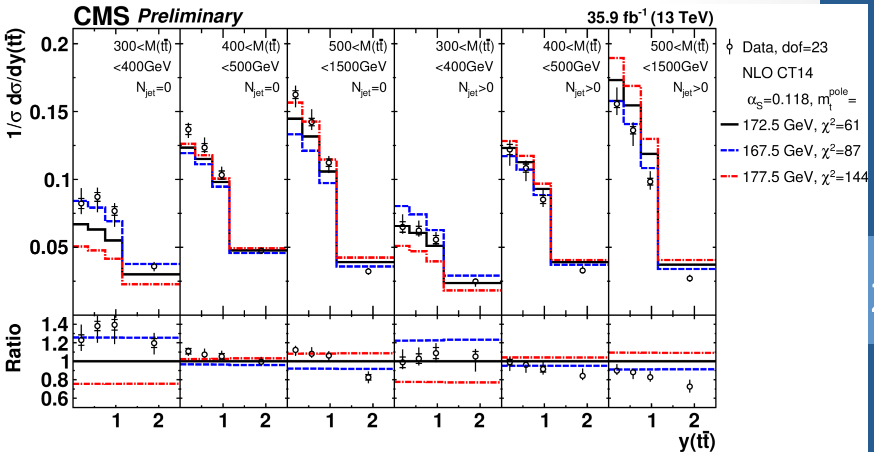
- In 3D @NLO (N_{jet}, m_{tt}, y_{tt})
  - Different trends of α_S and m_t
- Simultaneous fit of PDFs, α_s and m_t^{pole}:
  - → fully consistent extraction of α_s, m_t^{pole} and PDFs, but using also HERA data

$$\alpha_s(M_Z) = 0.1135^{+0.0021}_{-0.0017}(\text{total}),$$
$$m_t^{\text{pole}} = 170.5 \pm 0.8(\text{total})\ \text{GeV}.$$



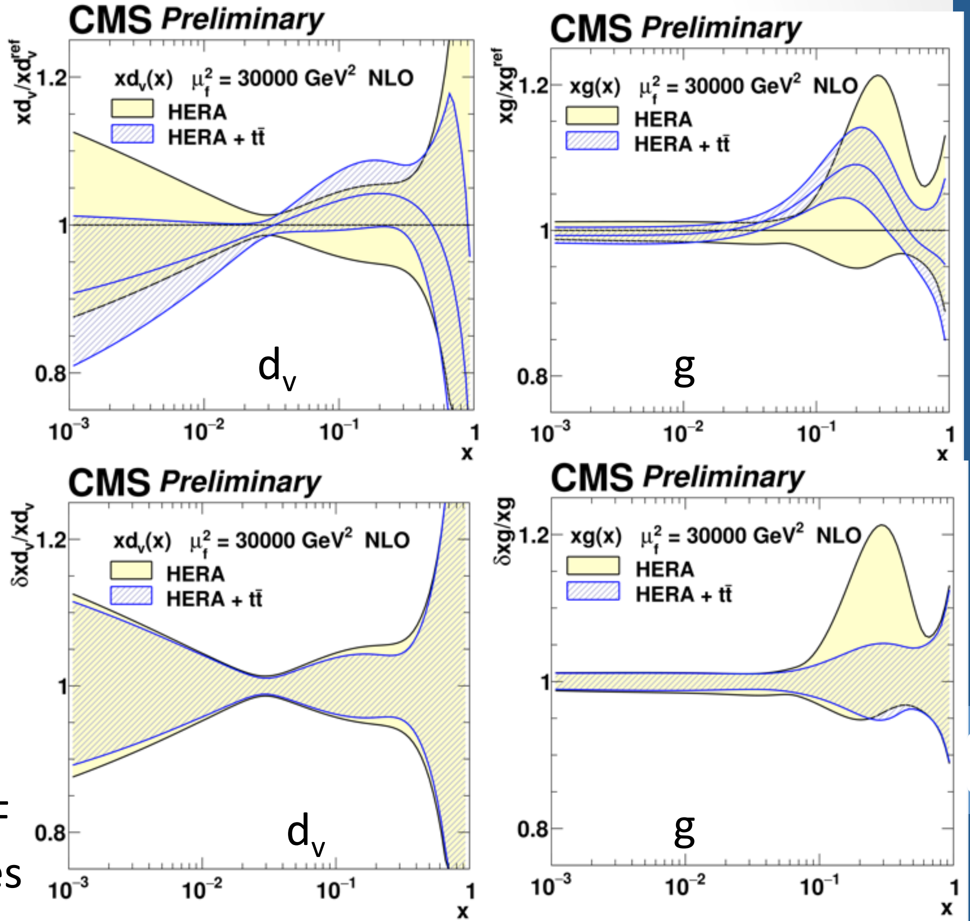






m_{top}, α_s, PDFs from diff σ_{tt} 2/2

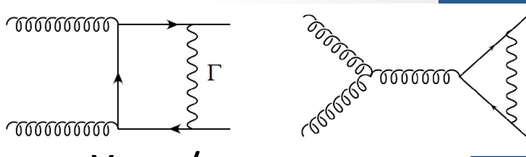
- Constraining the PDF
  - followed standard approach:
    - using HERA DIS data only
    - HERA + tt data to demonstrate added value from tt on PDF and α_s determination
  - reduced *g* uncertainty at high *x*
  - smaller impact on other distributions via corr.



Relative PDF uncertainties

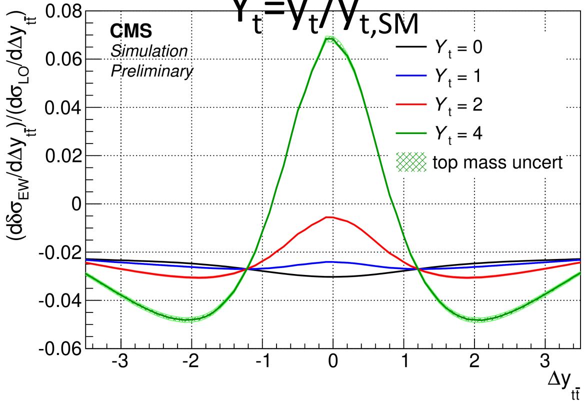
[CMS_PAS_Top_2017_004](CMS_PAS_Top_2017_004) New

Top Yukawa from diff XS 1/2

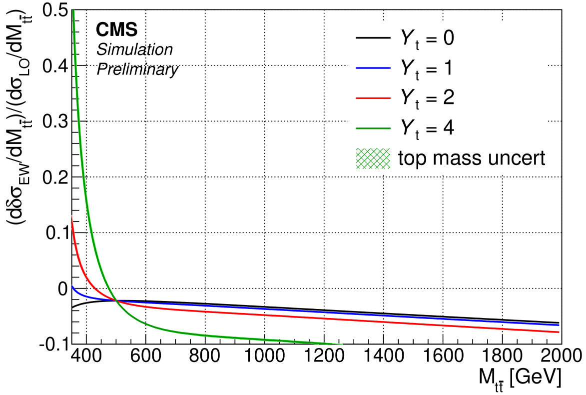


$Y_t = y_t / y_{t,SM}$

- [Analysis principle]
  - EW corrections enter XS at loop-induced order $\alpha_s^2\alpha_{weak}$ and make a small contribution to the total cross section
  - Calculate EW correction factors for different values of Y_t and apply them at parton level of tt simulated samples
  - From modified templates, obtain distributions at detector level that can be directly compared to the data



- [Analysis strategy]
  - Yukawa coupling extracted from M_{tt} and Δy_{tt} for different jet multiplicities
  - Low M_{tt} and small $|\Delta y_{tt}|$ regions are the most sensitive to Y_t
  - Analysis phase space M_{tt} 0.2 to 2TeV and from 0 to 6 in $|\Delta y_{tt}|$

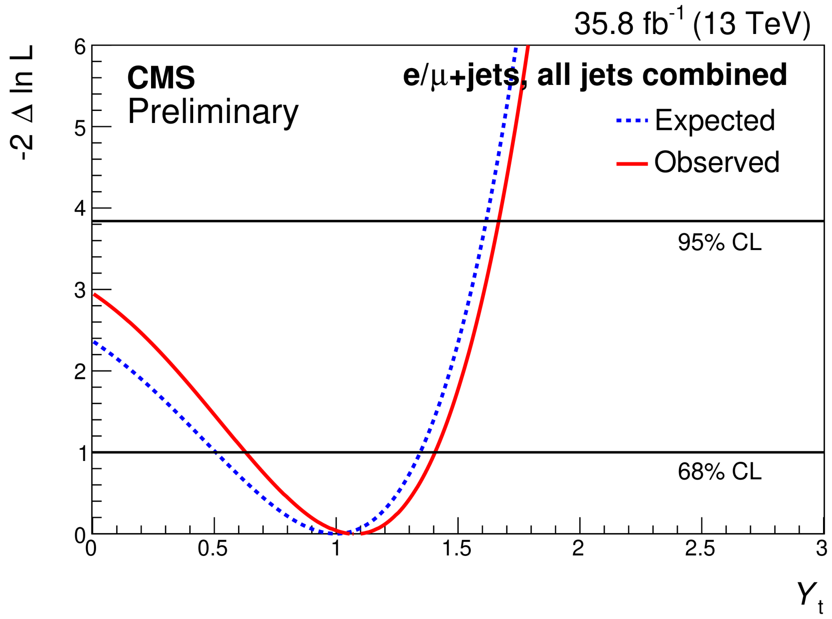


New

Top Yukawa from diff XS 2/2

- Results
  - Top-Yukawa coupling extracted by comparing data with the expected tt signal for different values of Y_t in a total of 57 bins in M_{tt}, Δy_{tt}, and N_{jets}
  - The value of the top quark Yukawa coupling is constrained to be less than 1.67 at the 95% confidence level
  - New way of extracting the top-Yukawa competitive with other methods

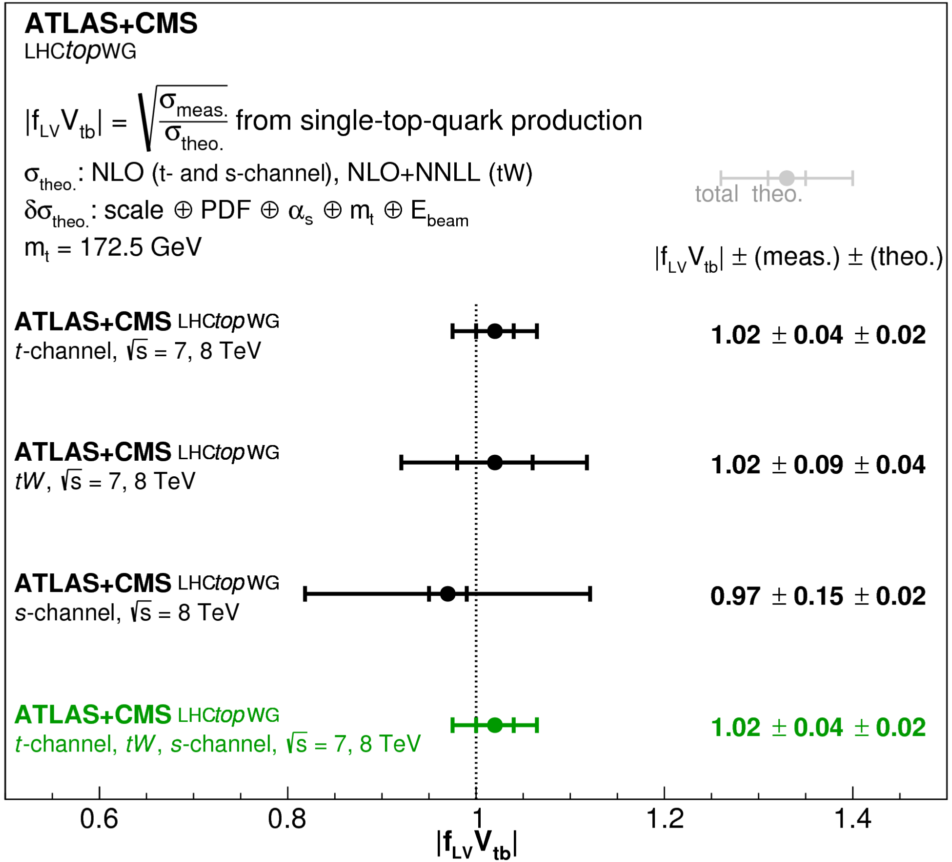
Channel	Expected 95% CL	Observed 95% CL
3 jets	$Y_t < 2.17$	$Y_t < 2.59$
4 jets	$Y_t < 1.88$	$Y_t < 1.77$
5 jets	$Y_t < 2.03$	$Y_t < 2.23$
Combined	$Y_t < 1.62$	$Y_t < 1.67$



V_{tb} Combination

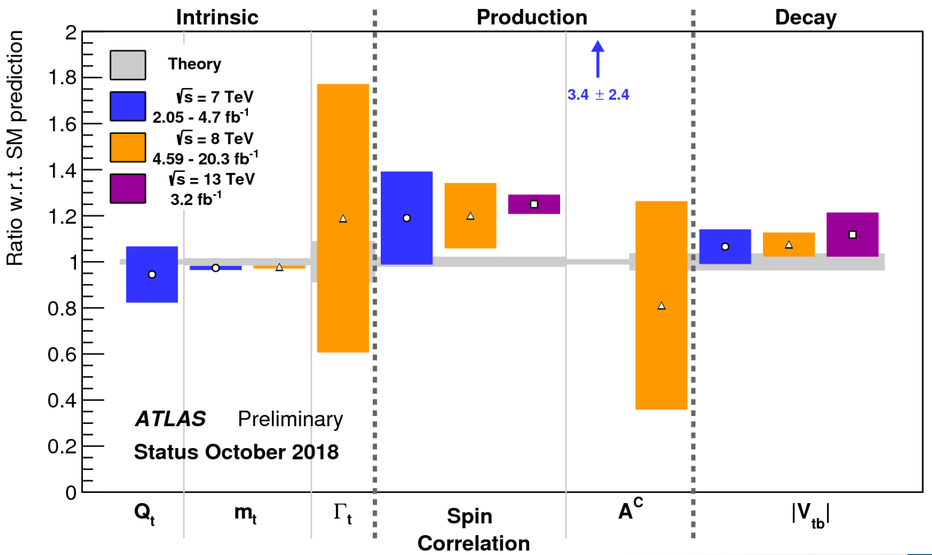
1902.07158

- In SM $f_{LV} = 1$
- Wtb vertex is a good probe for NP
- Direct measurements
  - assumes $V_{td}, V_{ts} << V_{tb}$
  - is independent on number of q generations
  - is independent of CKM unitarity
- Summary for the $|f_{LV} V_{tb}|$ combinations from the Run I cross-section measurements:
  - As expected, *t*-channel provides the largest contribution
- Total uncertainty: 4.3%
  - 30% improvement wrt the Tevatron combination PRL 115, 152003 (2015)



Outlook

- LHC experiments are doing very well with the top quark
- Top quark measurements have provided stringent tests of SM
- With the increasing luminosity new measurements can be made for the first time (see next talk by Danny)
- Top mass now known to 0.3% (0.5 GeV)
- More data to come, but 'straining' the theory
  - what are we actually measuring?
- Precise spin correlations measurements
  - a hint of a something?
- Much more beautiful results to come

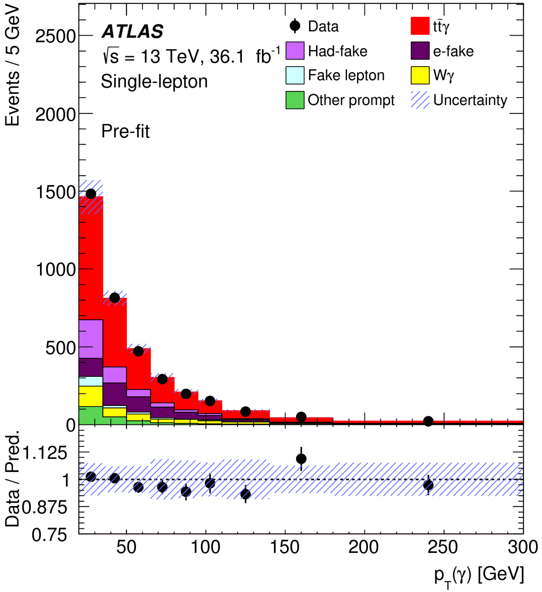


Additional material

tt+photon 1/2

[1812.01697](1812.01697)

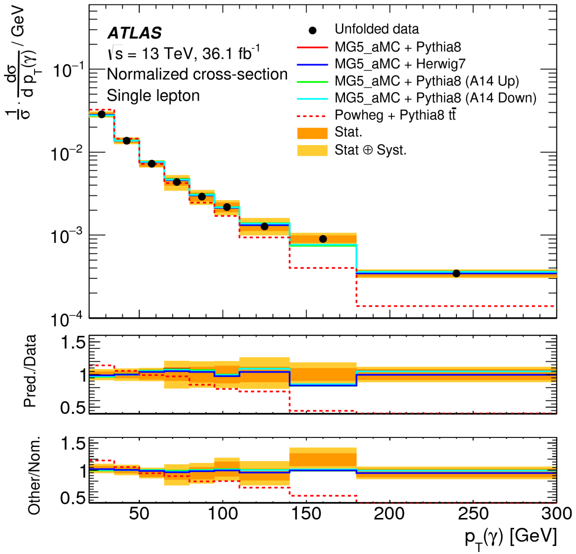
- ttγ probes the top EM coupling
  - Photons also emitted from ISR and decay products
  - ➔ Hard to disentangle, but angular information and isolation reduces ISR and FSR
- Analysis in single-lepton and di-lepton channels
  - Standard selection, plus isolated photon p_T>20 GeV
  - Di-lepton channel cleaner, but single lepton can reach higher photon p_T due to higher statistics
  - Main backgrounds from hadronic jets or electrons mis-identified as photon, or real γ+W/Z events
  - Photon ID and event-level MVAs to suppress bkgs

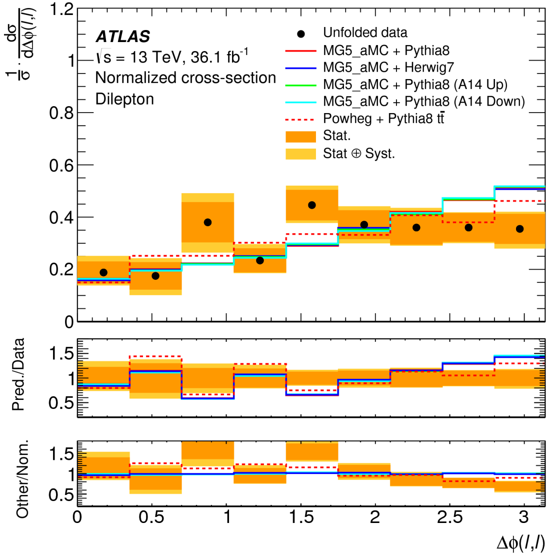


Channel	Single lepton	Dilepton
$t\bar{t}\gamma$	6 490 ± 420	720 ± 34
Hadronic-fake	1 440 ± 290	49 ± 27
Electron-fake	1 650 ± 170	2 ± 1
Fake lepton	360 ± 200	-
$W\gamma$	1 130	
$Z\gamma$		75 ± 52
Other prompt	690 ± 260	18 ± 7
Total	11 750 ± 710	863 ± 78
Data	11 662	902

tt+photon 2/2 [1812.01697]

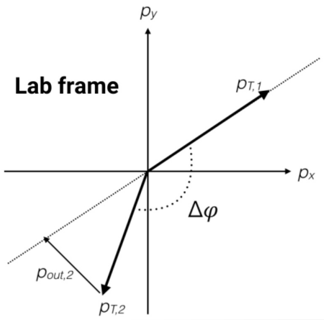
- Results:
  - Inclusive cross-section in fiducial region agrees with NLO predictions for ttγ
  - Normalised photon p_T spectrum agrees with LO ttγ ME calculations
    - Powheg+Pythia8 inclusive tt sample (photons from parton shower) is too soft
  - Dilepton $\Delta\phi$ is slightly less steep than prediction – modeling of spin-correlations?



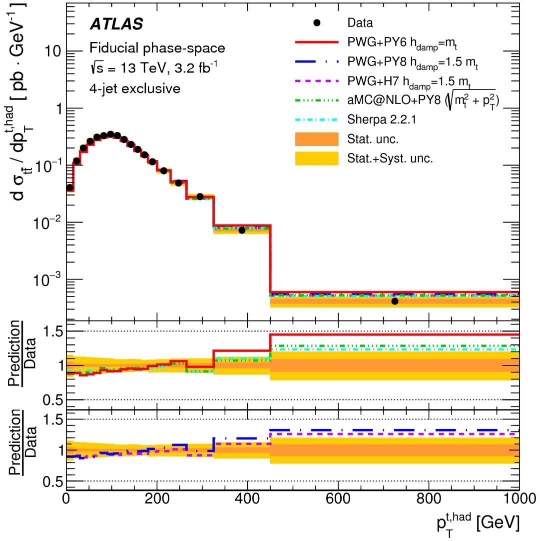


tt+jets Differential Cross-Section 1/3

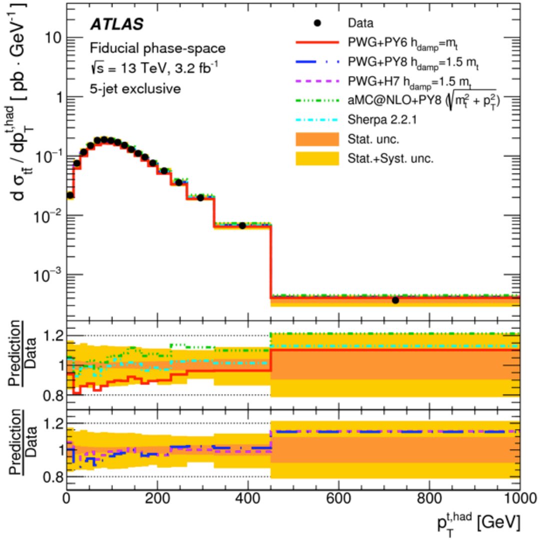
- The effect of gluon radiation on the tt kinematics is checked by measuring differential cross-sections for a given number of jets in the event (4, 5, ≥ 6)
- Analysis strategy
  - Events selected in the lepton+jets channel
  - *tt* kinematic variables corrected for the limited detector resolution via unfolding methods and extrapolated to the *fiducial* phase space
  - Measured the absolute and normalized differential cross section as a function of tt kinematic variables
    - p_T(tt), p_T(top-had)
    - $$\left|p_{\text{out}}^{t\bar{t}}\right| = \left|\vec{p}^{\,t,\text{had}} \cdot \frac{\vec{p}^{\,t,\text{lep}} \times \hat{z}}{|\vec{p}^{\,t,\text{lep}} \times \hat{z}|}\right|$$ out-of-plane transverse momentum, sensitive to radiation and used in MC tuning



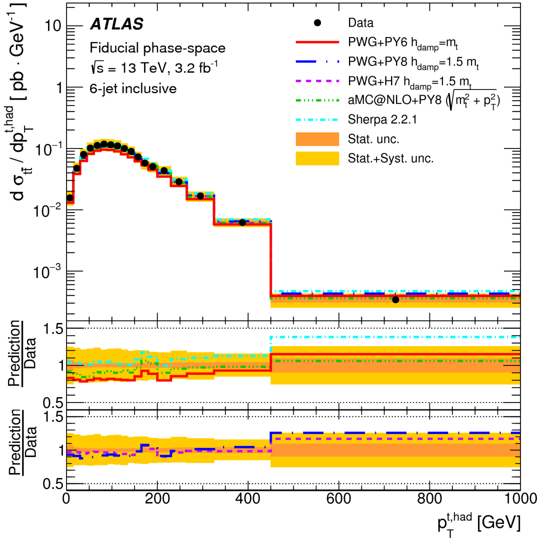
tt+jets Differential Cross-Section 2/3



N_{jets}=4



N_{jets}=5

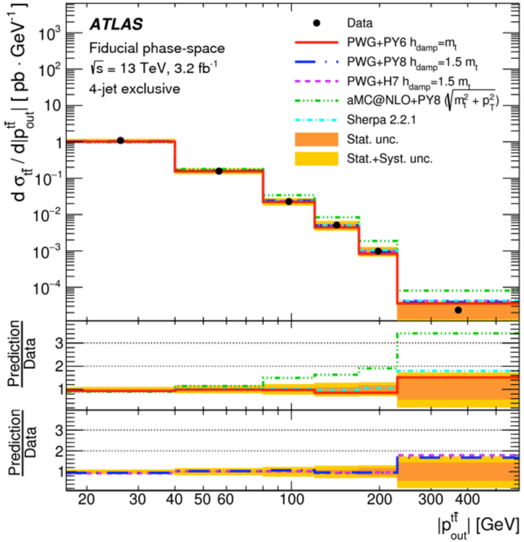


N_{jets}≥6

p_T(top, had)

Mis-modelling enhanced in the intermediate jet multiplicity region

tt+jets Differential Cross-Section 3/3



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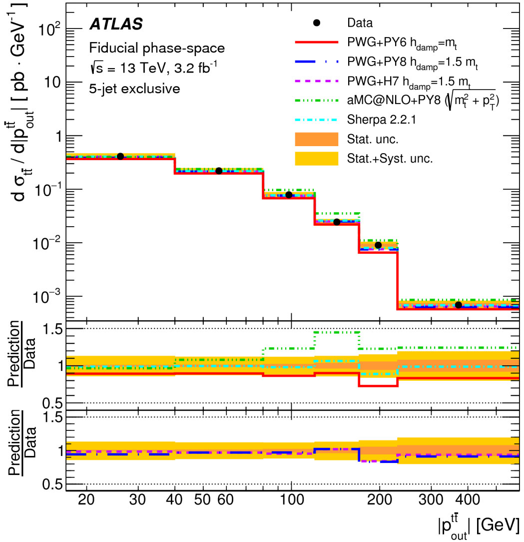

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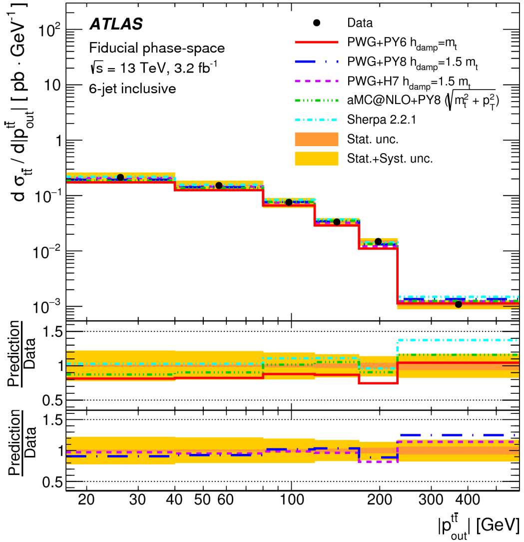


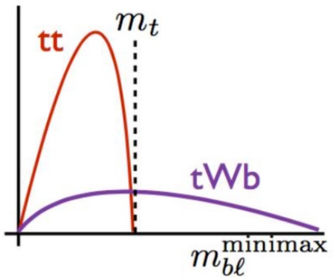
N_{jets}≥6

$|p_{out}(tt)|$

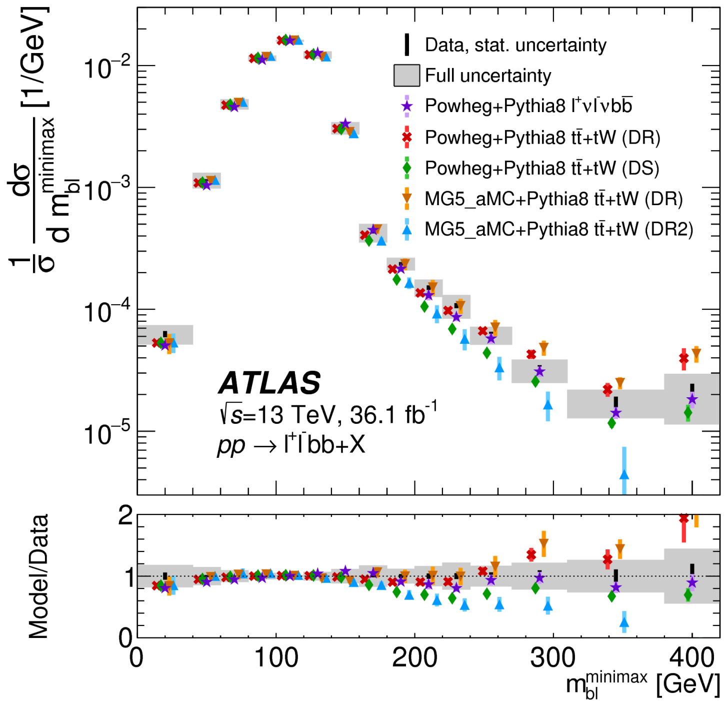
Significant mis-modelling for aMC@NLO+Pythia8 in the 4 and 5-jet multiplicity regions

Interference Wt And tt

1806.04667



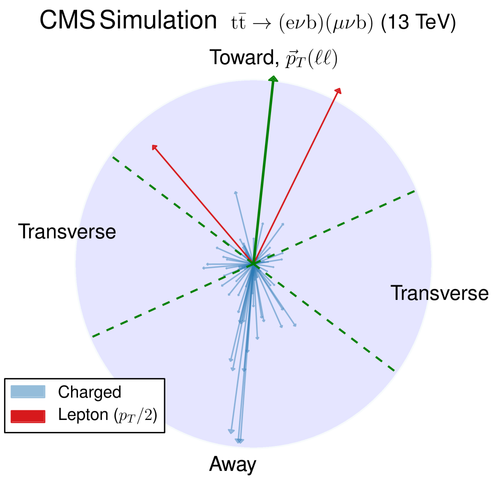
- *tW* diagrams beyond the leading order interfere with *tt*
  - Size of the interference dependent on the phase space
  - Can be important for searches
  - Both process are factorized in standard calculations (NWA)
- Different methods to handle the interference at NLO
  - Diagram removal:
    - removes all the tt diagram contributions (DR)
    - Removes the LO tt term but keep the interference (DR2)
  - Diagram subtraction: cancels the resonant tt contribution with a local subtraction term (DS)
  - $WbWb\ lvblvb$ in PowHeg: interference automatically handled
- Analysis/results
  - $m_{lb}^{minimax}$ sensitive to the tt/tWb interference
  - The bulk well described by all the predictions
  - Good agreement for $lvlvbb$ in the full range
  - Mismodelling in the tails by MG5_aMC+Pythia8 predictions (with opposite behavior)
  - PowHeg+Pythia8 DS and DR diverge in tails

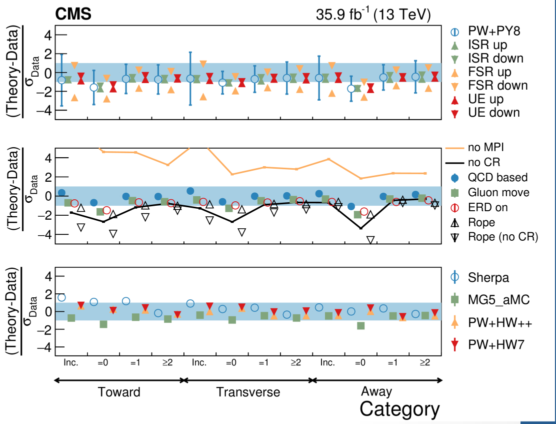


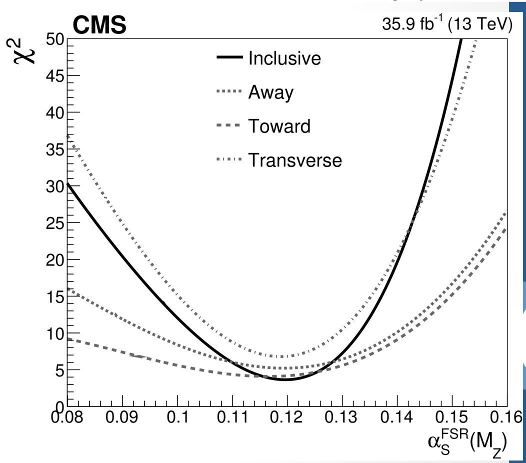
Underlying events in tt

1807.02810

- Universality in UE at an higher energy scale
  - UE model tested up to a scale of twice m_t
  - Measurements in dilepton invariant mass indicate that it should be alid at even higher scales
  - Can be used to improve systematic uncertainties in future top quark analyses
  - Results obtained show that a value of $\alpha_s^{FSR}(M_Z) = 0.120 \pm 0.006$ is consistent with the data
  - The corresponding uncertainties translate to a variation of the renormalization scale of √2





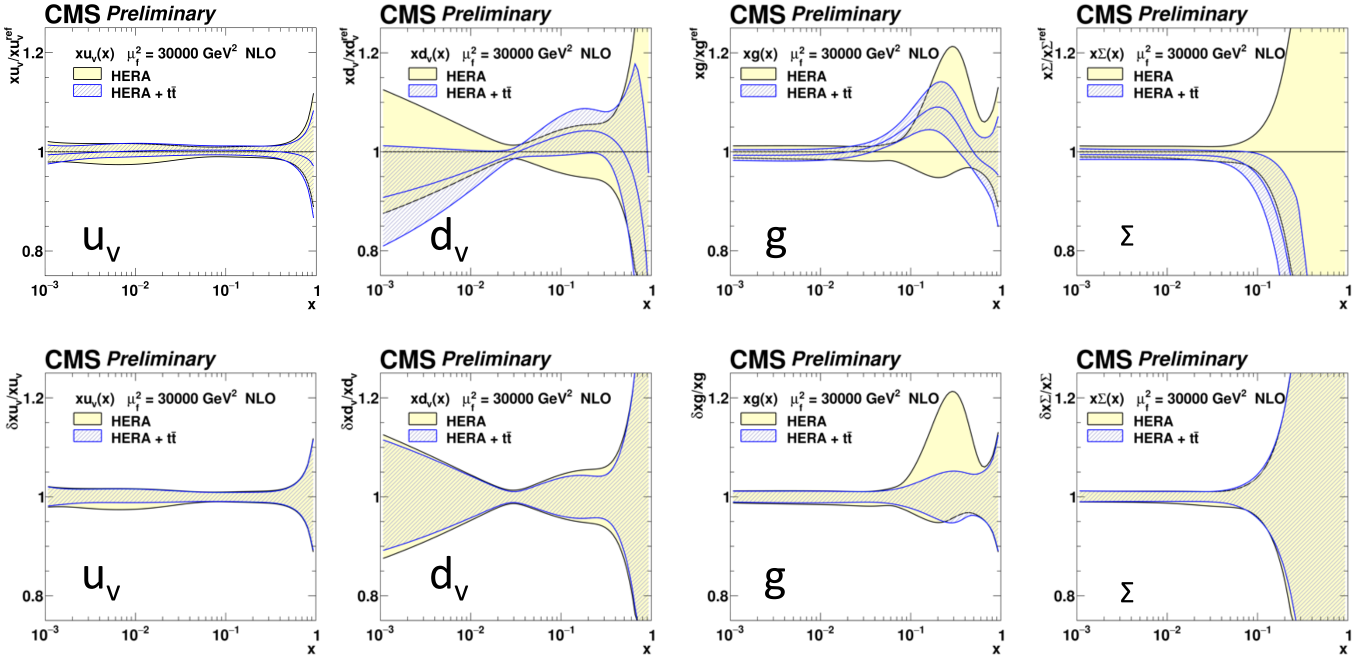


m_{top}, α_s, PDFs from diff σ_{tt} 3/3

TOP_18_04

- Interpreting the data
  - followed standard approach: using HERA DIS data only, or HERA + tt data to demonstrate added value from tt on PDF and α_s determination
  - settings follow HERAPDF2.0, use xFitter-2.0.0
  - input data: combined HERA DIS [1506.06042] + tt

reduced *g* uncertainty at high *x*
smaller impact on other distributions via corr.

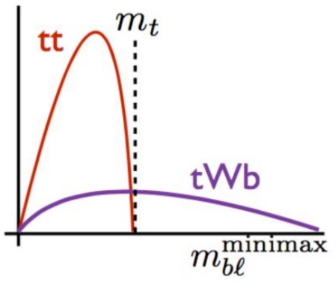


PDFs (α_s in HERA only fit set to α_s = 0.1135 ± 0.0016)

Relative PDF uncertainties

Interference Wt And tt

[1806.04667](https://arxiv.org/abs/1806.04667)



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