Experimental Summary

María Aldaya (DESY)

Virtual Edition

TOP2021: 14th International Workshop on Top Quark Physics,
13-17 September 2021

HELMHOLTZ
SPITZENFORSCHUNG FÜR
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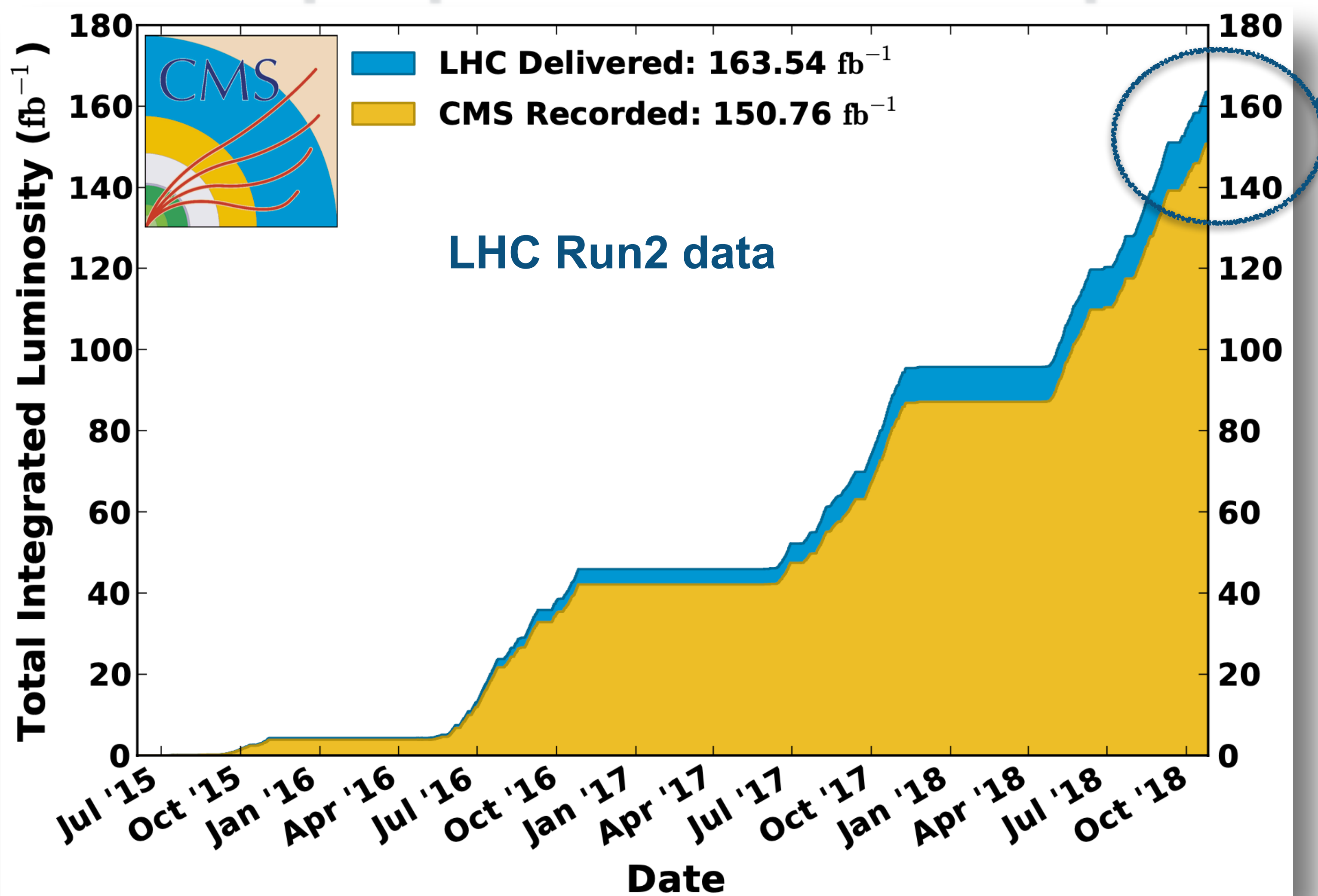
DESY

Top quarks: rich experimental programme



For top, this means:

~ 120M tt pairs

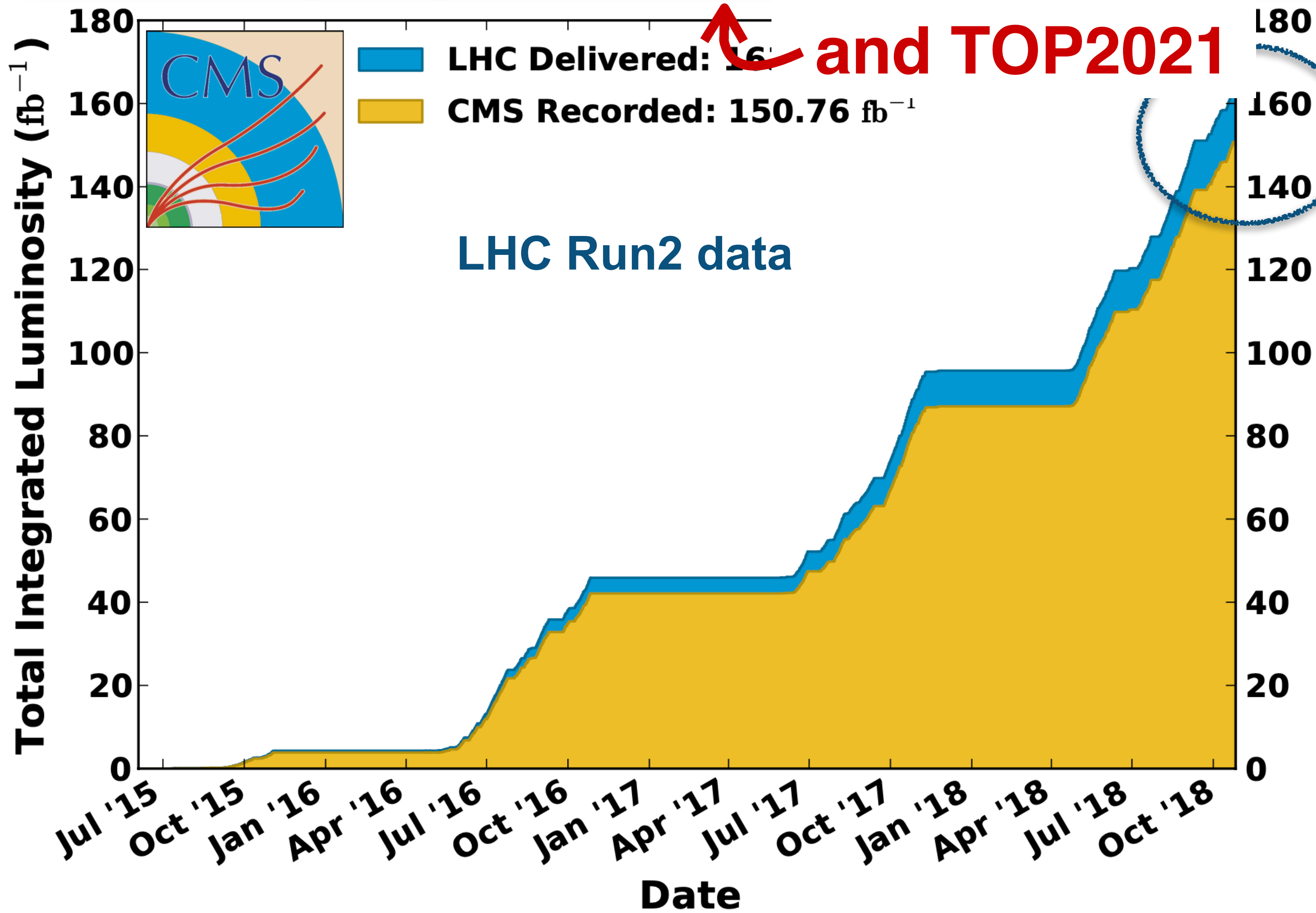
~ 30M single top

~ 120K ttZ, tZ

Focus of Run2 top physics (and beyond):

- Ultimate precision measurements
- Properties and couplings (tt and single top)
- Low cross section frontier: tt+X, t+X, tt+tt, tt+jets
- Interpretations (SM and BSM)

Top quarks: rich experimental programme



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- Interpretations (SM and BSM)

Many results presented at the workshop, too many to show here

Many new analyses from ATLAS and CMS over the last year

This talk: selection of most recent results — apologies if I missed your favourite one…!

Modelling & tuning

Giulia Negro

Good modelling of data, well-defined & small uncertainties, high-accuracy predictions are essential

"What's the point of having a 1% stat uncertainty if you're gonna stick a 20% Parton shower uncertainty on it…" ***Jay, ranting in a pub***

- ATLAS & CMS use same generators (main: Powheg+Pythia)
  - Very good agreement with data, but many regions with large mismodellings
  - Different tunes/shower settings
  - Difference in assessment of systematics

Current PS recommendations

Systematic unc.	CMS	ATLAS
ISR and FSR	Independent μ_R^{ISR} , μ_R^{FSR} scale variations with factor (2,0.5)	
UE	Variation of CP5 / A14 tune	
CR	Retuning UE with different CR models	
b fragmentation	Variations of Bowler-Lund r_B parameter of fragm. function	
Fragmentation & hadronization	Pythia 6 vs Herwig++ impact on jet energy response	Pythia 8 vs Herwig 7
Hadron decays	Varying B semi-leptonic BF within PDG value uncertainties	
Generator / NLO matching scheme	Powheg vs MC@NLO as cross-check	Powheg vs MC@NLO as uncertainty
ME-PS matching	Variation of h_{damp} that regulates first high-p_T emission	

Common CMS-ATLAS MC samples would help greatly in understanding and comparing many of these uncertainties!

Modelling & tuning

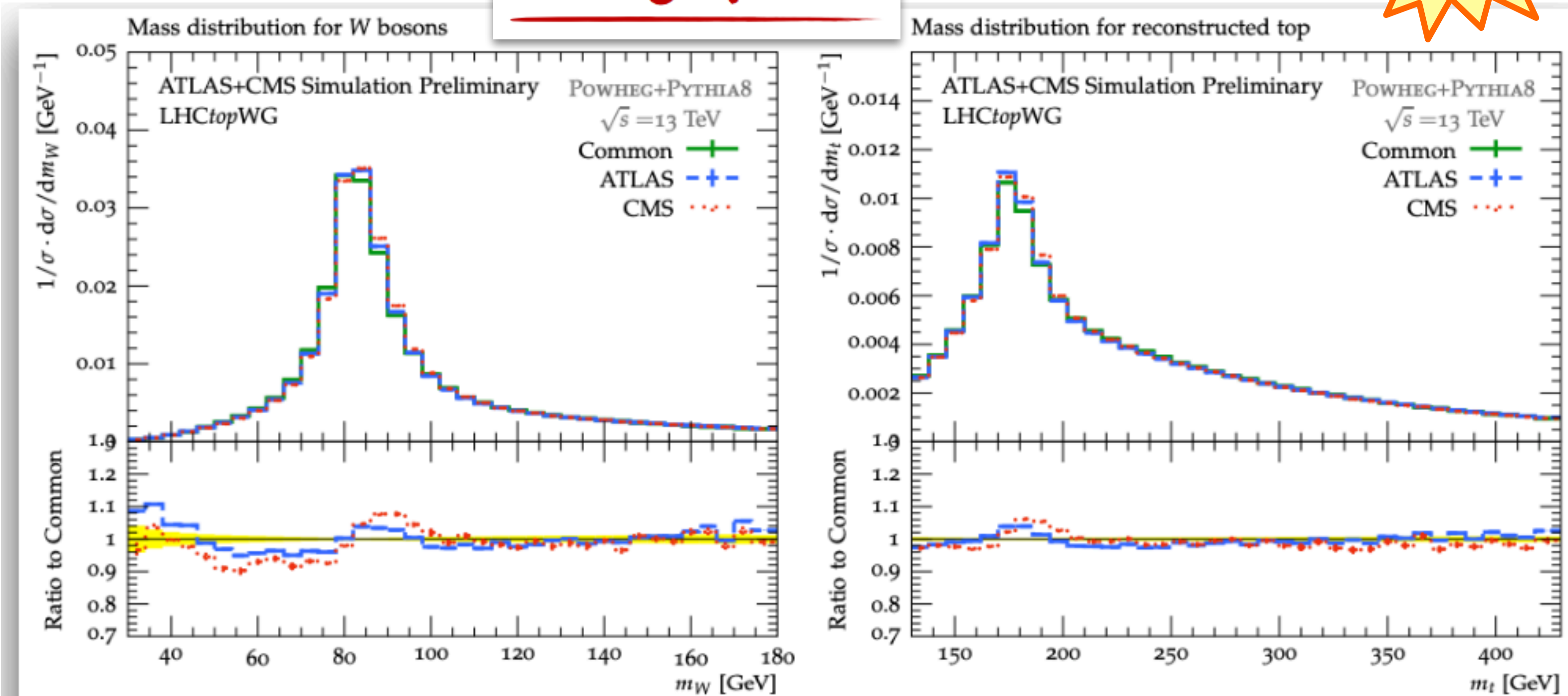
Giulia Negro

Towards first ever common ATLAS+CMS MC sample!

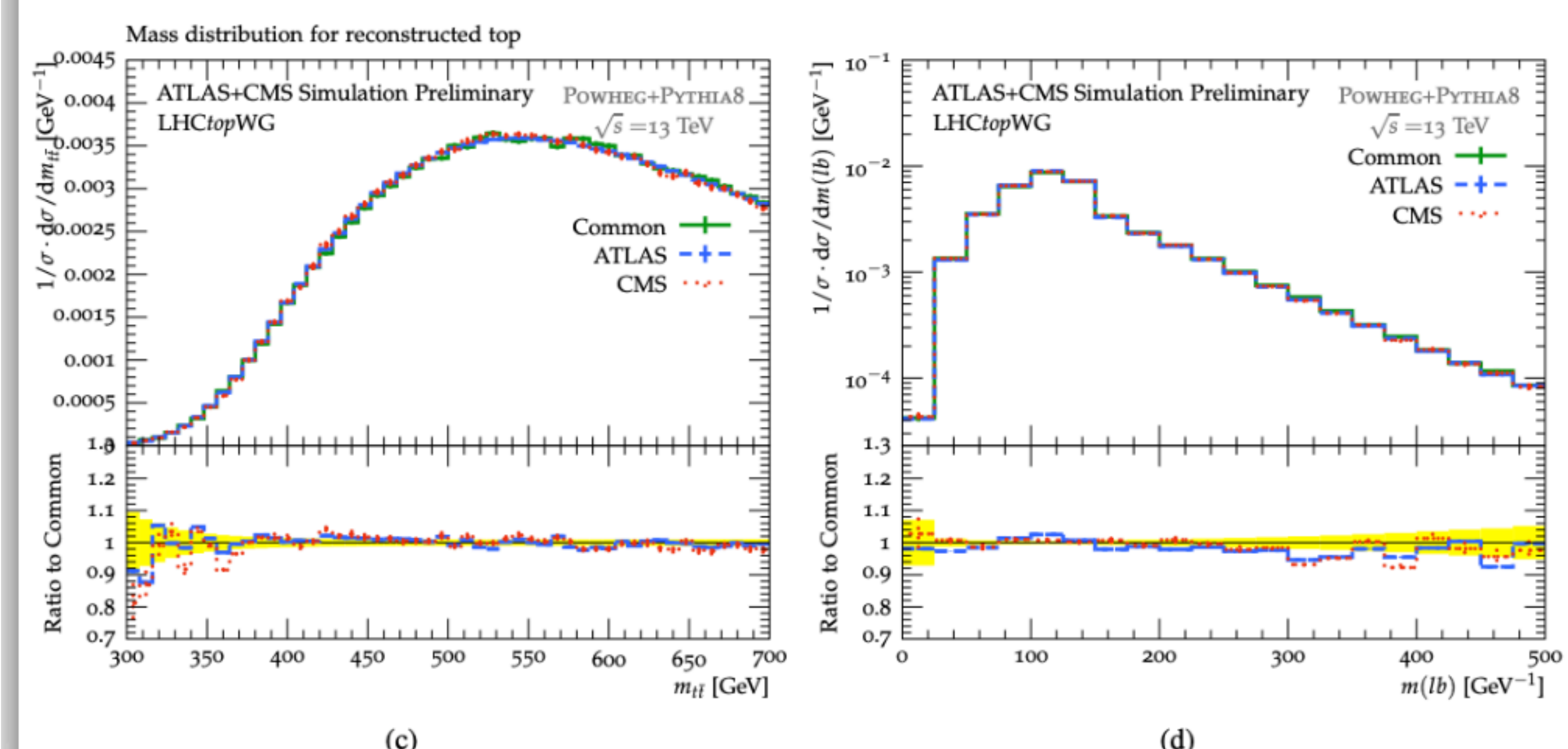
LHCtopWG

New

- Facilitate combinations & comparisons
- Understand correlations
- Use as baseline prediction
- v0.2 with more "physical" settings in progress



Common MC v0.1 (settings not yet optimized to data)

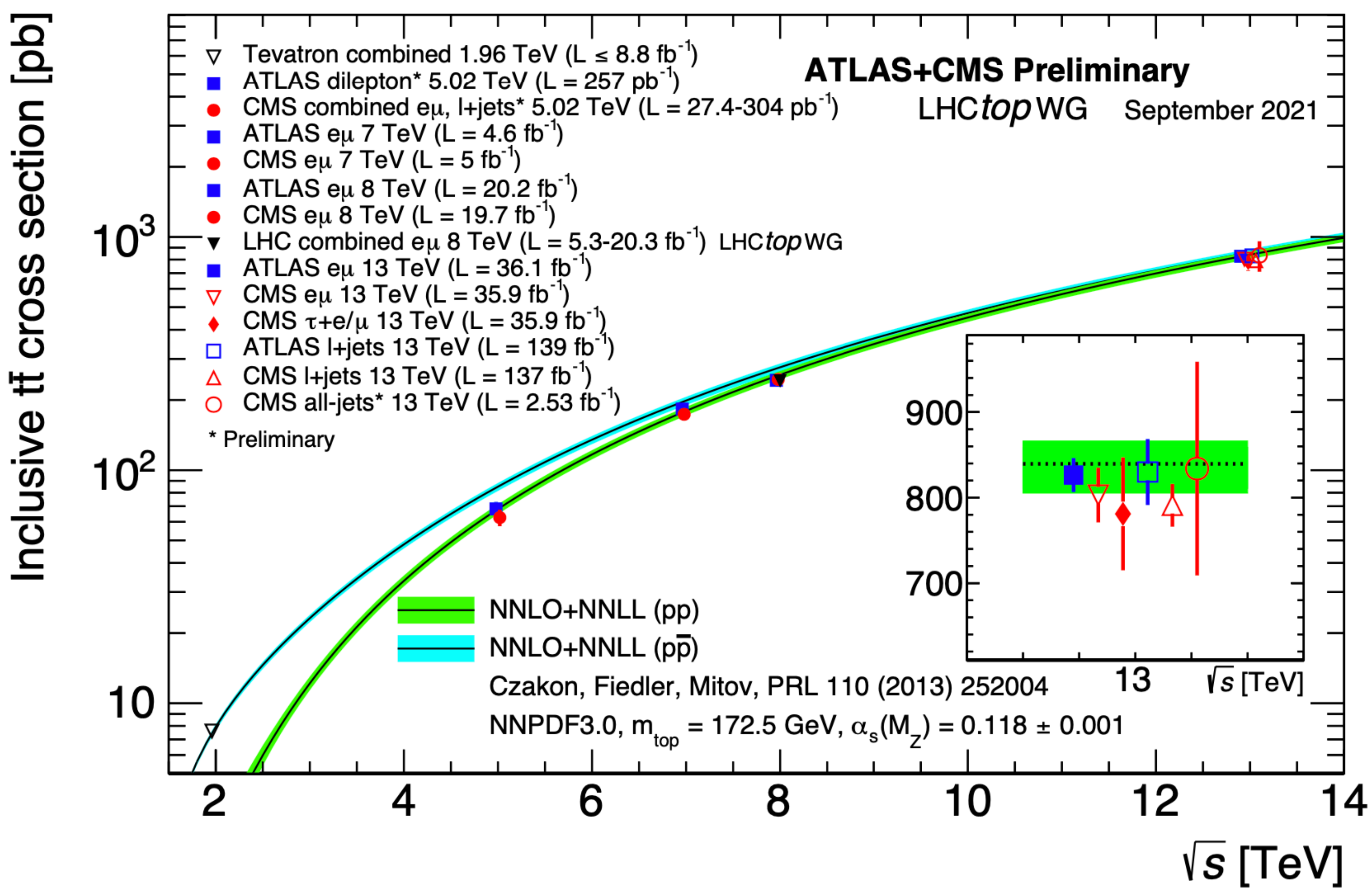


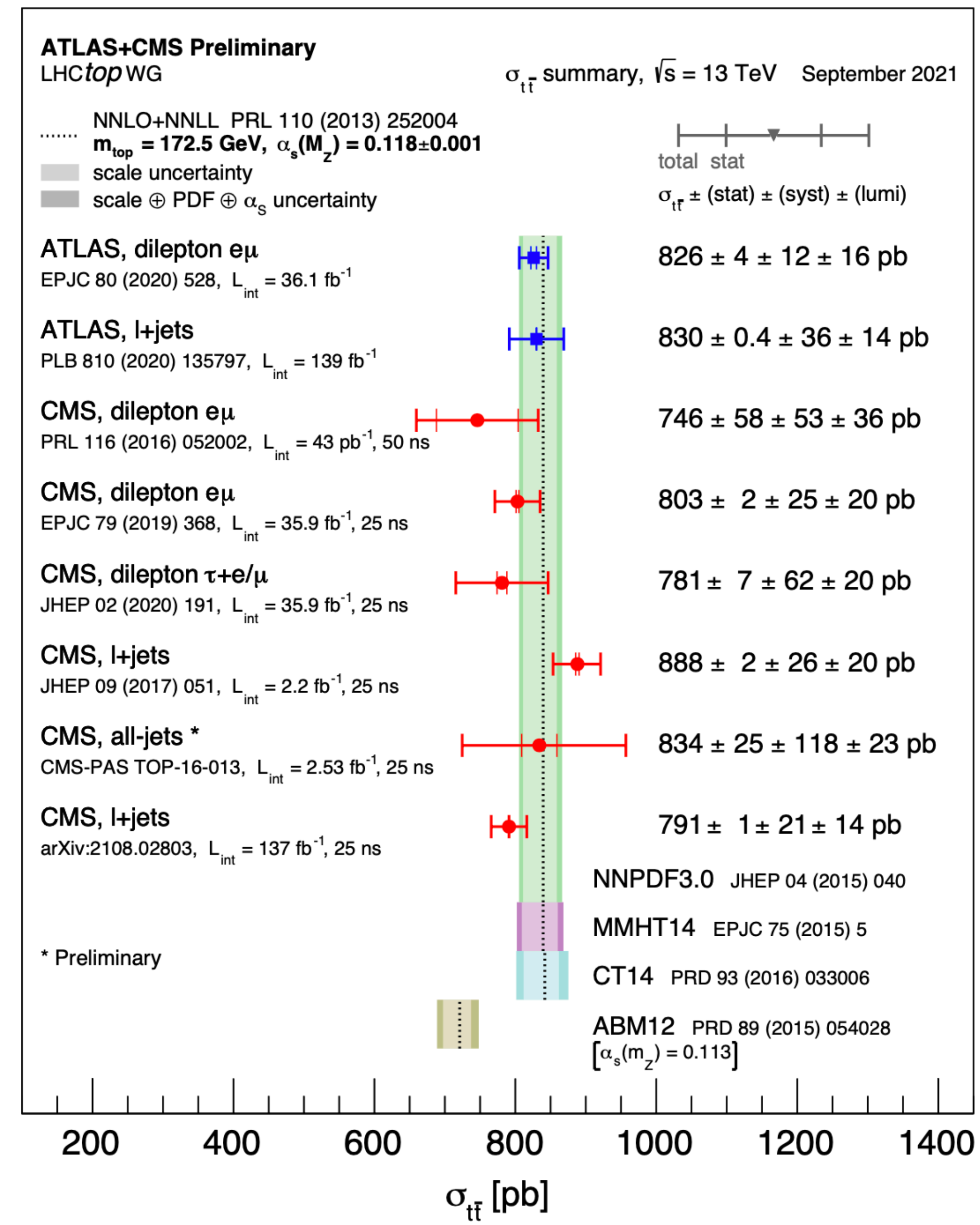
- Ultimate goal:
  - Real common sample using identical events
  - Common Pythia8 tuning using ATLAS & CMS data
  - Sharing of resources and prescriptions for nominal & systematics

Inclusive tt cross sections

Luca Martinelli

Measured in all channels and at all energies, at unprecedented precision



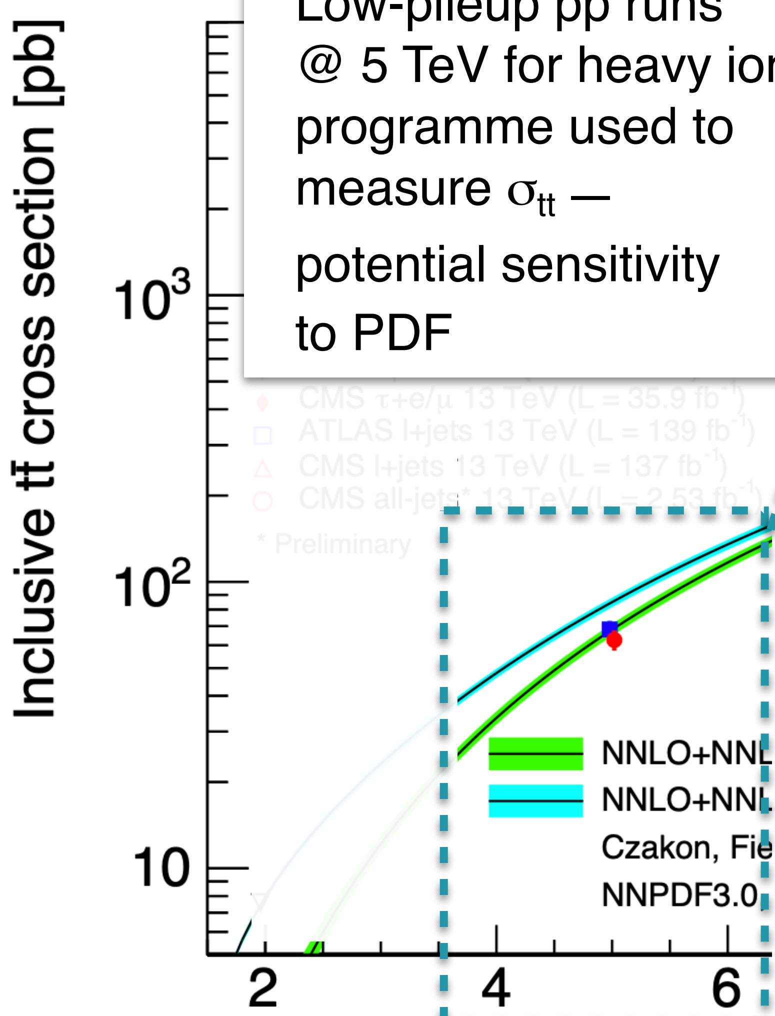


Inclusive tt cross sections

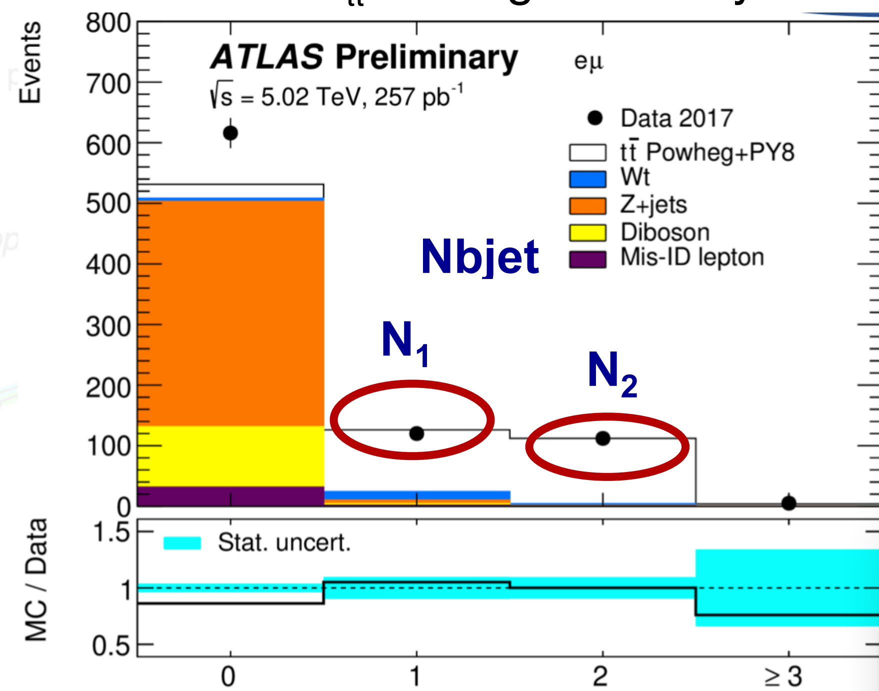
Luca Martinelli
YSF Carlos Vico

Measured in all channels and at all energies, at unprecedented precision

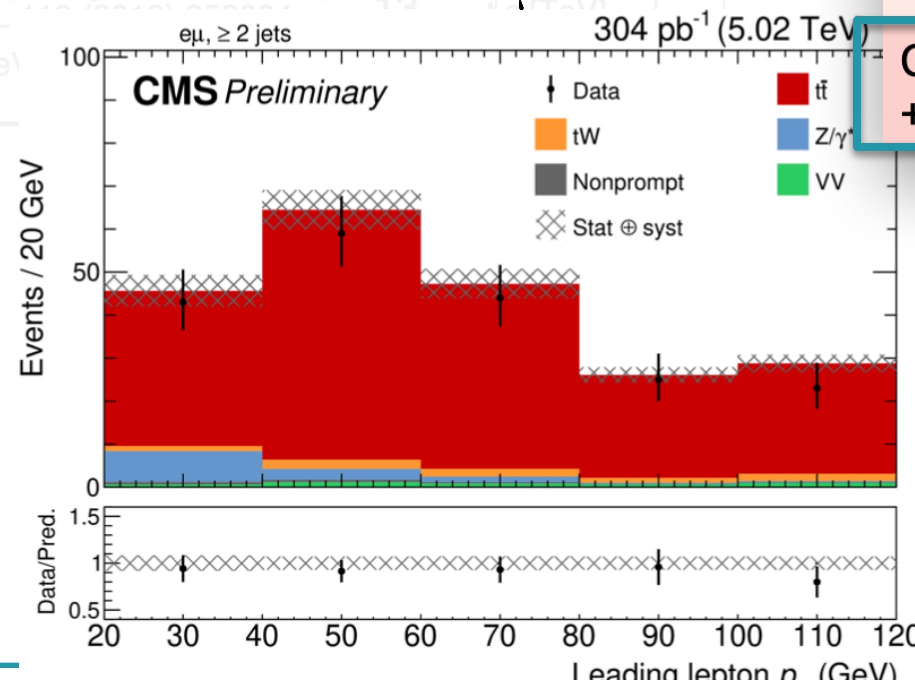
Low-pileup pp runs @ 5 TeV for heavy ion programme used to measure σ_{tt} — potential sensitivity to PDF



- ATLAS: "Standard" strategy: simultaneous extraction of σ_{tt} & b-tag efficiency in dileptons



- CMS: cut & count in eμ events



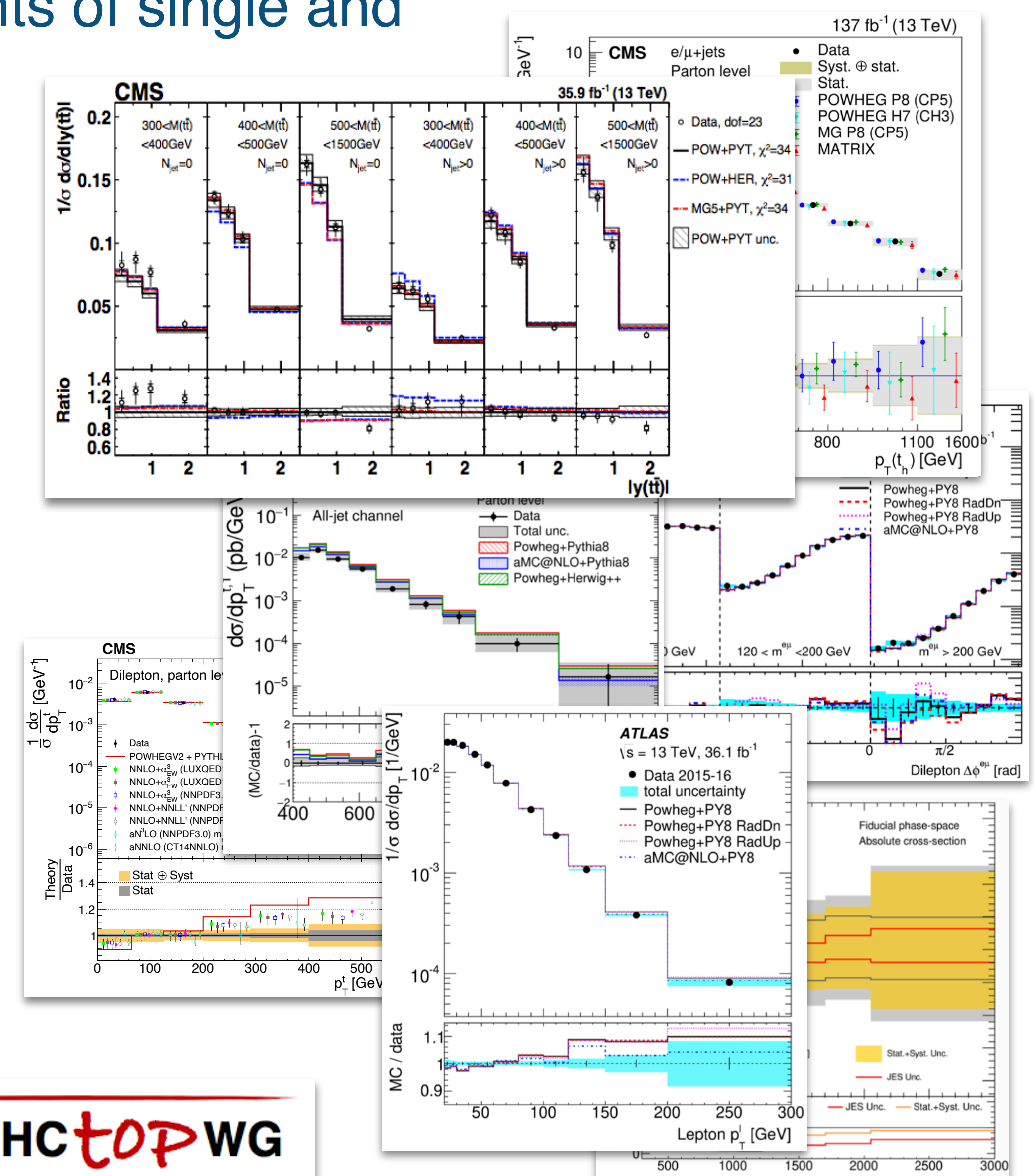
Results	σ_{tt} (± stat, ± syst+lumi)
ATLAS 2017 ll	66.0 ± 4.5 ± 2.0 pb
CMS 2017 eμ	60.3 ± 5.0 ± 2.9 pb
CMS 2017 eμ + 2015 l+jets	62.6 ± 4.1 ± 3.0 pb

Differential tt cross sections

Johannes Erdmann
Luca Martinelli
Poster Petr Jacka

High precision, most comprehensive set of measurements of single and multidifferential tt distributions at 13 TeV

- Knowledge of tt production cross section improved significantly in Run2
  - New analysis techniques constraining systematic uncertainties
  - Larger samples allow exploring corners of phase space (eg. boosted regime)
  - Cross sections used to extract SM parameters with high precision, and set limits on EFT
- All channels explored; parton, particle levels; different phase spaces
- Results across different channels/experiments are consistent
- Most measurements are well described by SM predictions, in some cases challenging theory precision
  - but many regions with large mismodelling (in particular, 2D-differential distributions)



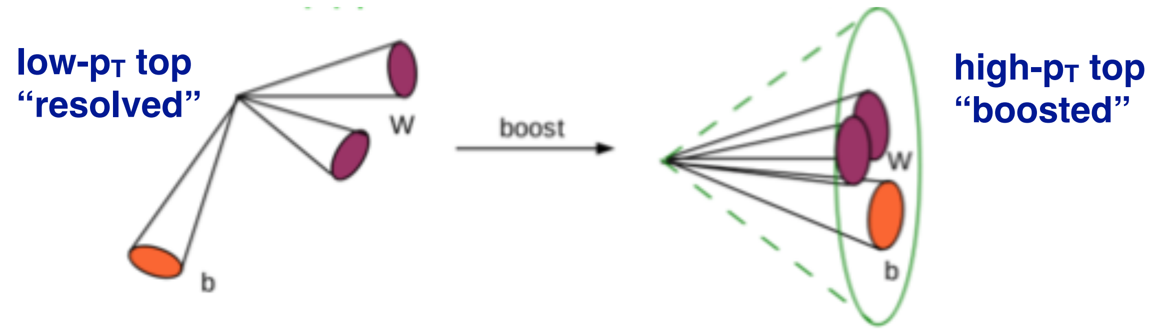
LHCtopWG

- Challenge:
  - improve modelling uncertainties, improve predictions
  - Compare ATLAS vs CMS vs theory and identify trends, similarities, differences

tt in the boosted regime

Johannes Erdmann
Luca Martinelli
Poster Petr Jacka

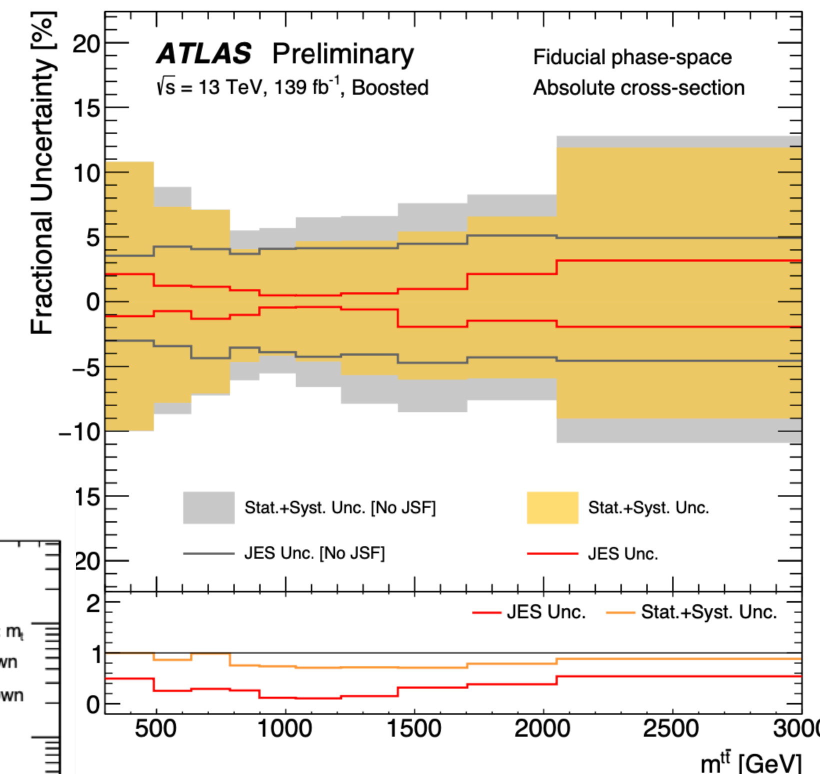
- Measure tops at high p_T using optimized event selection & reconstruction up to TeV range

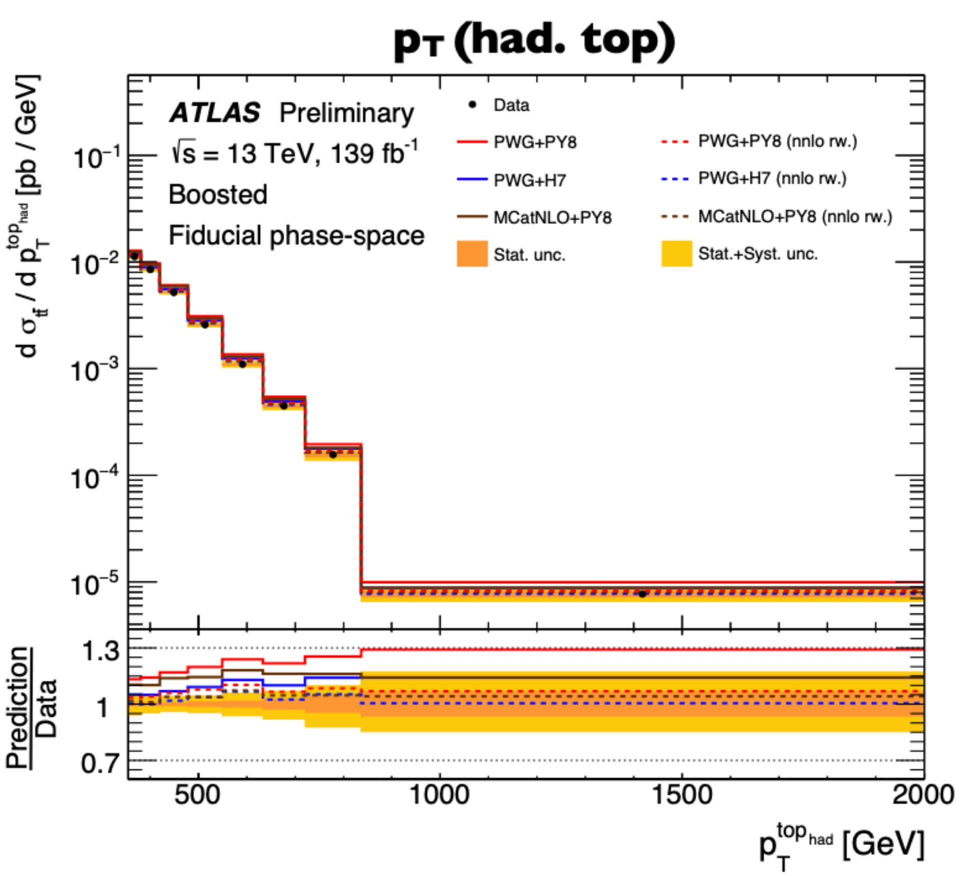


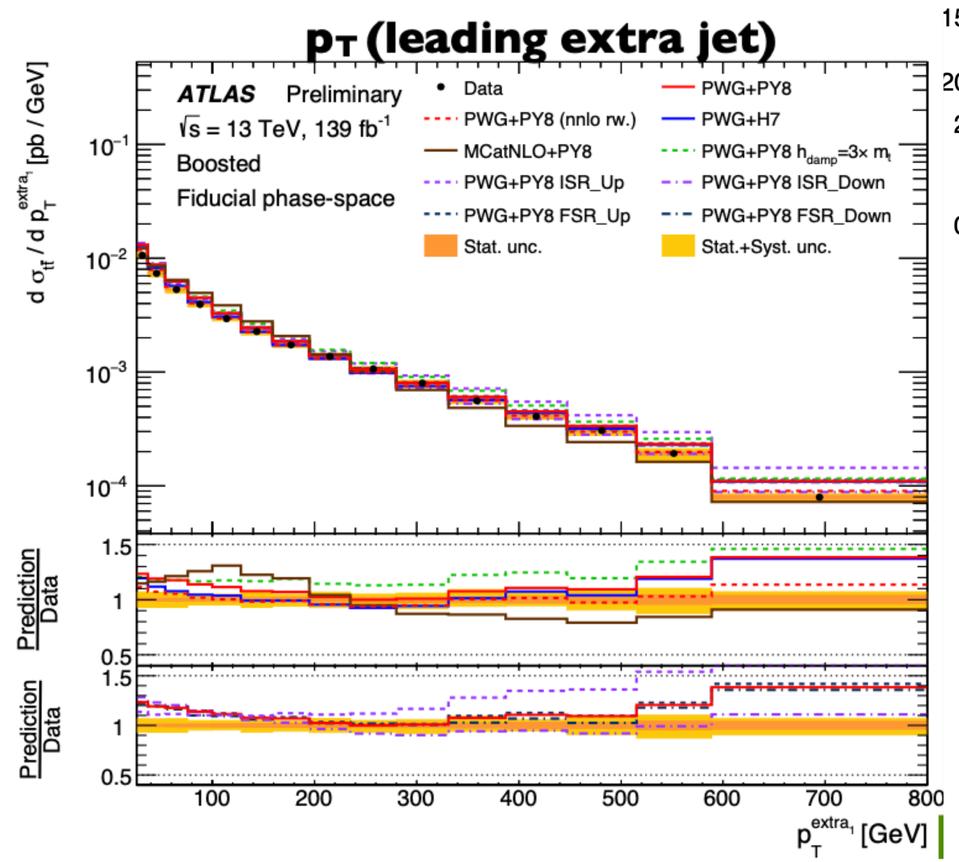
- Re-cluster R = 0.4 jets with anti-kT R = 1
- 120 < m_{jet} < 220 GeV

- ATLAS, **l+jets**: 1 large-R jet, pT > 355 GeV
    - Jet energy scale calibrated using mt
- 1D and 2D differential cross sections as a function of top, tt, and additional jets, particle level

New





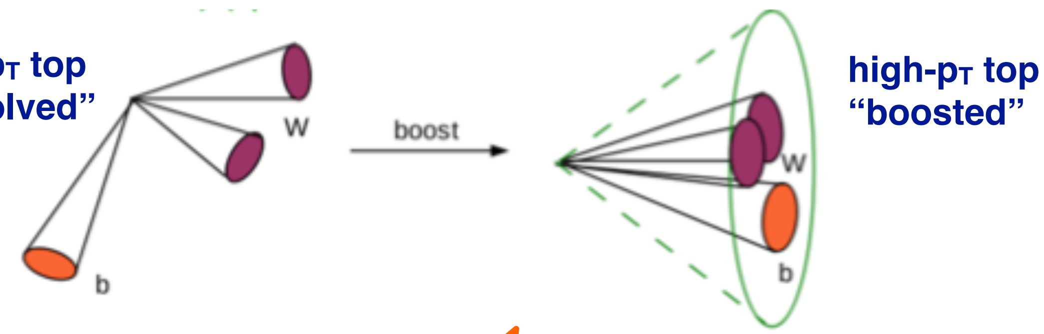


- top p_T softer in data
- Reweighting the MC predictions to the NNLO parton-level improves the agreement
- The modelling of the additional radiation events is not good for all the tested generators (matrix elements with up to one additional jet)
- Good agreement in shape

$t\bar{t}$ in the boosted regime

Johannes Erdmann
Poster Petr Jacka

- Measure tops at high p_T using optimized event selection & reconstruction up to TeV range

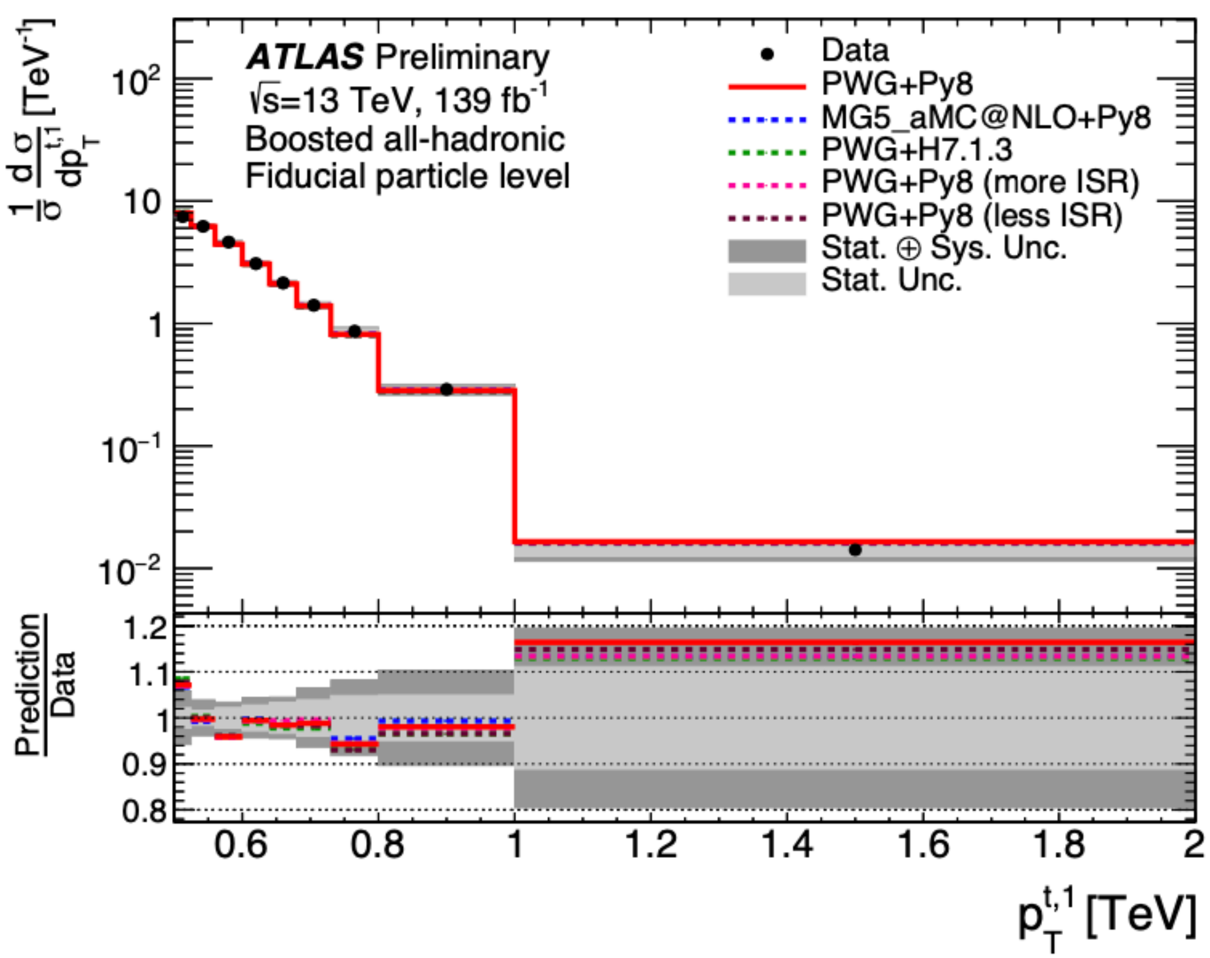


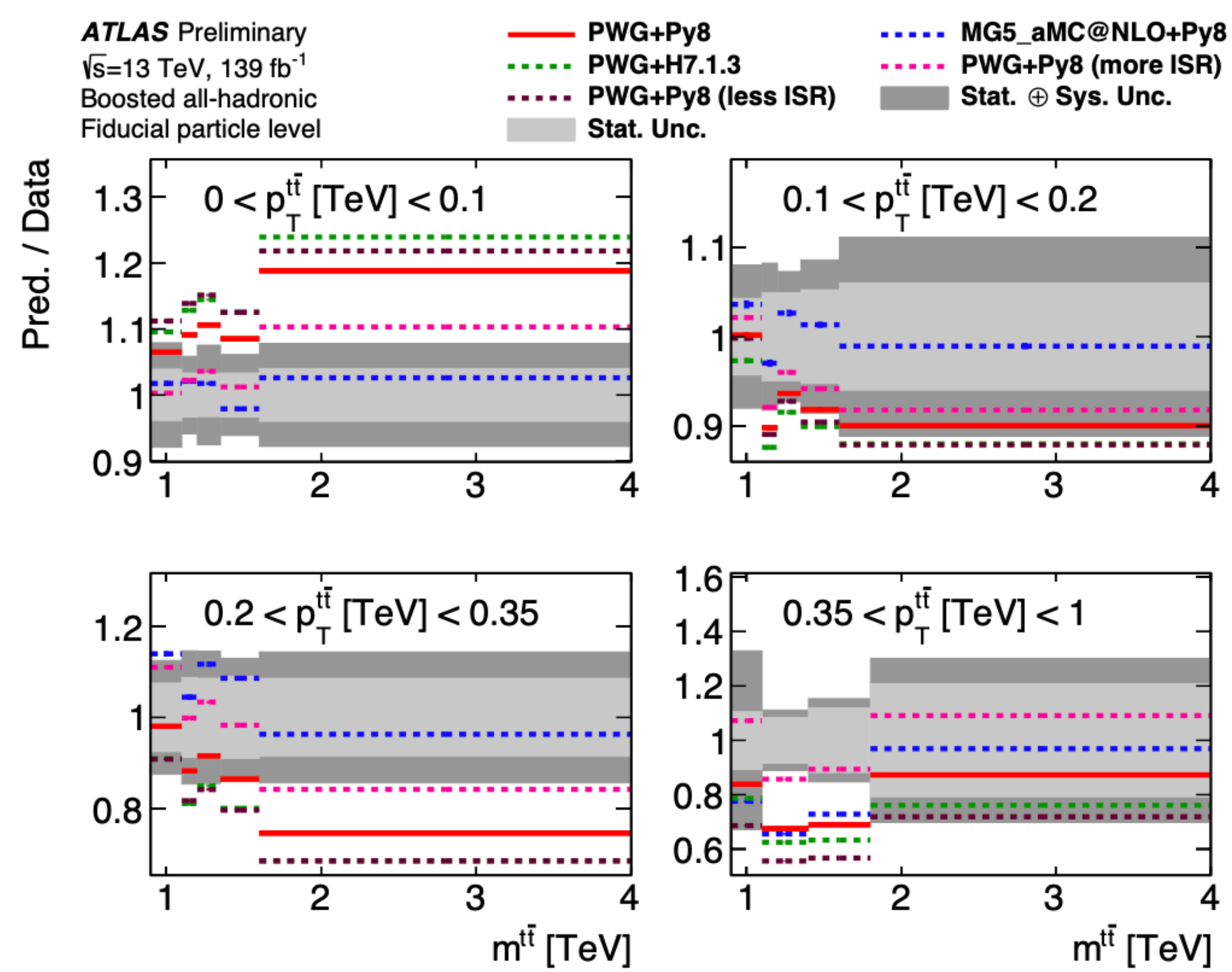
- Re-cluster R = 0.4 jets with anti-kT R = 1
- 120 < m_{jet} < 220 GeV

- ATLAS, **all+jets**: 2 large-R jet, pT > 500, 350 GeV
  - Use Top-tagger calibrated on l+jets data

TOP2021

- 1D-3D differential cross sections, parton & particle level

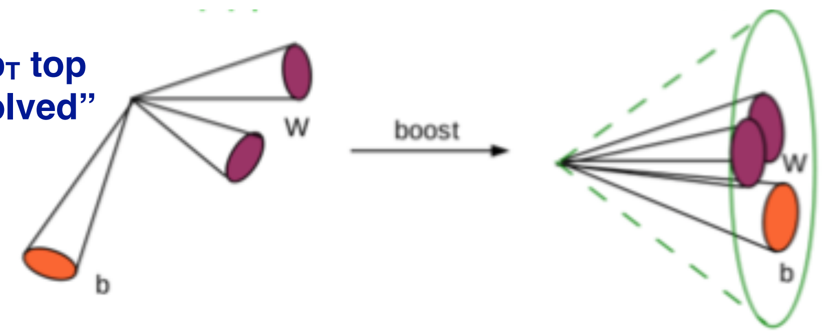




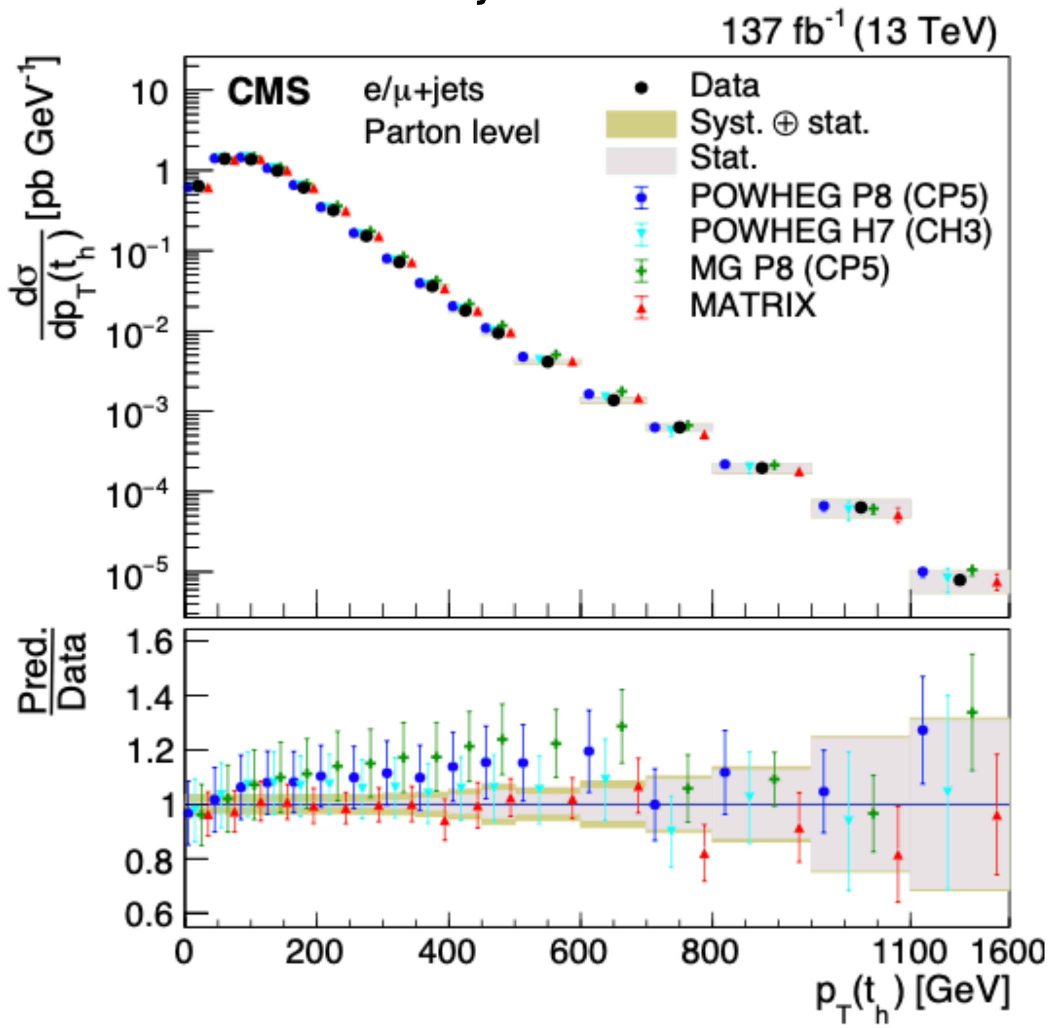
and in the full spectrum!

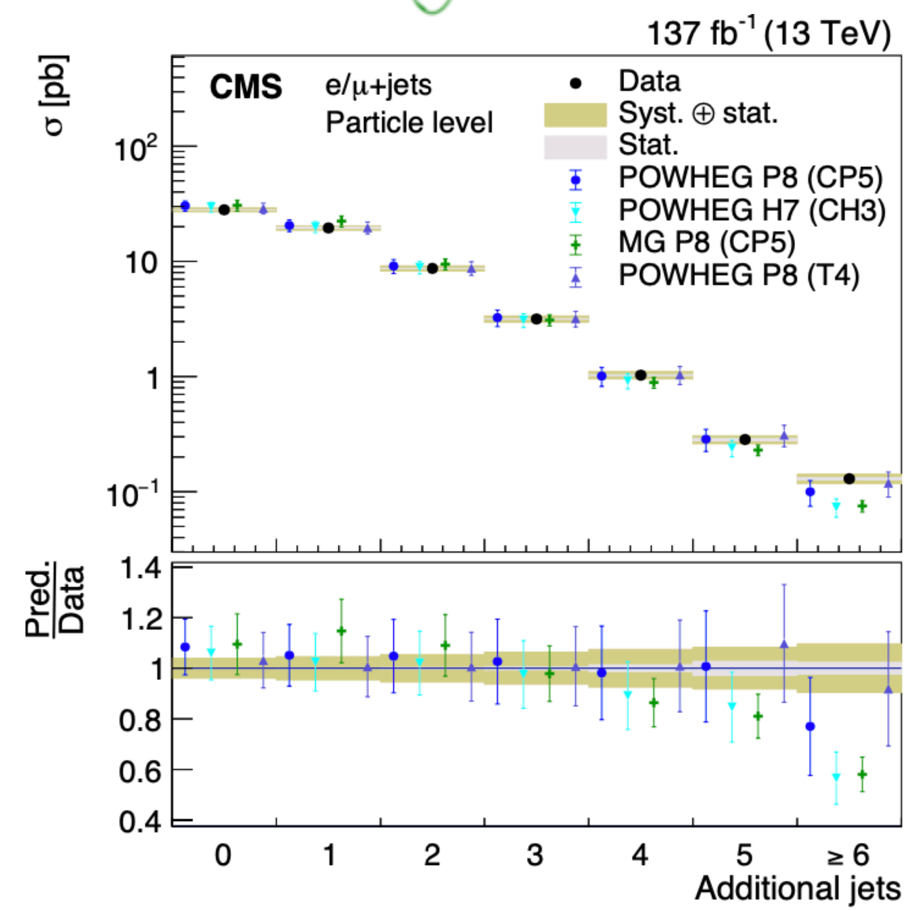
Luca Martinelli

- Measure tops in the full kinematic range using optimized event selection & reconstruction up to TeV range



- CMS, l+jets: for the 1st time, combined fit of resolved and boosted event categories
    - 1D and 2D differential cross sections of top, tt and additional jets



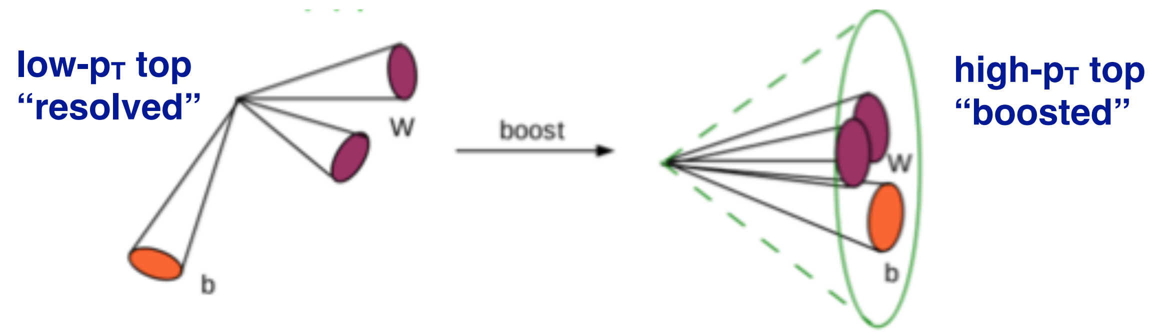


- Generally good agreement with MC predictions
- Softer top pT in data wrt MC, better described by NNLO calculation (MATRIX)
- Jet observables and multiplicities more difficult to describe

and in the full spectrum!

Luca Martinelli

- Measure tops in the full kinematic range using optimized event selection & reconstruction up to TeV range



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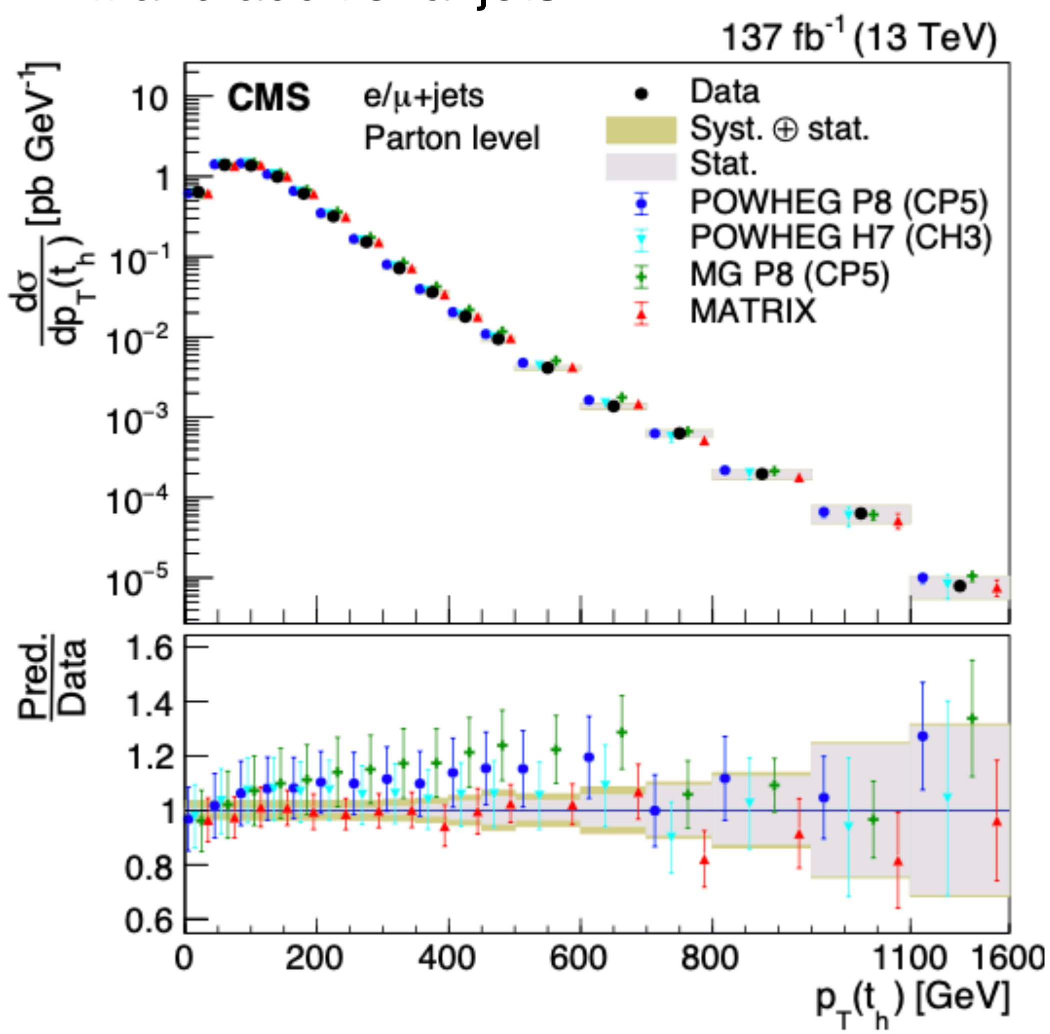
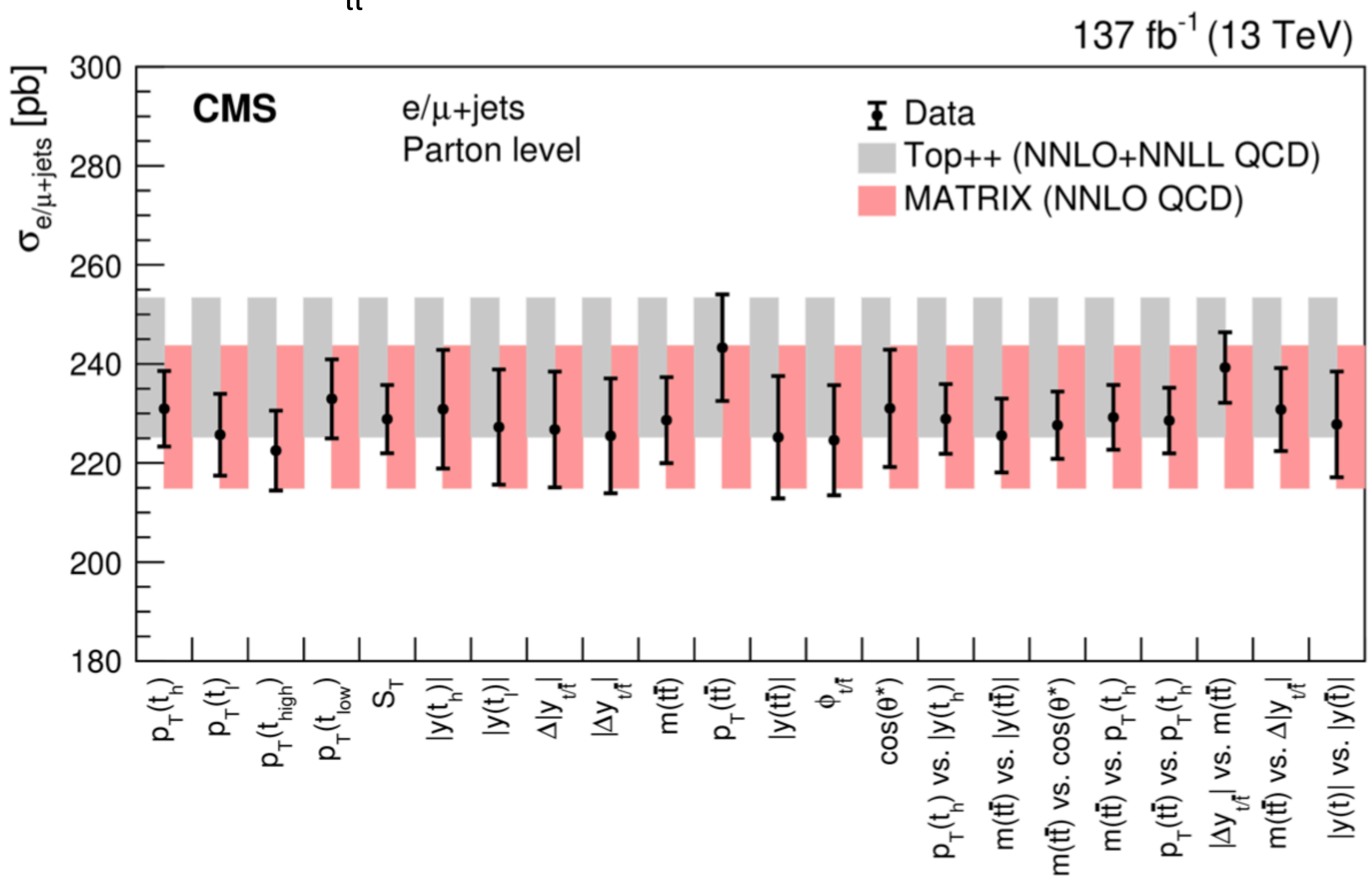


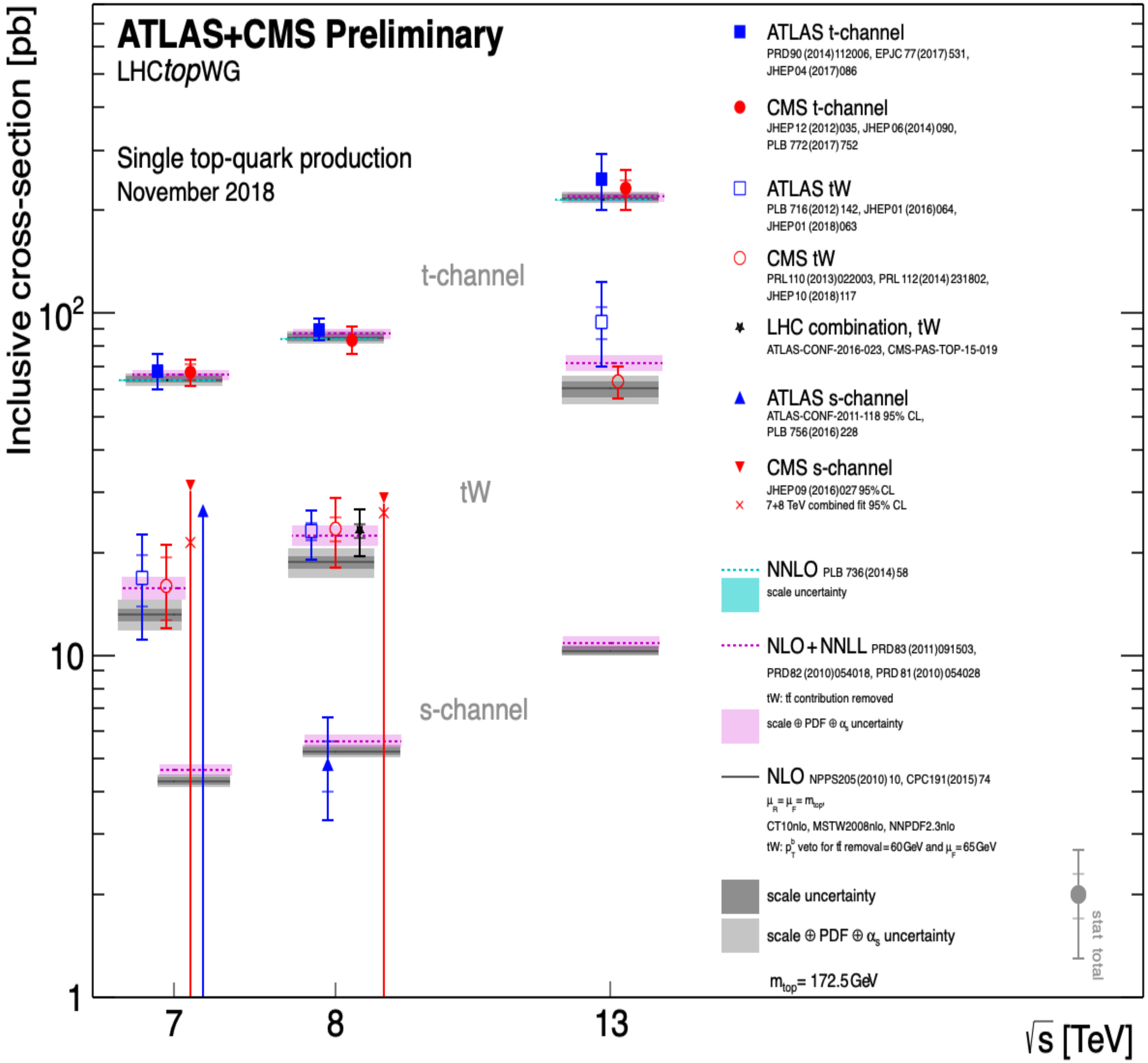
- Inclusive σ_{tt} = sum of all bins of differential cross section



$\sigma = 791 \pm 1\,(stat) \pm 21\,(syst) \pm 14\,(lumi)\;pb$ (3.2%) !!

Single top production

Victor Rodriguez
YSF Duncan Leggat
YSF Alejandro Soto

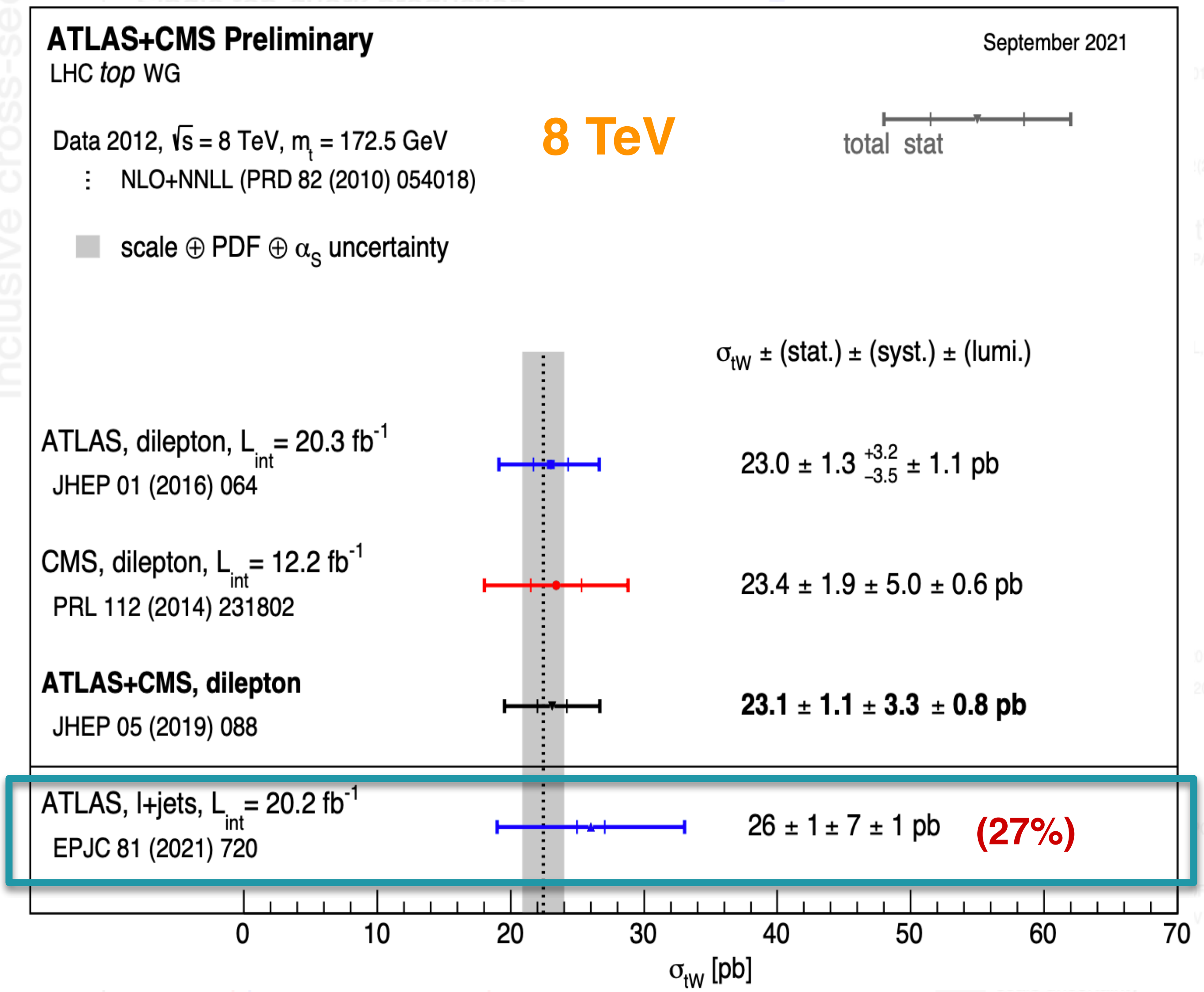


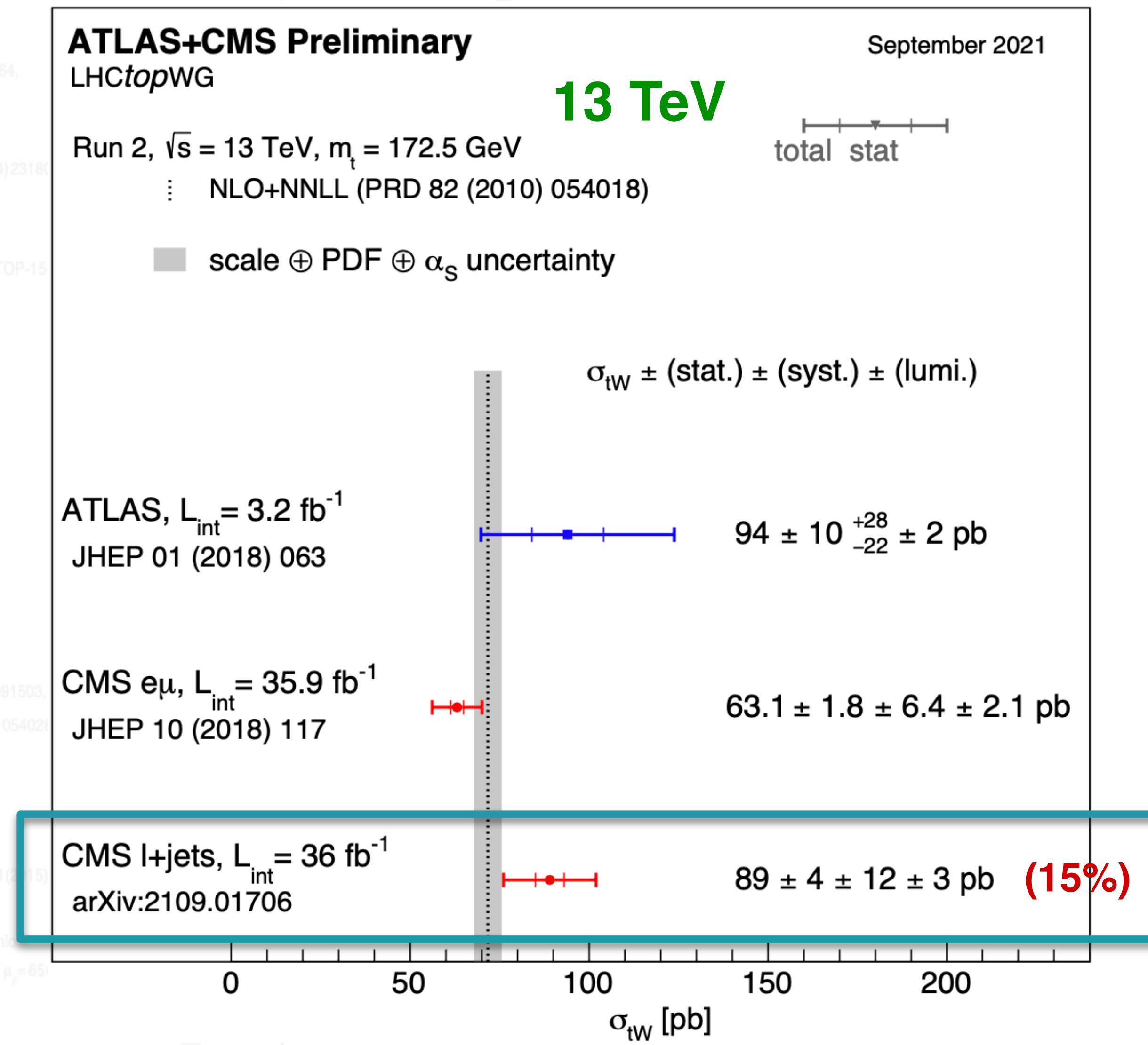
- Run2: single top cross section as high as tt at 8 TeV
- Measured all production modes (s-channel not yet at 13 TeV)
- MVA techniques needed to enhance sensitivity to the signal
- Ramping up to era in precision
  - Differential cross sections
  - Properties

Single top production

Victor Rodriguez
YSF Duncan Leggat
YSF Alejandro Soto

tW also measured in l+jets



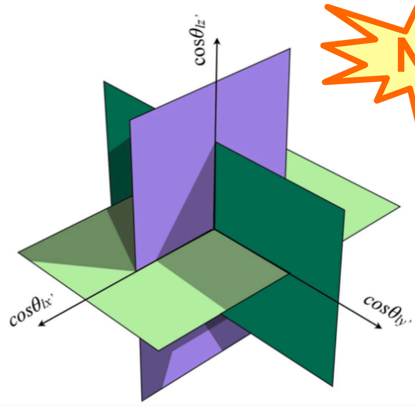


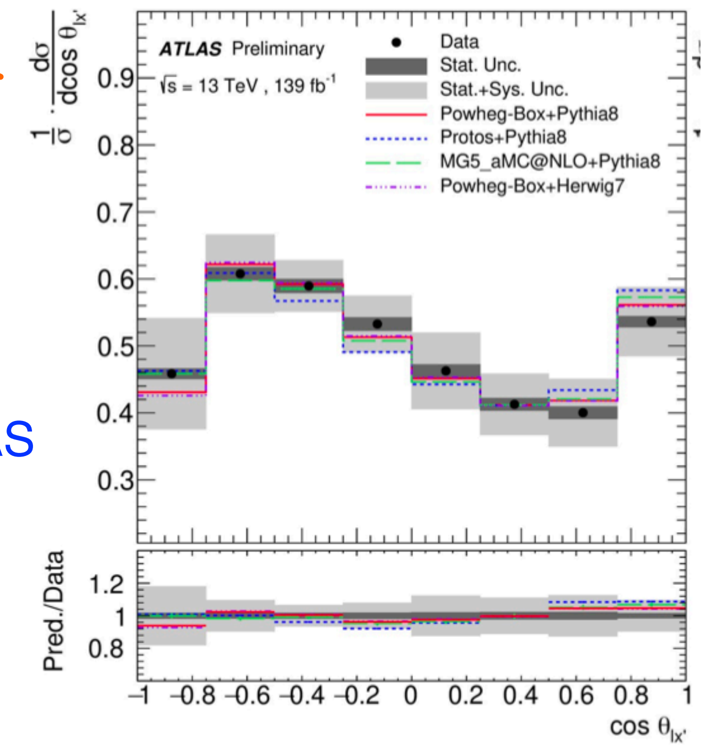
Single top differentially

Victor Rodriguez
YSF Alejandro Soto

- Wealth of differential measurements in different production and decay modes
- Overall good agreement with MC predictions

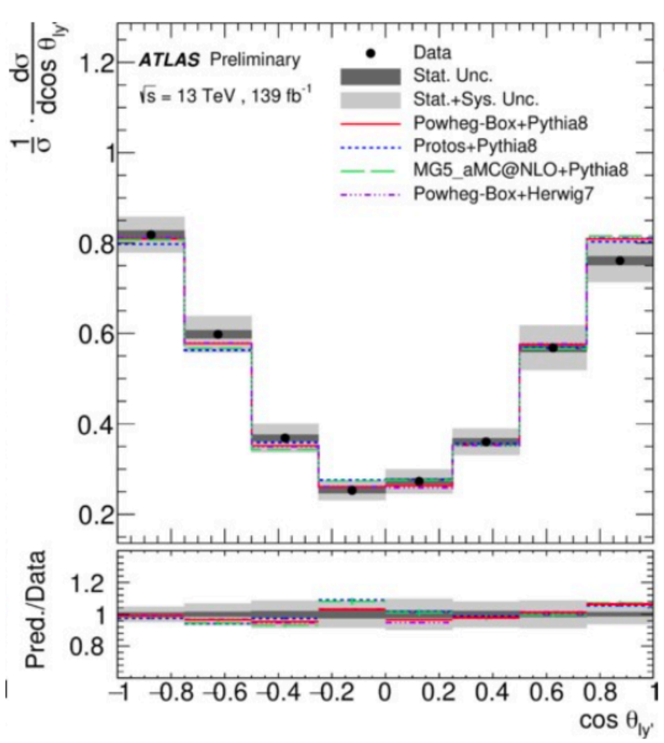
New

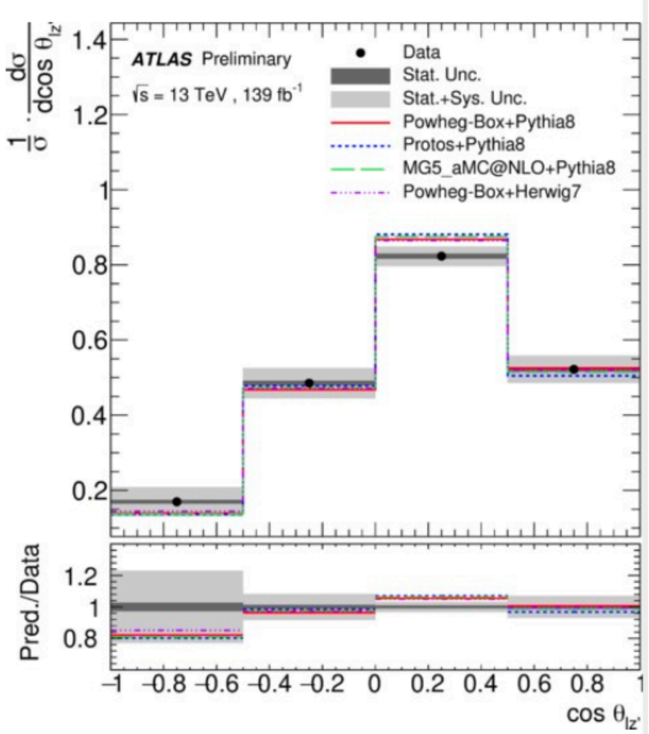




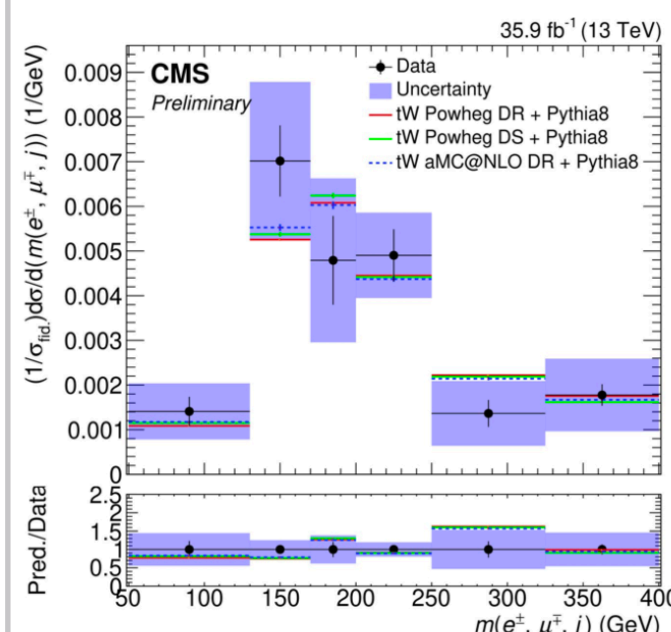
t-channel, ATLAS

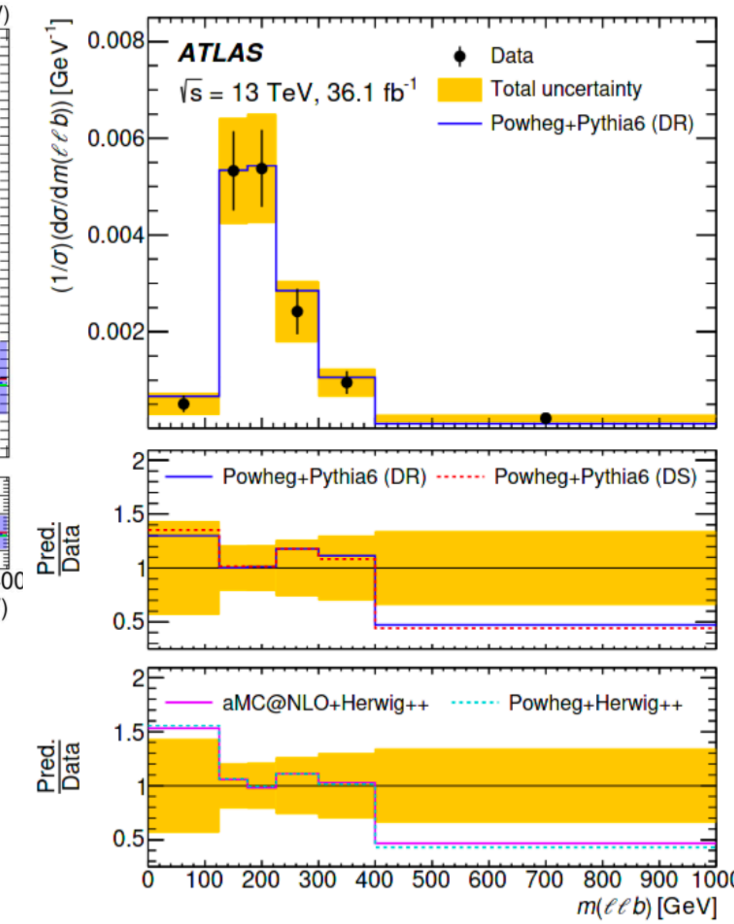
Angular observables to measure polarization and anomalous couplings





tW-channel, CMS and ATLAS



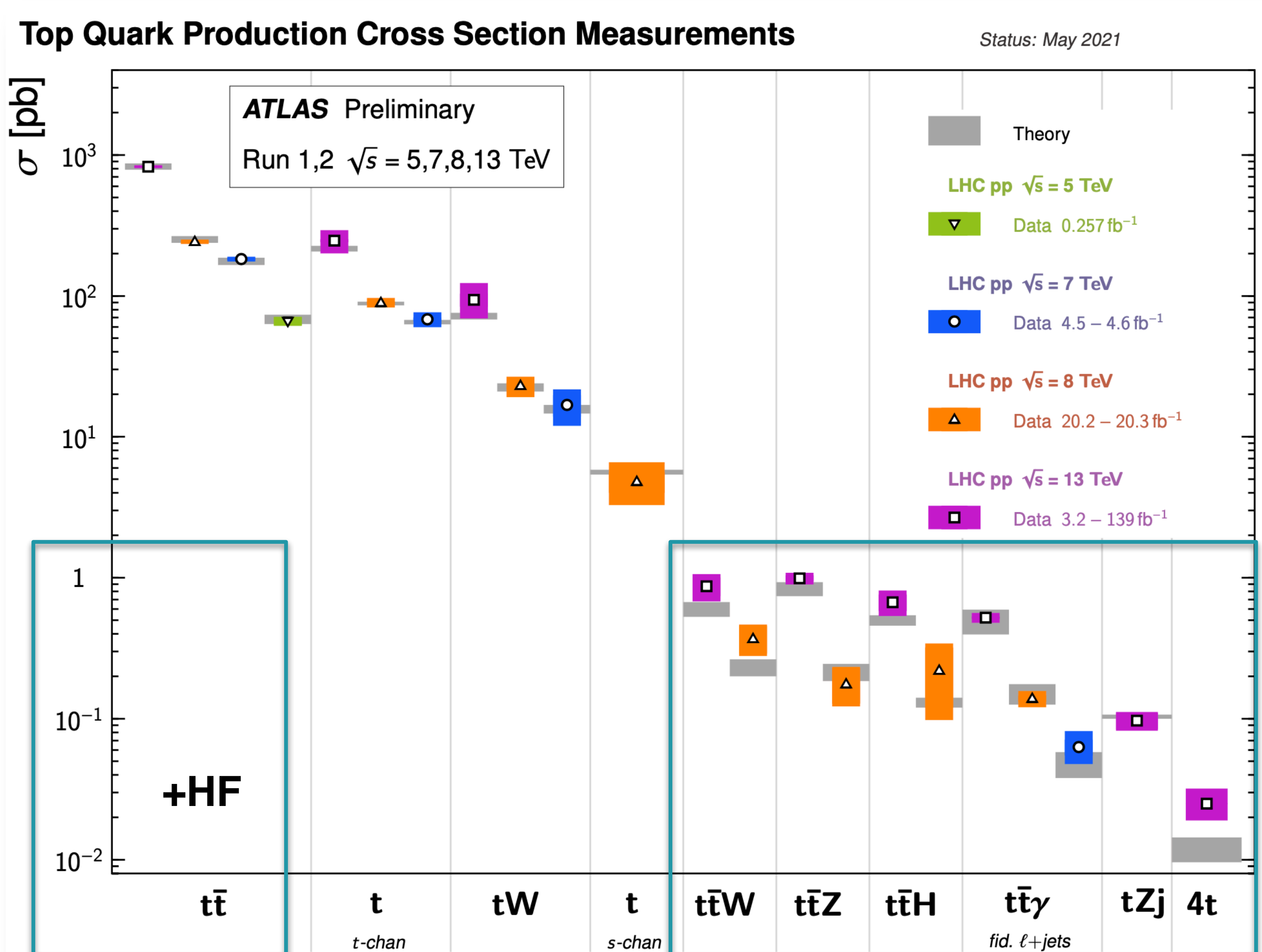


- Challenge: difficult to compare between experiments: different binning, phase space

Top+X production

Timothee Thevenaux-Pelzer
Joscha Knolle
Andrej Saibel

- Very low production cross sections O(fb)
- Former rare processes (eg. ttZ) are now reaching precision regime in Run2
- Rarer processes (eg. tZq) becoming available
- Challenging measurements with complex final states
  - Vert complex analyses, exploit MVA techniques
- Differential measurements, reinterpretation of results (EFT and other models) start to appear

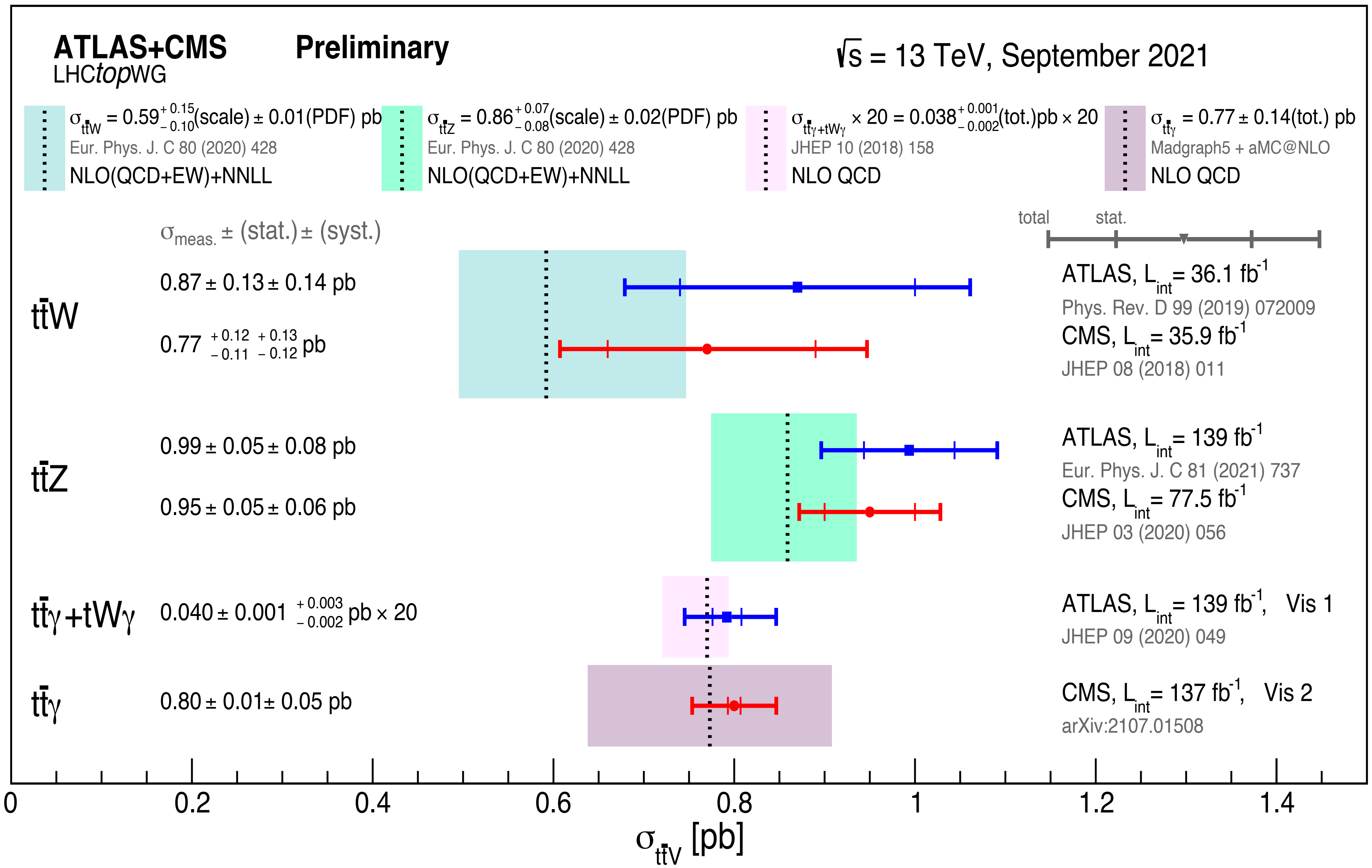


Good agreement with SM calculations, small discrepancies (eg, ttW and 4top)

ttV cross sections

Laurynas Mince
Joscha Knolle

- Probing top-electroweak couplings, which can be modified by BSM effects
- Multiple analysis regions defined with different flavour tagging requirements, lepton flavour, basic kinematics



- Slight tension in ttW, consistently observed also in ttH (multilepton) and 4top analyses in both ATLAS and CMS

  —> need to improve theoretical and experimental understanding

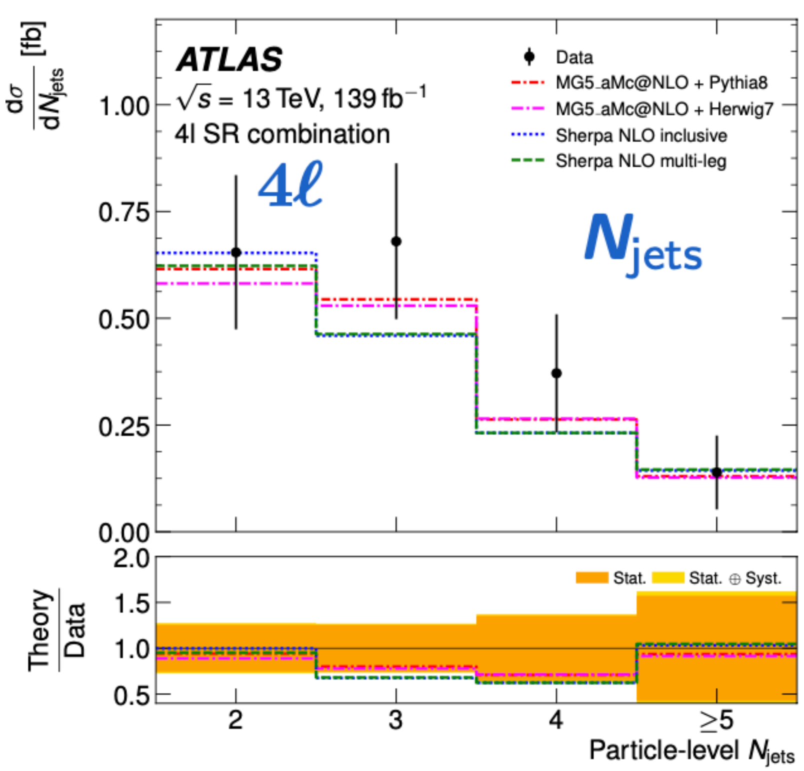
- Systematic uncertainties start to dominate for some processes

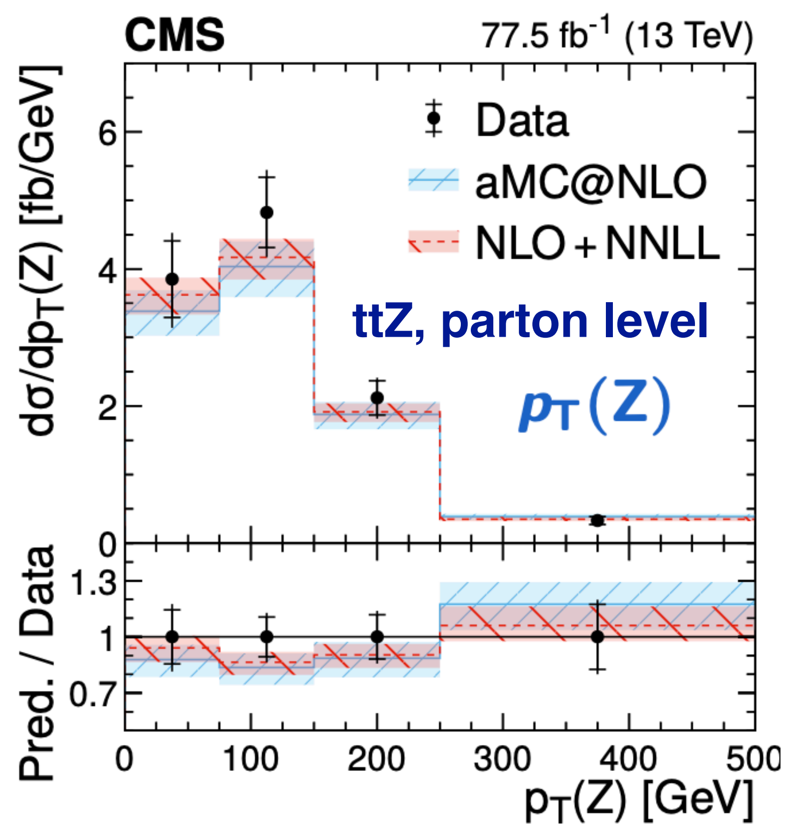
ttV cross sections

YSF Dominik Babal
Joscha Knolle

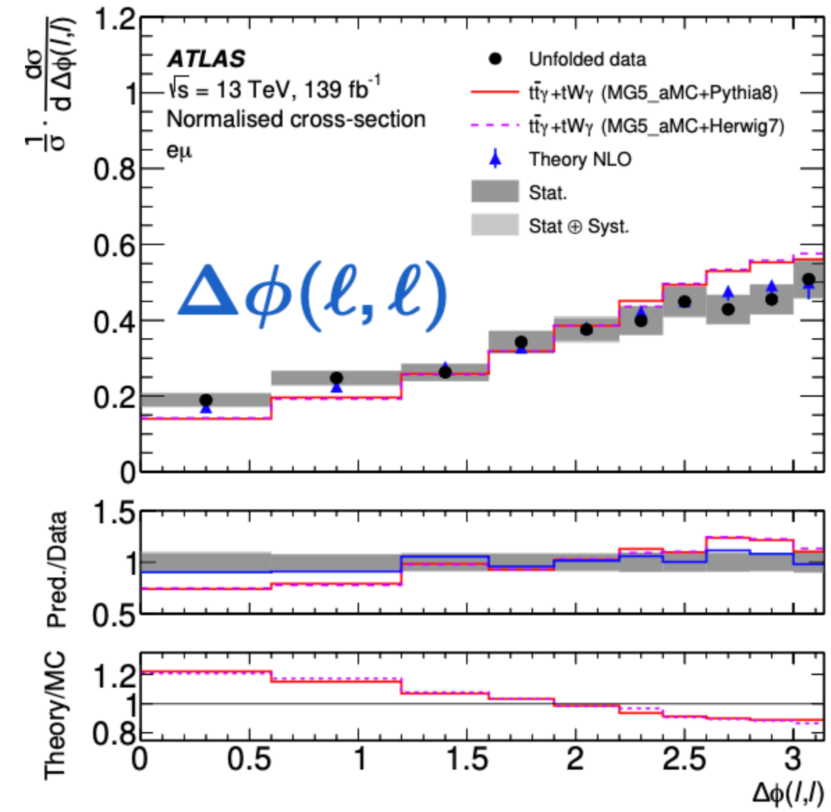
- Probing top-electroweak couplings, which can be modified by BSM effects
- Multiple analysis regions defined with different flavour tagging requirements, lepton flavour, basic kinematics
- Many differential measurements appearing: parton and particle level, fiducial and full phase space, comparing data to various MC and theory calculations
    - Used to set constraints on EFT and/or measure properties

ttZ, particle level

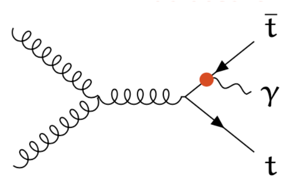




ttγ+tWγ, particle level



- Still statistics limited, general good agreement with predictions, especially NLO calculations



ttγ production in CMS

Gianny Mestdach
Joscha Knolle

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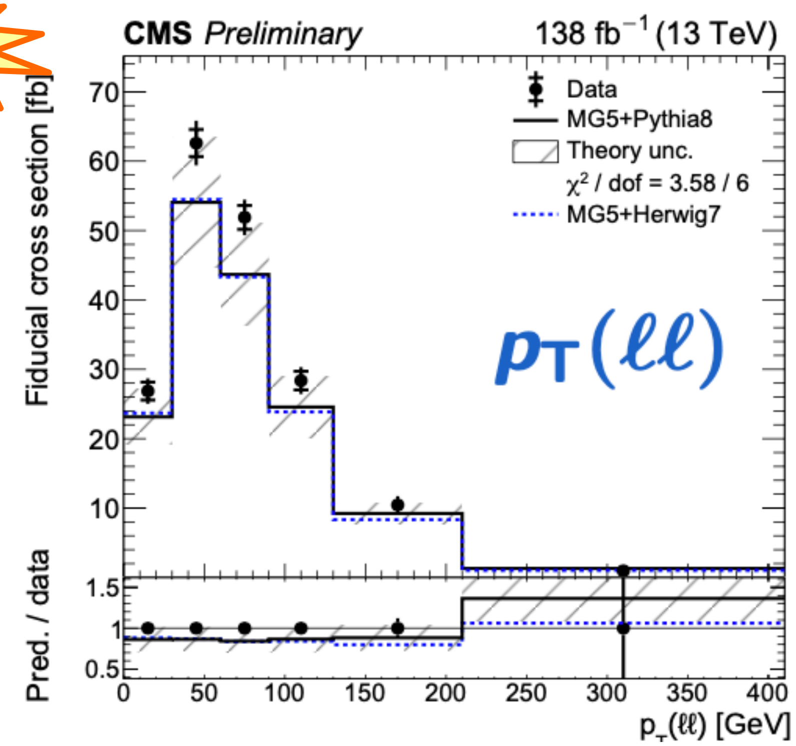
- Dileptons: 2l, 1γ, ≥ 1-bjet
  - Fit to pT(γ) per lepton flavour

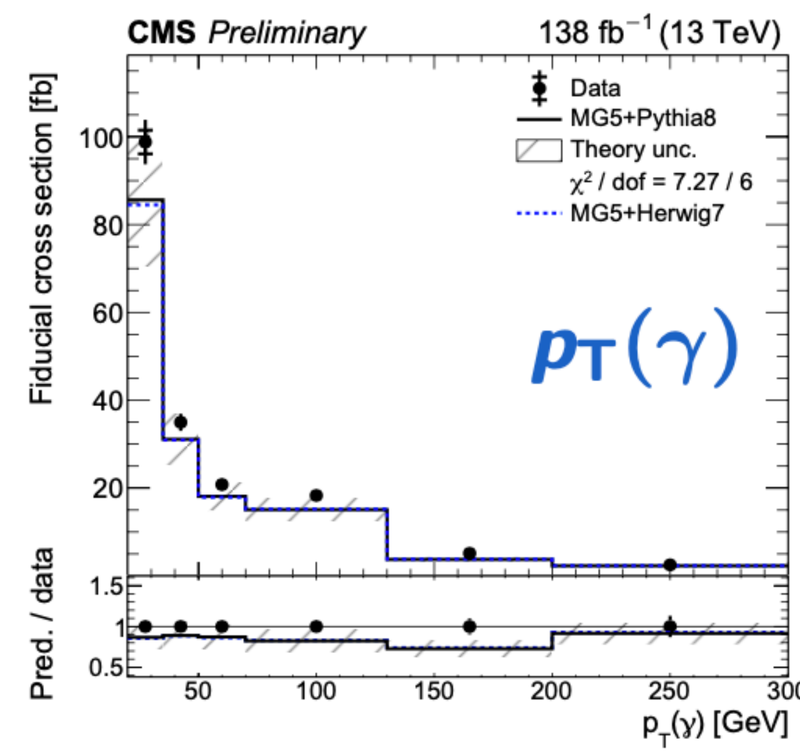
measured cross section:

$174.4 \pm 2.5\,(\text{stat}) \pm 6.1\,(\text{syst})$ fb $\pm 3.8\%$

in agreement with NLO prediction: 153 ± 25 fb

MG5_aMC@NLO+Pythia8





- l+jets: 1l, 1γ, ≥ 3-jet, ≥ 2-bjets
  - Fit in m(3j) bins by flavour and jet multiplicity, plus CR pT(γ) bins

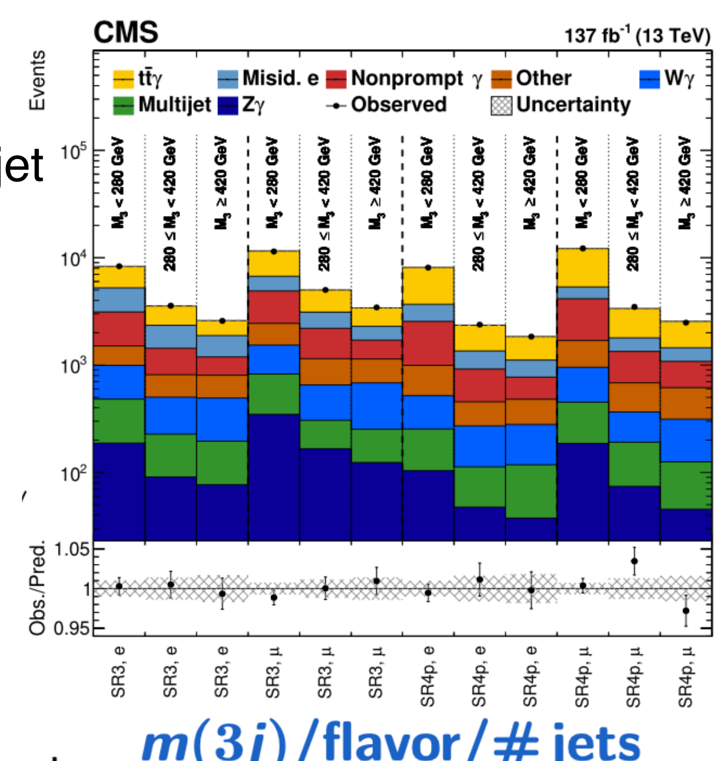
measured cross section:

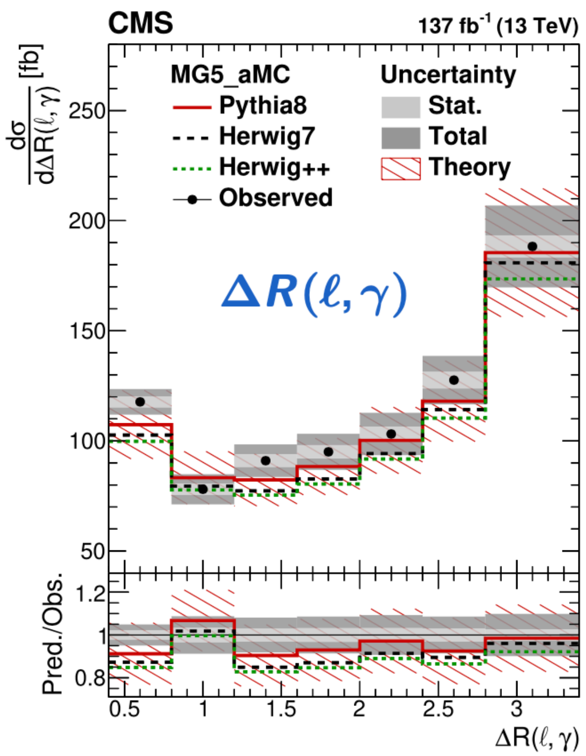
$800 \pm 7\,(\text{stat}) \pm 46\,(\text{syst})$ fb $\pm 5.8\%$

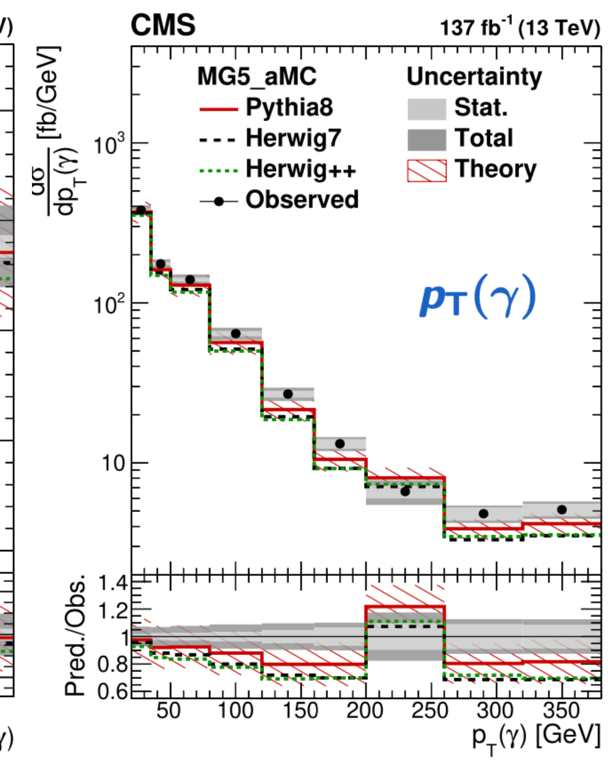
in agreement with NLO prediction: 773 ± 135 fb

MG5_aMC@NLO+Pythia8

pt γ

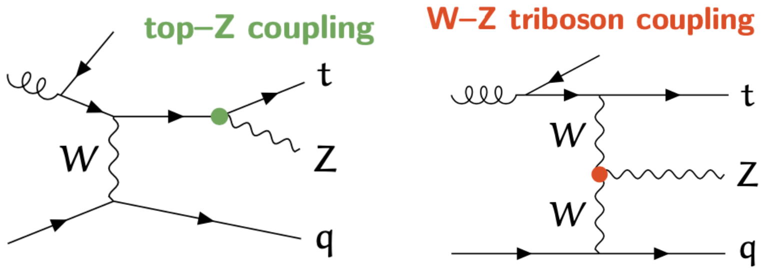






tZq cross sections

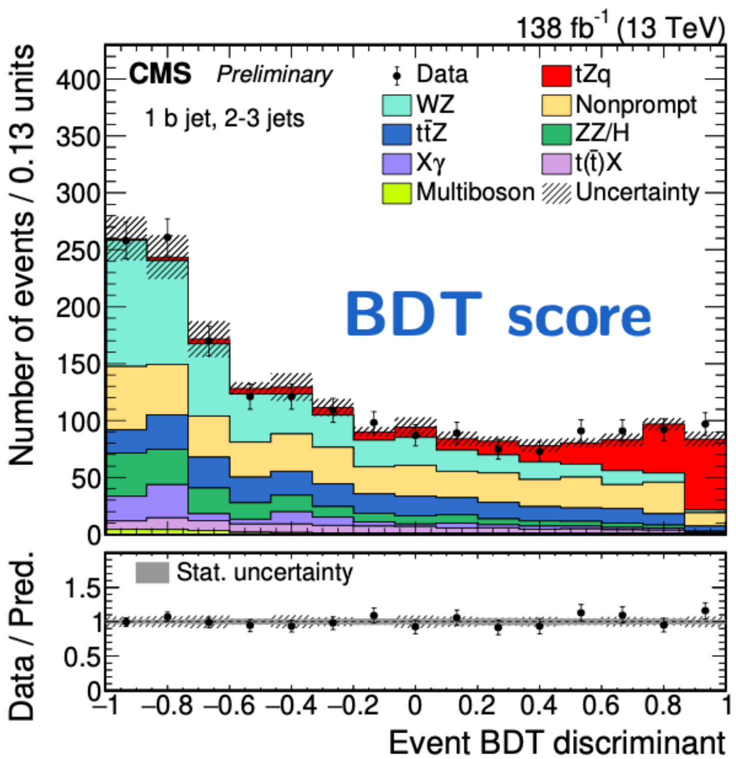
Joscha Knolle

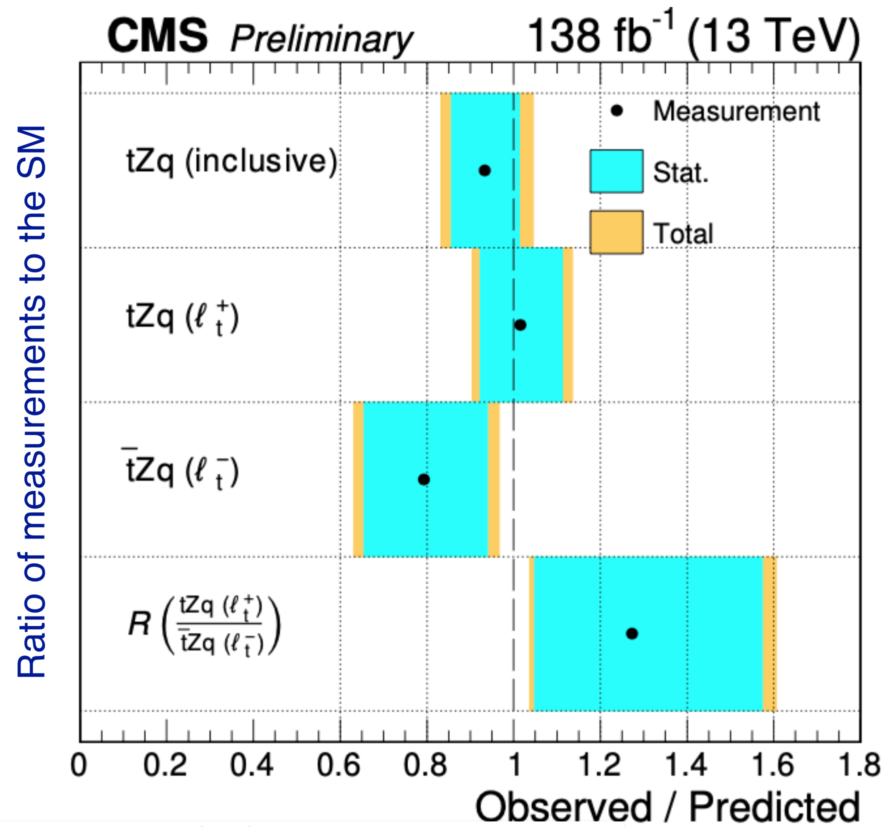


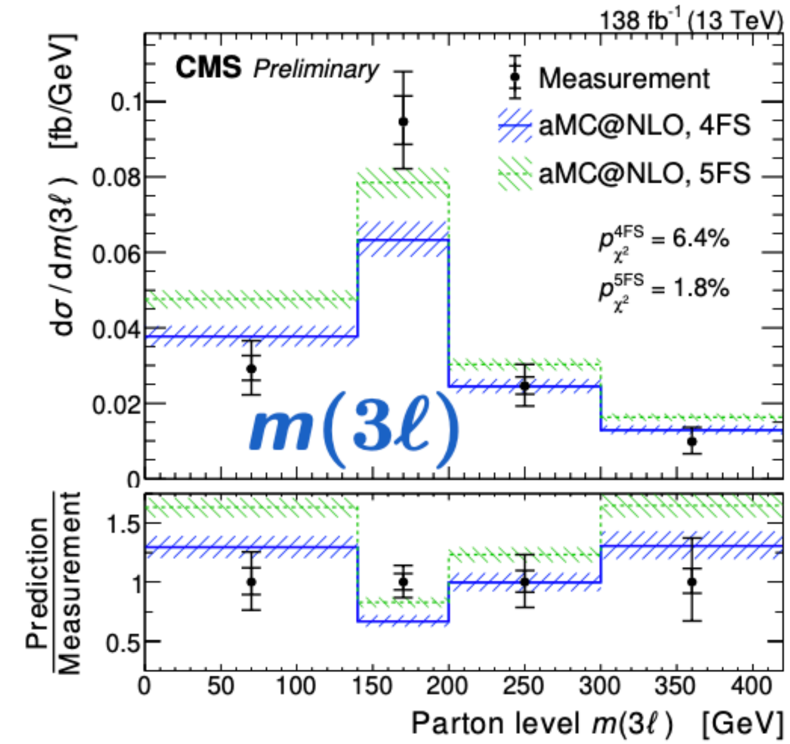
- First ever tZq differential cross sections !

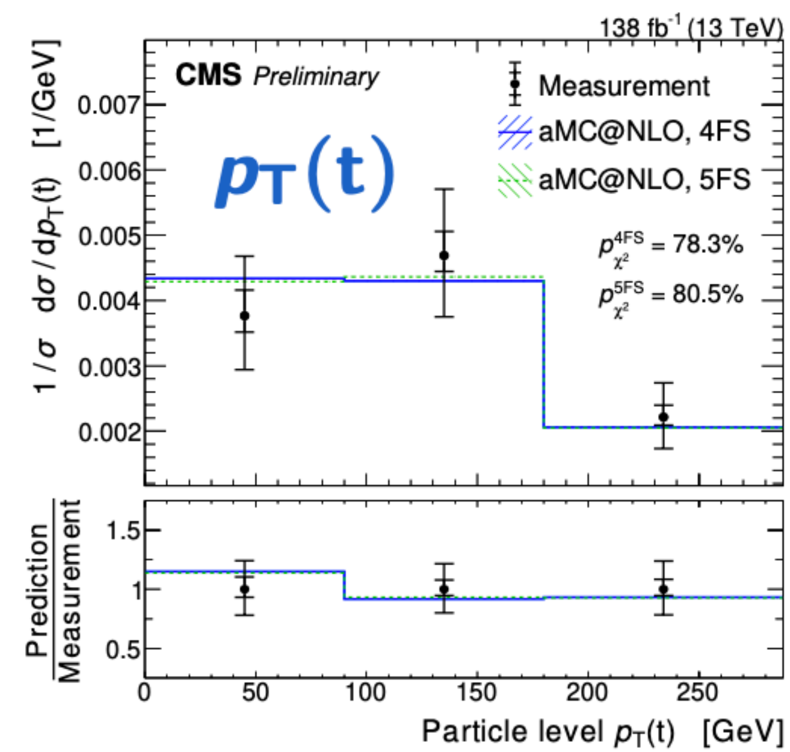
- CMS: 3l events, binned in jet/btag multiplicities

New









cross section definition: $t\ell^+\ell^-q$ with $m(\ell\ell) > 30$ GeV

measured cross section: $87.9\ ^{+7.5}_{-7.3}\,(\text{stat})\ ^{+7.3}_{-6.0}\,(\text{syst})$ fb $\pm 11\%$

in agreement with NLO 5FS prediction: 94 ± 3 fb

- ATLAS (139 fb^{-1}):

cross section definition: $t\ell^+\ell^-q$ with $m(\ell\ell) > 30$ GeV

measured cross section: $97 \pm 13\,(\text{stat}) \pm 7\,(\text{syst})$ fb $\pm 14\%$

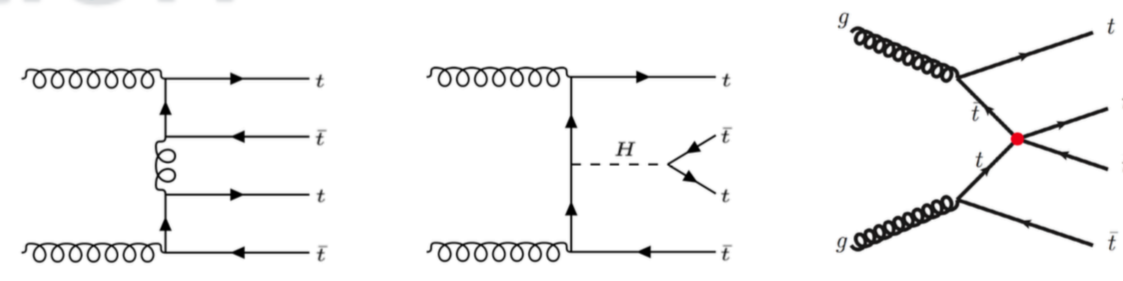
in agreement with NLO prediction: $102\ ^{+5}_{-2}$ fb MG5_aMC@NLO

4top production

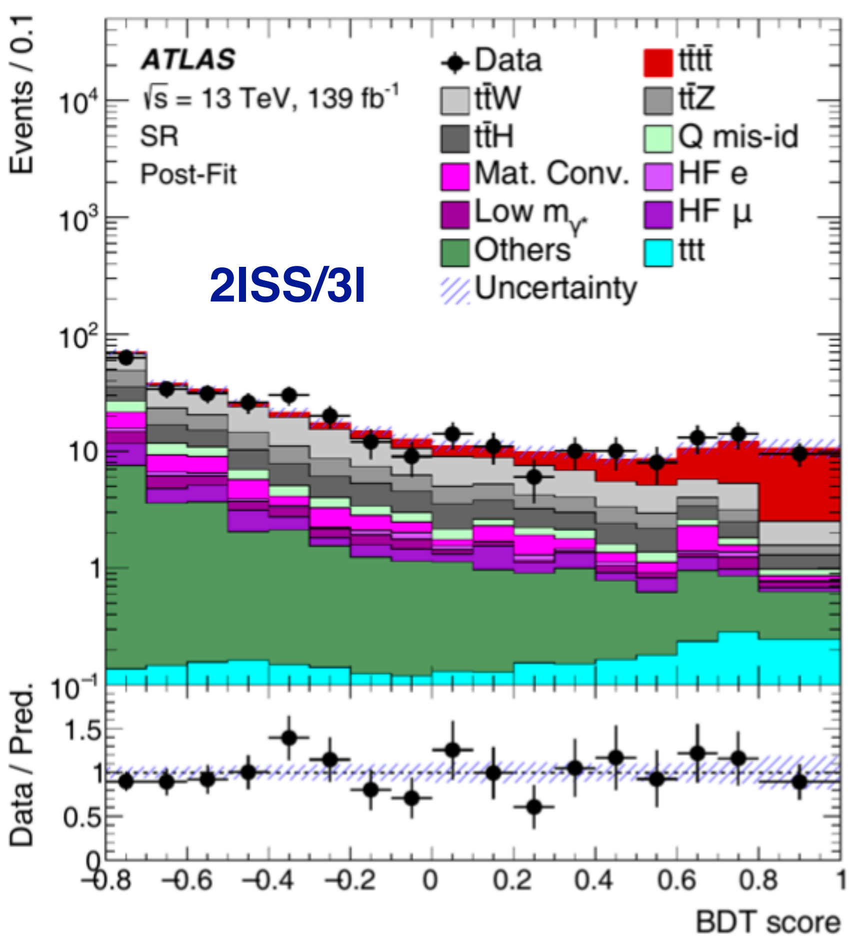
Timothee Thevenaux-Pelzer

Very rare, **not (quite) yet observed**:
σ(4top) ~ 12 fb^{-1} (NLO+EW)

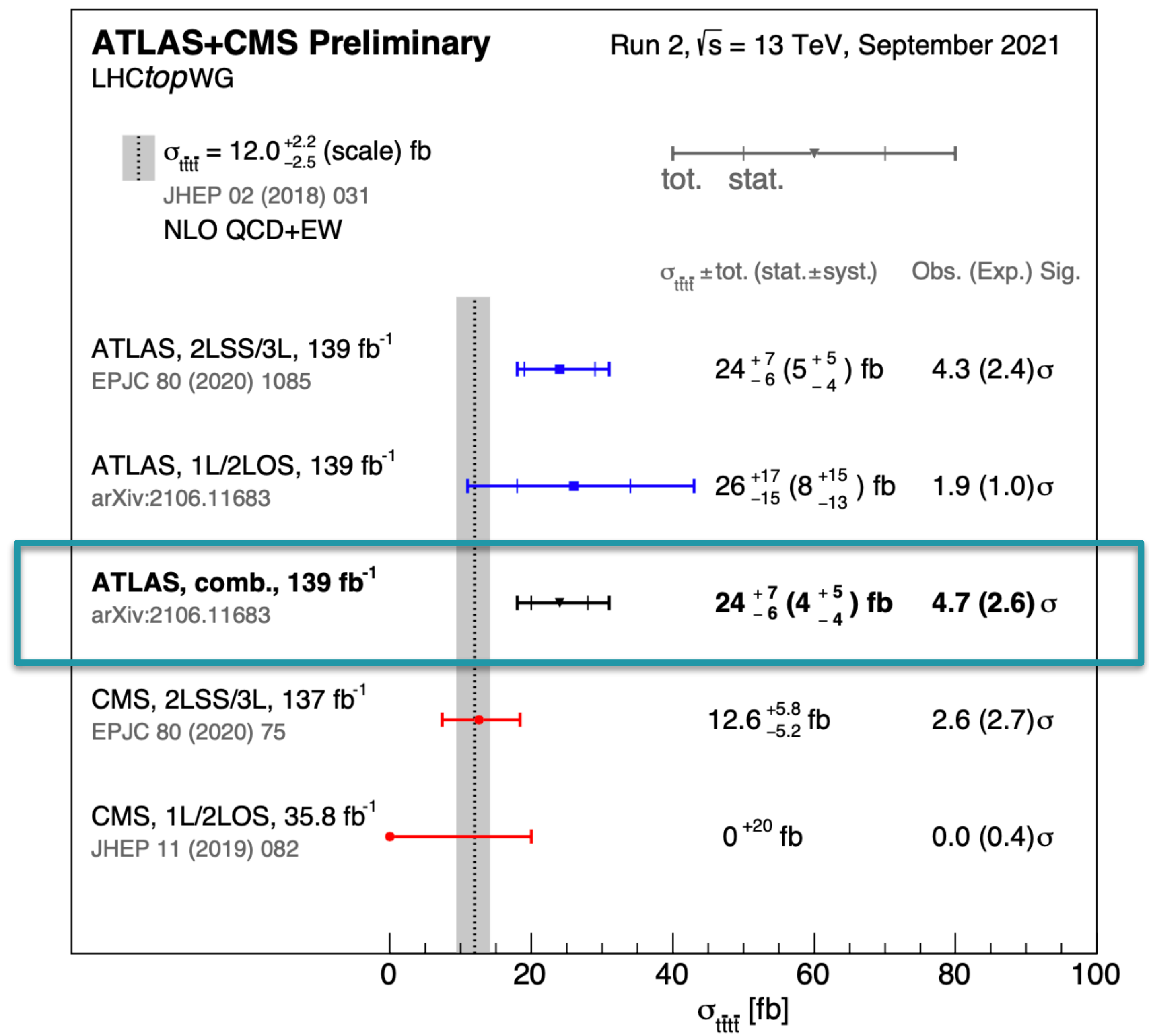
Sensitive to BSM, direct access to top-Higgs Yukawa coupling



- ATLAS: many event categories defined by lepton charge and multiplicity, number of jets and btags

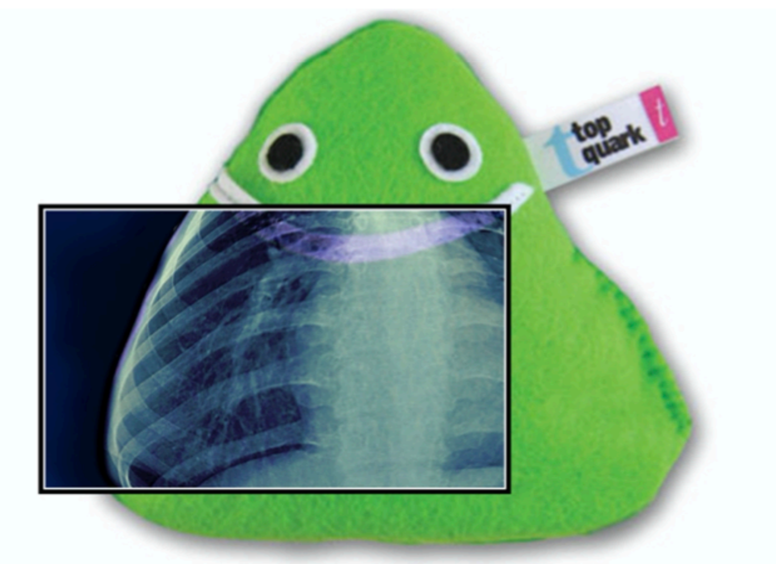


→ observed (expected) significance : 4.7(2.6) σ
→ result consistent with SM prediction within 2.0 σ



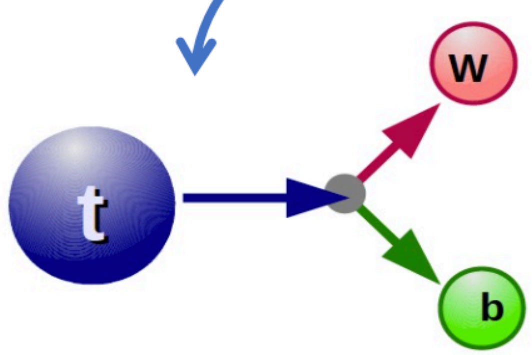
Thomas Stevenson
Sebastian Wuchterl
Jay Howarth

Top properties



Intrinsic properties:

- Mass
- Charge
- Lifetime
- Width
- …



Decays:

- Various decay channels
- SM & BSM
- Couplings *W, Z, γ & H*
- Spin correlations
- …

from M. Worek

Top mass

Sebastian Wuchterl

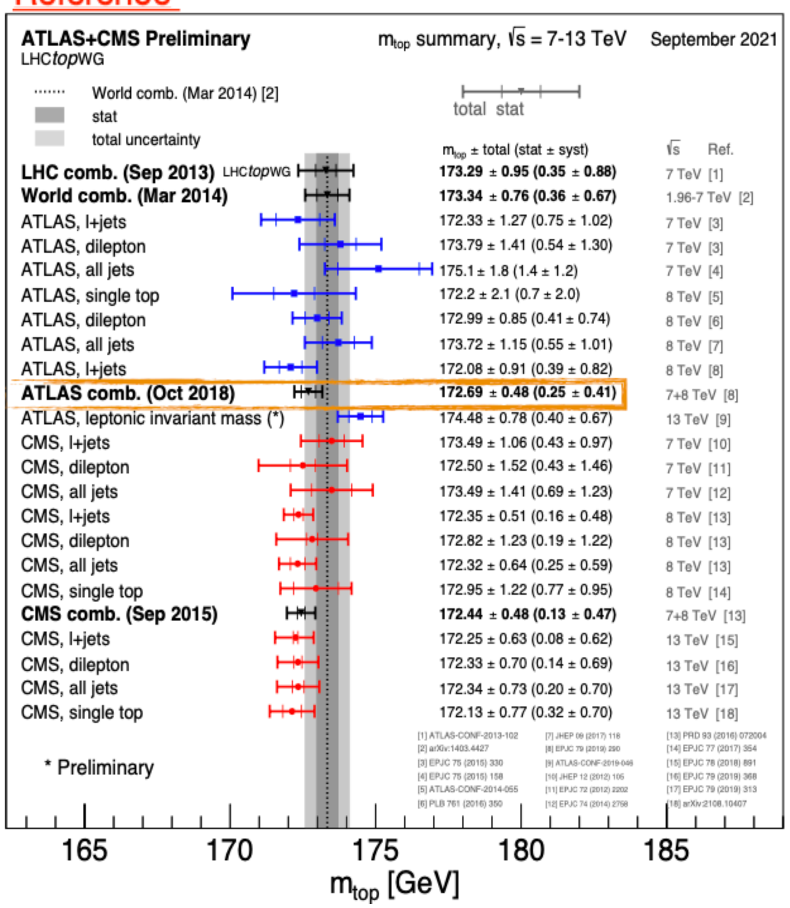
Fundamental parameter in the SM, not an observable: scheme-dependent

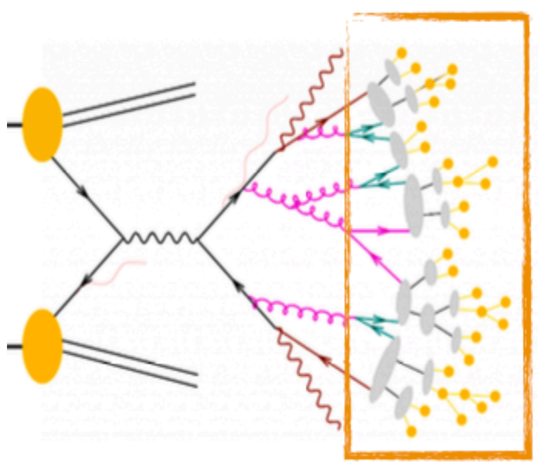
Direct measurements m_t^{MC} ⟷ m_t indirect measurements

- measuring m_t^{MC} using reconstructed decay products
  - very high experimental precision
    - ~0.5 GeV
  - relies on details of MC simulation

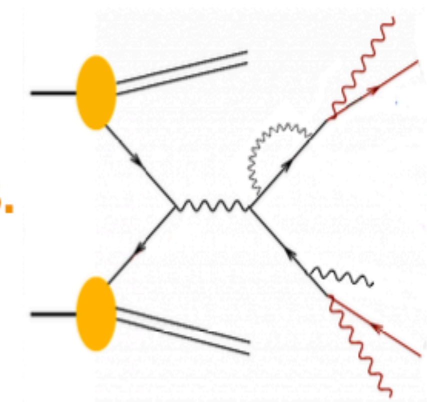
- extract m_t in well defined renormalisation scheme (pole, $\overline{\text{MS}}$, ...)
- measuring cross section with direct sensitivity to m_t
  - either inclusive or differential

Reference





VS.



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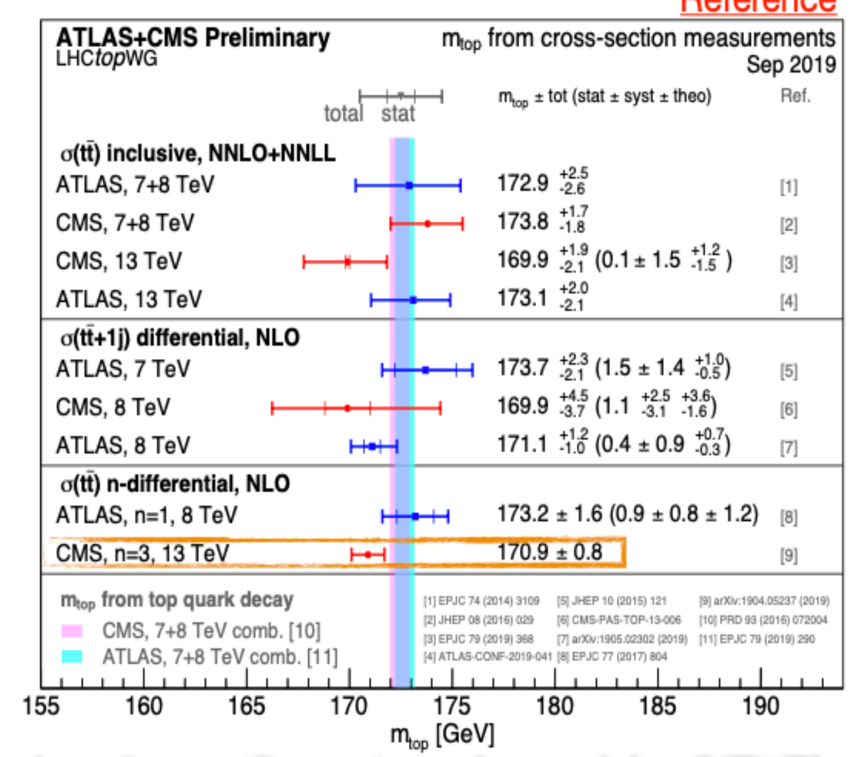

$$m_t^{MC} = m_t^{pole} \pm \Delta_{MC}\ O(1GeV)$$

Top mass

Sebastian Wuchterl

Fundamental parameter in the SM, not an observable: scheme-dependent

Direct measurements m_t^{MC} ⟷ m_t **indirect measurements**

- measuring m_t^{MC} using reconstructed decay products
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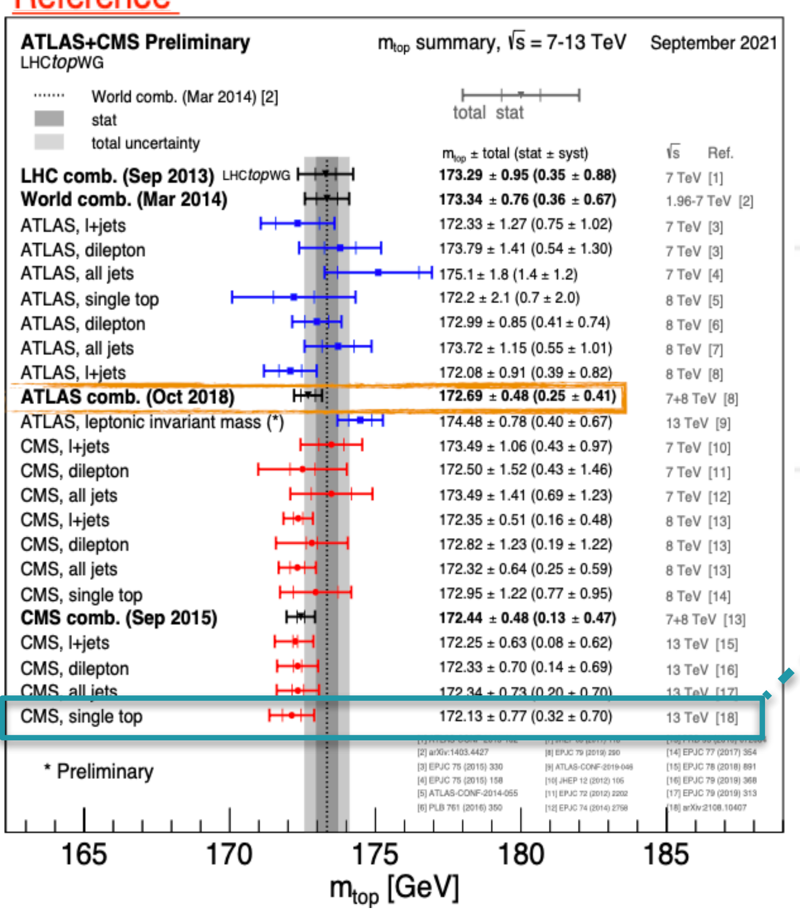
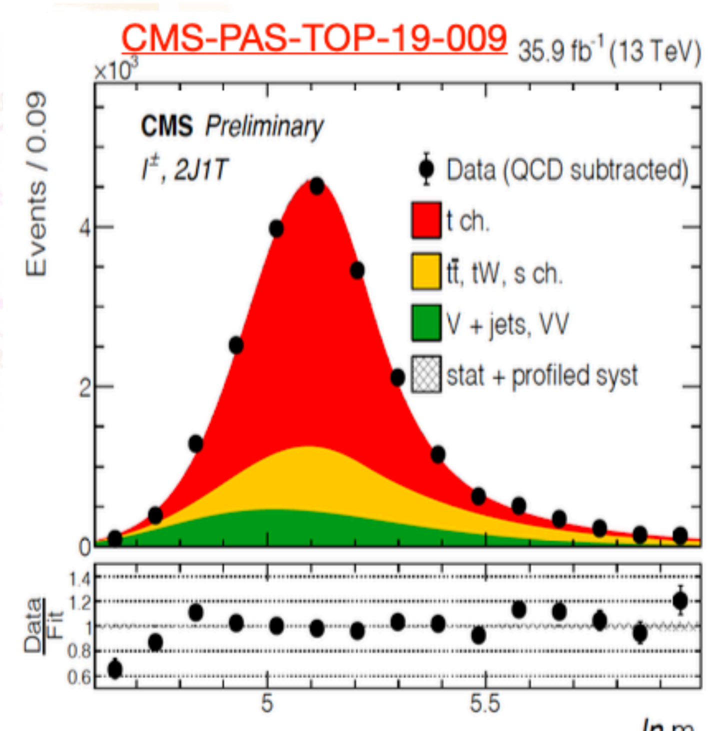


$$m_t^{MC} = m_t^{pole} \pm \Delta_{MC}\ O(1GeV)$$

New techniques and complementary phase spaces may have different systematics

- CMS: m_{top} from t-channel in l+jets (e/μ + 2jets of which 1 bjet)
  - BDT used to increase signal purity



m_{top} = 172.13 ± 0.77 GeV **(0.45%)**

first time sub-GeV precision in single top phase space

- top and anti-top mass also measured separately (test CPT invariance)

Johannes Erdmann
YSF Javier Aparisi
Sebastian Wuchterl

Top mass

Fundamental parameter in the SM, not an observable: scheme-dependent

Direct measurements m_t^{MC} ⟷ m_t **indirect measurements**

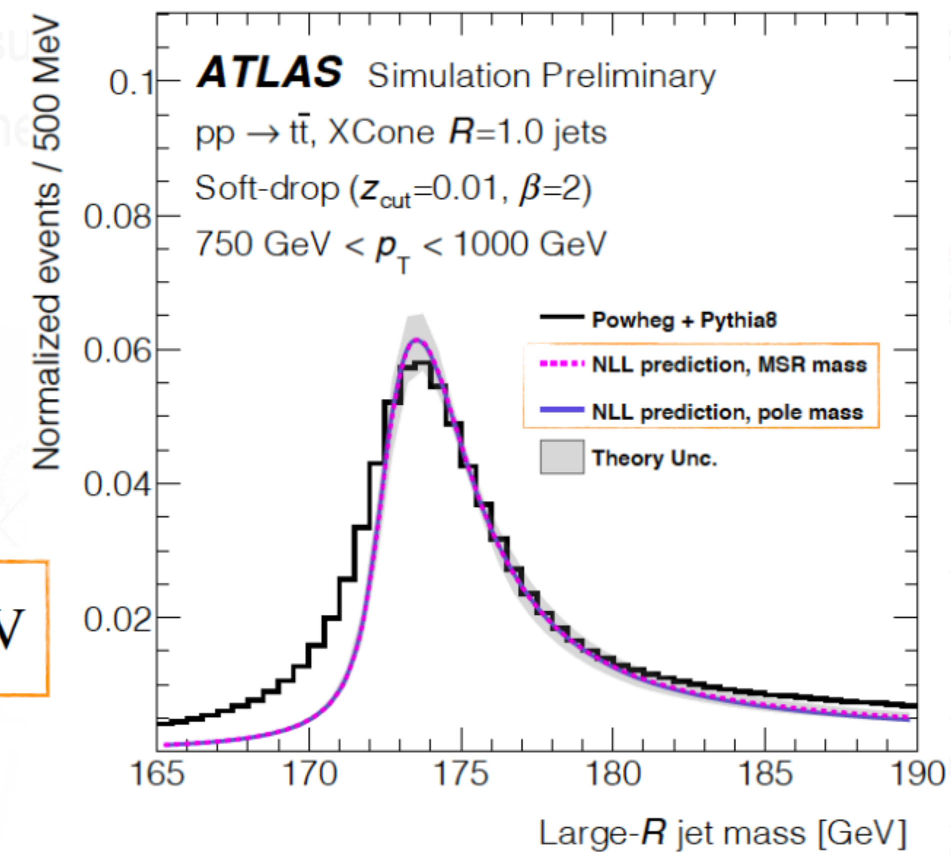
ATLAS MC study towards understanding better the ambiguities between m_t^{MC} and m_t **New**

- Better understood in the boosted regime
- Interpretation of m_t^{MC} obtained by comparing MC distributions with calculations within well-defined theoretical framework → pole mass or MSR mass schemes
  - MSR mass, similar to the $\overline{MS}$ mass, depends on a scale → Setting the scale to 1 GeV: **$m_t^{MSR}(1\ GeV) \approx m_t^{pole}$**

$$m_t^{MC} = \begin{matrix} m_t^{MSR}(1\,GeV) \\ \cancel{m_t^{pole}} \end{matrix} \pm \Delta_{MC}\ O(1GeV)$$

$$m_t^{MC} = m_t^{MSR}(1\ \mathrm{GeV}) + 80^{+350}_{-410}\ \mathrm{MeV}$$

ATL-PHYS-PUB-2021-034



- CMS measurement of m_{top} from boosted jet mass (m_{jet}) observable:

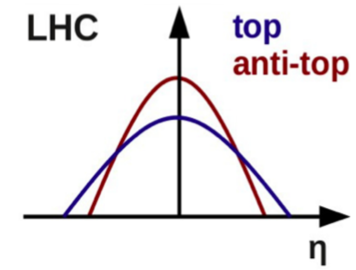
$$m_t = 172.6 \pm 0.4\,(\mathrm{stat}) \pm 1.6\,(\mathrm{exp}) \pm 1.5\,(\mathrm{model}) \pm 1.0\,(\mathrm{theo})\ \mathrm{GeV}$$

Top asymmetries

Johannes Erdmann

Jay Howarth

Top-pair angular asymmetries may indicate BSM top production interfering with SM



Ac

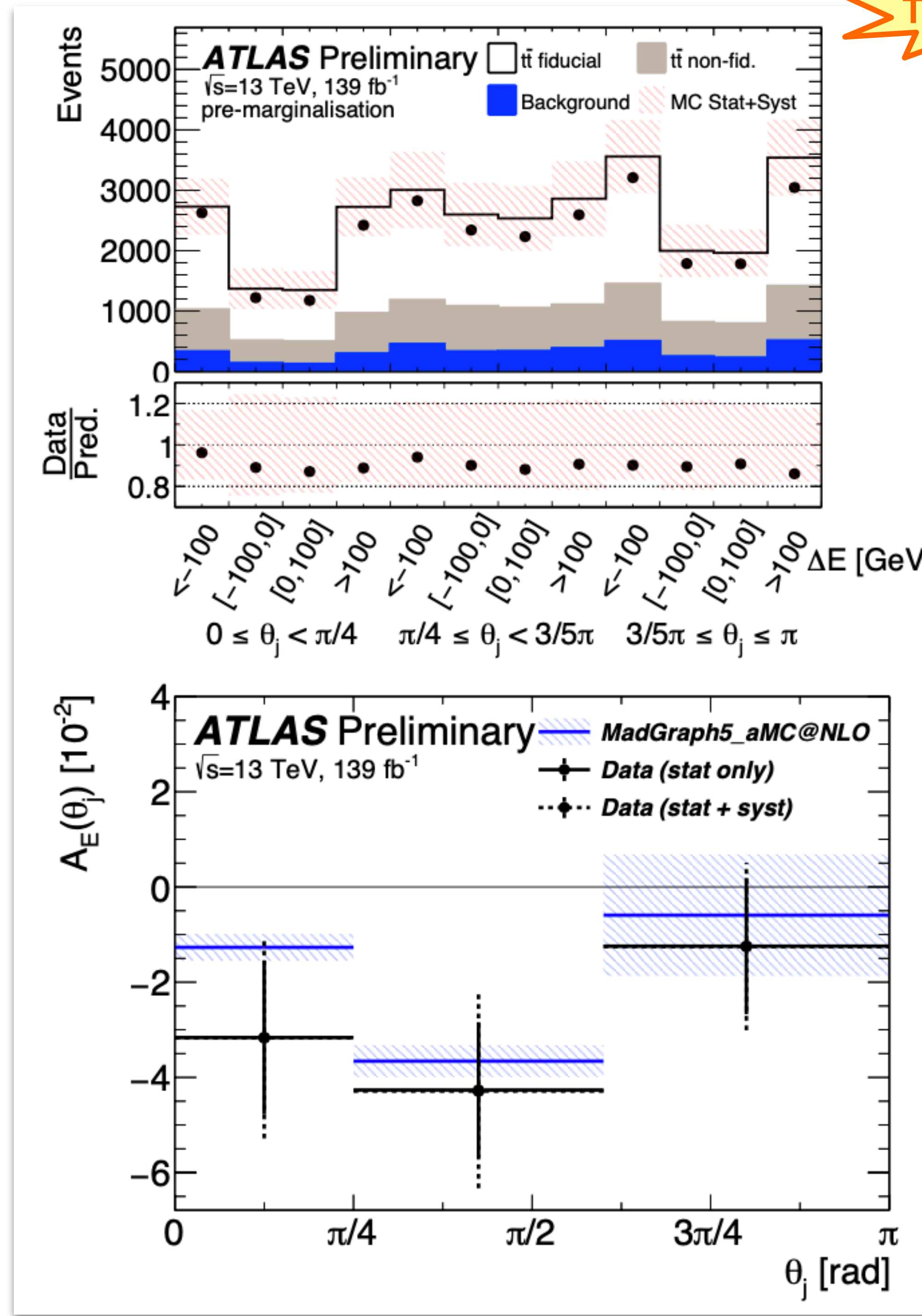
- NLO effect, can be enhanced by BSM physics

TOP2021

- Usually charge asymmetry measured as rapidity asymmetry
- Here: measure energy asymmetry in boosted $t\bar{t}$ +jet (single lepton)
- θ_j: angle of additional jet to z-axis
- $\Delta E = E_t - E_{\bar{t}}$: energy difference
- Top quark charge from lepton
- Define asymmetry:

$$A_E = \frac{\sigma(\theta_j|\Delta E>0)-\sigma(\theta_j|\Delta E<0)}{\sigma(\theta_j|\Delta E>0)+\sigma(\theta_j|\Delta E<0)}$$

- Statistical uncertainty dominates

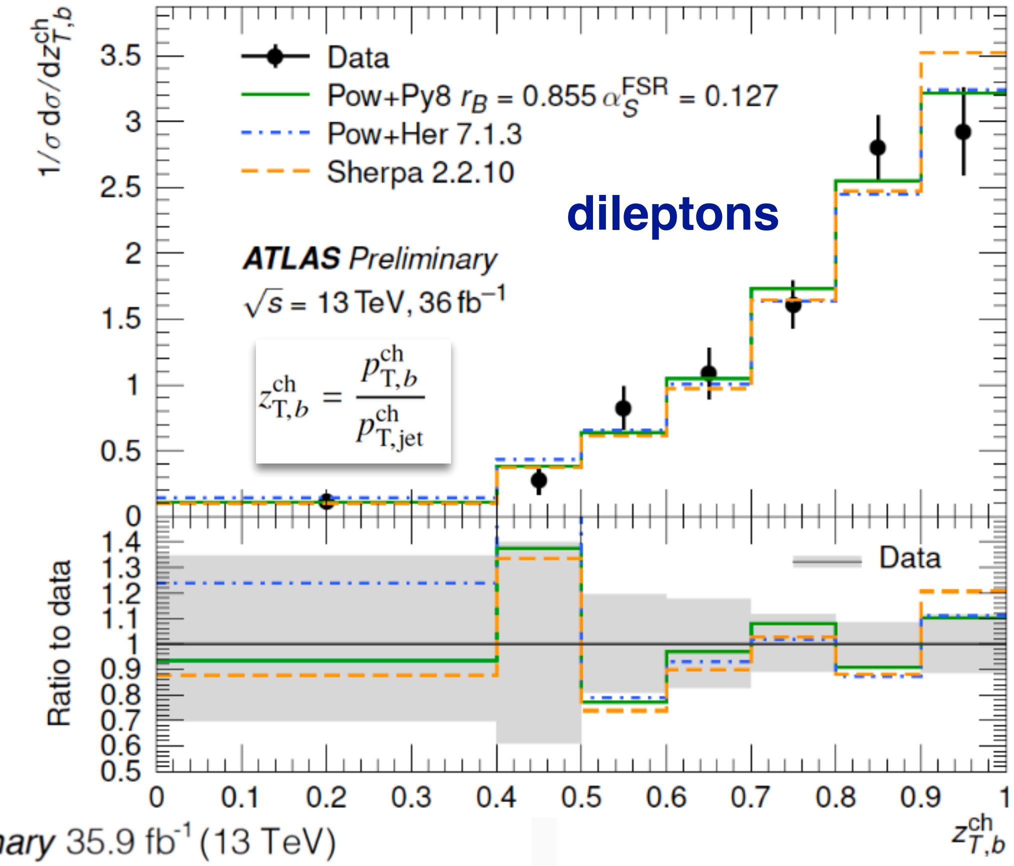


Giulia Negro
YSF Brent Yates
Sebastian Wuchterl

b-fragmentation in tt

Fundamental test of pQCD and parton shower formalism

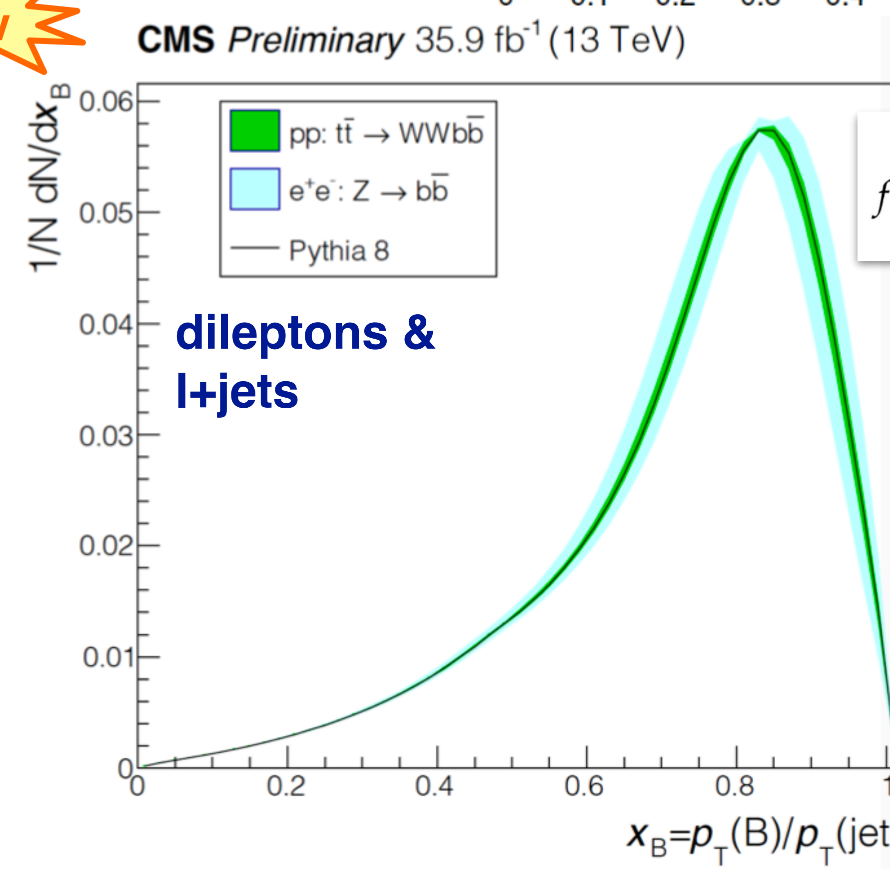
- —> important for many high-precision measurements, eg. top mass
- Current determination relies on LEP measurements at the Z pole
- At LHC: use jet observables
- ATLAS: inclusive track-based observables
  - Unfold to particle level, compare to generators and tunes



New

- CMS: use charm mesons (D0, J/psi) reconstructed inside b-quark jets by charged particles to measure the b-fragmentation parameter r_b
  - First time at LHC:

$$r_b = 0.858 \pm 0.037\,(\text{stat}) \pm 0.031\,(\text{syst}).$$



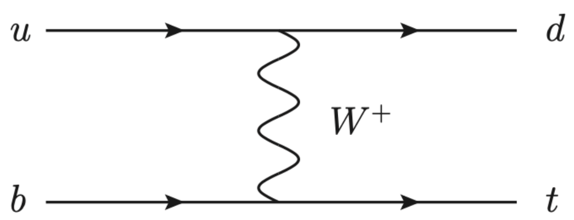
Lund-Bowler model:

$$f(z) = \frac{1}{z^{1+r_q b m_q^2}}(1-z)^a \exp\left(-\frac{b m_T^2}{z}\right)$$

- Data in agreement with models tuned on LEP data

Single top polarization in ATLAS

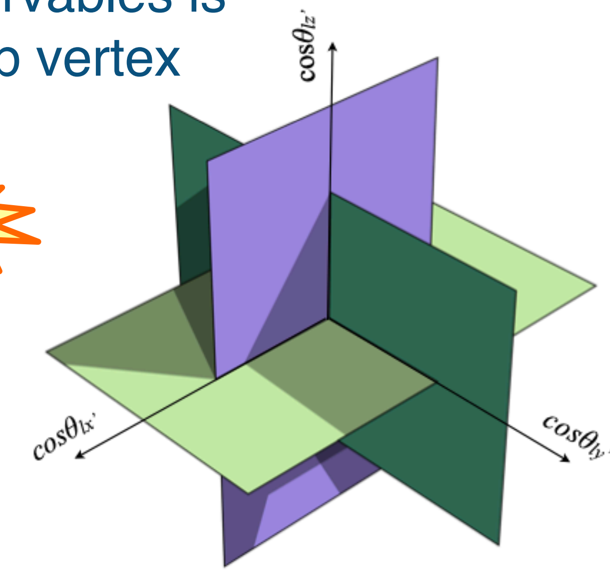
Jay Howarth



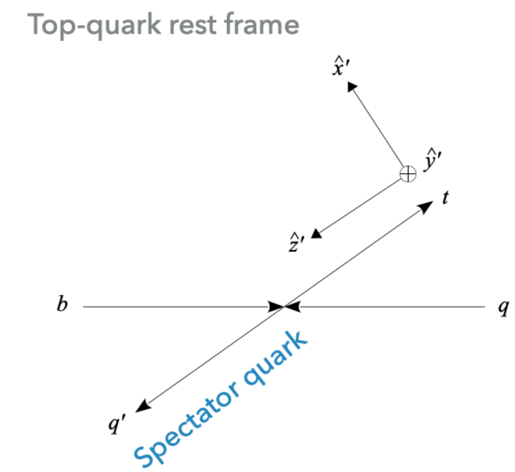
Measurement of polarization observables is sensitive to BSM effects in the Wtb vertex

New

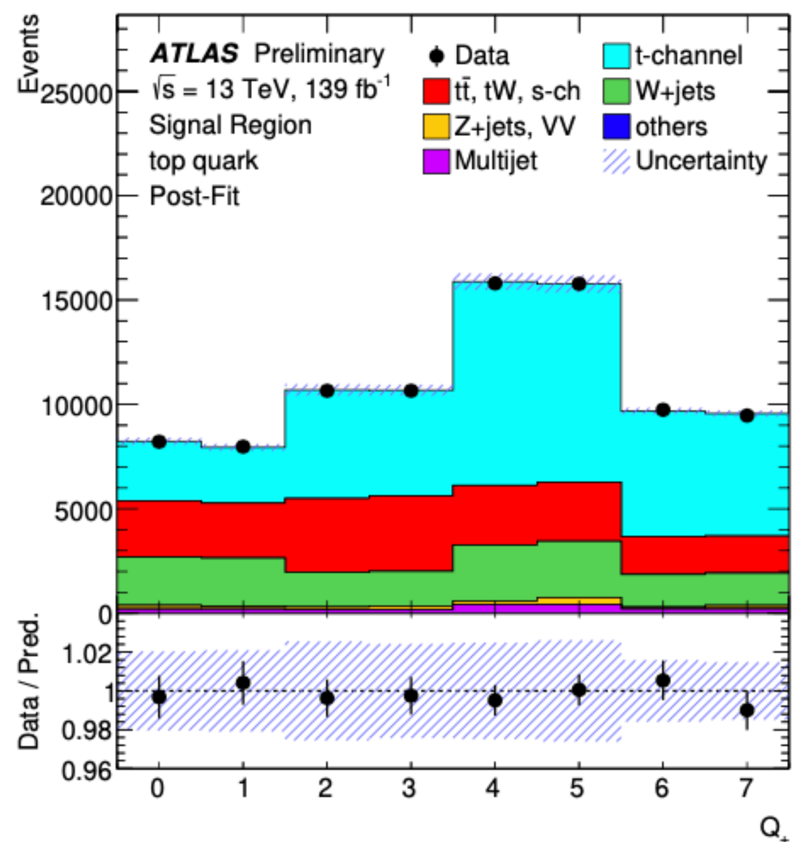
- First measurement of the full polarization vector via angular distributions of leptons for both tops and antitops
- Q variable: divide phase space in 8 regions depending on the direction and sign of the polarization

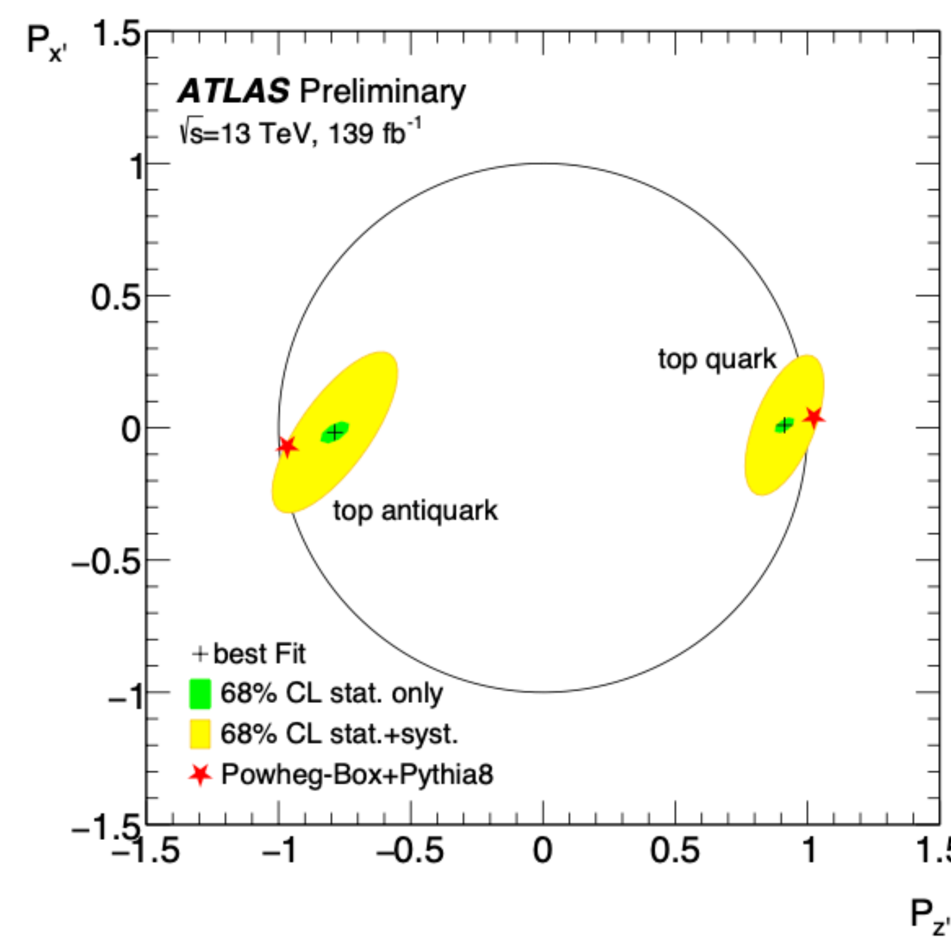


3D space divided into 8 octants



x', y', z' angles constructed using spectator jet in the top rest-frame



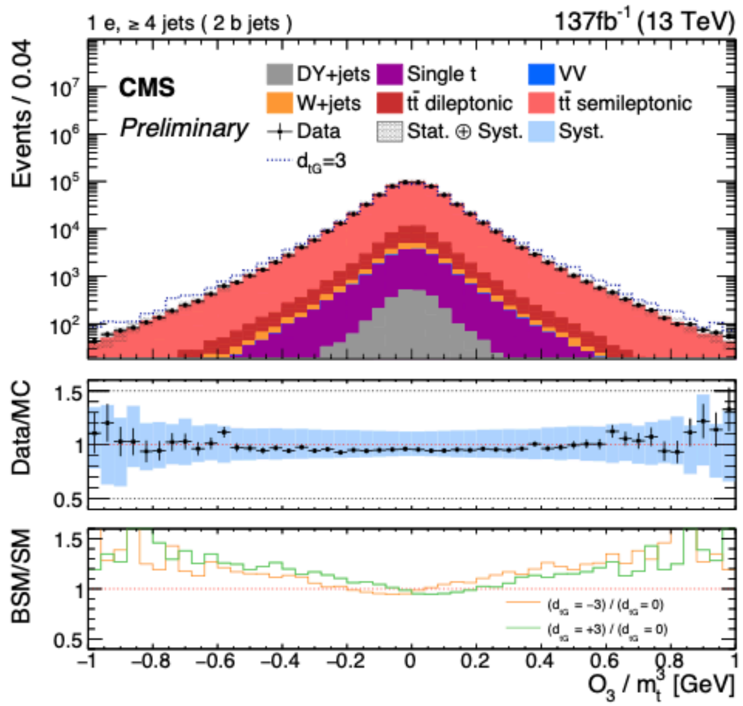


$P_x = -0.02 \pm 0.20$ $P_y = -0.007 \pm 0.051$ $P_z = 0.91 \pm 0.10$

More anomalous couplings

Thomas Stevenson

- CMS: Probing CP with asymmetries based on 4 T-odd observables using l+jets tt events



$$O_3 = Q_\ell \epsilon(p_b, p_{\bar{b}}, p_\ell, p_{j_1}) \propto Q_\ell \vec{p'}_b \cdot (\vec{p'}_\ell \times \vec{p'}_{j_1})$$

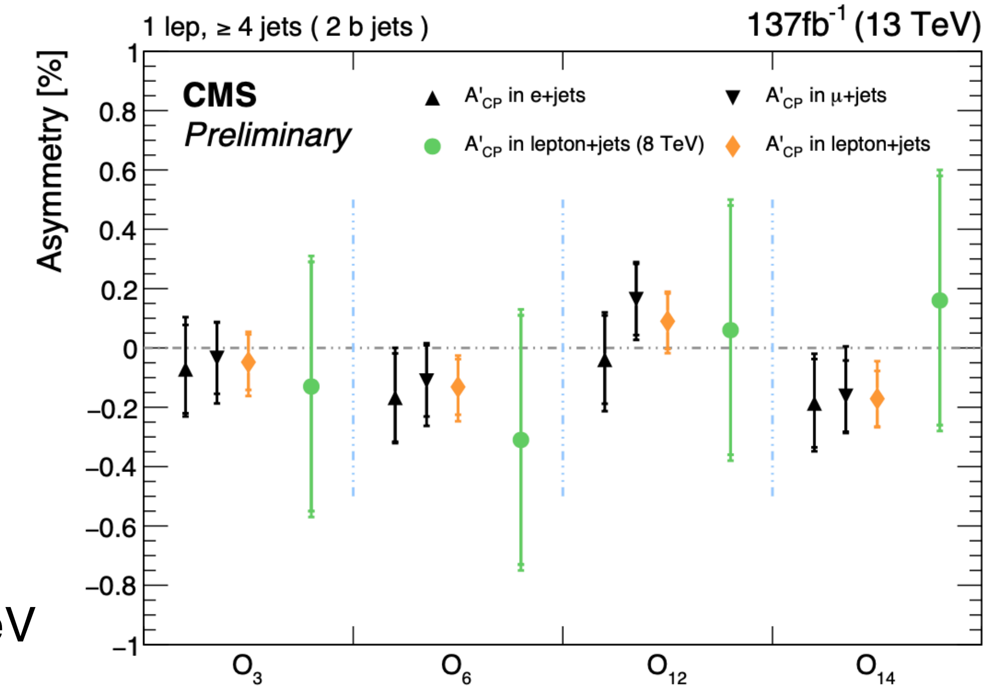
$$O_6 = Q_\ell \epsilon(P, p_b - p_{\bar{b}}, p_\ell, p_{j_1}) \propto Q_\ell (\vec{p}_b - \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1})$$

$$O_{12} = q \cdot (p_b - p_{\bar{b}}) \epsilon(P, q, p_b, p_{\bar{b}}) \propto (\vec{p}_b - \vec{p}_{\bar{b}})_z \cdot (\vec{p}_b \times \vec{p}_{\bar{b}})_z$$

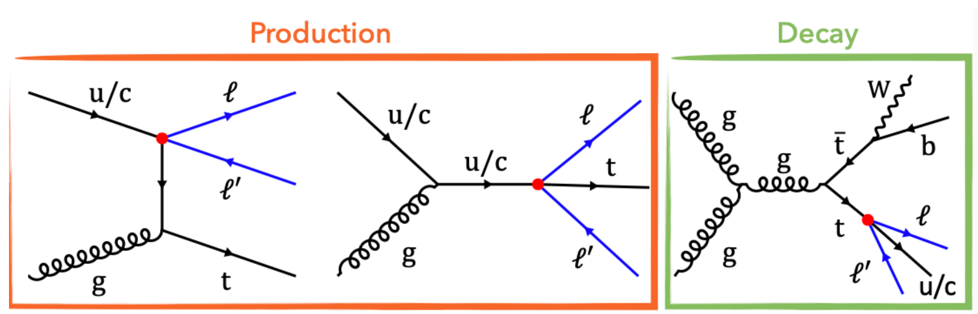
$$O_{14} = \epsilon(P, p_b + p_{\bar{b}}, p_\ell, p_{j_1}) \propto (\vec{p}_b + \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1})$$

$$A_{CP}(O_i) = \frac{N(O_i > 0) - N(O_i < 0)}{N(O_i > 0) + N(O_i < 0)}$$

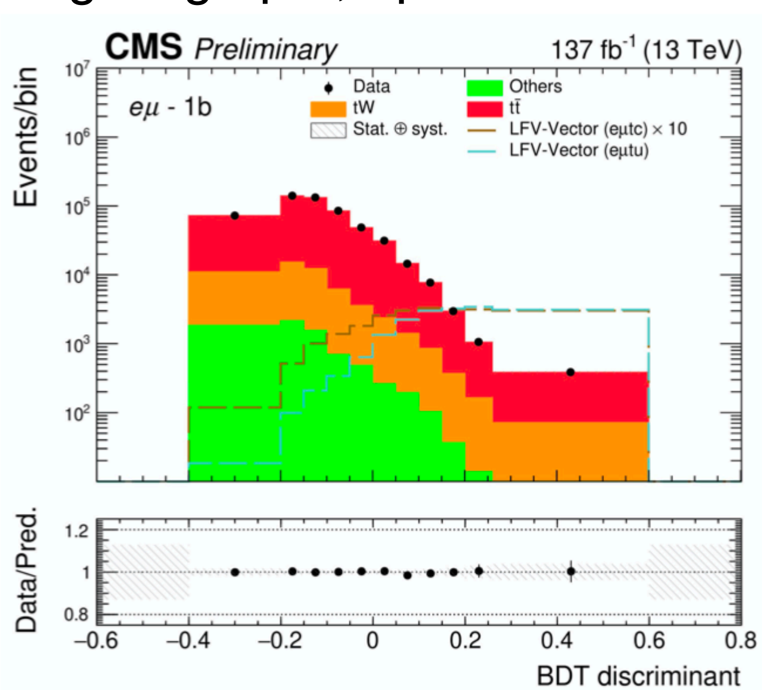
- No evidence for CP violating effects
- Uncerts reduced by factor 3 wrt 8 TeV

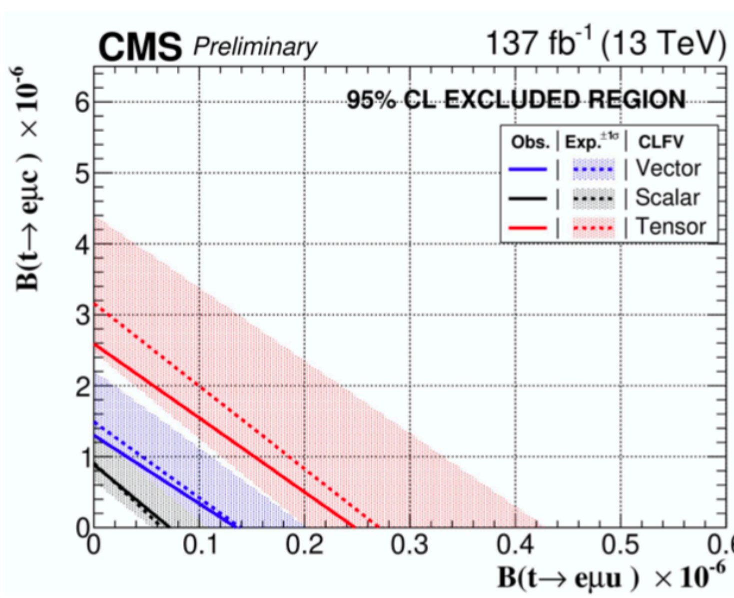


- CMS: Search for lepton flavour violation
  - Targeting eμtu, eμtc interactions



New



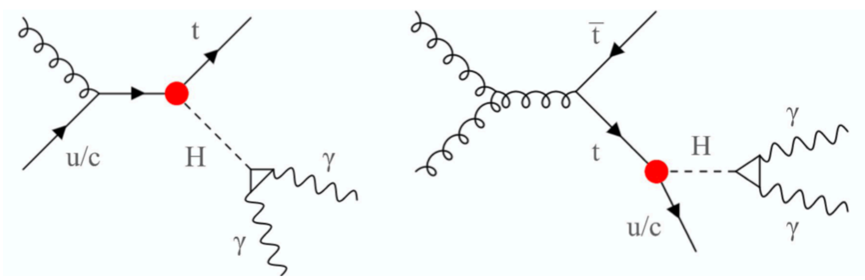


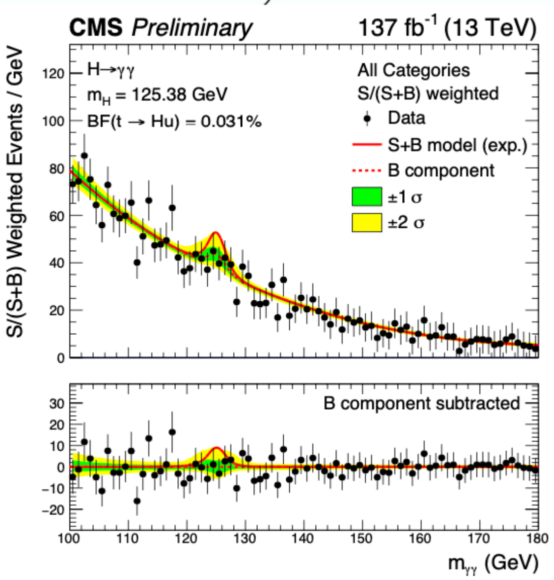
FCNC searches

Thomas Stevenson

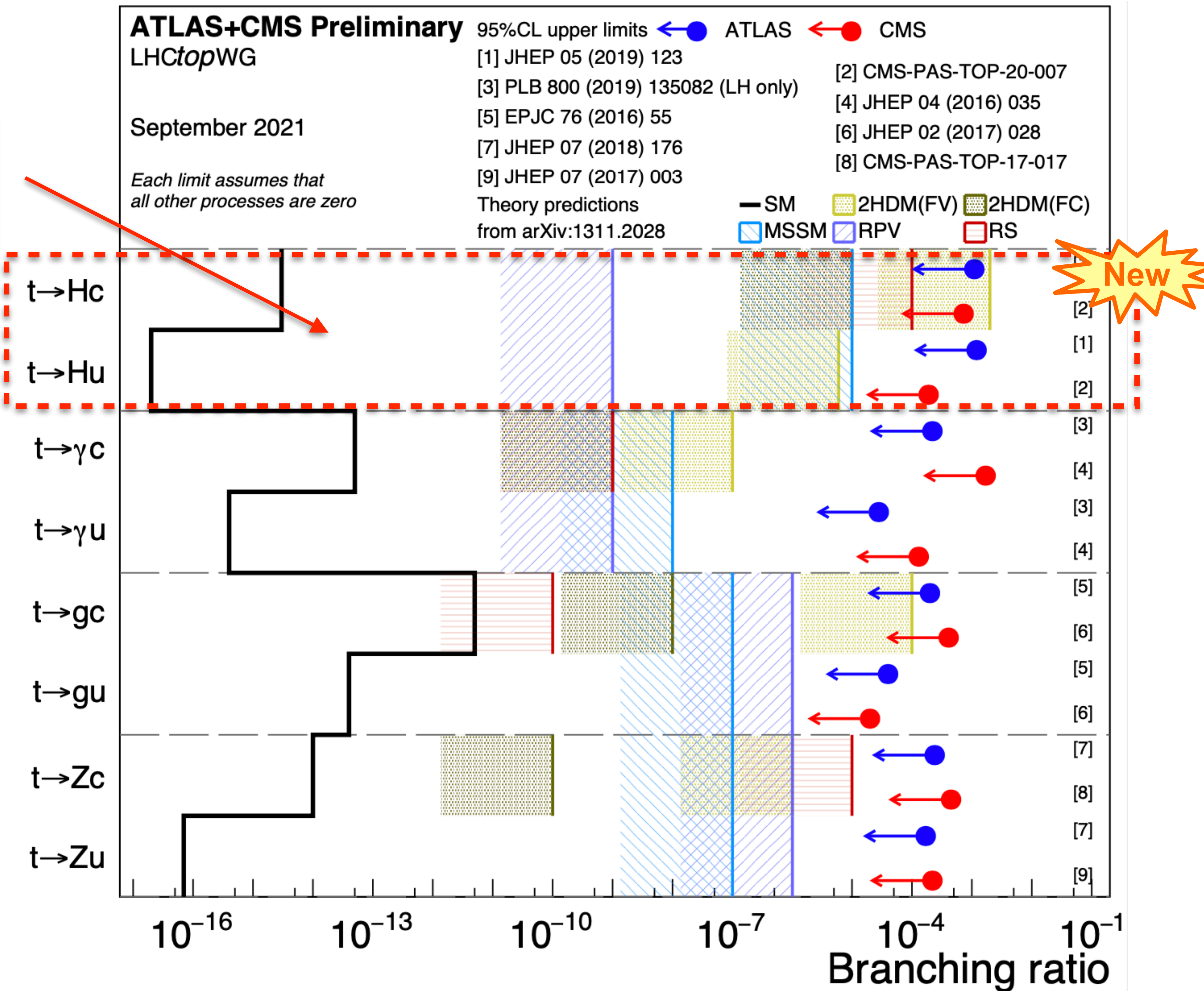
Flavour Changing Neutral Currents are highly suppressed in SM
—> enhancement is clear sign of BSM physics

- CMS: search for t-H($\gamma\gamma$) FCNC in production and decay





$\mathcal{B}(\mathrm{t} \to \mathrm{Hu})$	1.9×10^{-4} (3.1×10^{-4})
$\mathcal{B}(\mathrm{t} \to \mathrm{Hc})$	7.3×10^{-4} (5.1×10^{-4})



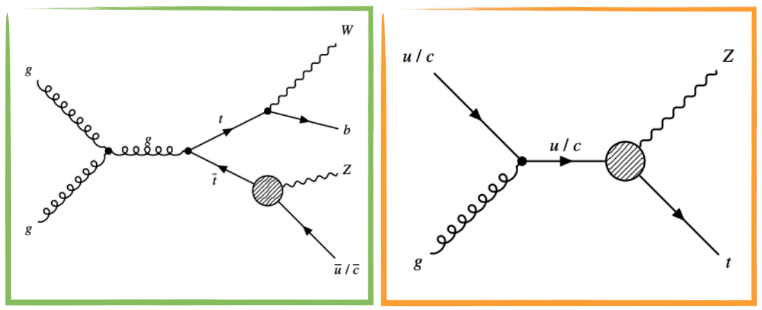
- Search also for t-H(bb) FCNC in production and decay, less stringent

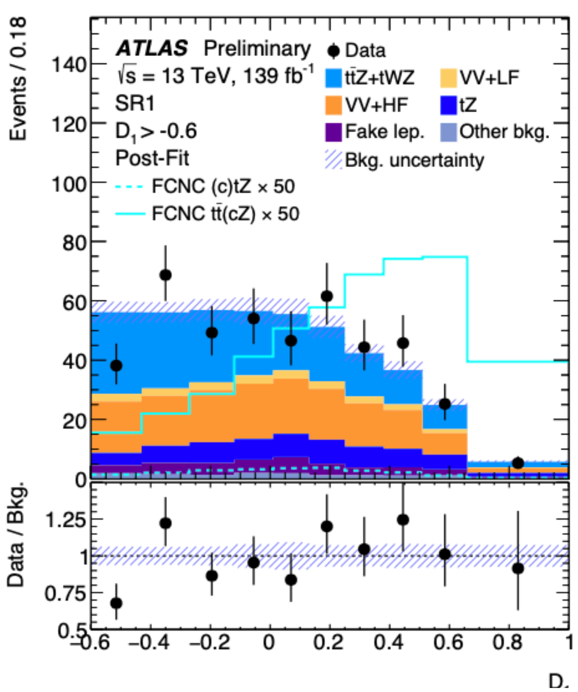
FCNC searches

Thomas Stevenson

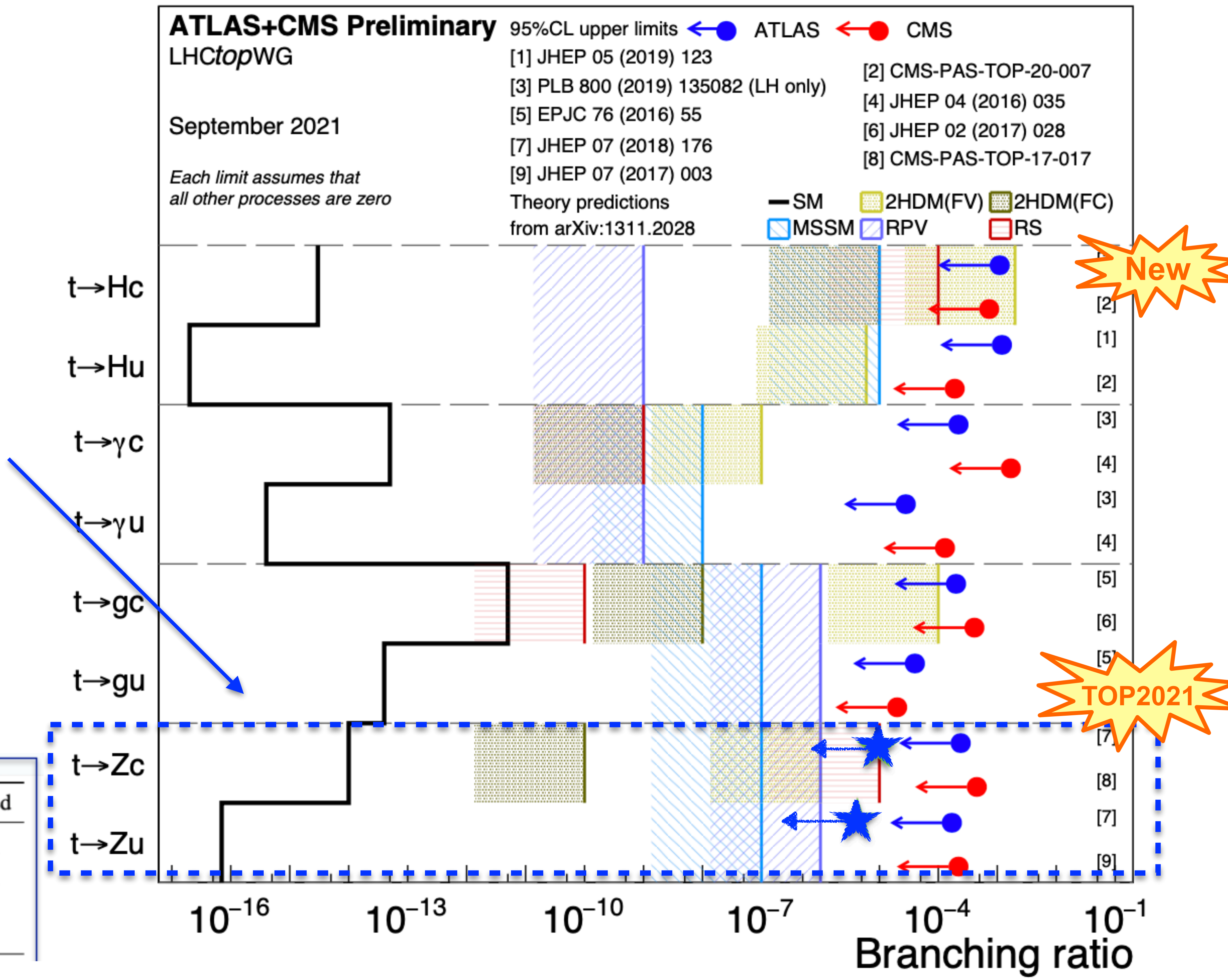
Flavour Changing Neutral Currents are highly suppressed in SM
—> enhancement is clear sign of BSM physics

- ATLAS: search for t-Z FCNC in production and decay





Observable	Vertex	Coupling	Observed	Expected
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZu	LH	6.2	$4.9^{+2.1}_{-1.4}$
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZu	RH	6.6	$5.1^{+2.1}_{-1.4}$
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZc	LH	13	11^{+5}_{-3}
$\mathcal{B}(t \to Zq)$ $[10^{-5}]$	tZc	RH	12	10^{+4}_{-3}



Effective Field Theory

Dennis Schwarz

- So far no evidence of BSM physics at the LHC
- Direct detection might be out of range at $\Lambda \gg E_{\text{LHC}}$

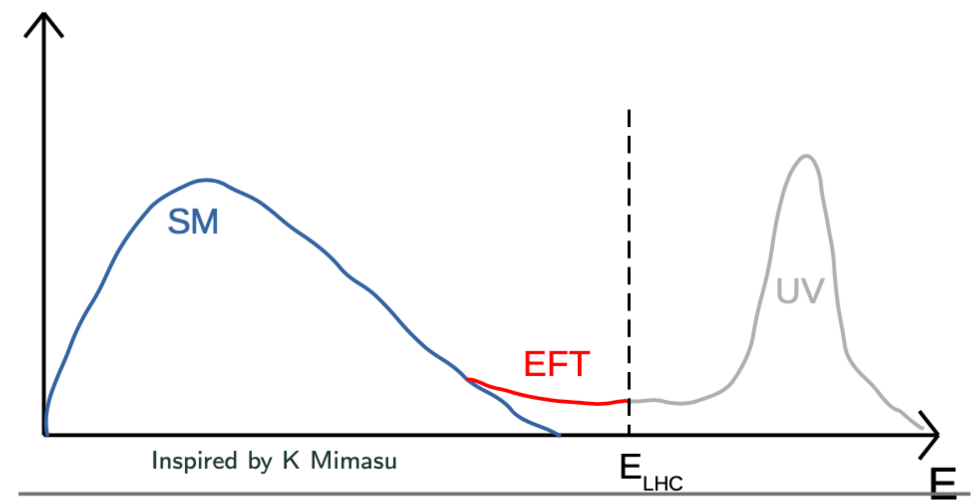
$\rightarrow$ Expand SM: $\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i$

(here: dim-6 expansion, dim-5 and dim-7 would violate lepton/baryon numbers)

- Wilson coefficients c_i modify the SM vertices

$\rightarrow$ Deviations visible in SM precision measurements

- Model independent



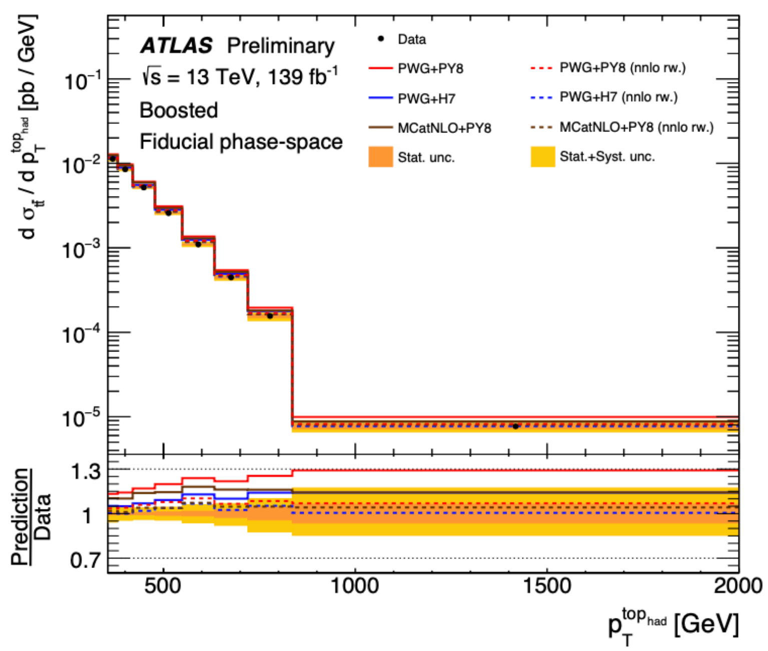
- In the top sector, EFT effects can be observed in various final states: $t\bar{t}$, $t\bar{t}Z$, $t\bar{t}\gamma$, $t\bar{t}H$, tZq, ...
- Two ways of using EFT:
  1. Re-parametrization of cross section measurements
  2. Dedicated EFT measurements

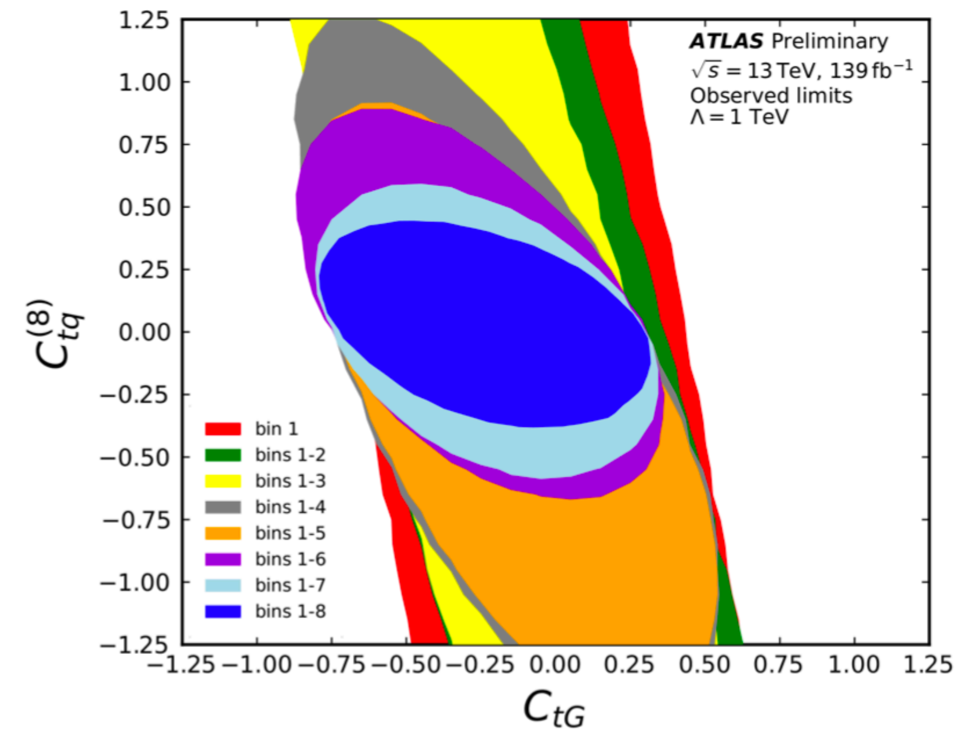
Plenty of results already available, more to come !

EFT in tt and t-channel

Thomas Stevenson
Dennis Schwarz

- **Boosted tt cross section in l+jets** (ATLAS): parametrize bin content as a function of C_{tG} and $C_{tq}^{(8)}$



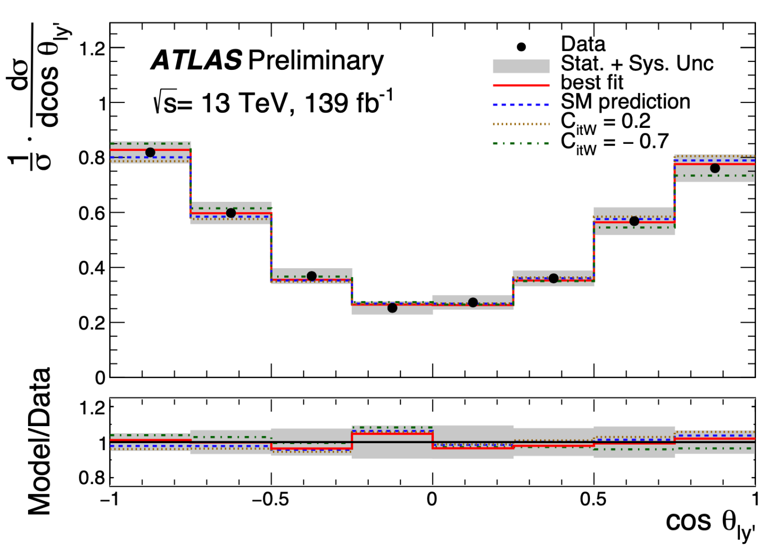


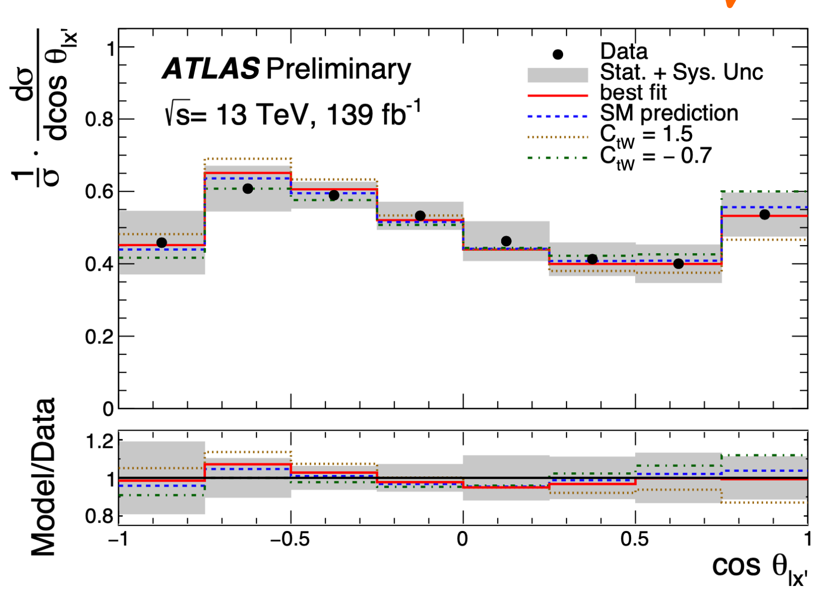
New

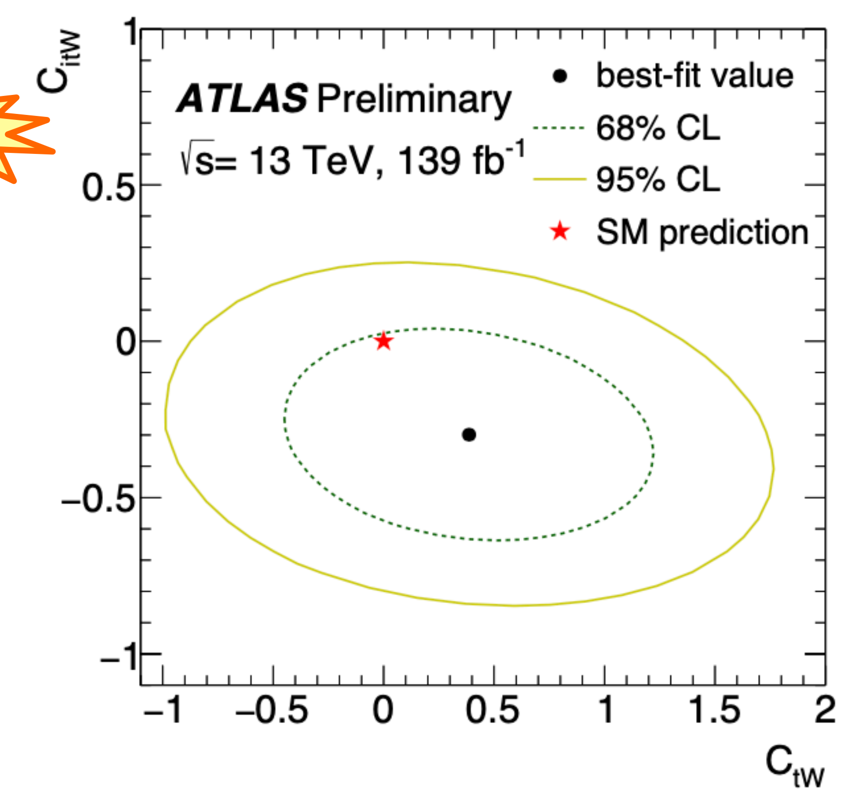
- c_{tG} sensitive to inclusive cross section
- $c_{tq}^{(8)}$ affects high-p_T region

- **Single top polarization** (ATLAS): use angular observables sensitive to new physics in Wtb vertex

New





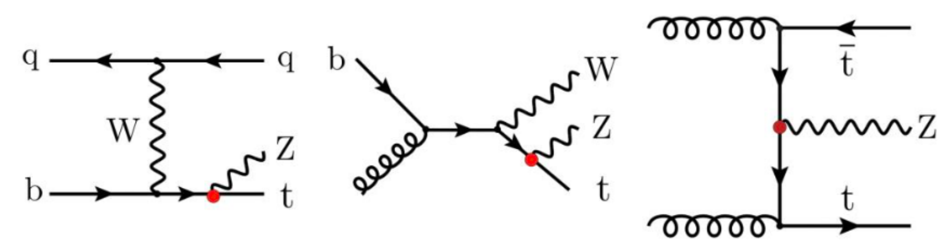


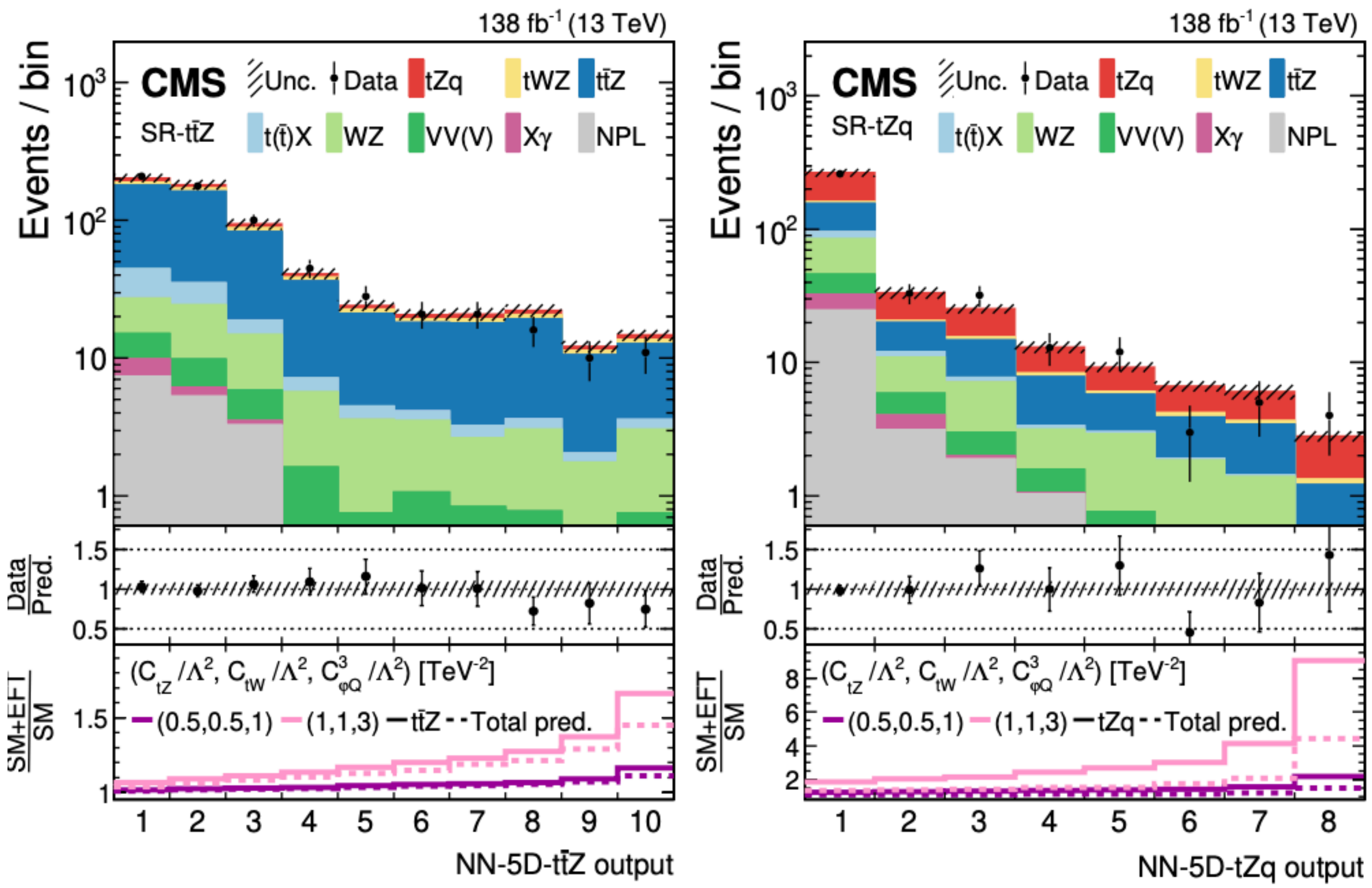
New

tZq and ttZ EFT limits

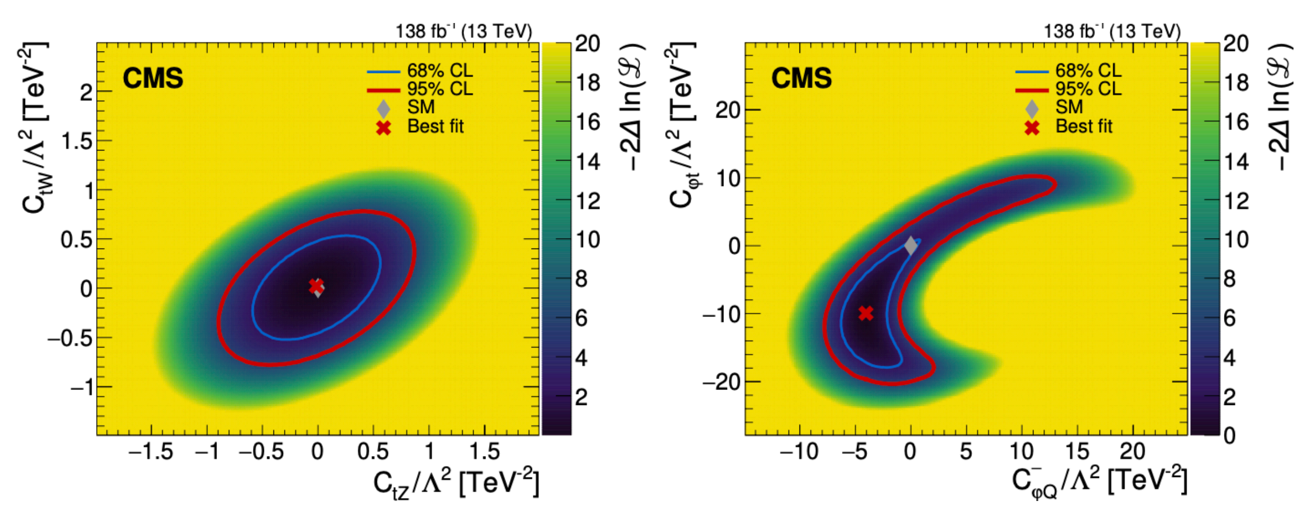
Dennis Schwarz

- CMS: First dedicated EFT analysis exploiting ML techniques
- Target ttZ, tZq, tWZ signals
- Consider events with 3/4 leptons, divided into signal and control (WZ/ZZ) regions
- MVAs trained to separate SM processes, and SM from EFT scenarios





- 5 operators considered: $\mathcal{O}_{tZ}$, $\mathcal{O}_{tW}$, $\mathcal{O}^{3}_{\varphi Q}$, $\mathcal{O}^{-}_{\varphi Q}$, $\mathcal{O}_{\varphi t}$
- Training for single operators and simultaneously (5D)



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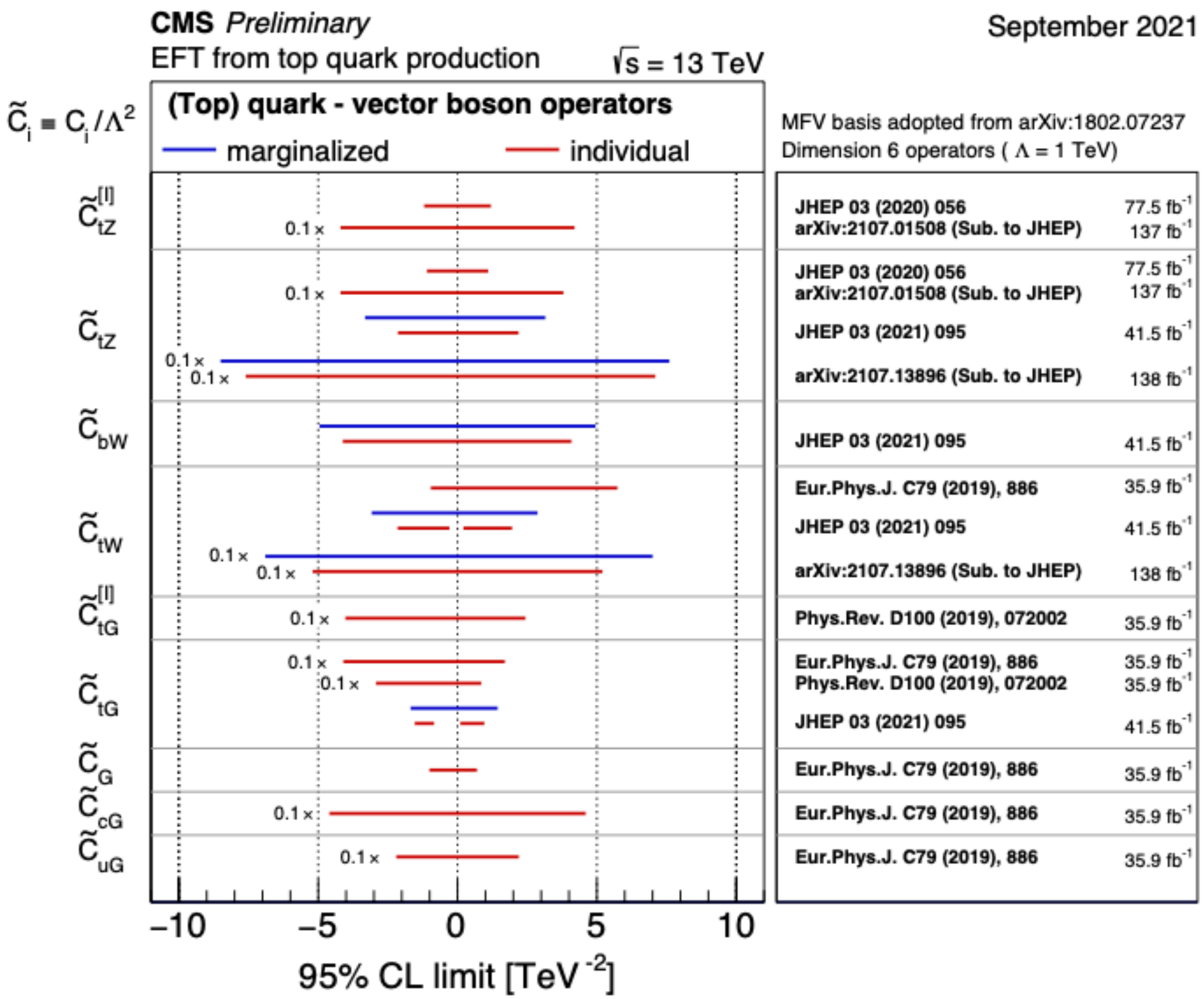
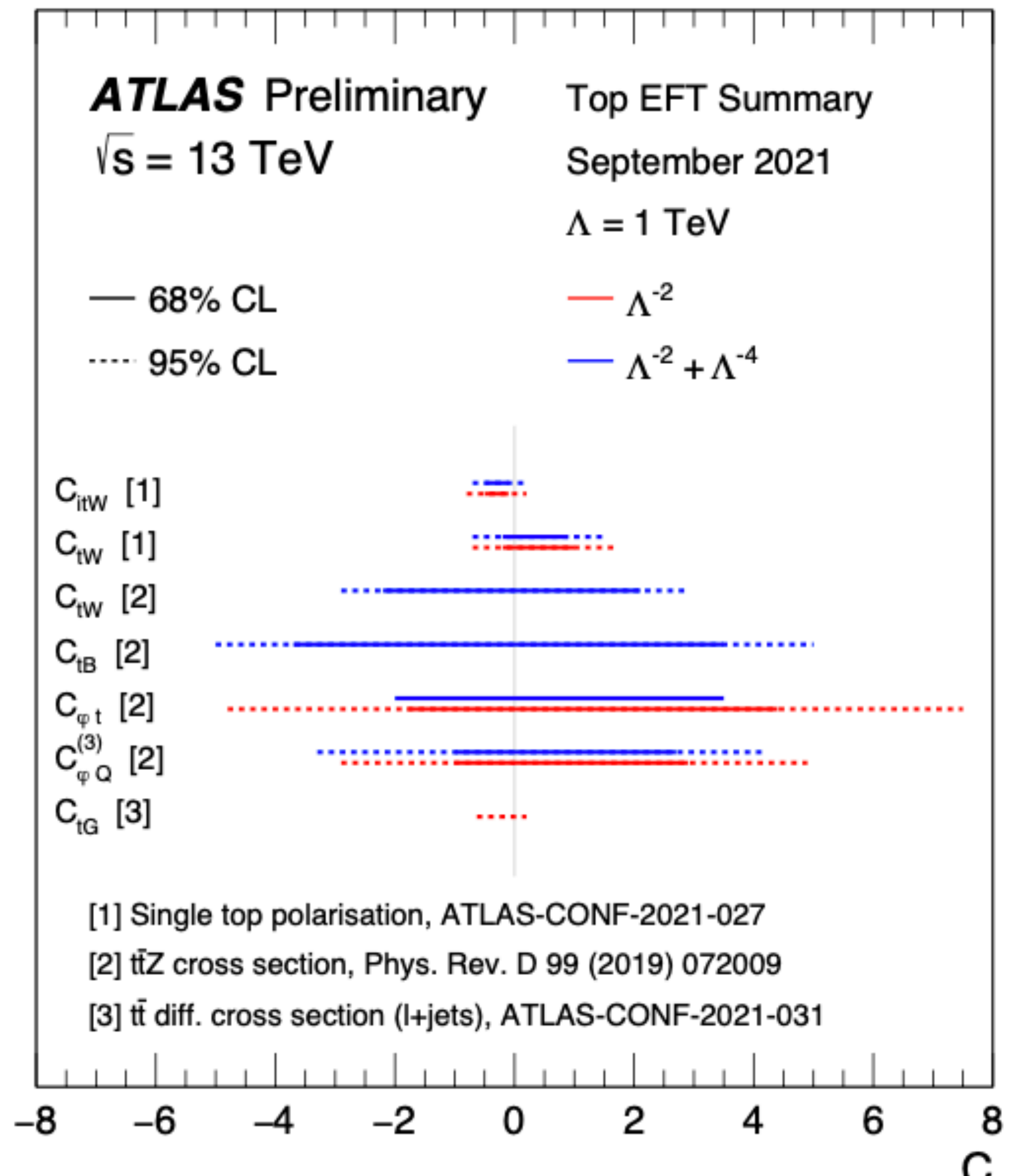
TOP EFT picture emerging

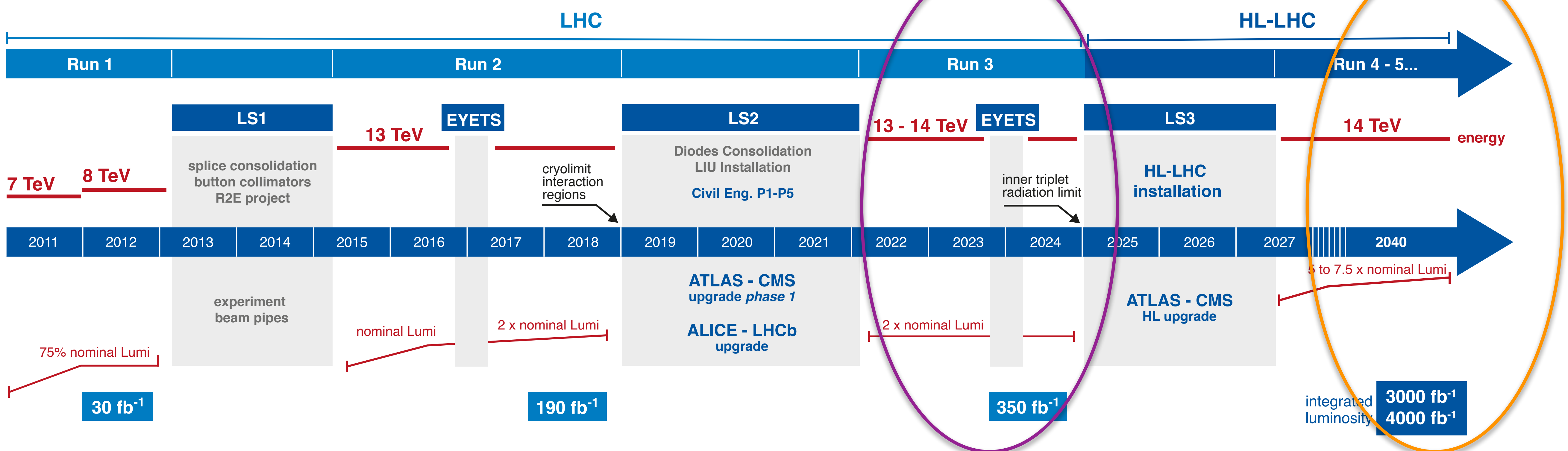




- Challenges and opportunities:
  - More global approaches to capture experimental correlations, EFT at particle level and ML to boost sensitivities
  - Transition to NLO where possible
  - Joint effort by experiment and theory —> LHC EFT WG, LHCtopWG

LHC Run3 and HL-LHC

Gianluigi Arduini
Jan Kieseler



- Preparation for Run3 is in full swing. Beam commissioning starts on 8 March 2022
  - Full intensity only expected in Summer 2022
  - Current integrated luminosity estimate (2022-2024): ~ 160-200 fb-1
  - Magnet training target lowered from 7 TeV to 6.8 TeV to reduce risks —> final word expected soon
  - Also planned: ion run (Pb-Pb or p-Pb), oxigen run (O-O, p-O)
  - Experiments are commissioning detectors and software

- LH-LHC is already taking shape, experiments working on necessary upgrade for the detectors
  - Expect improved momentum resolution, larger eta acceptance, timimg capabilities

Top at HL-LHC

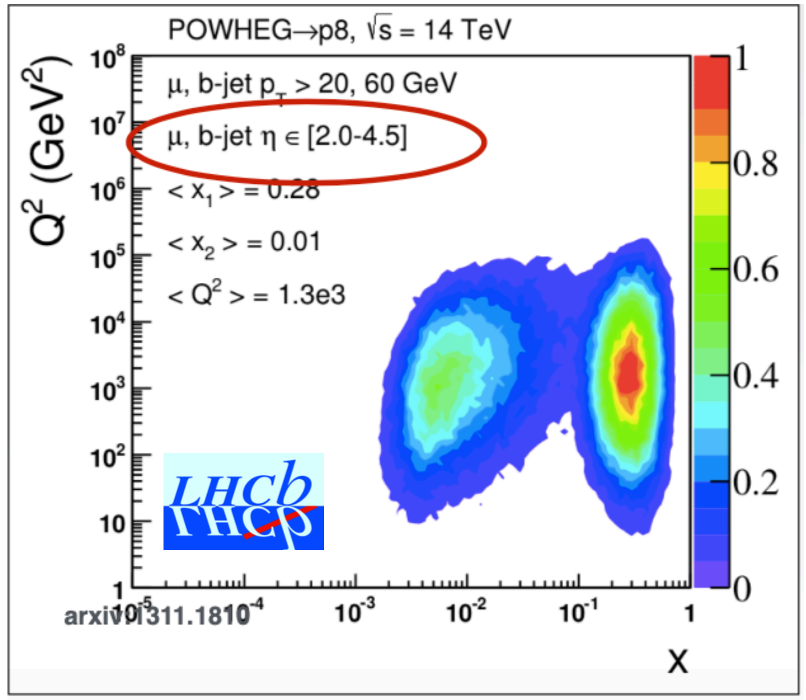
Jan Kieseler

HL-LHC
- 14 TeV → not a bump-hunt machine
- 3-4 ab-1
- 140-200 Pileup

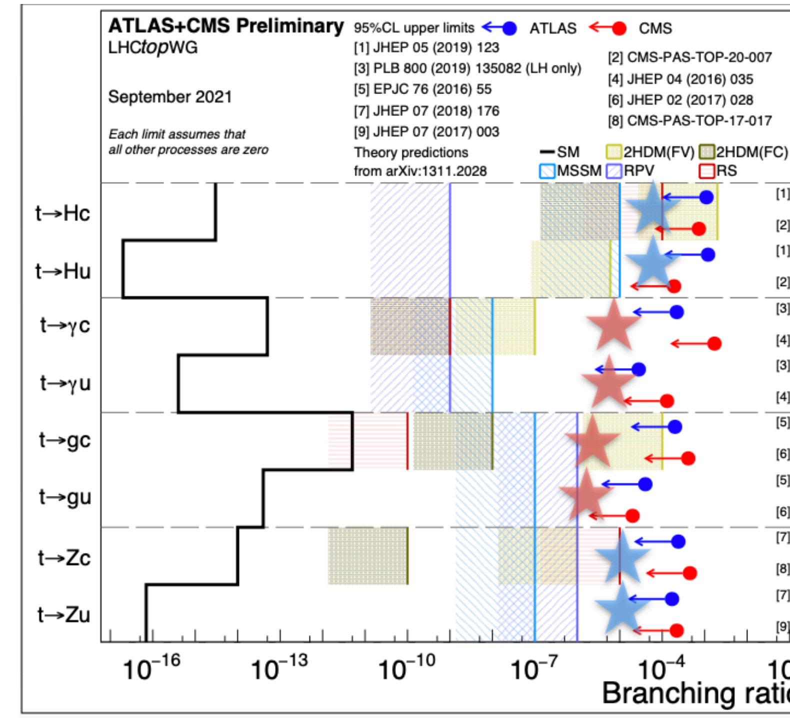
Huge yield (in terms of approx. top units)
- 3B ttbar events
- 300M tW
- 30M s-channel
- 3M ttV
- 30k 4 top

Unprecedented challenges for detectors and reconstruction
- Radiation
- Occupancy
- Particle density

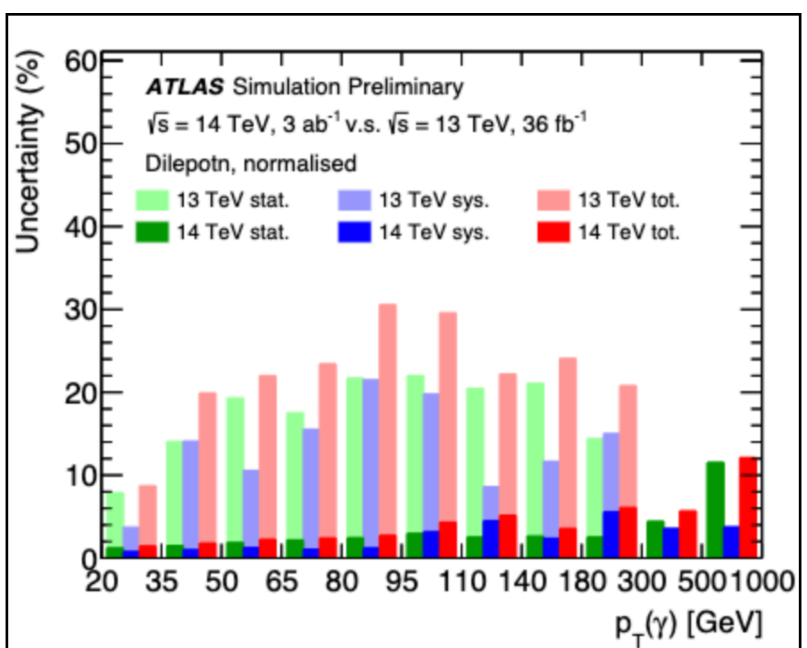
- Very forward top (LHCb): access to high-x PDF, essential to understand potential signs for new heavy states



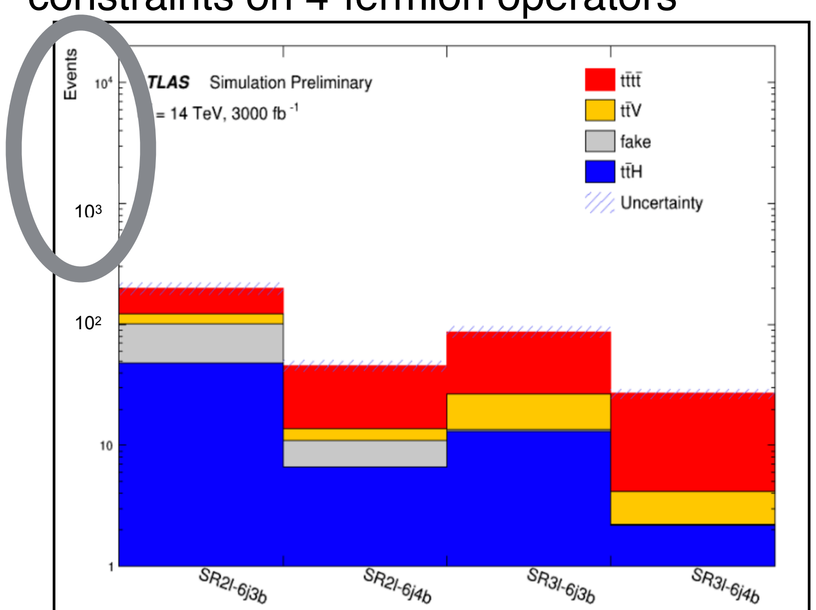
- FCNC: expect improvements by ~1 order of magnitude



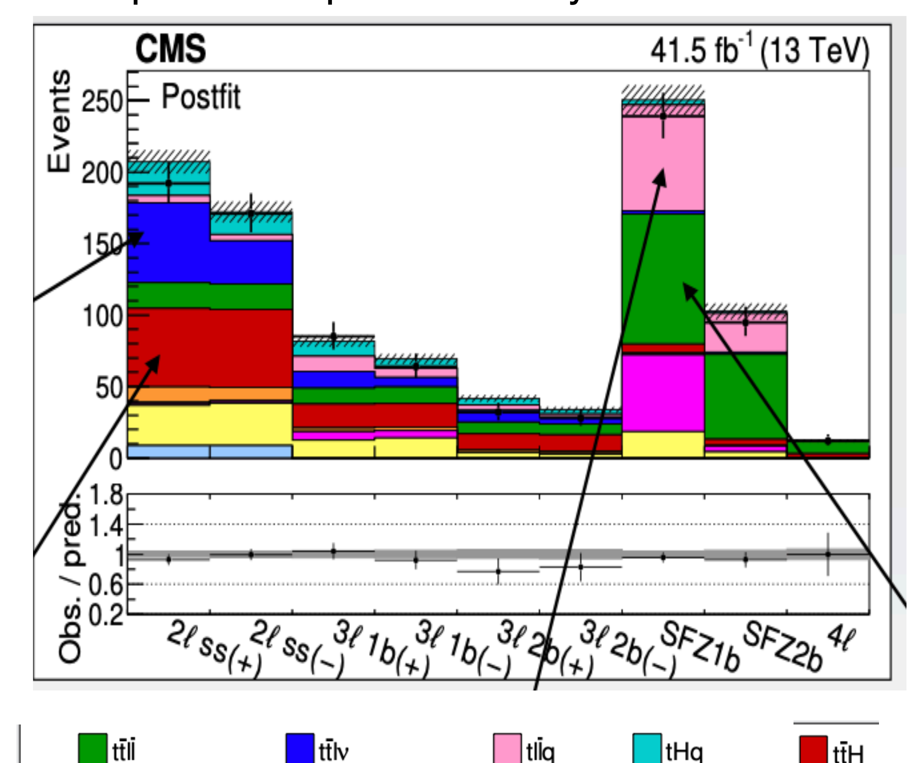
- ttgamma:



- 4top: improvement up to ~11% possible, constraints on 4-fermion operators



- Exploit multi-process analyses



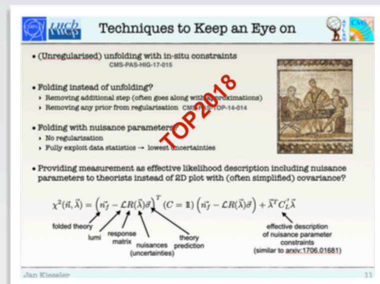
Top at HL-LHC: challenges

Jan Kieseler

- Beating systematics for precision measurements will be a must
- Further improvement on analysis techniques and tools   Clara Nellist
- Ensure constraints are physically meaningful:
  - Understand uncertainty correlations, model impact of statistical fluctuations

Go further up the Systematics Wall: techniques

- Unfolding with in-situ constraints / uncertainty marginalisation



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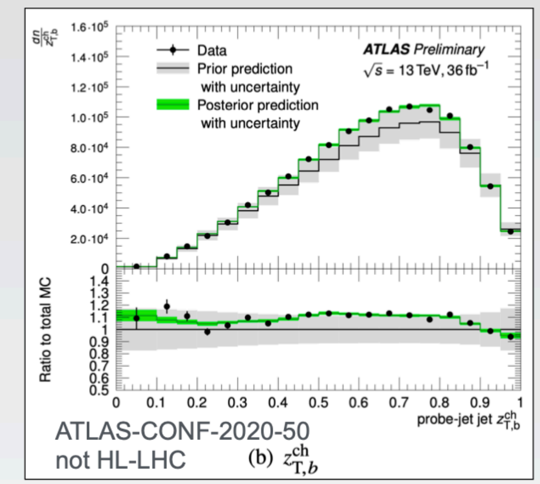
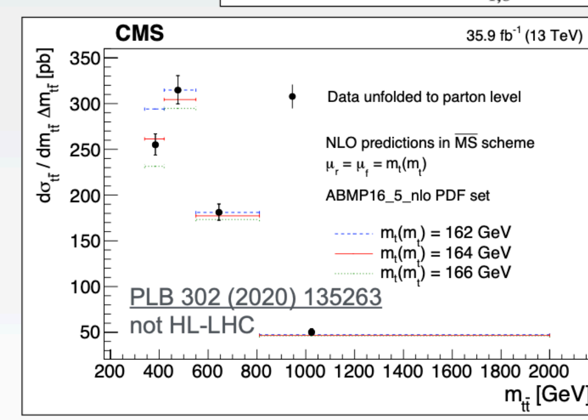
01/14/21 | By Stephanie Melchor

The ATLAS collaboration has begun to publish likelihood functions, information that will allow researchers to better understand and use their experiment's data in future analyses.



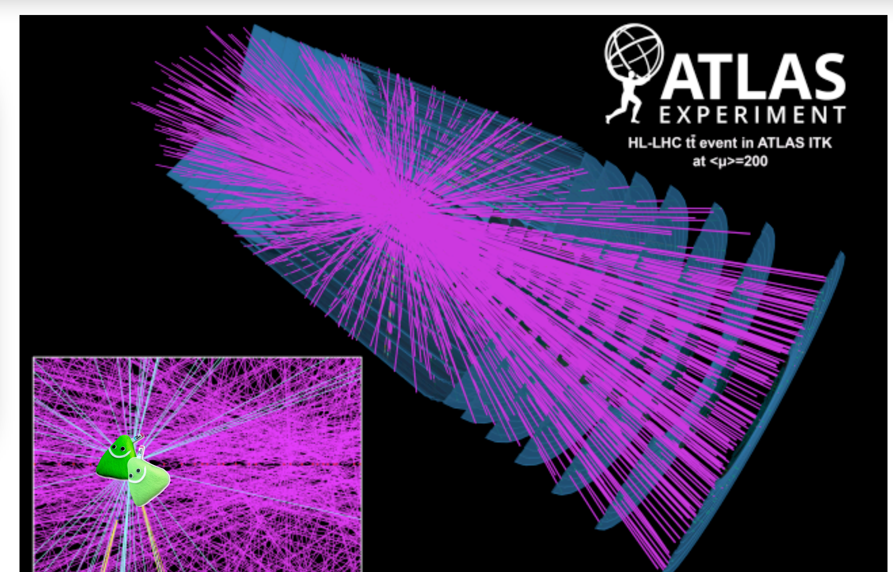
- We are on a good path, let's keep climbing

- Use *differentiable programming* to find optimal analysis working points
  - Code written using differentiable programming tools allows **optimising free parameters automatically** with powerful gradient descent methods
  - Optimise not only for best Signal/Background but also to find **best classifier to constrain systematics** [1,2]
  - Direct simulation based inference [3]   → possibly Clara's talk
  - These also offer direct access for ***multi-process optimisations***



[1] Inferno ,[2] Neos, [3] Cranmer et al. and therein

- **Dire need of a paradigm change** from by-eye optimisations of many, many parameters, e.g. working points, cuts, … reconstruction algorithms to *differentiable implementations* that allow to use modern optimisation tools
  - Really find an optimum: *end-to-end* optimisation
  - More time for new developments/analysis, less maintenance work
  - Chance to solve computing challenges too



Closing comments

- **Very successful second virtual Top Quark Workshop, many interesting discussions**
  - **Very well attended: ~160 people connected**
  - **Huge thanks to all poster and talk presenters for the excellent quality**
  - **Huge thanks to the organizers for the great workshop**

- **Top physics experimental programme at the LHC is thriving**
  - **Many new ATLAS and CMS results with full Run2 data — expect a lot more to come!**

- **Interpretations of measurements are in full swing**
  - **SM parameters, EFT, BSM, generator tuning…**

- **Run3 is about to start, HL-LHC is around the corner**
- **Many exciting proposals for top physics at future colliders**

- **Let's discuss at TOP2022** (hopefully in person again…!)

Additional information

Modelling & tuning

Poster Dimbi Rafanoharana Giulia Negro

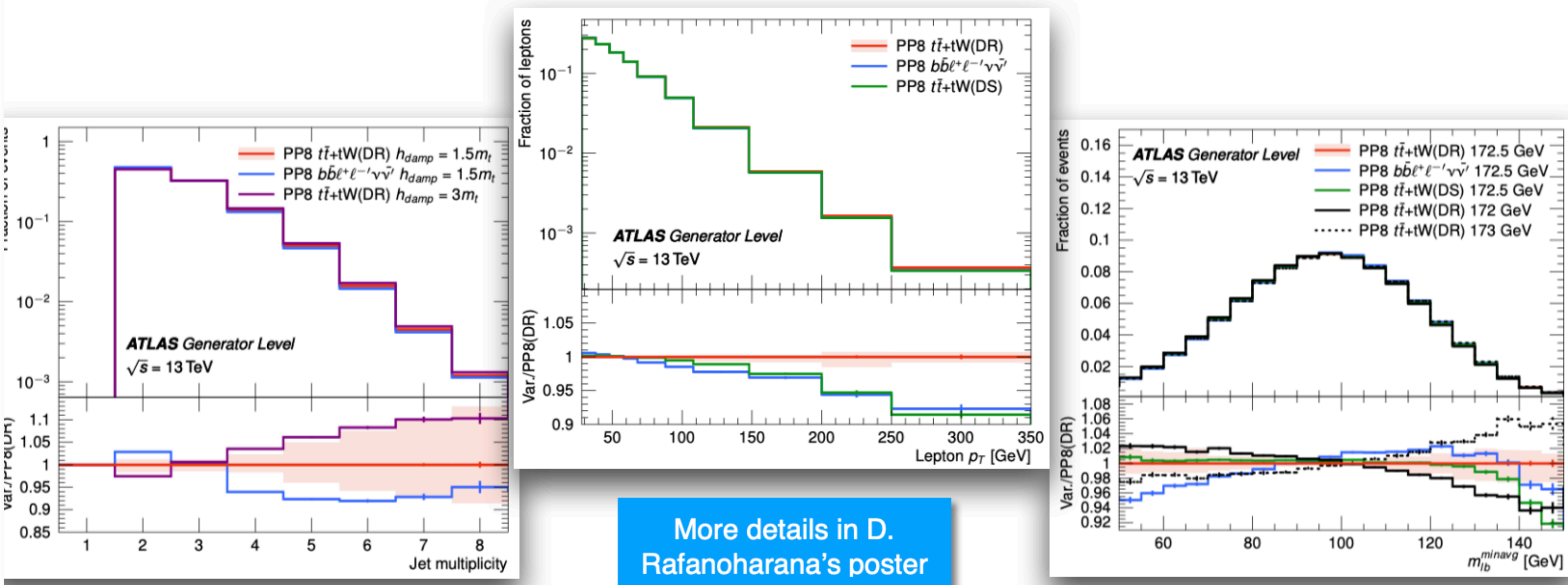
Implemented and validated in 2018 in CMS

bb4l sample

NEW results from ATLAS

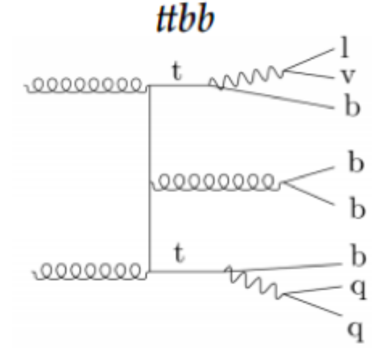
TOP2021

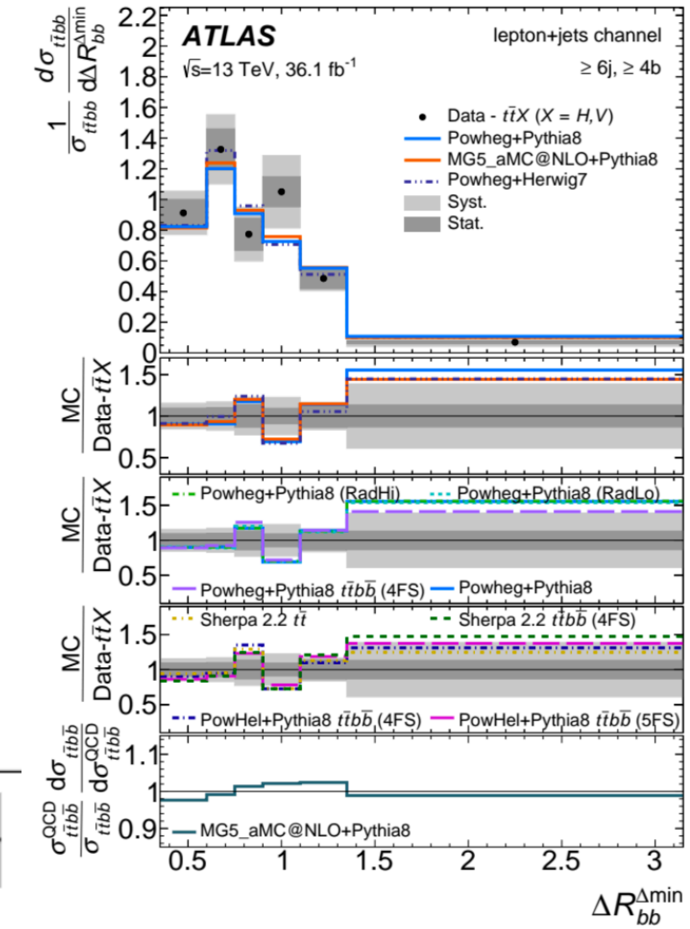
- A $t\bar{t}$ sample including all off-shell effects (i.e. double, single and non-resonant contributions):
  - improves description of the off-shell phase space (currently modelled by tt+tW) for searches
  - provides a theoretically more solid definition of the top quark mass
  - one of the best MC setups for $t\bar{t}$ but currently implemented only for different flavour leptons processes → difficult to use directly in comparisons with data



More details in D. Rafanoharana's poster

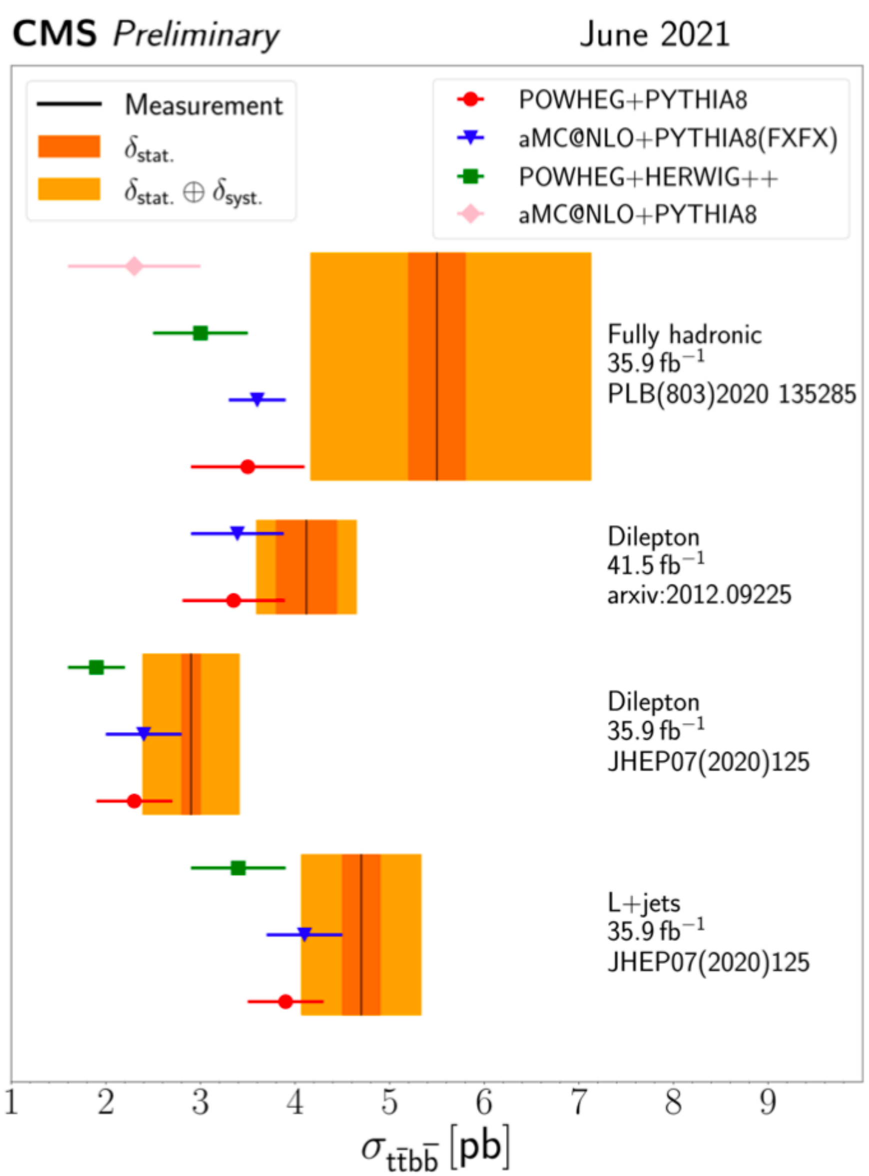
tt+Heavy flavour

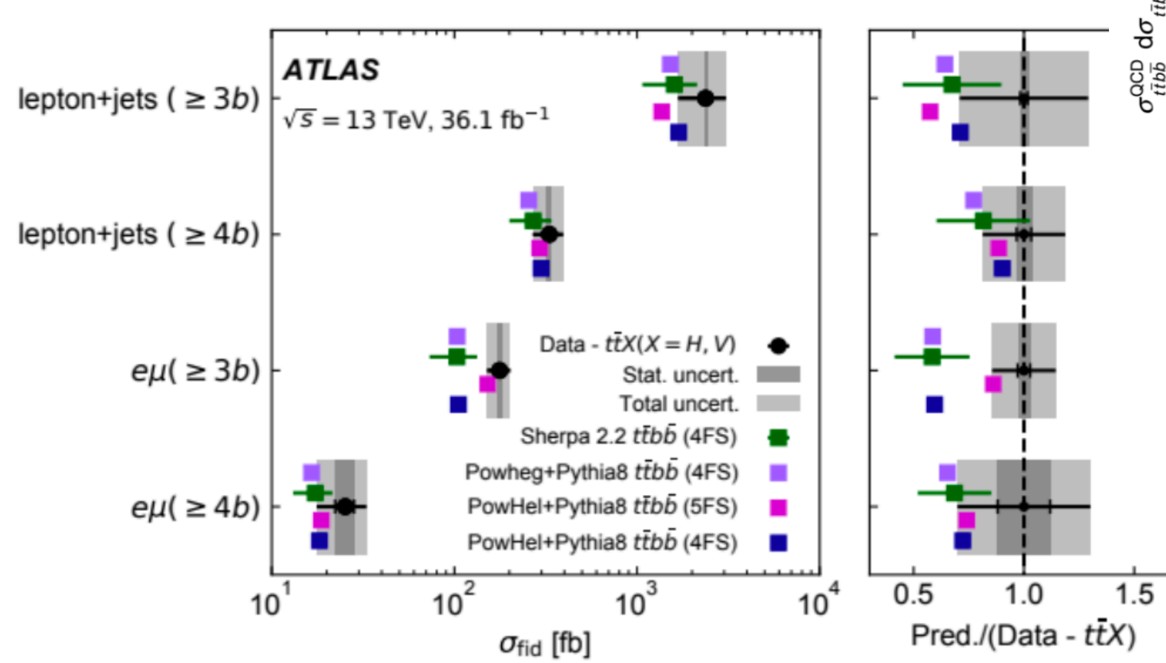




Major background for tt+H(bb) and 4top

- Challenging to model, complex final state
- CMS: first measurement of tt+cc, in agreement with predictions
- Underprediction of 1-2sigma by all MC simulations
- Results using full Run2 still to come, including more differential measurements





	Result	POWHEG	MADGRAPH5_aMC@NLO
Fiducial phase space			
$\sigma_{t\bar{t}c\bar{c}}$ [pb]	$0.207 \pm 0.025 \pm 0.027$	0.187 ± 0.038	0.189 ± 0.032
$\sigma_{t\bar{t}b\bar{b}}$ [pb]	$0.132 \pm 0.010 \pm 0.015$	0.097 ± 0.021	0.101 ± 0.023
$\sigma_{t\bar{t}LL}$ [pb]	$5.15 \pm 0.12 \pm 0.41$	5.95 ± 1.02	6.32 ± 0.94
R_c [%]	$3.01 \pm 0.34 \pm 0.31$	2.53 ± 0.18	2.43 ± 0.17
R_b [%]	$1.93 \pm 0.15 \pm 0.18$	1.31 ± 0.12	1.30 ± 0.16
Full phase space			
$\sigma_{t\bar{t}c\bar{c}}$ [pb]	$10.1 \pm 1.2 \pm 1.4$	9.1 ± 1.8	8.9 ± 1.5
$\sigma_{t\bar{t}b\bar{b}}$ [pb]	$4.54 \pm 0.35 \pm 0.56$	3.34 ± 0.72	3.39 ± 0.66
$\sigma_{t\bar{t}LL}$ [pb]	$220 \pm 5 \pm 19$	255 ± 43	261 ± 37
R_c [%]	$3.36 \pm 0.38 \pm 0.34$	2.81 ± 0.20	2.72 ± 0.19
R_b [%]	$1.51 \pm 0.11 \pm 0.16$	1.03 ± 0.08	1.03 ± 0.09