GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Experimental summary

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15th International Workshop on Top-Quark Physics (TOP2022)

September 4-9 2022,
Durham, UK

Personal biased selection

She is doing her best

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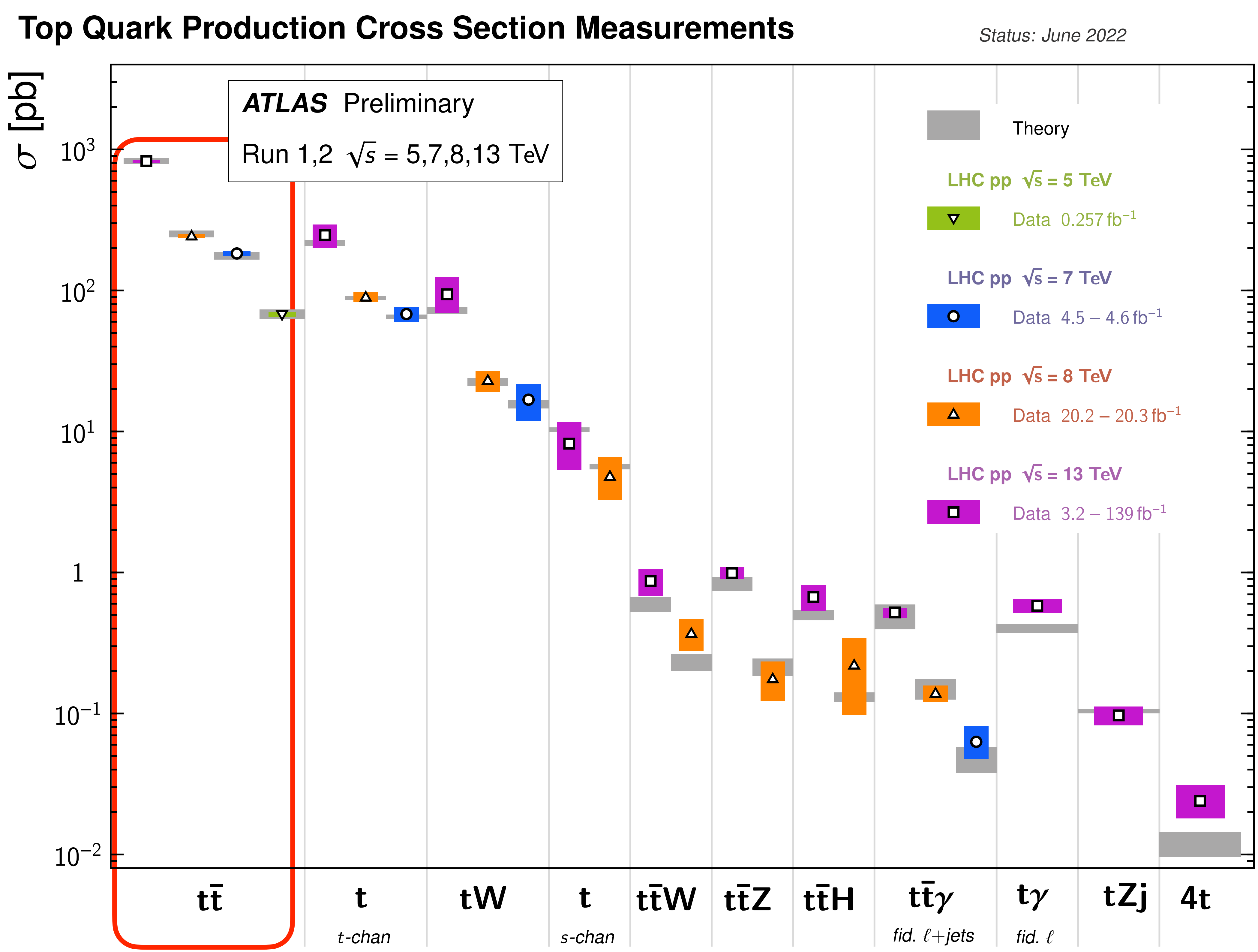
Highlights and trends Top2022

Personal biased selection

- First top pair cross section measurement by CMS at 13.6 TeV with <8% precision after 2 months of data taking!
- 4-top search in all-hadronic final state
  - never thought it is possible
- Top mass with profiling… What uncertainty we expect for full run 2 ?
- No discussion "What mass do we measure?"
  - do we finally have the answer?
- Almost no dedicated discussion of MC modelling and uncertainties
- ATLAS announced discovery of new uncertainty: recoil to colour in PS
- MVA routinely everywhere: event reconstruction, 2 and multiclass
- New trends in top properties measurements:
  - unfolding instead of template fits
  - more and more using t+X events in addition to top pair/single top
  - analysis with boosted objects
- The most frequently pronounced words
  - "off-shell effects" , "bb4l"

Top pair production

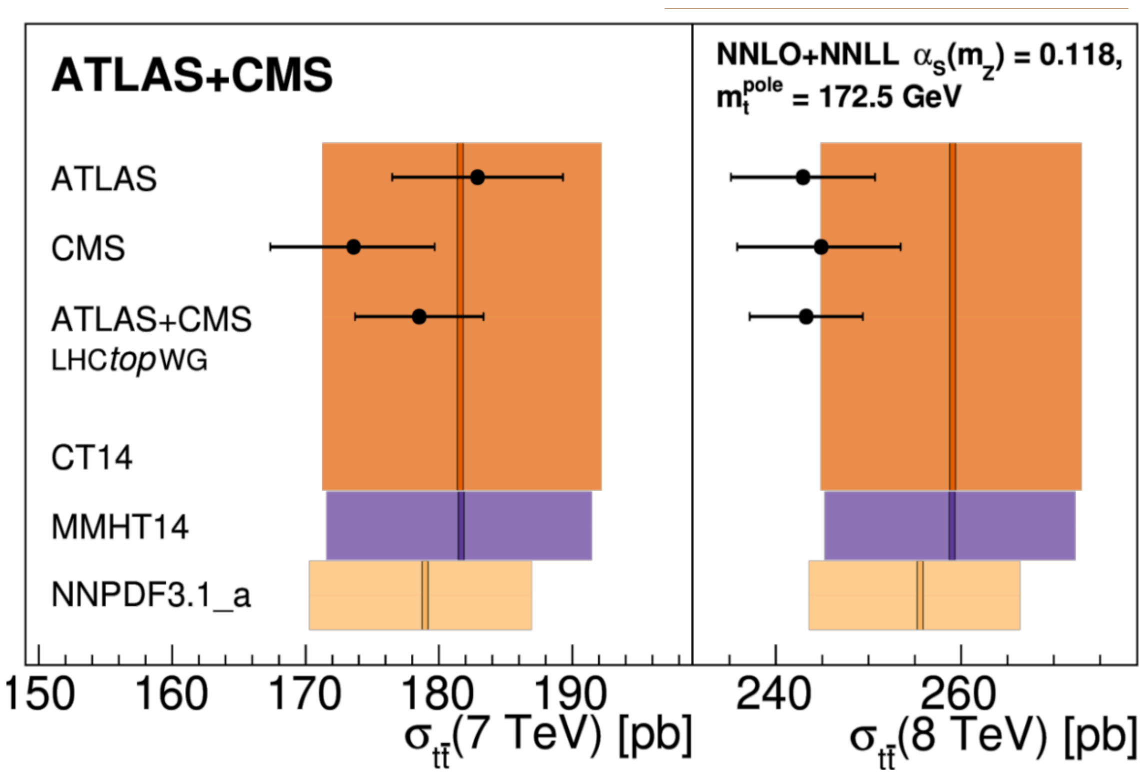


Top cross sections

P.Hansen

ATLAS+CMS combination 7/8 TeV

- inputs: eμ channel with best precision
- CONVINO tool to combine counting and PL fit

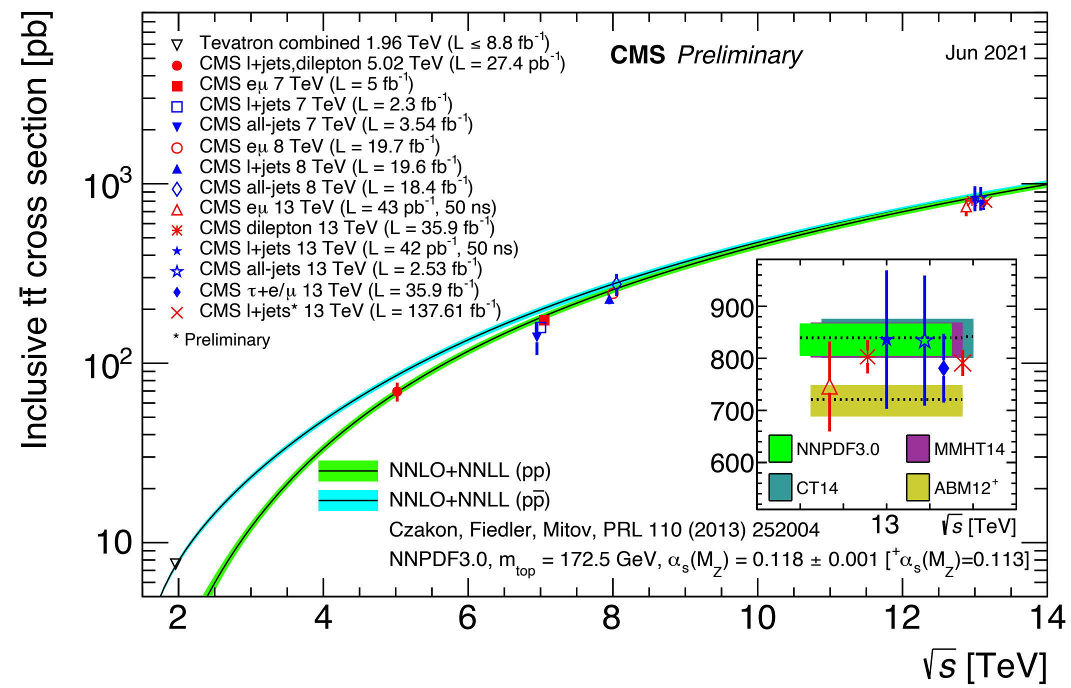


$$\sigma_{t\bar{t}}\ (\sqrt{s} = 7\,\text{TeV}\ ) \quad = \quad 178.5 \pm 4.7\ \text{pb}$$
$$\sigma_{t\bar{t}}\ (\sqrt{s} = 8\,\text{TeV}\ ) \quad = \quad 243.3^{+6.0}_{-5.9}\ \text{pb},$$

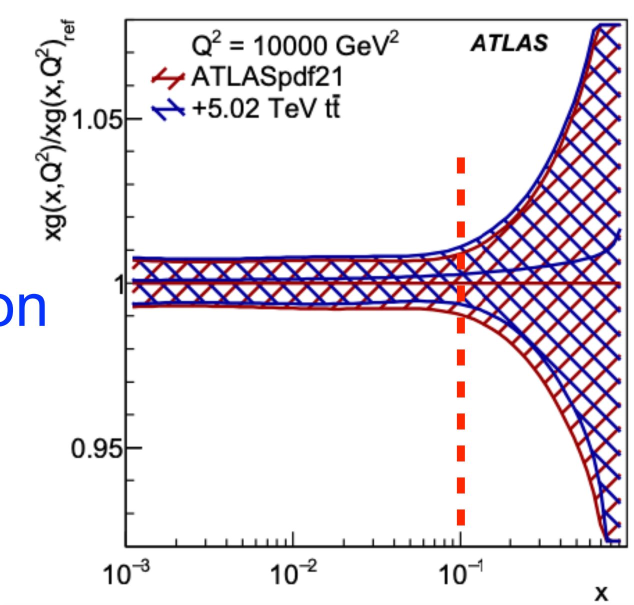
- 25% reduction of uncertainties

$$\alpha_S(m_Z) = 0.1170^{+0.0021}_{-0.0018}$$

Measurements at 5.02 TeV



- Impressive agreement with QCD predictions from 5.02 to 13 TeV and a magnitude of cross section
- Reduced uncertainty on *xg(x)* by 5% at x=0.1



Measurement in eμ channel

P.Hansen

$$N_1 = L\sigma_{t\bar{t}}\ \epsilon_{e\mu}2\epsilon_b(1 - C_b\epsilon_b) + N_1^{\text{bkg}}$$
$$N_2 = L\sigma_{t\bar{t}}\ \epsilon_{e\mu}C_b{\epsilon_b}^2 + N_2^{\text{bkg}}$$

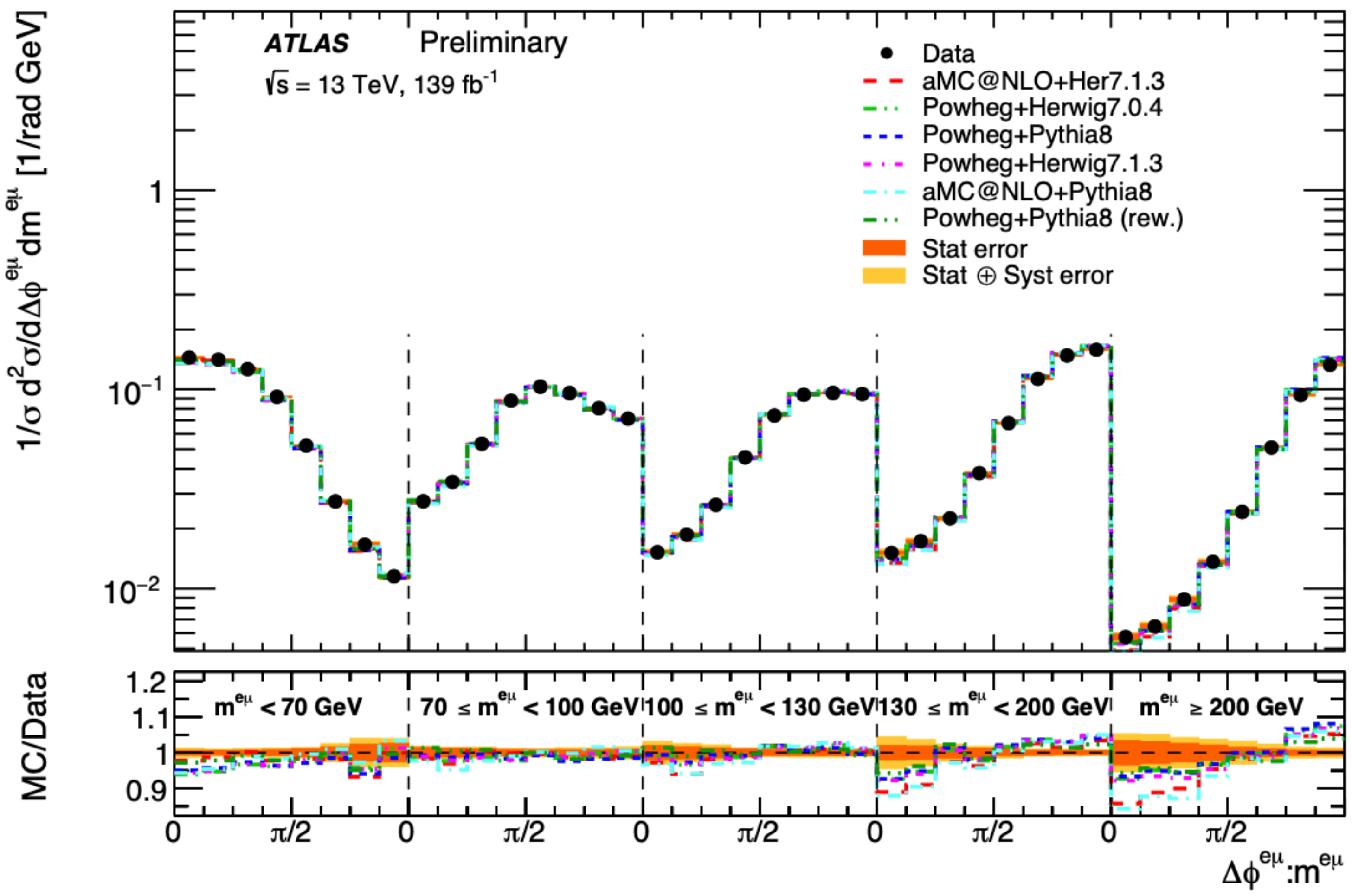
- Full Run 2 data set
- Inclusive and 8 2D distributions
- Same method as in previous measurements
- For differential applied in each bin

$$\sigma_{t\bar{t}} = 836 \pm 1(stat) \pm 12(syst) \pm 16(lum + E_{cms})$$

2.4% uncertainty

- Largest uncertainties from luminosity and Wt
- No improvement in precision compared to 36/fb result

Have we reached precision limit?



- Wt systematics is a limiting factor in many measurements and searched

- Tension between data and prediction in lepton pT.
- Reweighing of top pT in PH+P8 to reproduce the NNLO improves agreement
- Same effect in ΔΦ vs $m^{e\mu}$

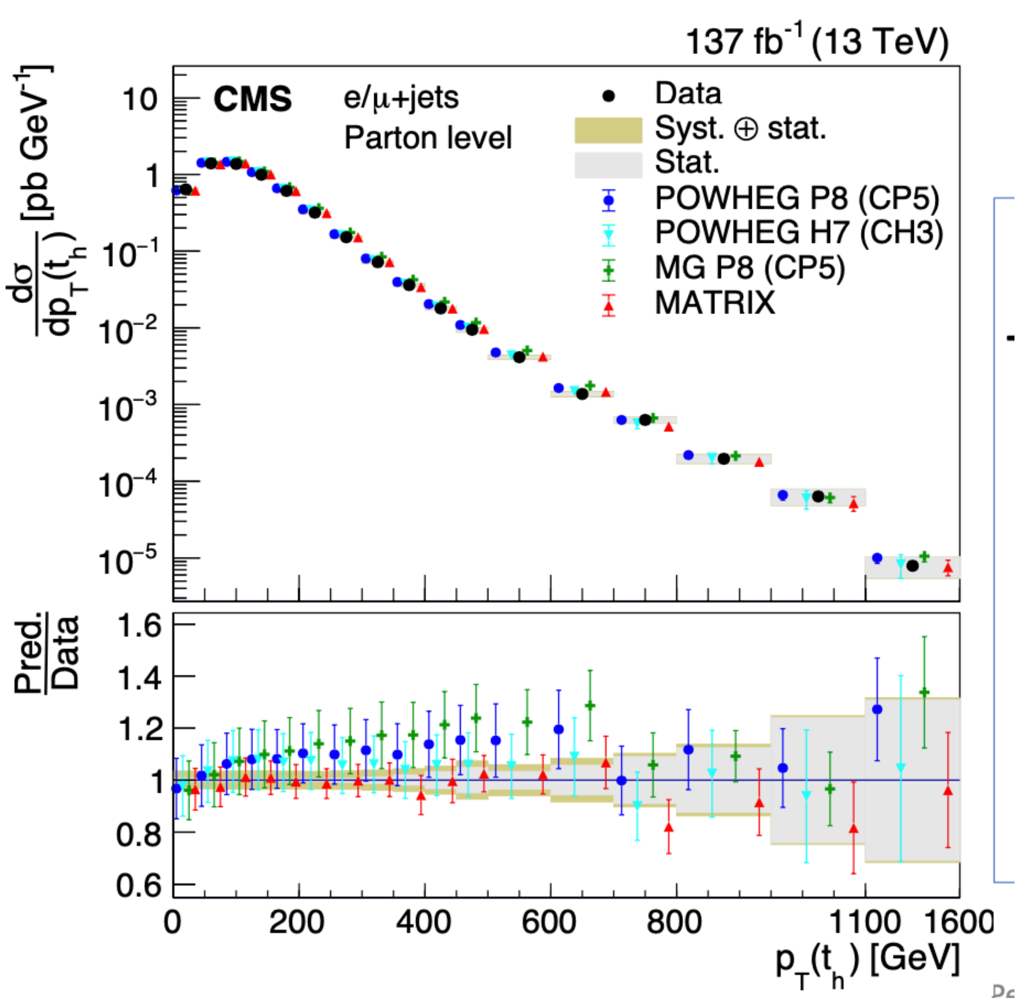
Single lepton final state

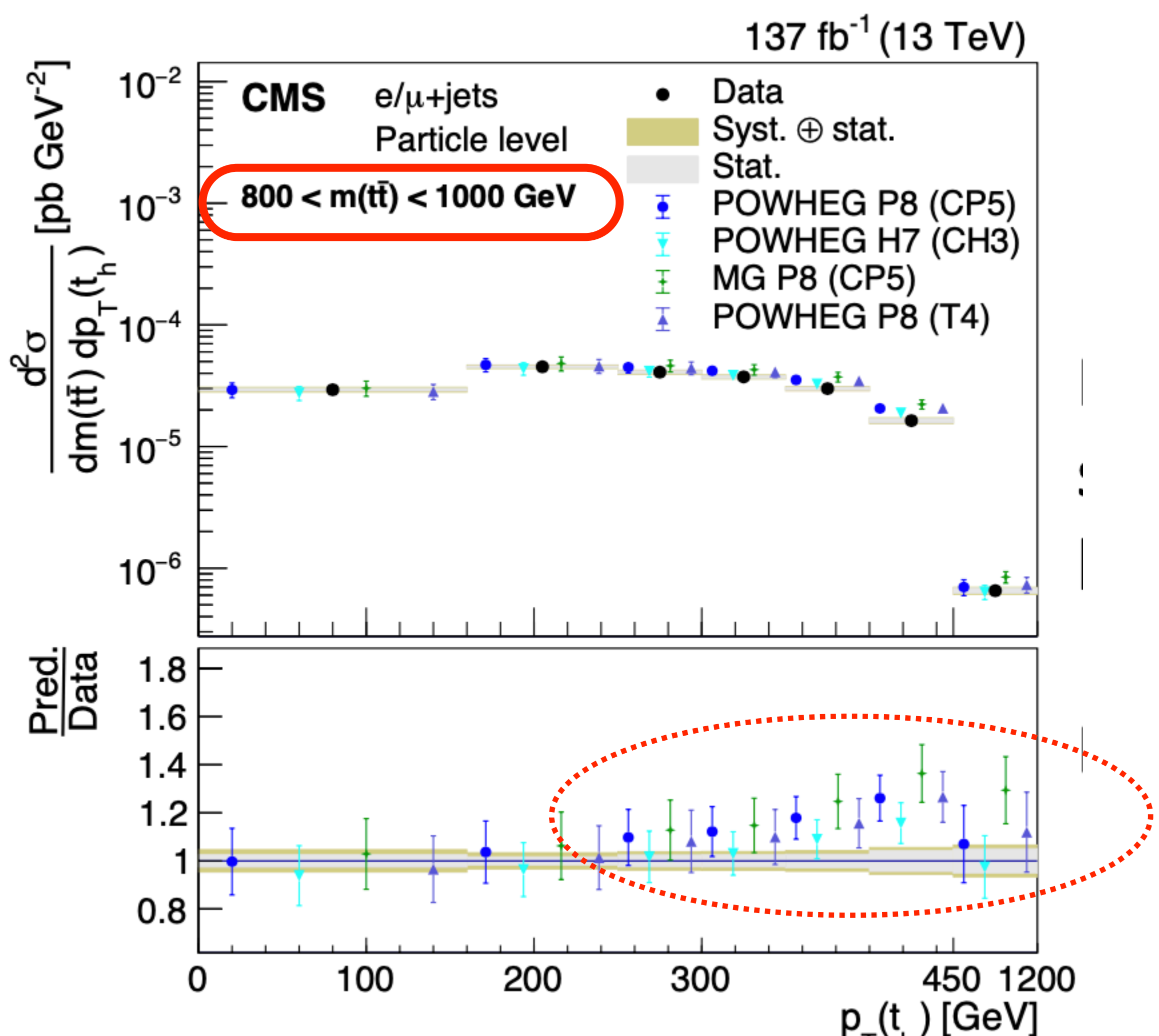
P.Hansen

- CMS analysis included resolved and boosted topologies
- Inclusive, parton and particle level cross sections
- Expanded phase space compared to dilepton channel

$$\sigma_{t\bar{t}} = 791 \pm 1\,(\mathrm{stat}) \pm 21\,(\mathrm{syst}) \pm 14\,(\mathrm{lumi})\,\mathrm{pb}$$

3.2% uncertainty
most precise in this channel





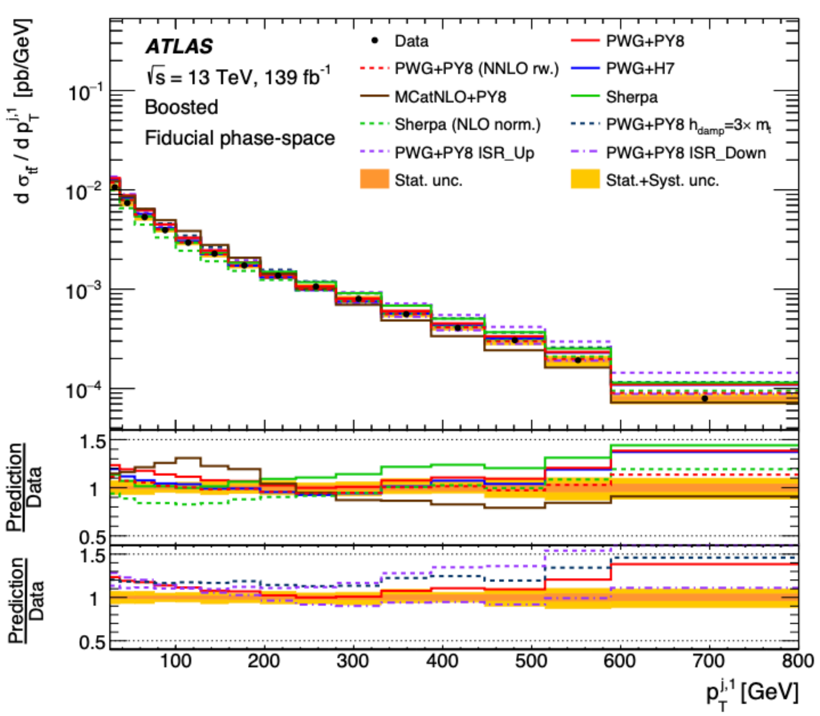
- All studied MC have problems in 2D distributions, especially for variables related to radiation, not covered by fixed-order calculations

Measurements in boosted topology

P.Hansen
J. Jamieson

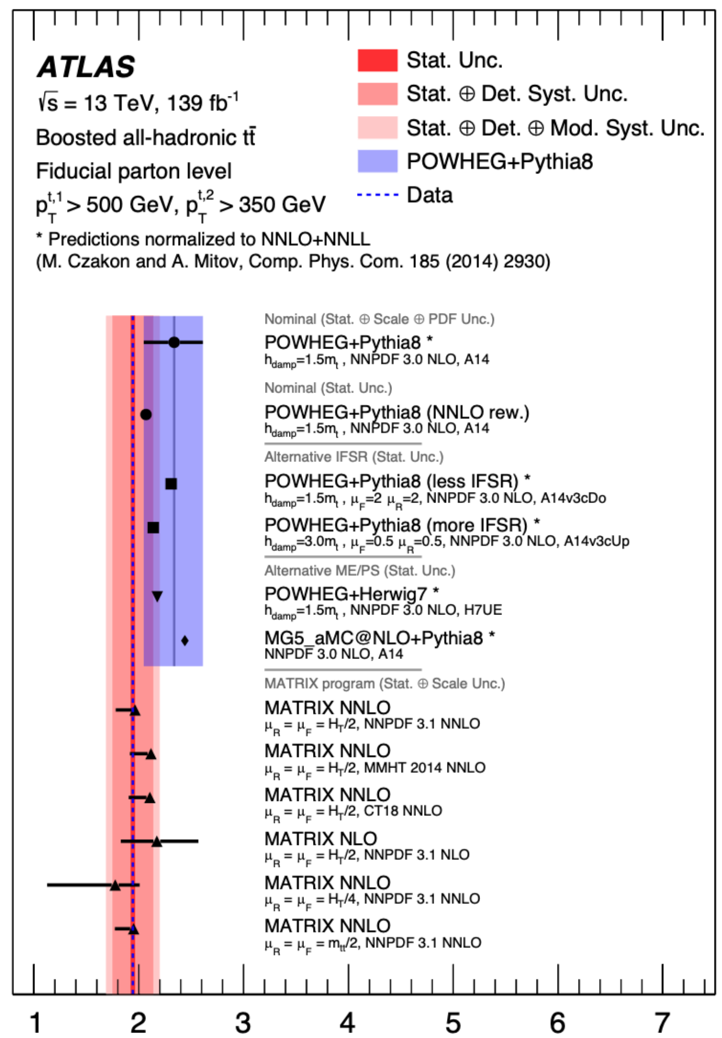
Single lepton channel

- Significant reduction of JES uncertainty due to in-situ JES calibration
- Problems with modelling additional jets and 2D distributions and azimuthal distances to hadronic top



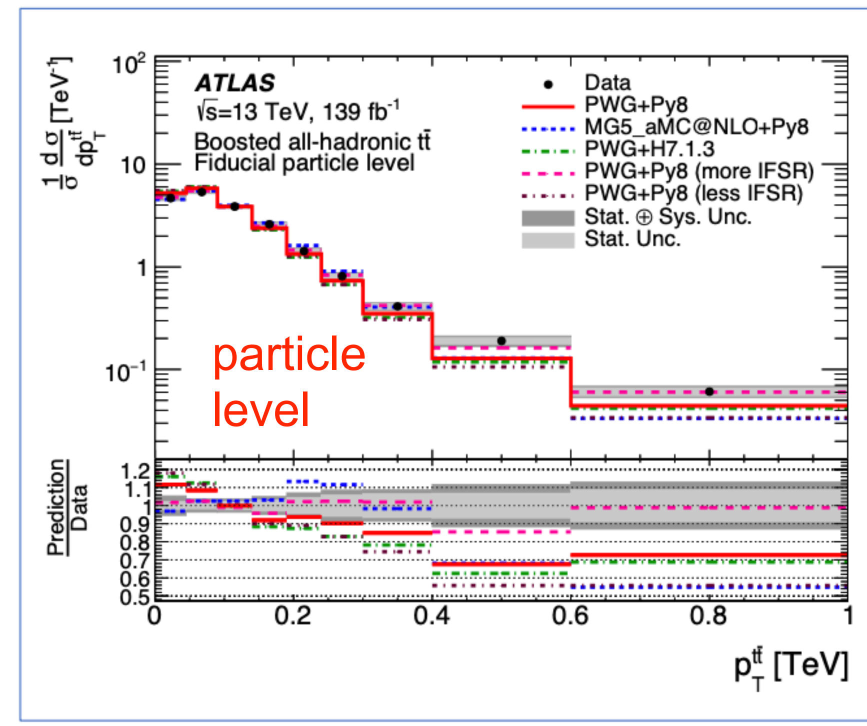
pT of leading additional jet

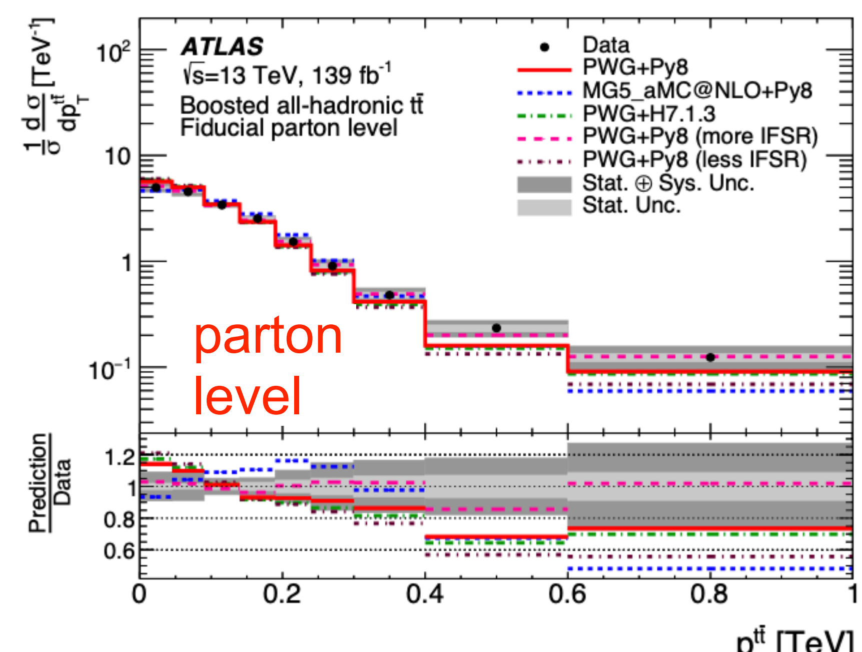
All-hadronic channel



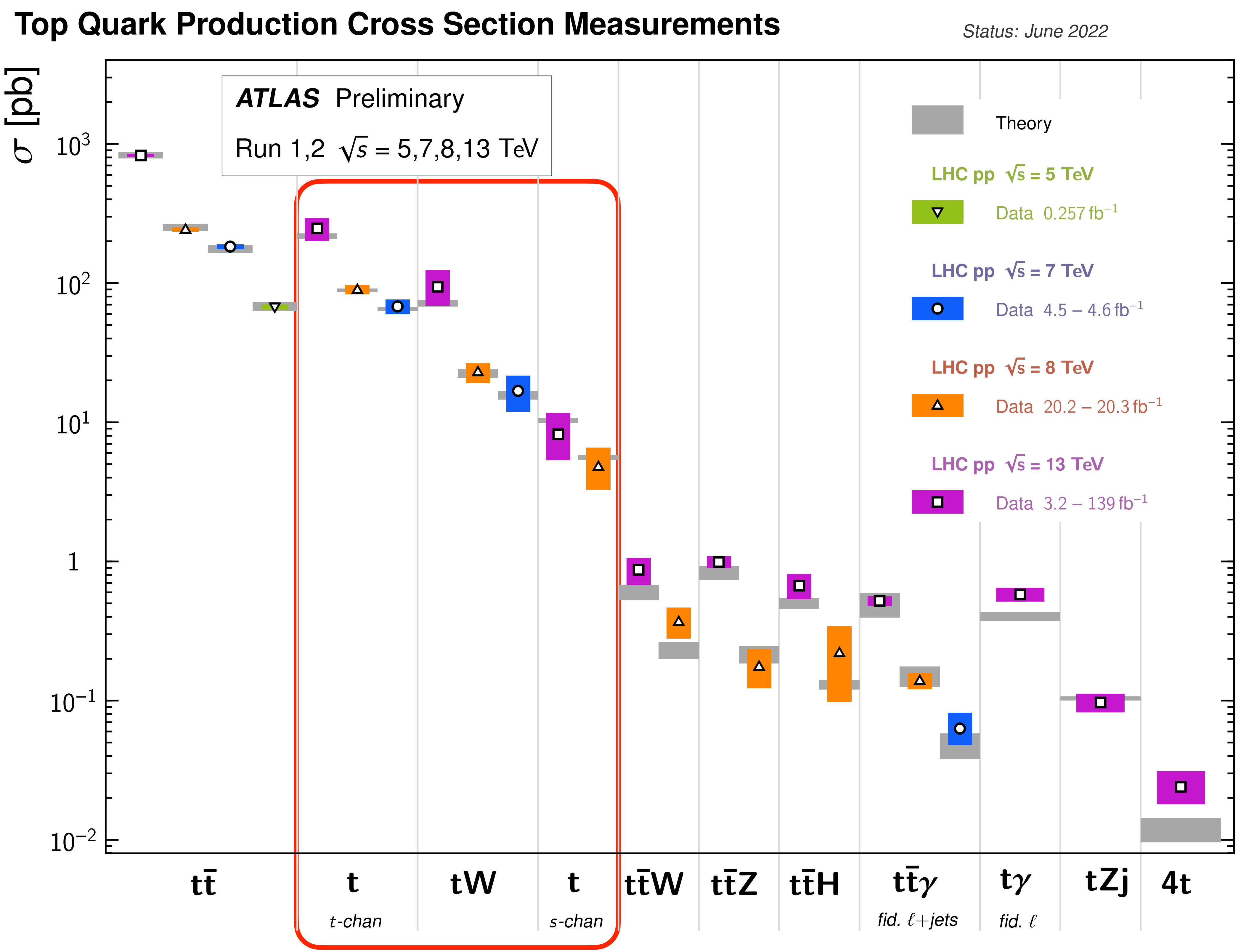
- MATRIX reproduces the fiducial cross-section better than the NLO models.
- Reweighing the NLO to NNLO top pT helps to reproduce data

tt system pT



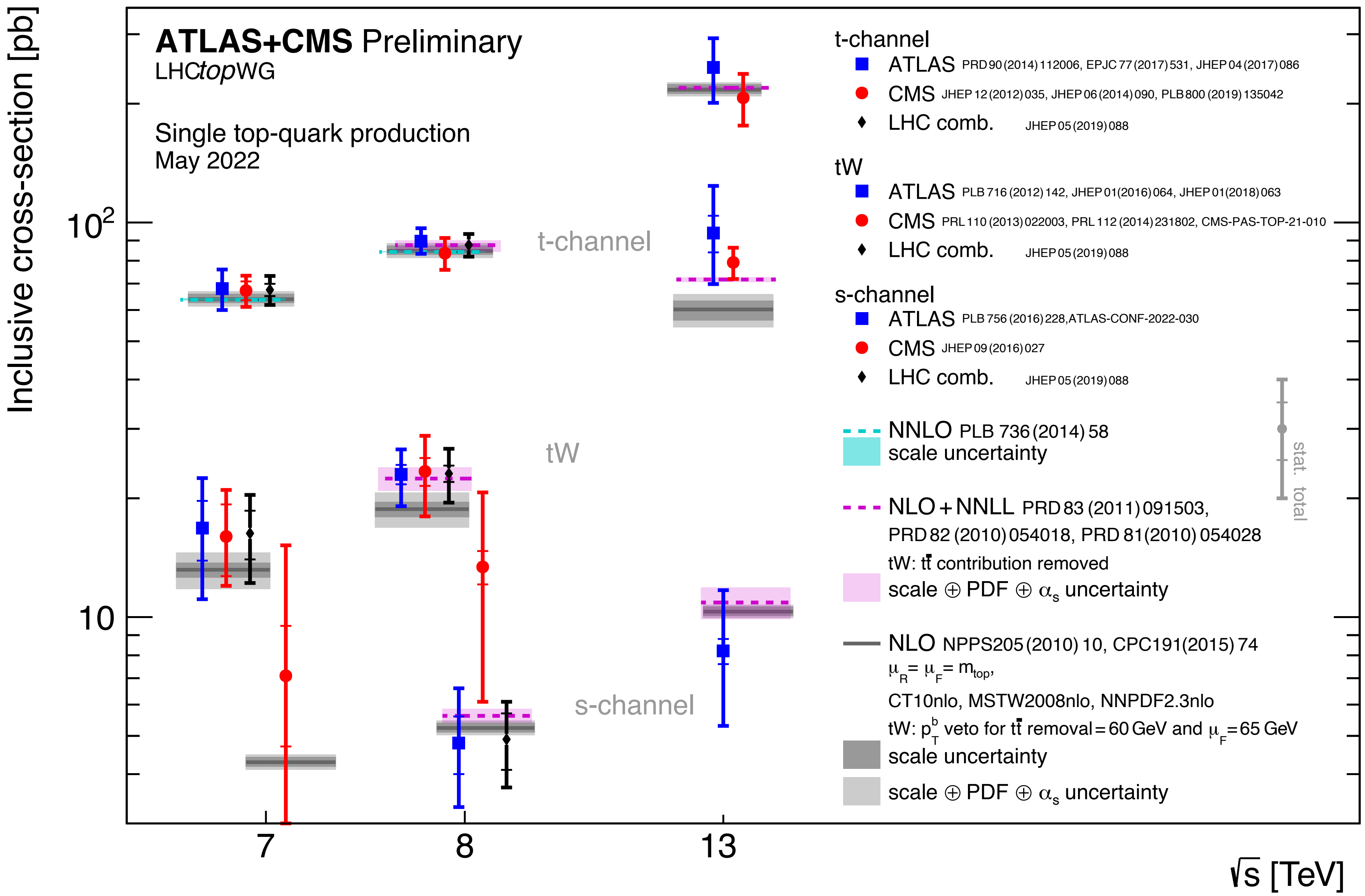


Electroweak top production

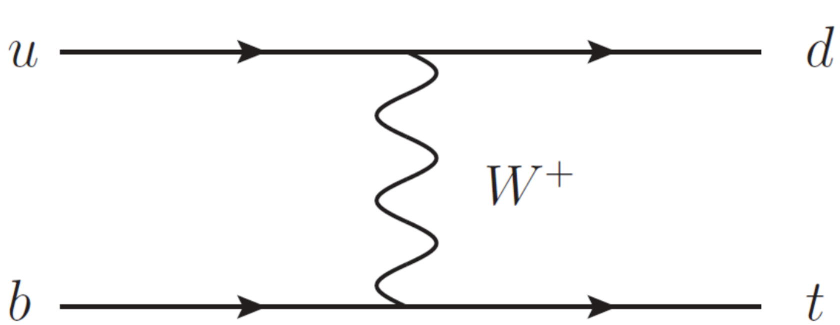


Single top production

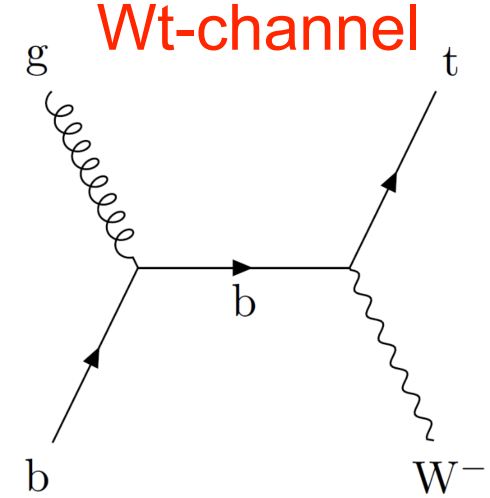
A.S.Rodrigues



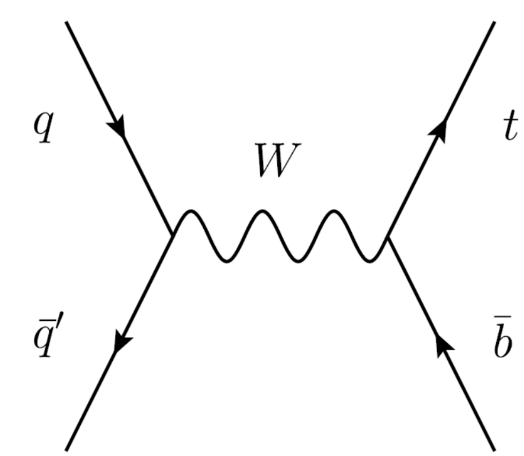
t-channel



Wt-channel



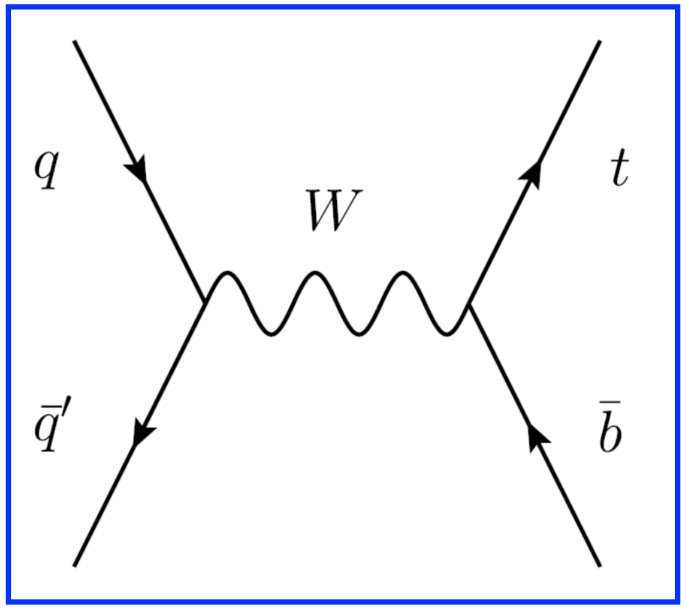
s-channel

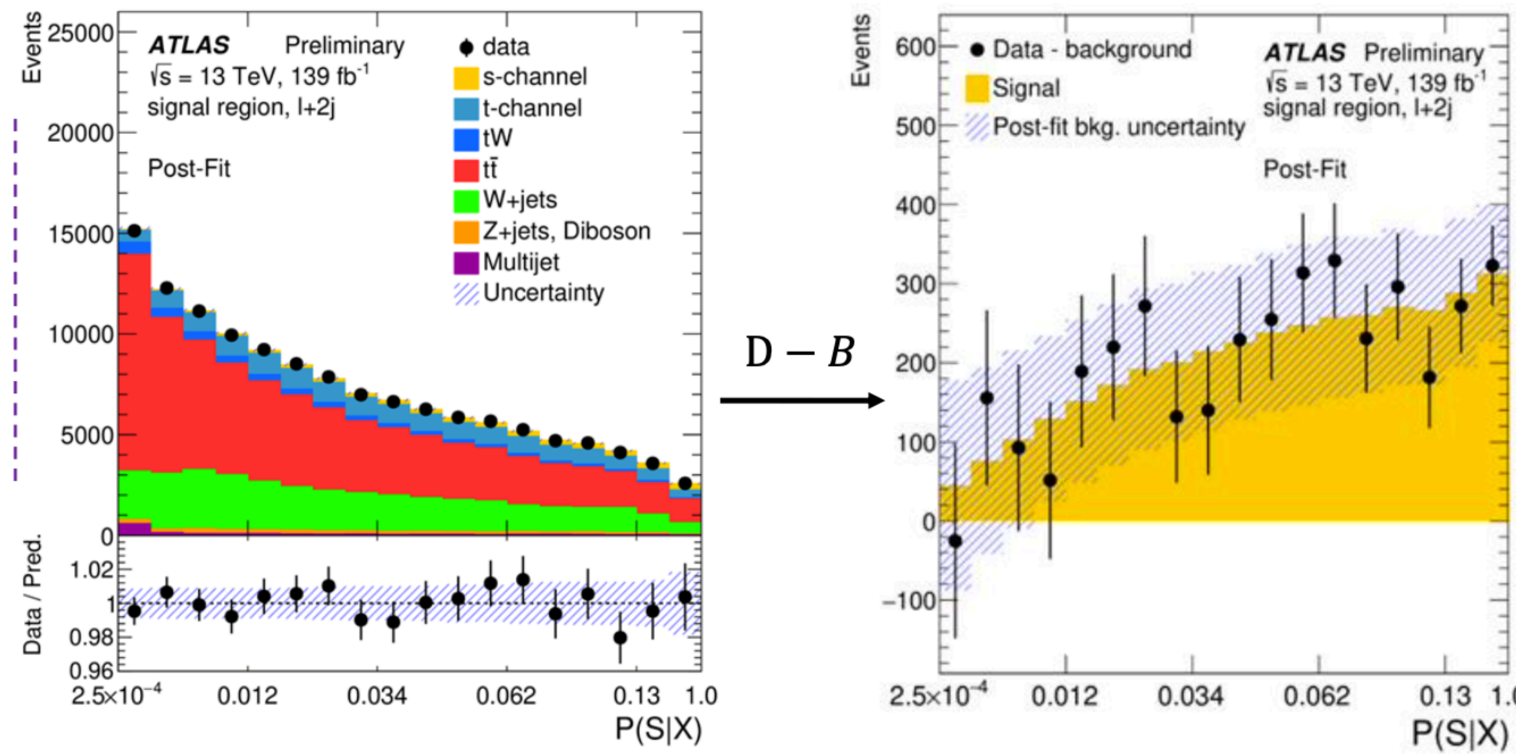


s-channel cost section

A.S.Rodrigues
J.Kempster

- Observed at Tevaton combining D0 and CDF
- Very complicated at LHC: small cross section, large and different backgrounds
- Matrix Element technique to separate S/B





- **Result:**

$$\sigma_{\text{meas.}} = 8.2 \pm 0.6\,(\text{stat.})^{+3.4}_{-2.8}\,(\text{syst.})\text{ pb}$$

- Compatible with SM prediction:

$$\text{NLO: } \sigma_{\text{pred.}} = 10.32^{+0.40}_{-0.36}\text{ pb}$$ Hathor v2.1

Significance 3.3 (3.9) obs.(exp)

dominated by modelling and JES

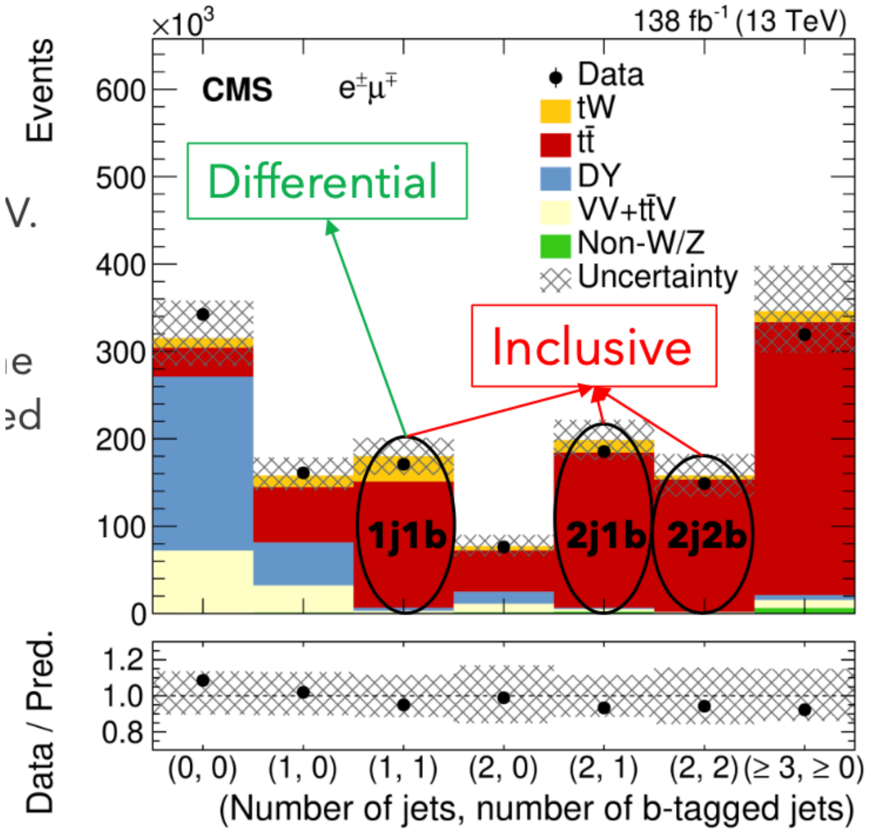
Source	$\Delta\sigma/\sigma$ [%]
$t\bar{t}$ normalisation	$+24/-17$
Jet energy resolution	$+18/-12$
Jet energy scale	$+18/-13$
Other s-channel modelling sources	$+18/-8$

not clear if Run 3 will help

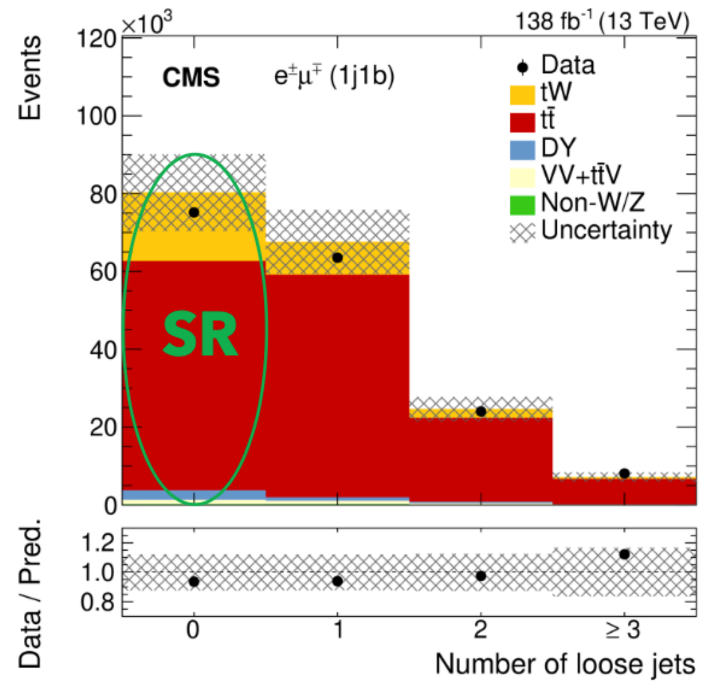
Wt channel

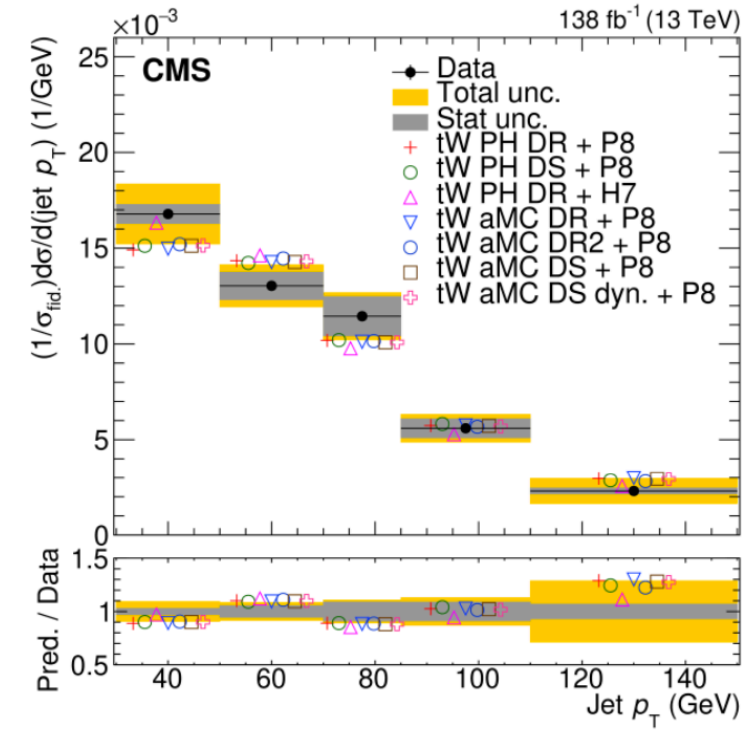
A.S.Rodrigues

- Inclusive and differential cross section in eμ channel



veto events with ≥1 loose jets.



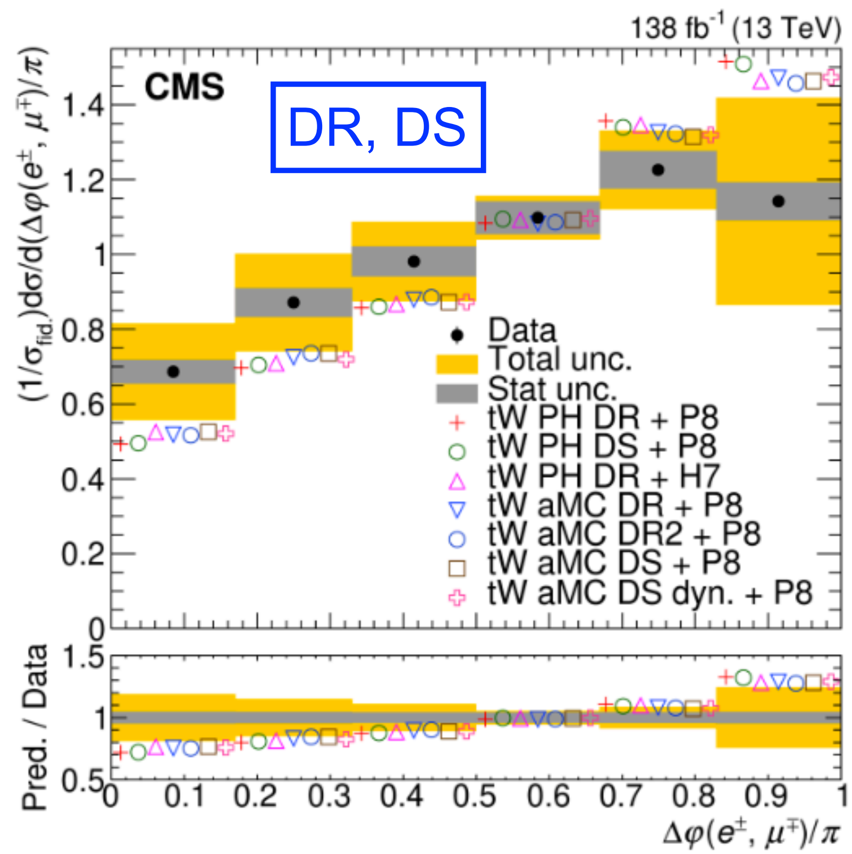


$$\sigma_{tW} = 79.2 \pm 0.8\ (\text{stat}) \pm^{7.0}_{7.2}\ (\text{syst}) \pm 1.1\ (\text{lumi})\ \text{pb}$$

10% uncertainty

In agreement with predictions

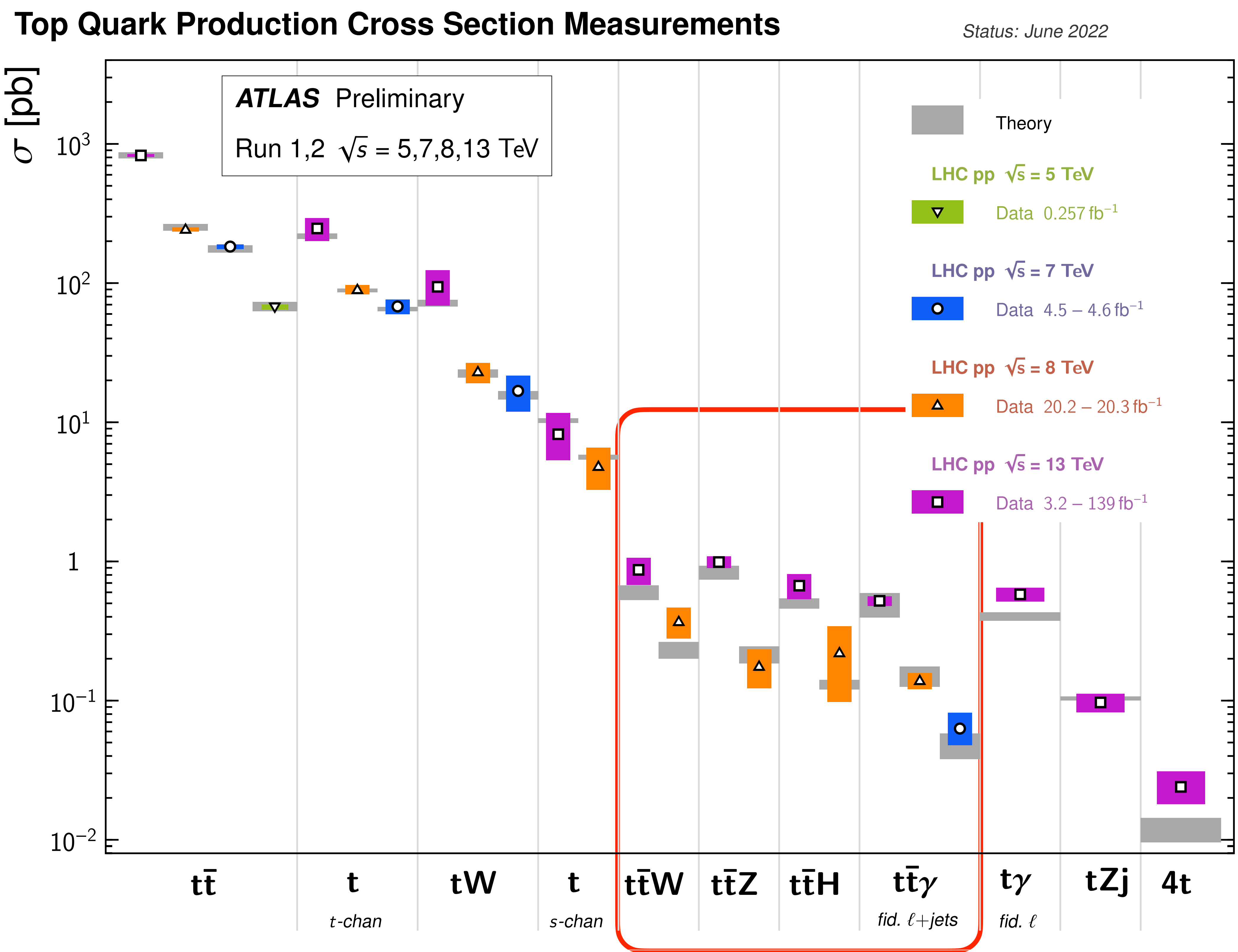
- Wt is also measured in single lepton channel by ATLAS (8 TeV) and CMS (13 TeV)
- Less precise than dilepton



As in ttbar Δφ modelling is challenging

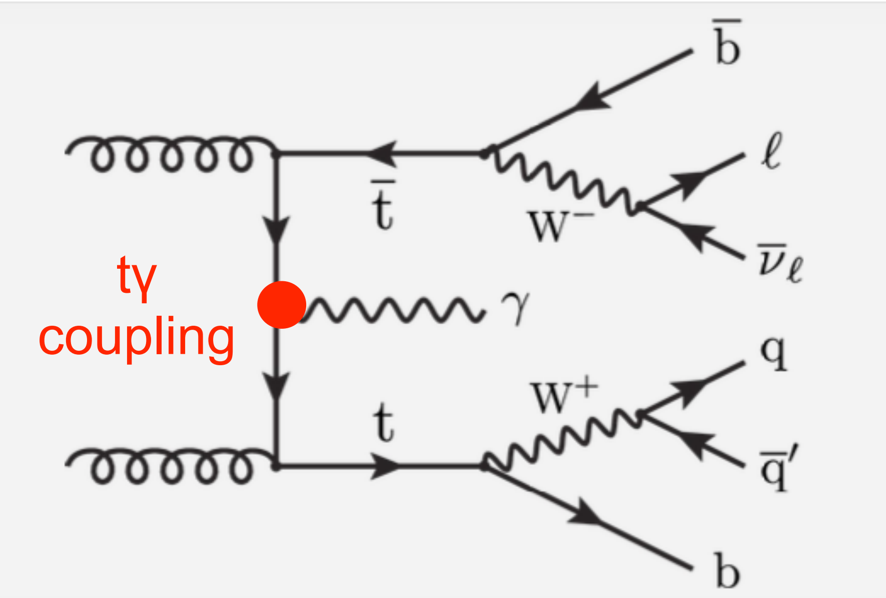
No significant difference between DR and DS overlap removal schemes

tt+X production

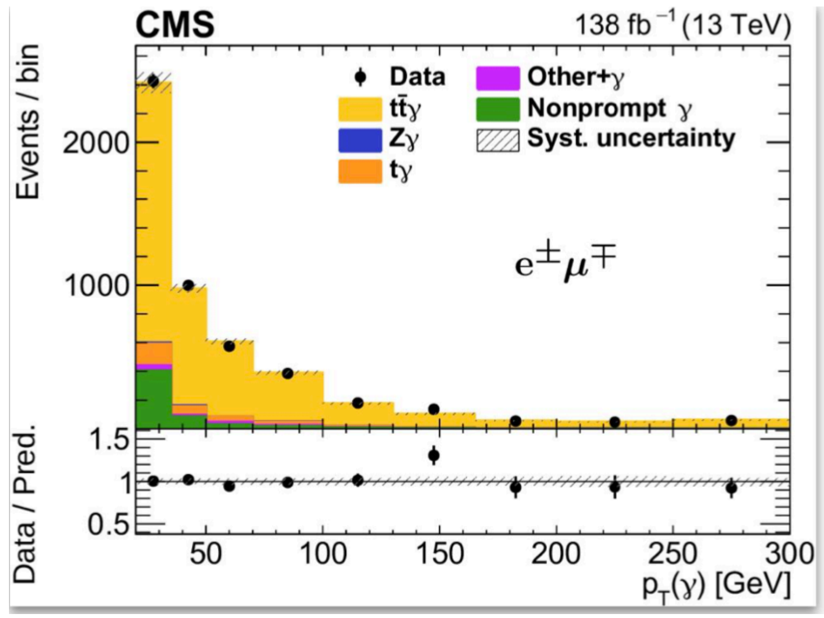


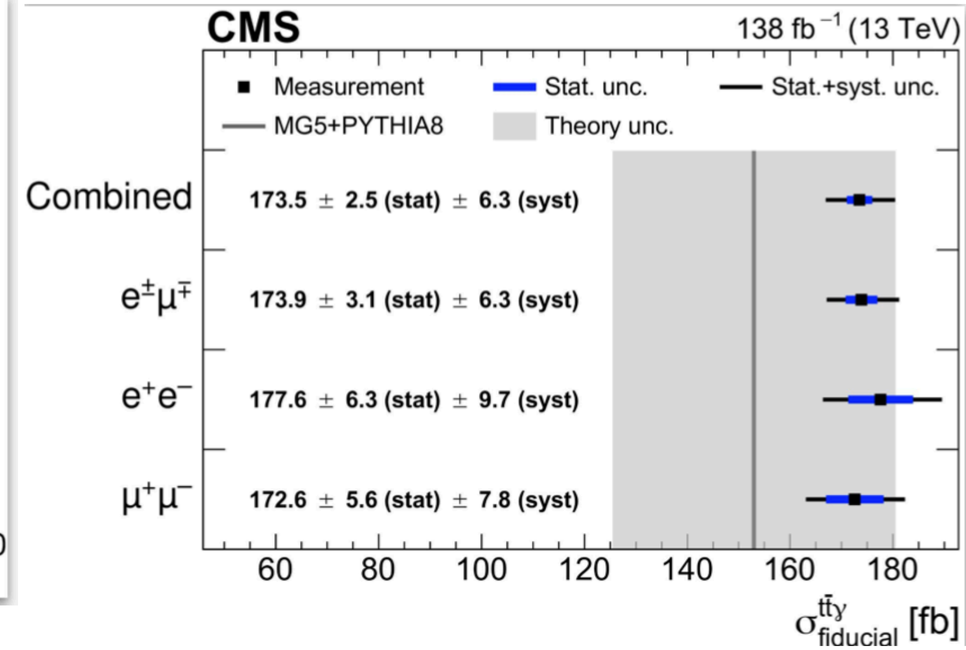
ttγ production

J. van der Linden

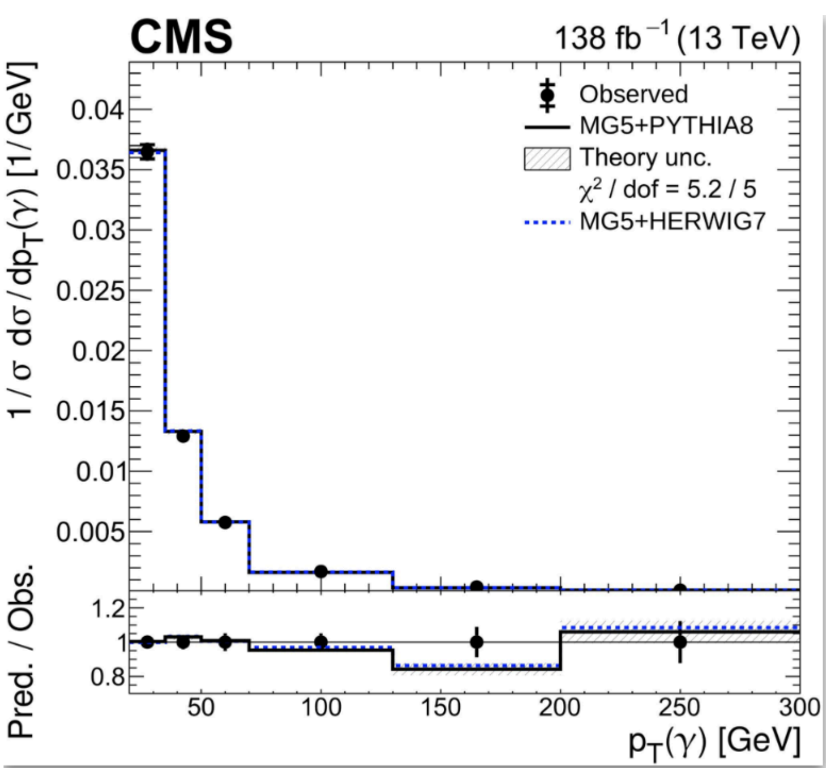


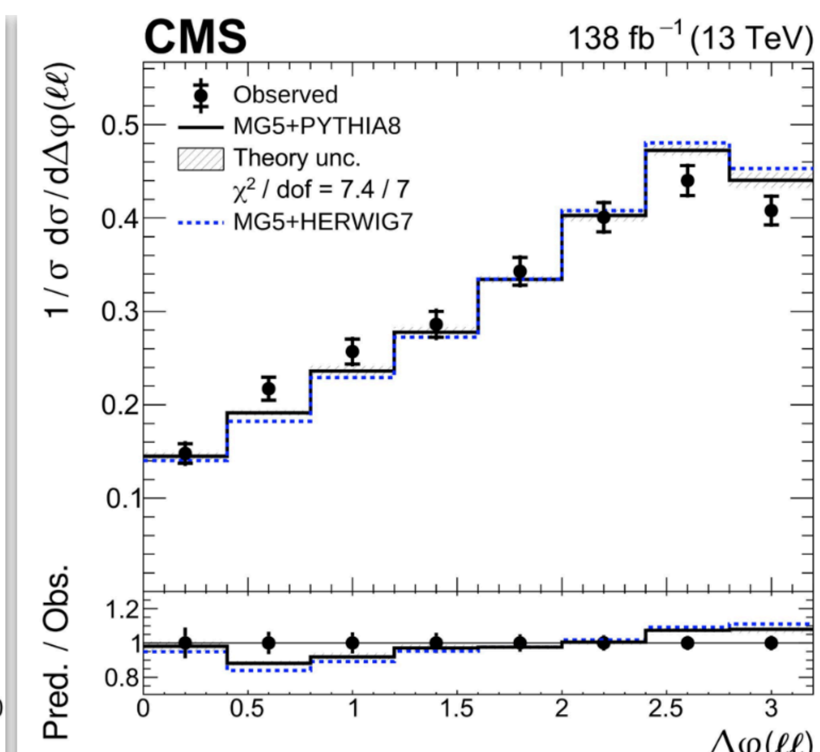
- New CMS measurement in dilepton channel





- Precision 4%
- Prediction from MG5aMC (LO+NLO k-factor) is lower





No MC simulation with ttγ NLO in production and decay is available

- Photon kinematics well-described by MG5aMC simulations
- Some trends in lepton observables and lepton+γ observables

ttZ measurements

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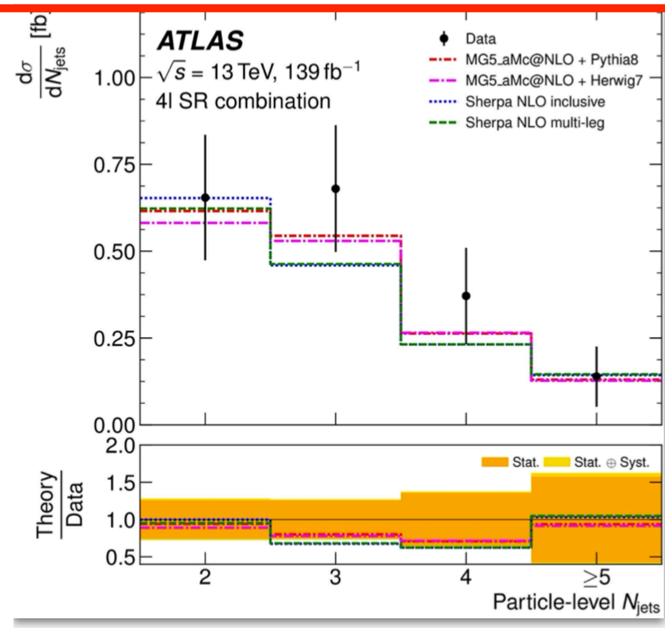
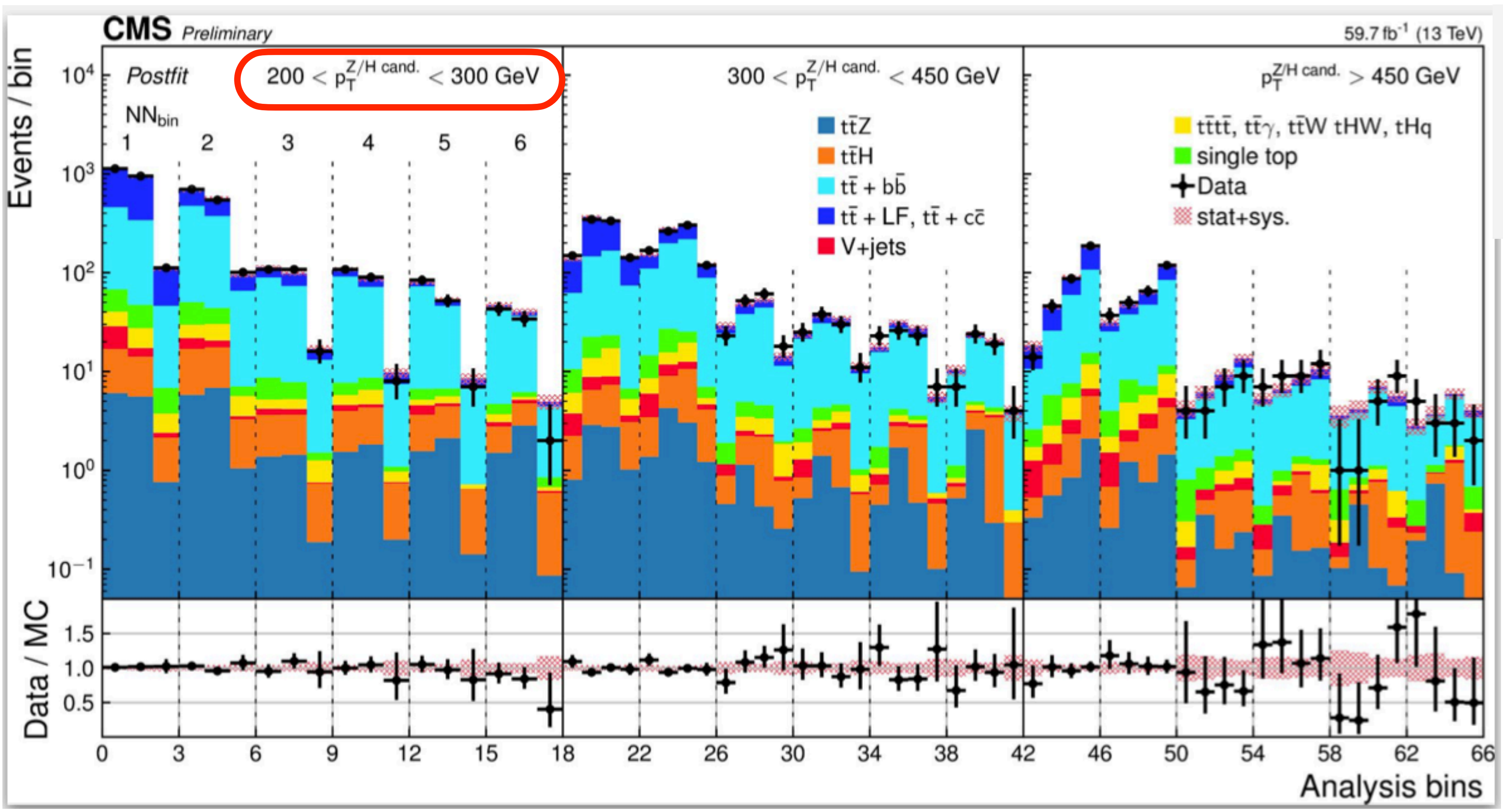
J. van der Linden

Channel	$\mu_{t\bar{t}Z}$
Trilepton	$1.17 \pm 0.07\,(\text{stat.})\,^{+0.12}_{-0.11}\,(\text{syst.})$
Tetralepton	$1.21 \pm 0.15\,(\text{stat.})\,^{+0.11}_{-0.10}\,(\text{syst.})$
Combination ($3\ell + 4\ell$)	$1.19 \pm 0.06\,(\text{stat.}) \pm 0.10\,(\text{syst.})$

- Precision 10%
- Slightly higher than prediction

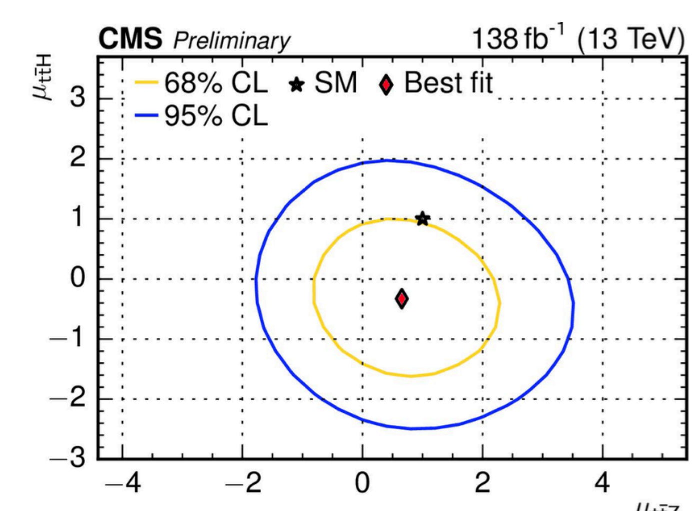


- Measurement of ttZ(bb) and ttH(bb) in boosted regime



Signal strength	Observed	Stat.
$\mu_{t\bar{t}Z}$	$0.65\,^{+1.04}_{-0.98}$	$^{+0.80}_{-0.75}$
$\mu_{t\bar{t}H}$	$-0.27\,^{+0.86}_{-0.83}$	$^{+0.72}_{-0.65}$

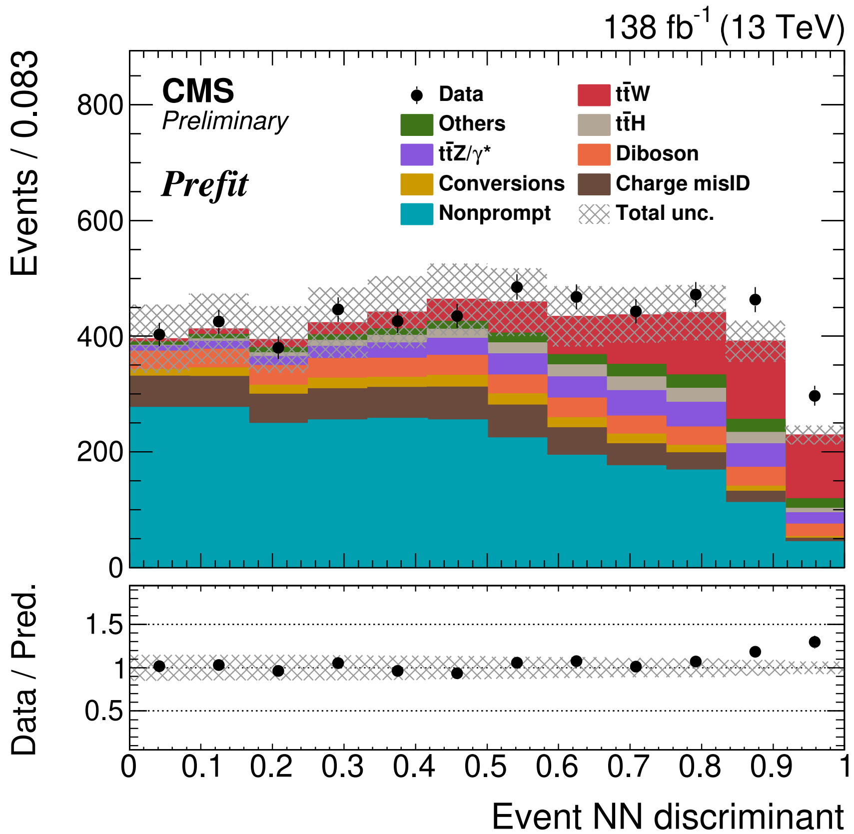
Limited by statistics

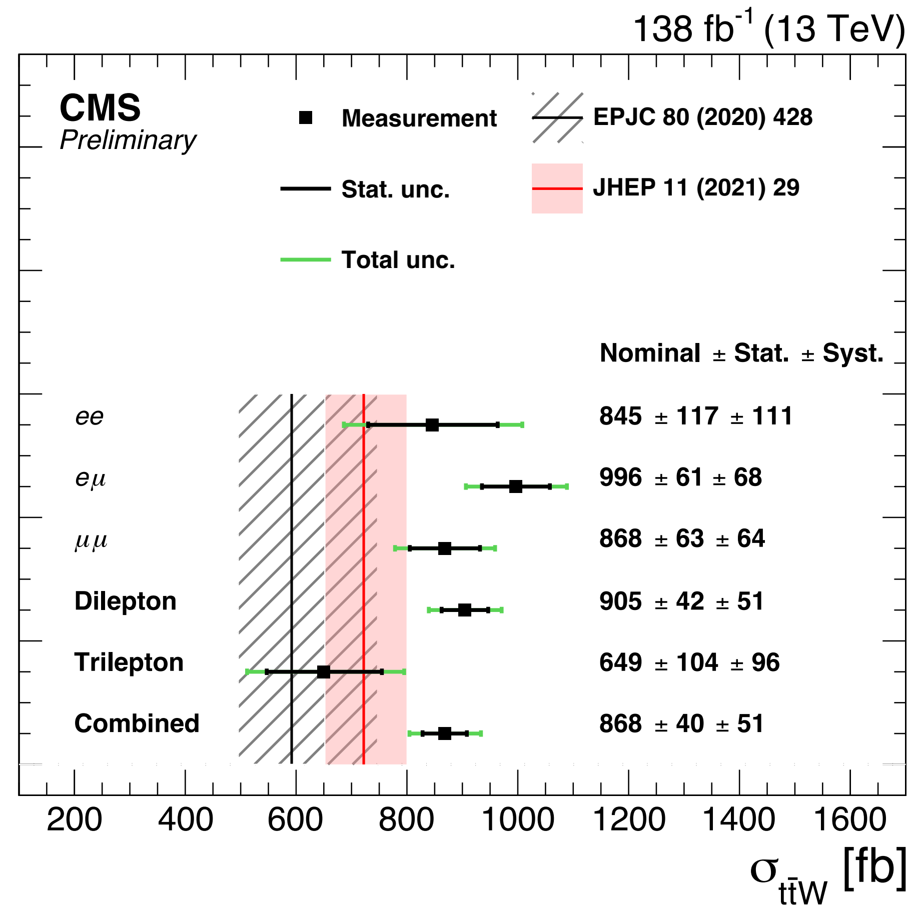


ttW measurement

J. van der Linden

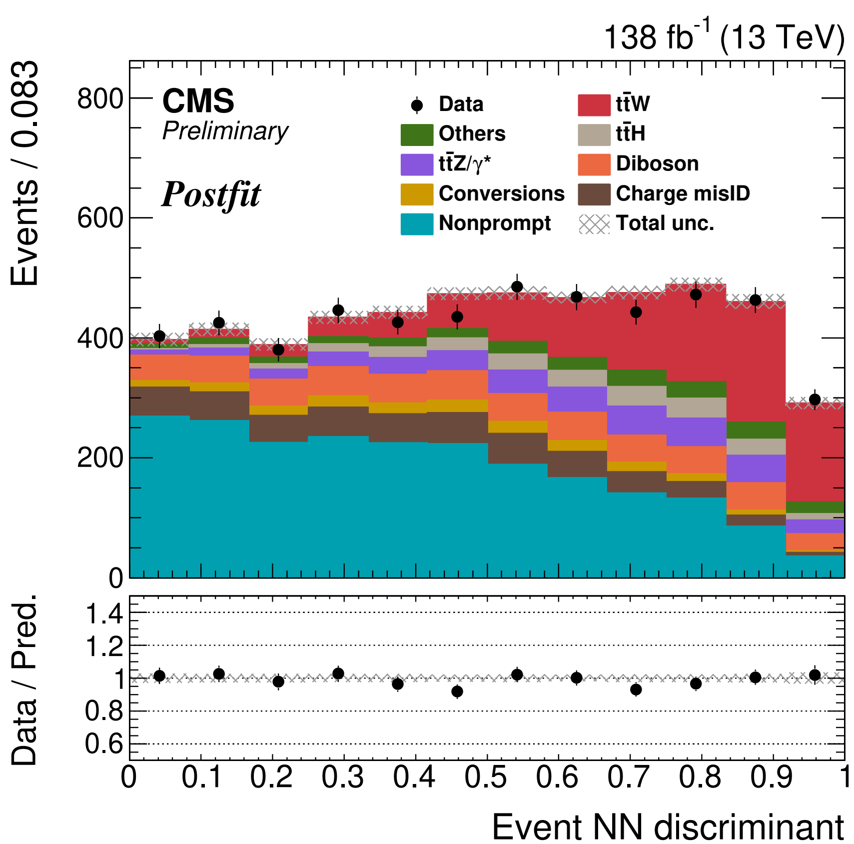
- 2-lepton Same Sign and tri-lepton final states

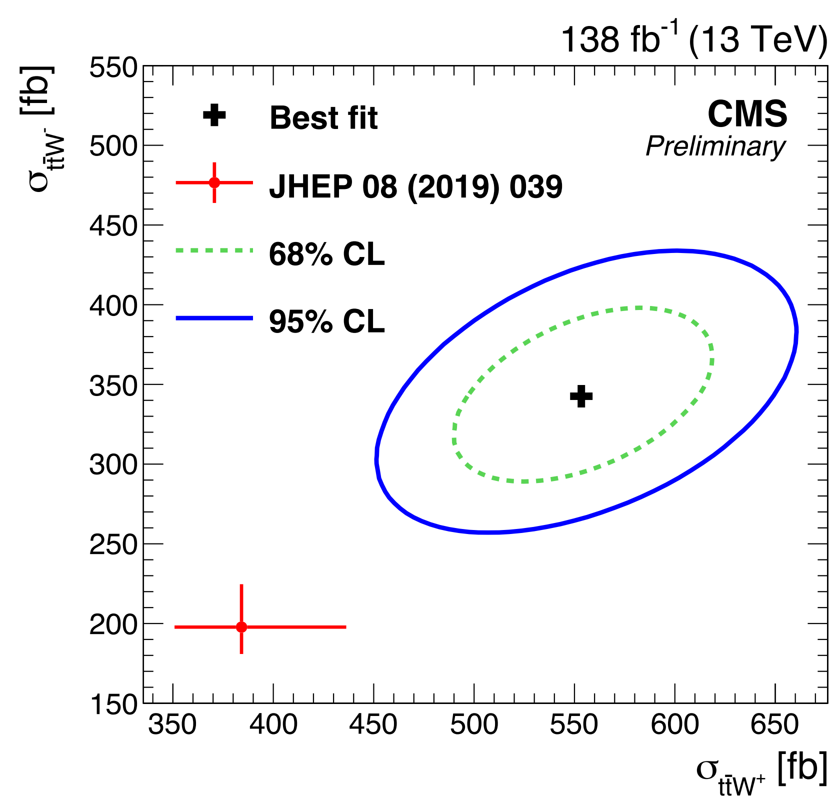




Assumed ttW SM σ_{ttW} = 592 fb

Combined cross section corresponds to μ_{ttW} = 1.47

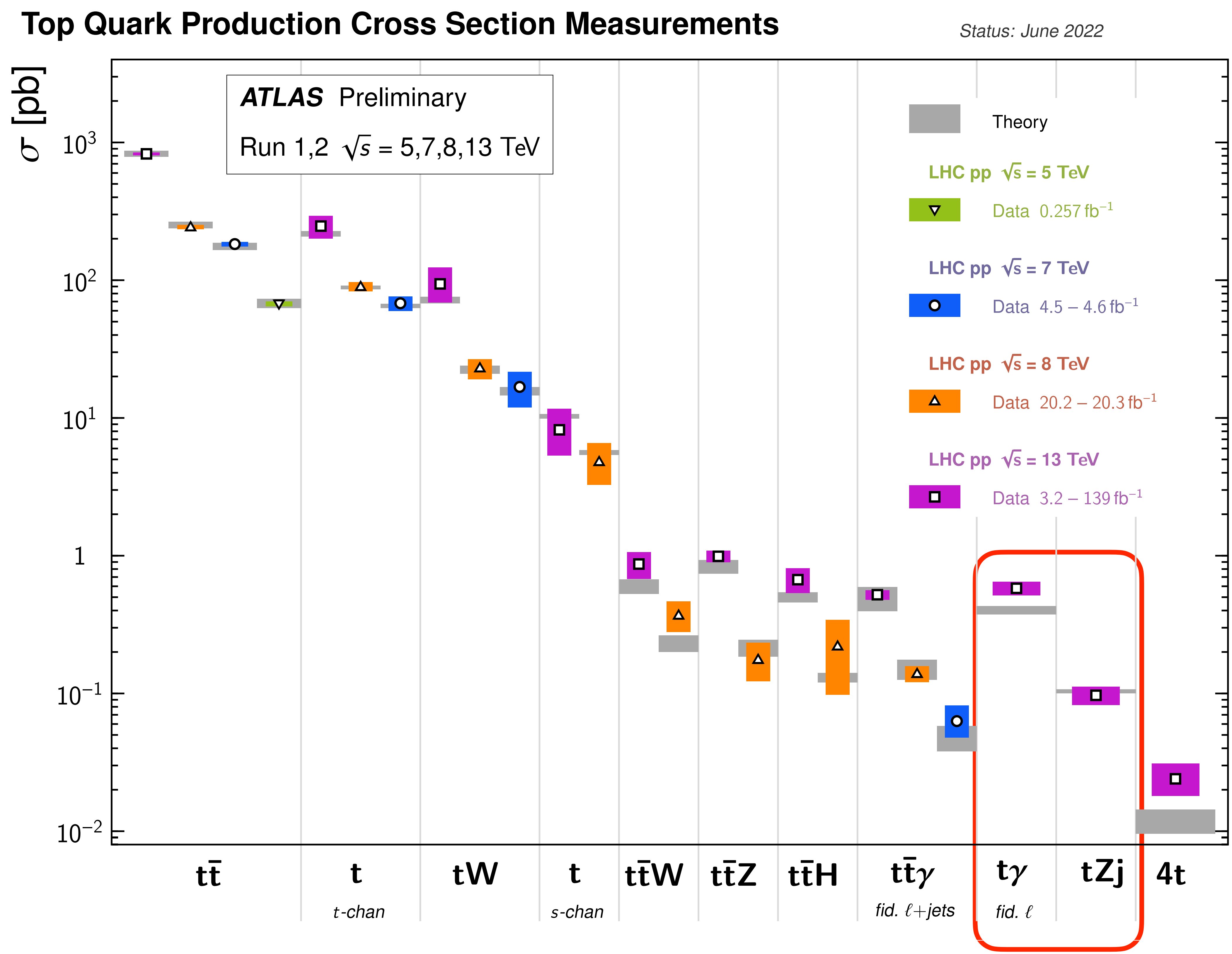




R(ttW+/ttW−) = 1.61 ± 0.15 (stat) $^{+0.07}/_{-0.05}$ (syst)

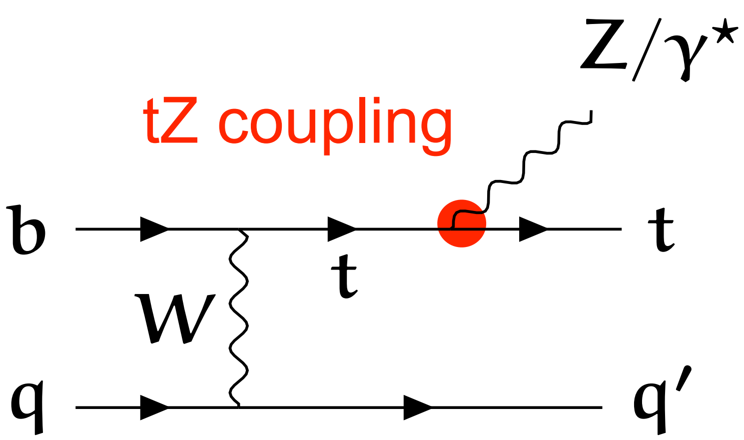
Significant deviation from prediction for ttW+/ttW- ratio = 1.94+0.37-0.24

t+X production



tZq production

J.Lambert

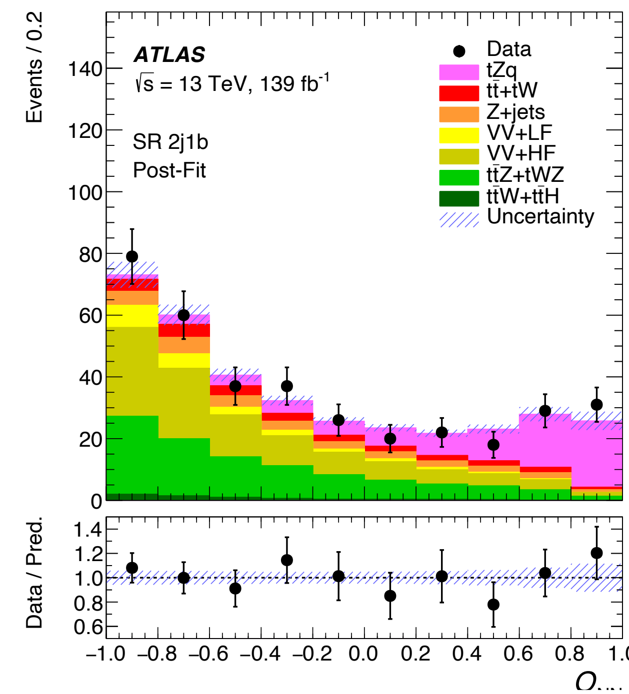


Z(ℓℓ)

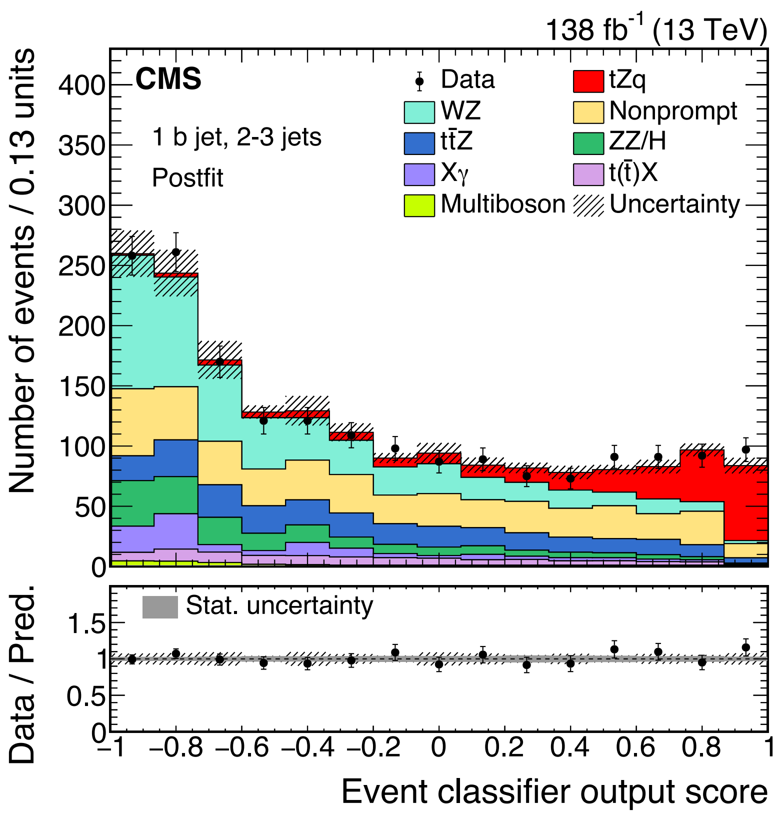
bℓν

forward jet

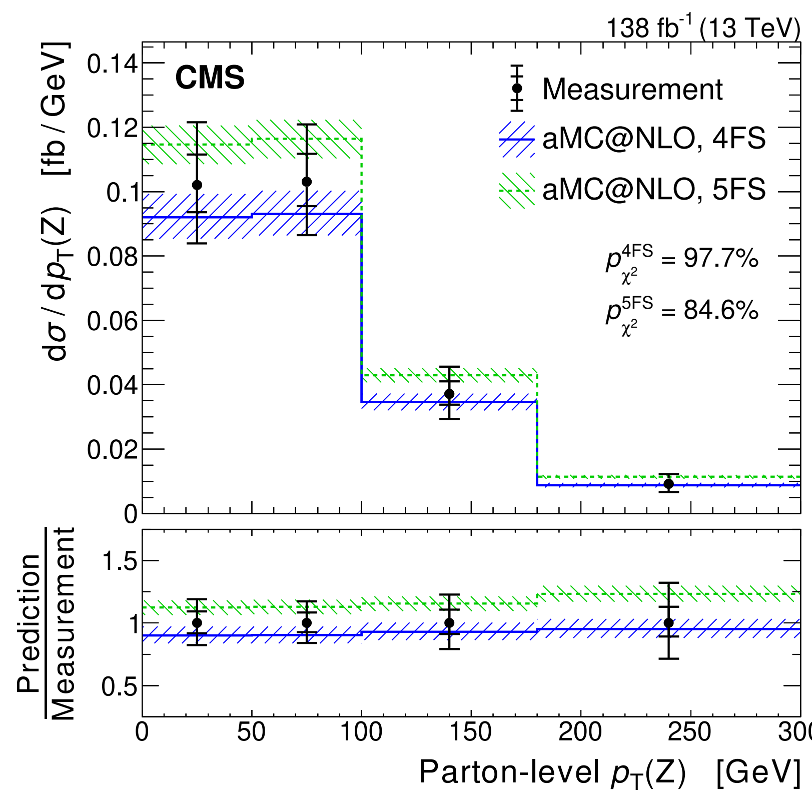
- Observed by ATLAS and CMS
- New CMS analysis with full run2 data set



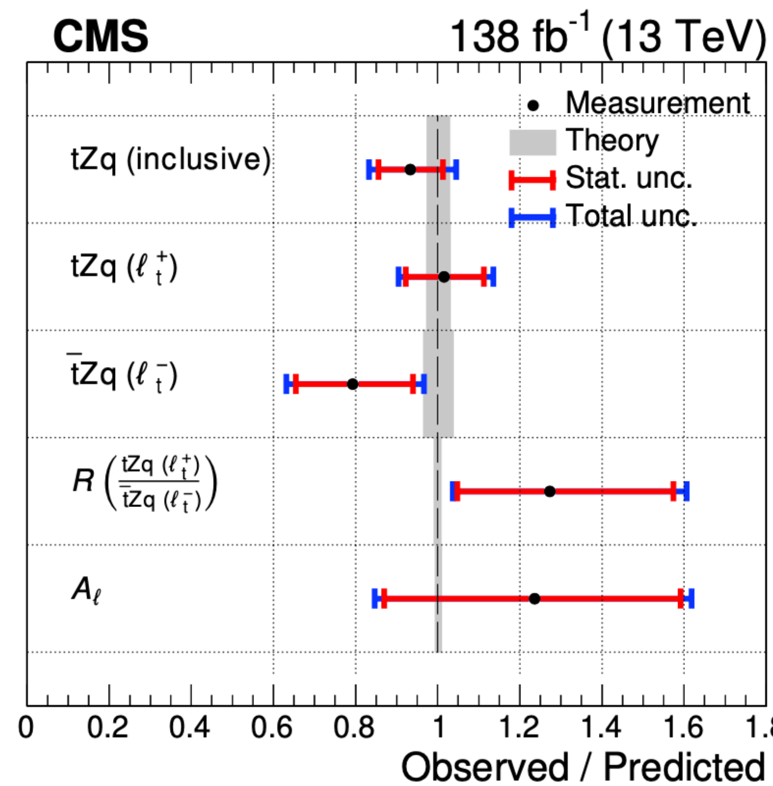
cross section measured with 14% uncertainty



11% cross section uncertainty



first parton and particle level differential measurements



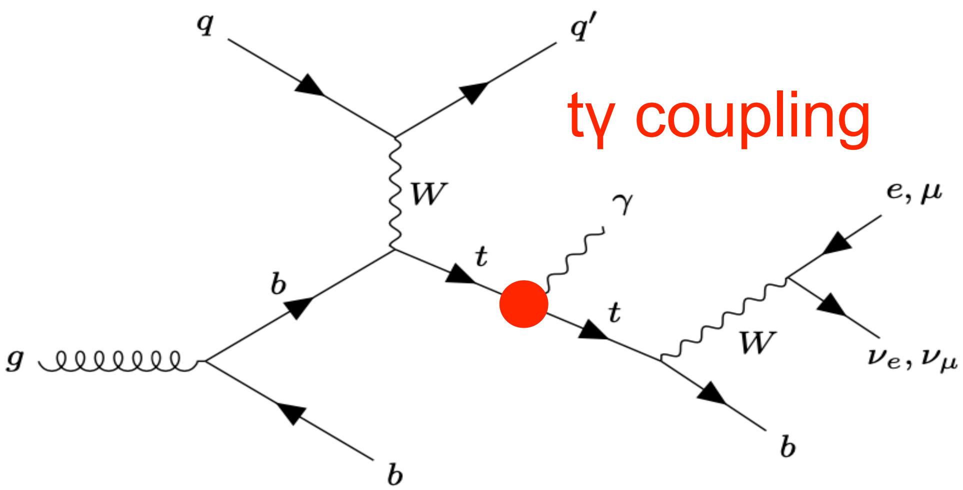
first measurement of ratio

$$R\left(\frac{tZq\ (\ell_t^+)}{\bar{t}Zq\ (\ell_t^-)}\right)$$

Precision is expected to improve with more statistics in Run 3

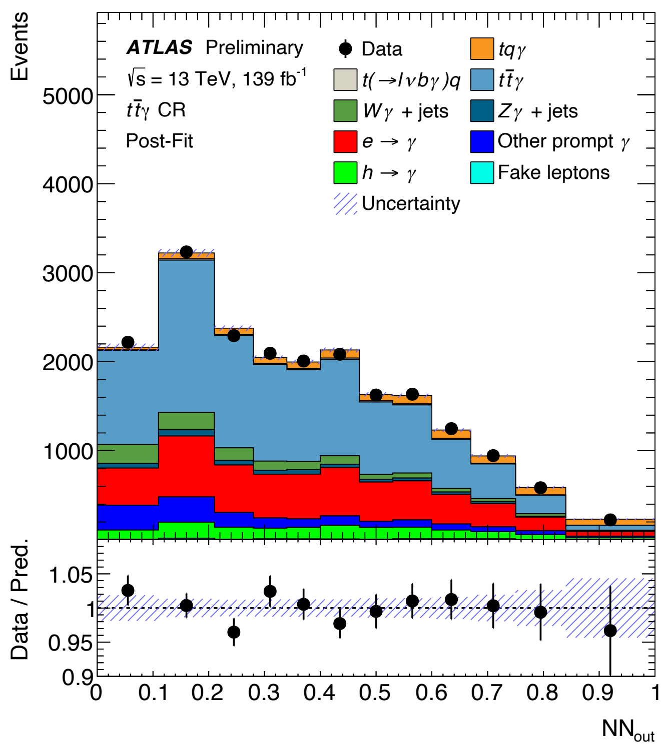
tqγ production

J.Lambert

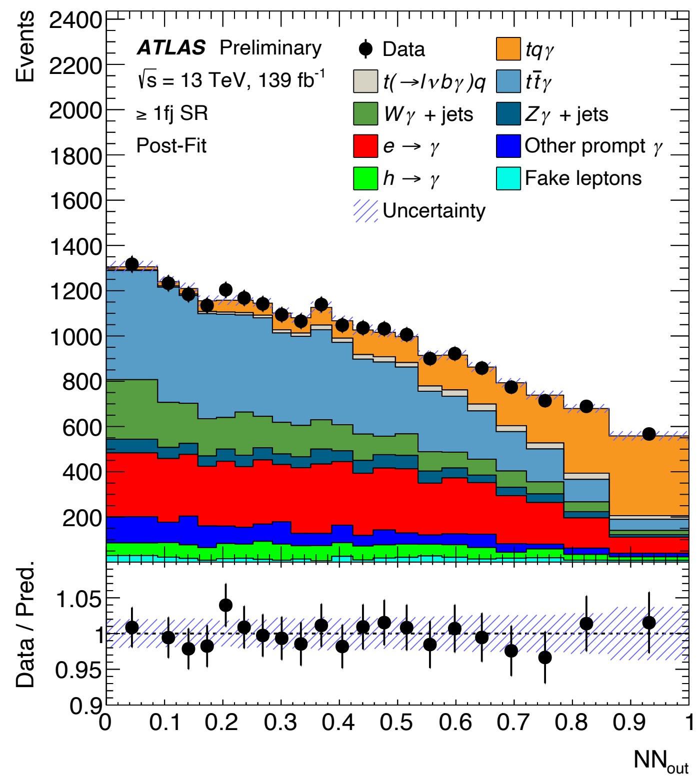


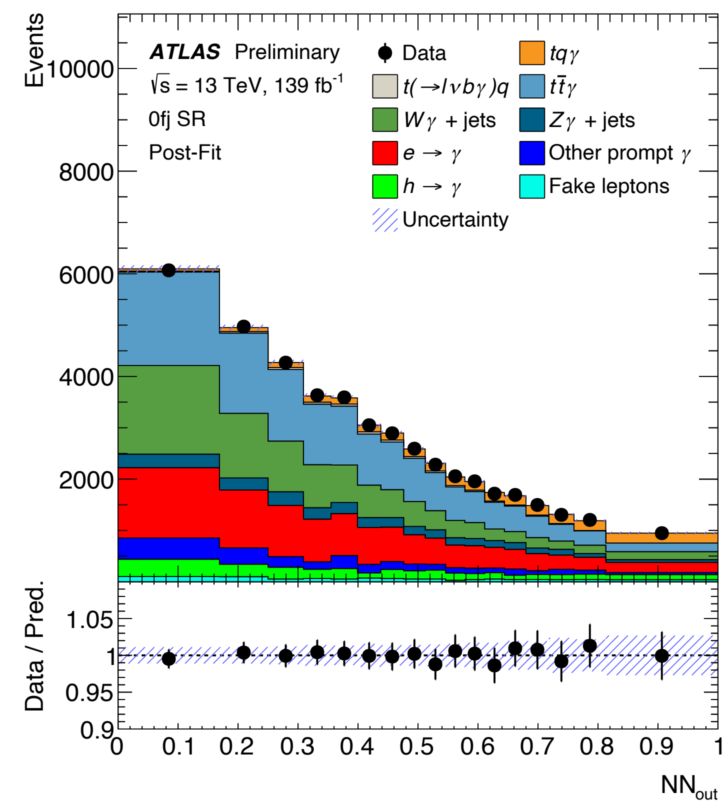
- First evidence from CMS using ~36/fb of data
- New ATLAS analysis with full run 2 data

Largest background from ttγ



Signal regions (NN)





Observed (expected) significance is 9.1σ (6.7σ)

~40% higher that prediction

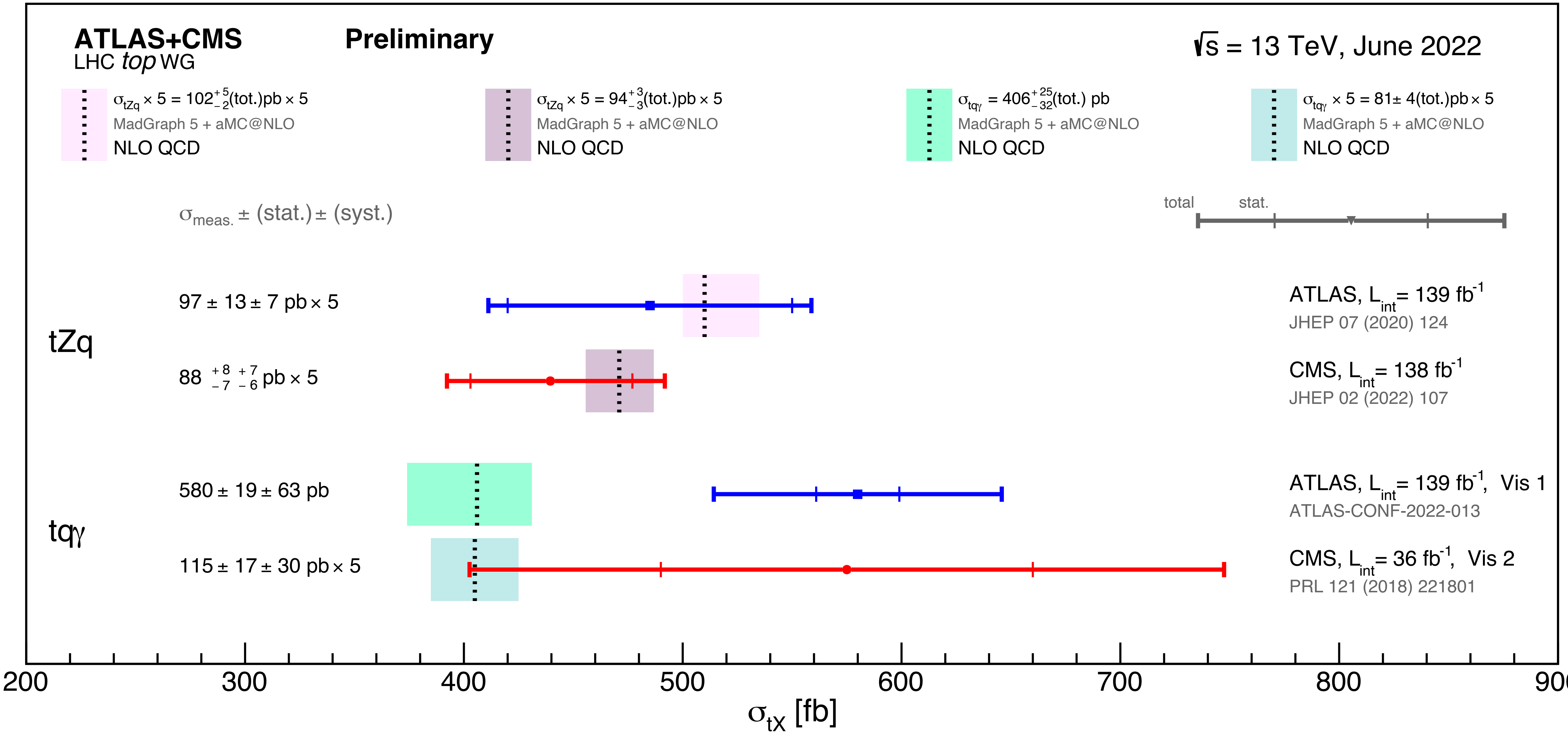
Parton level cross section: $\sigma(tq\gamma)\,\mathcal{B}(t \to \ell\nu b) = 580 \pm 19(\text{stat.}) \pm 63(\text{syst.})\text{fb}$

Particle level cross section $\sigma(tq\gamma)\,\mathcal{B}(t \to \ell\nu b) + \sigma(t \to \ell\nu b\gamma)q = 287 \pm 8(\text{stat.})^{+32}_{-31}(\text{syst.})\text{fb}$

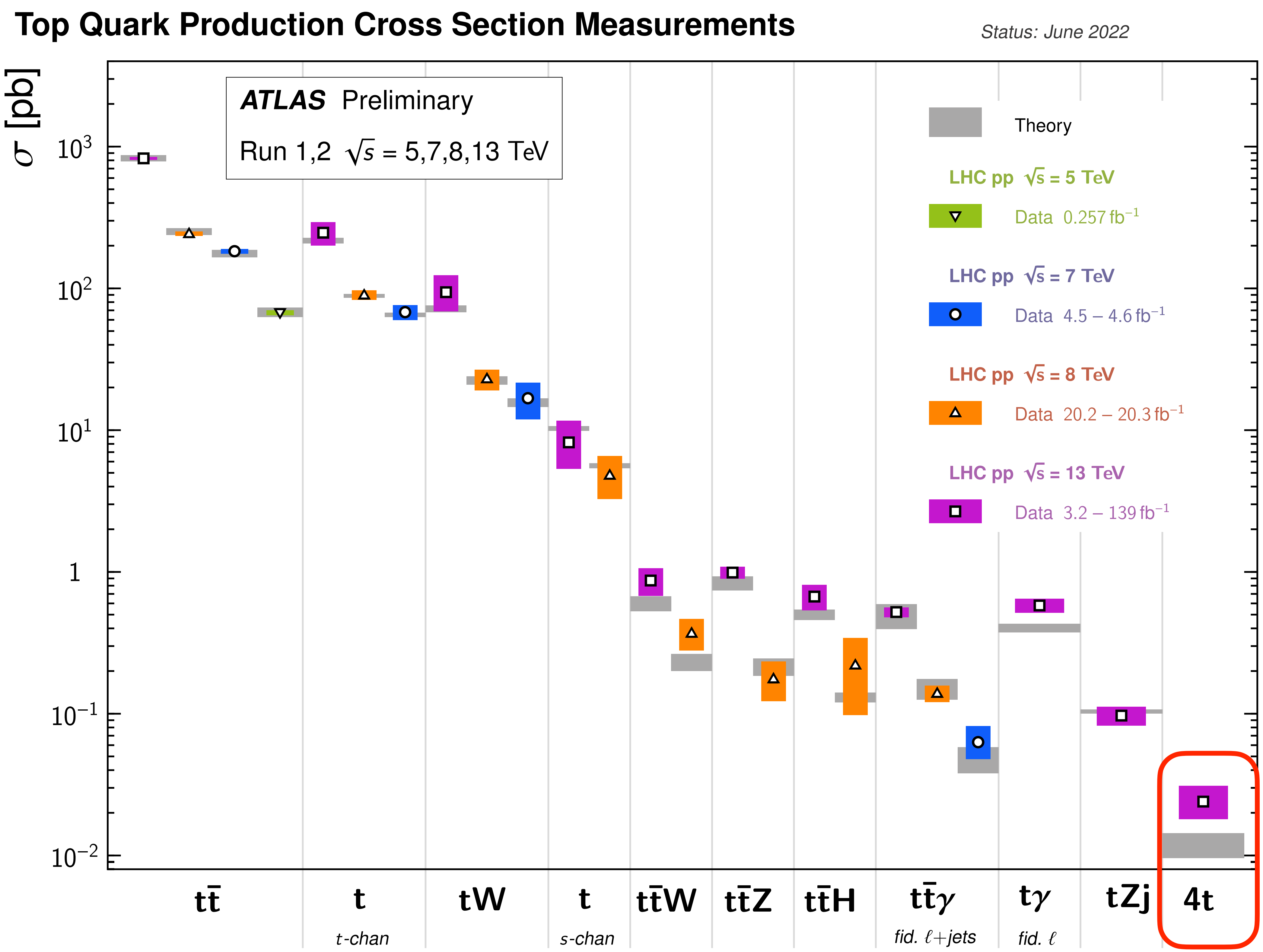
Compatible with the SM within 2.5(1.9)σ at parton(particle) level

t+X summary

J.Lambert

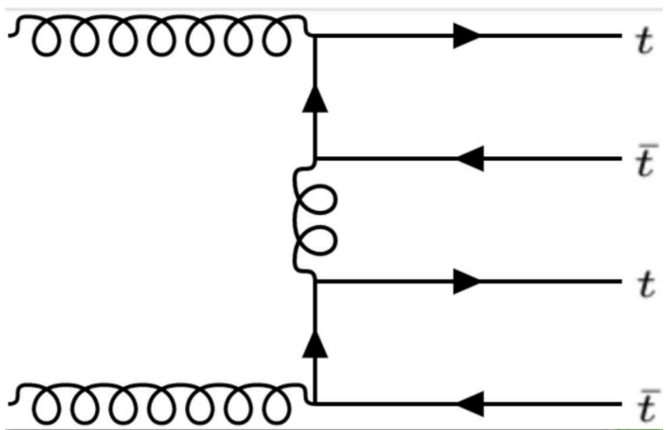


tt+X production



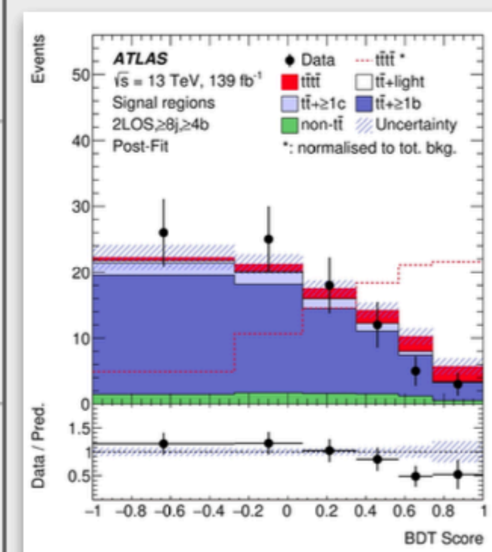
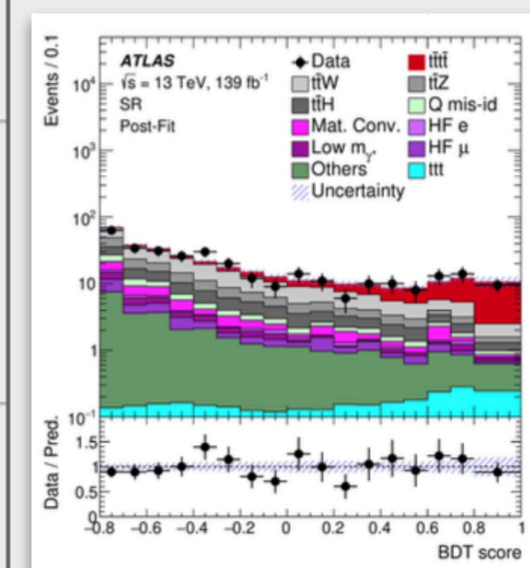
4-top searches

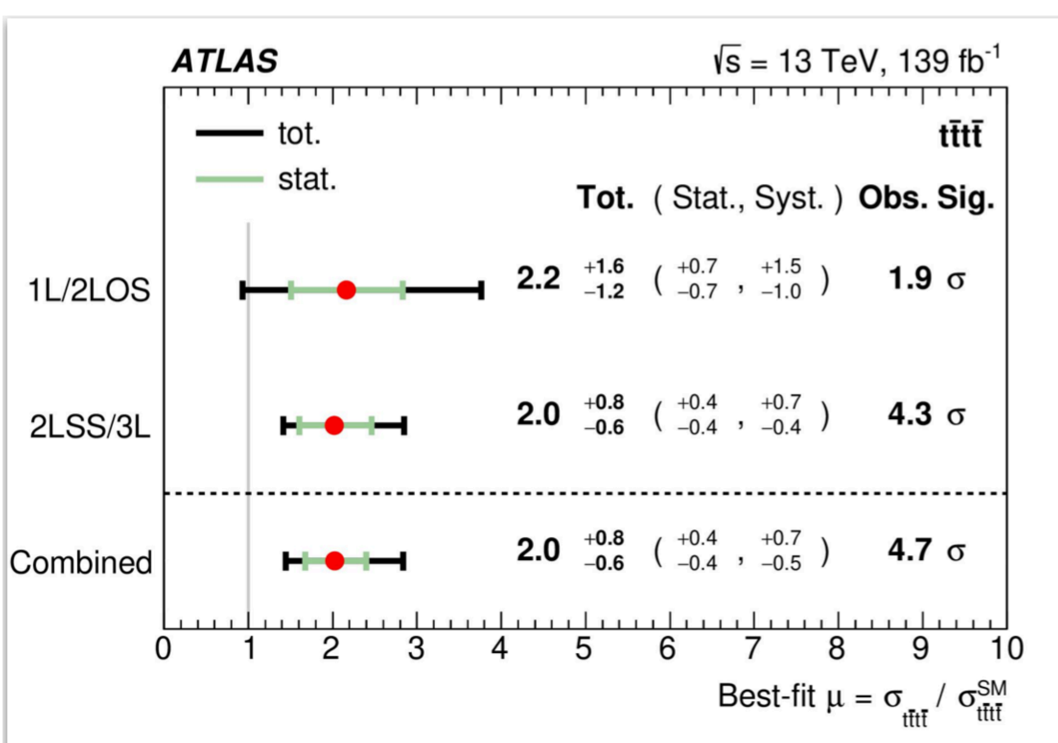
J. van der Linden



Heaviest particle final state

Many different final states

ATLAS EXPERIMENT	0ℓ	1ℓ	2ℓ (OS)	2ℓ (SS)	3ℓ+
2018		JHEP 11 (2021) 118 		EPJC 80 (2020) 1085 	
2017					
2016					



Measured cross-section: $\sigma(\text{tttt}) = 24\ ^{+7}/_{-6}$ fb (4.7σ)

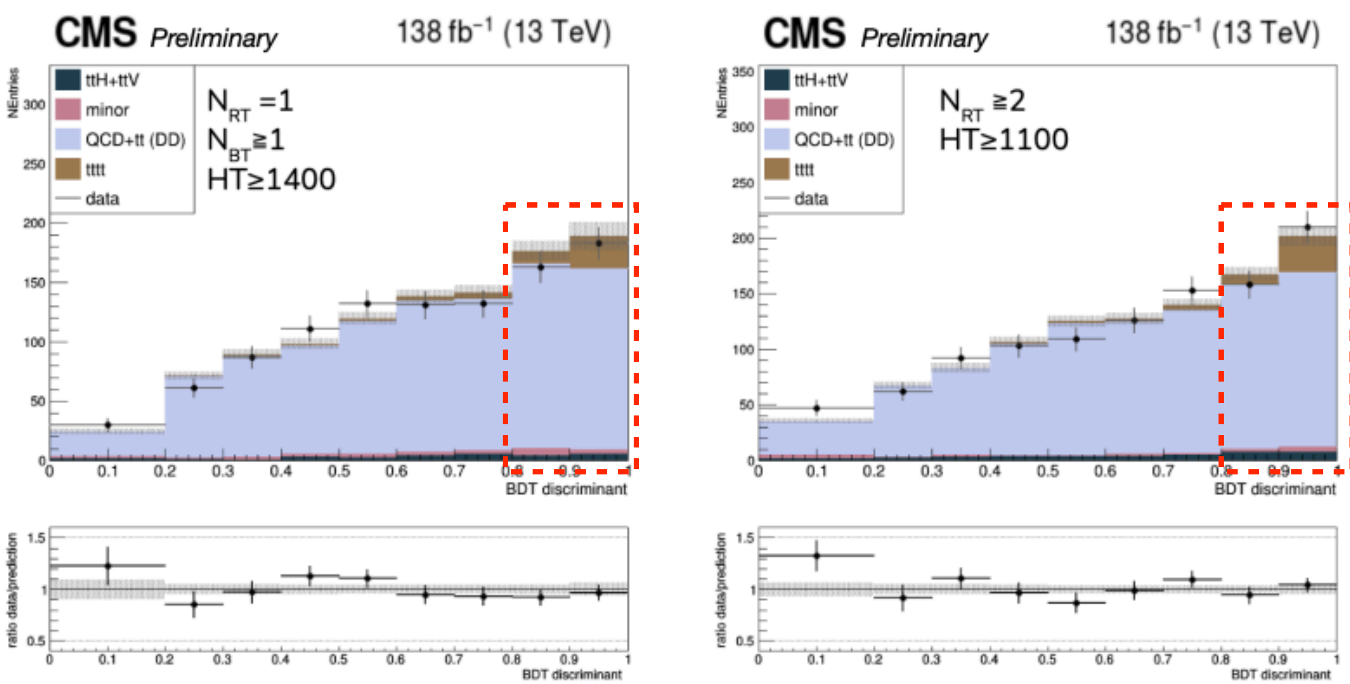
Predicted NLO QCD+EW: $\sigma(\text{tttt}) = 12.0\ ^{+2.2}/_{-2.5}$ fb

Compatible within 2σ

J. van der Linden
M. Quinnan
N. Manganelli

1-lepton, 2-lepton OS, all-hadronic channels

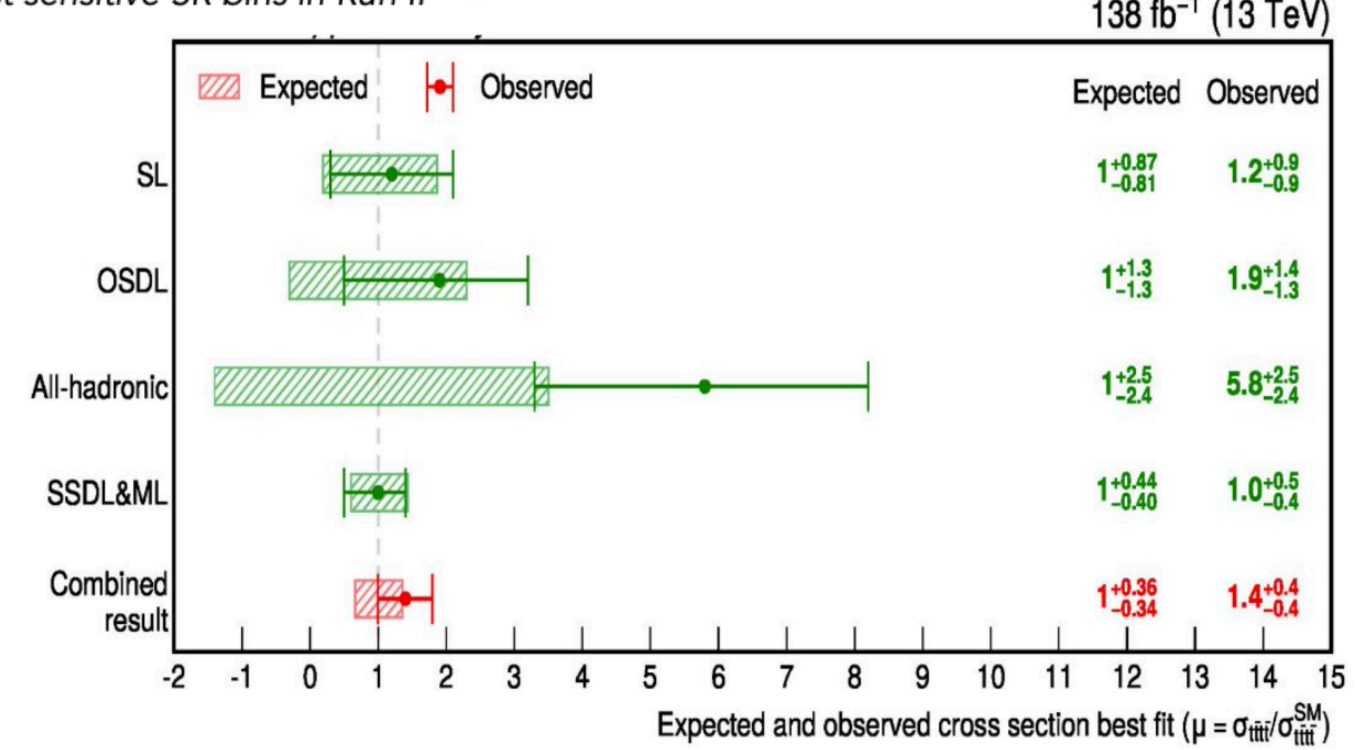
Channels with large tt+bb and multi jet (all-hadronic) backgrounds



Example post-fit S+B BDT discriminant distributions in most sensitive SR bins in Run II

Large excess in data in most sensitive regions in all-hadronic channel

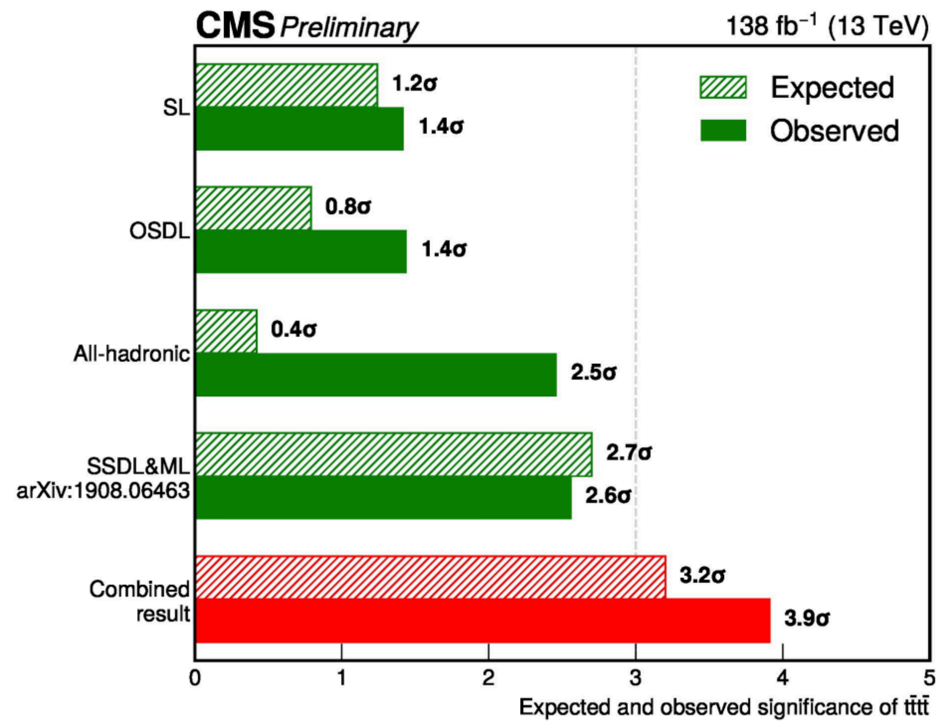
- Combined signal-strength and significance: **$\mu(tttt) = 1.4 \pm 0.4\ (4.0\sigma)$**
- Limited by data statistics and ttbb background modelling



4-top summary

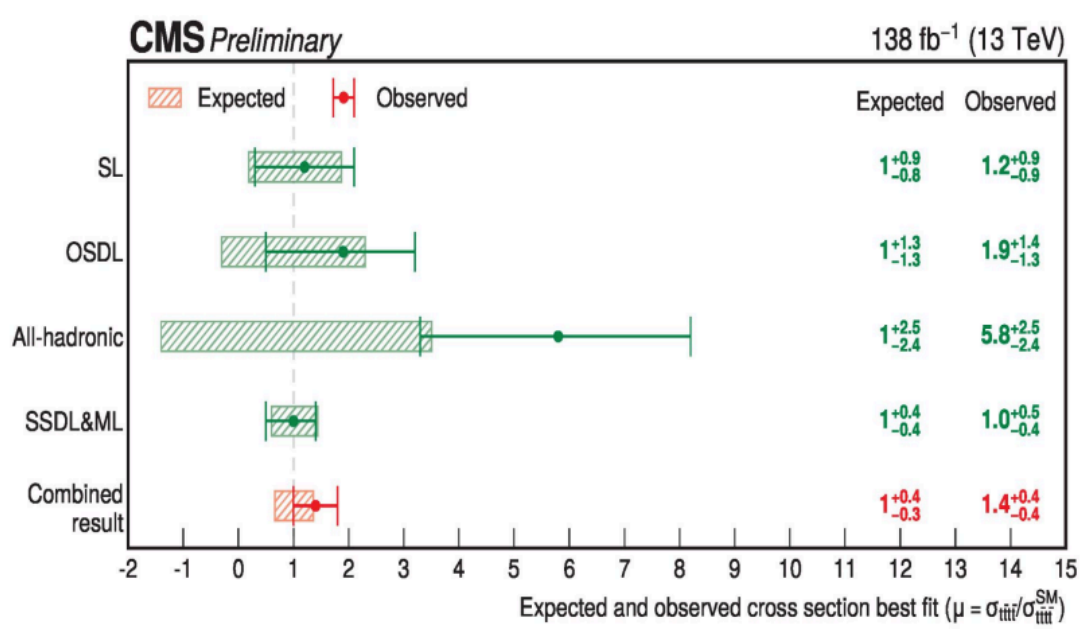
Significance

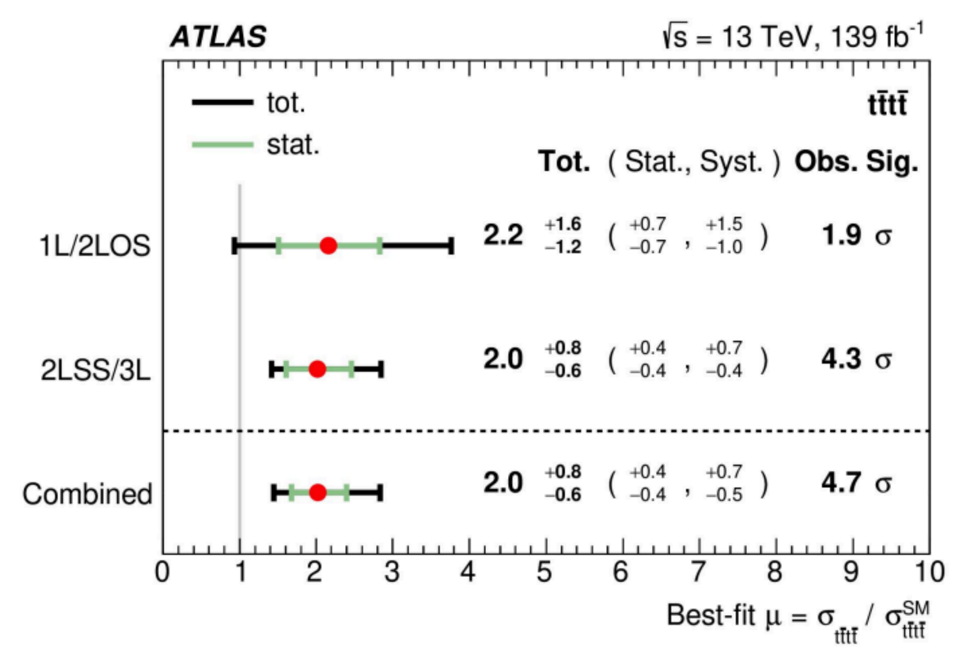
N. Manganelli



CMS-PAS-TOP-21-005

ATLAS JHEP 11 (2021) 118





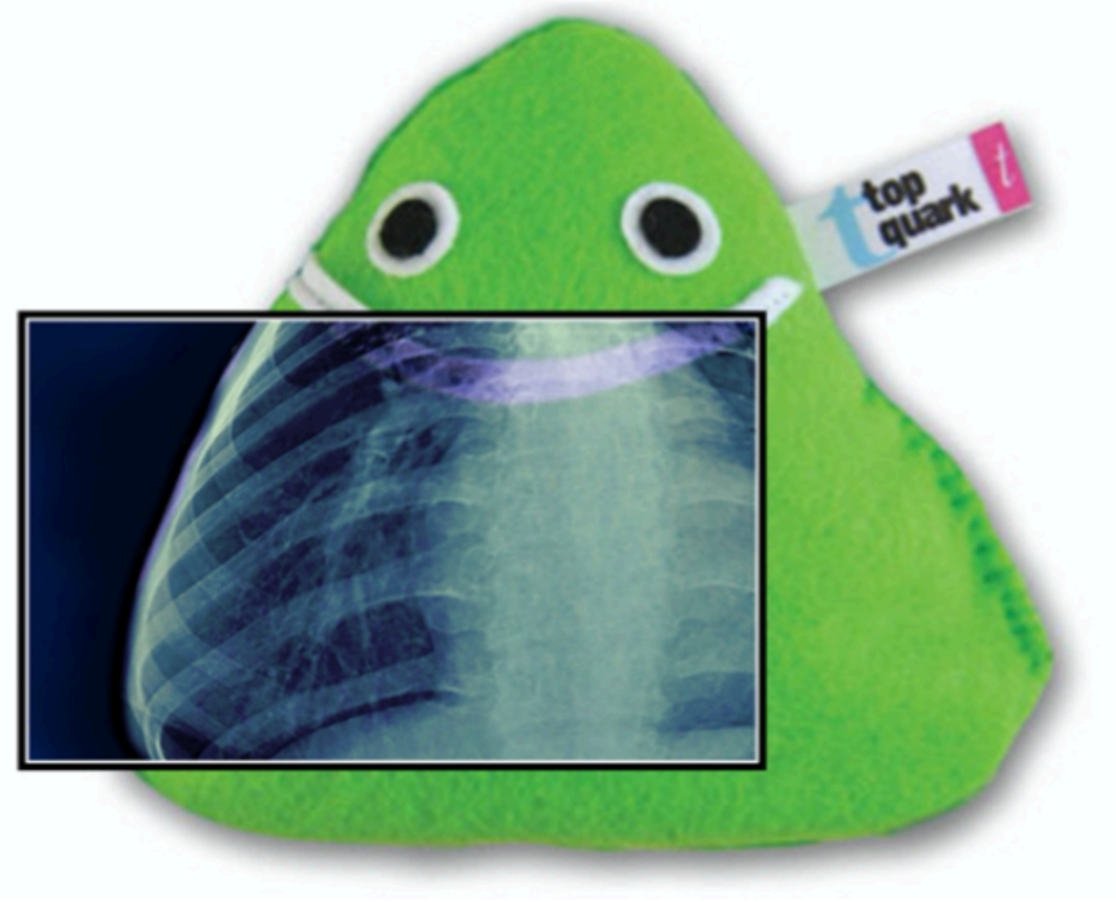
expected significance: 3.2 σ
observed significance: 3.9 σ

expected significance: 2.6 σ
observed significance: 4.7 σ

Top quark properties

- Many recent and new measurements
- Now measured not only in ttbar but also in tt+X events
- Main trend —> use unfolding

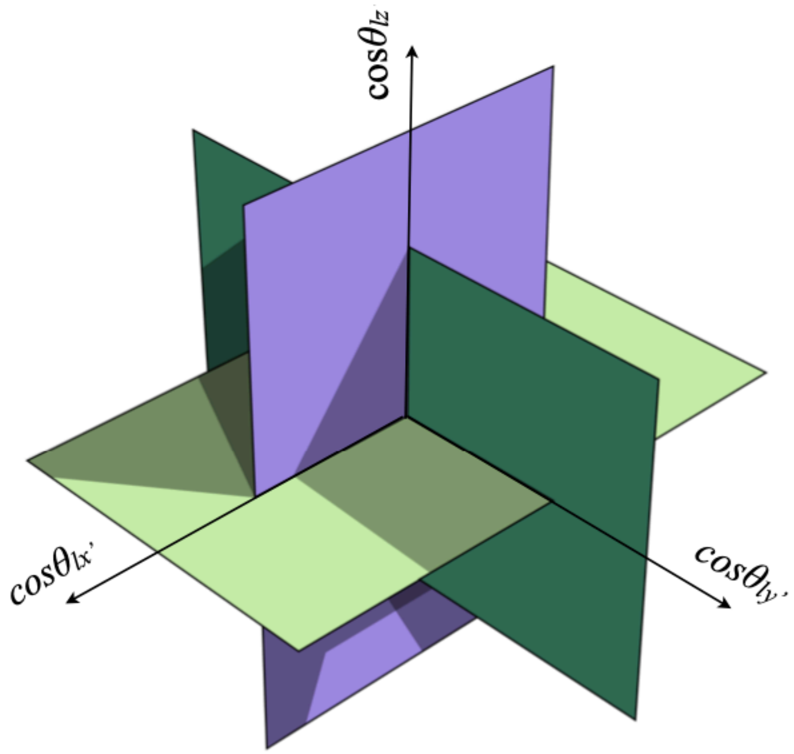
Top spin
Top polarisation
Asymmetries
B-fragmentation
Color reconnection
CP properties
mass



Top polarisation

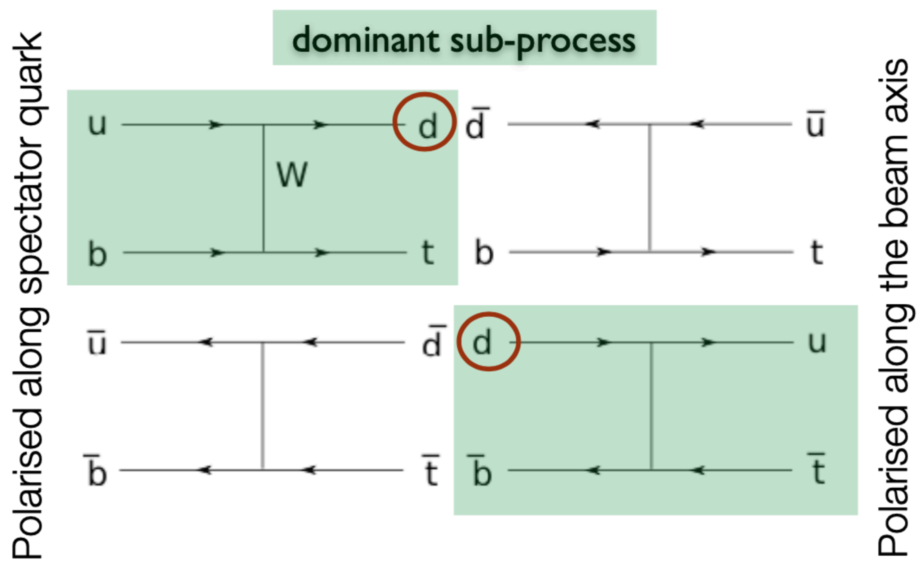
M.Watson

- Top quarks in t-channel are strongly polarised



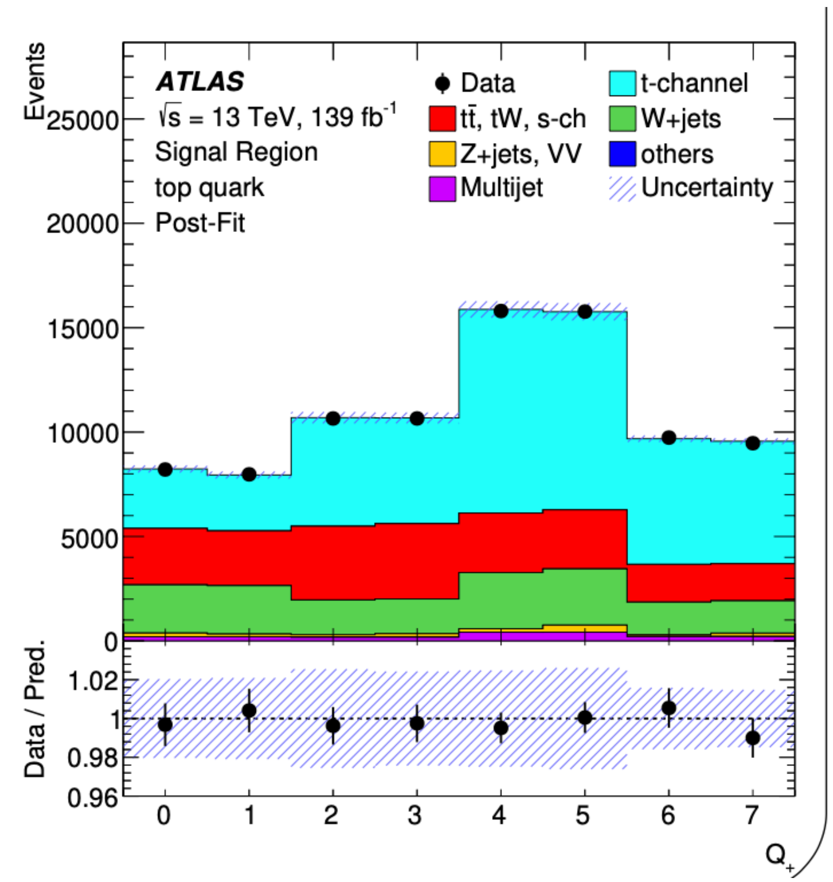
t-quark along spectator quark direction

anti-t opposite incoming quark direction



Signal regions defined by sign of $\cos\theta_{li}$ and lepton charge

$P^t_{x'}$	$+0.01 \pm 0.18$	(± 0.02)
$P^{\bar{t}}_{x'}$	-0.02 ± 0.20	(± 0.03)
$P^t_{y'}$	-0.029 ± 0.027	(± 0.011)
$P^{\bar{t}}_{y'}$	-0.007 ± 0.051	(± 0.017)
$P^t_{z'}$	$+0.91 \pm 0.10$	(± 0.02)
$P^{\bar{t}}_{z'}$	-0.79 ± 0.16	(± 0.03)

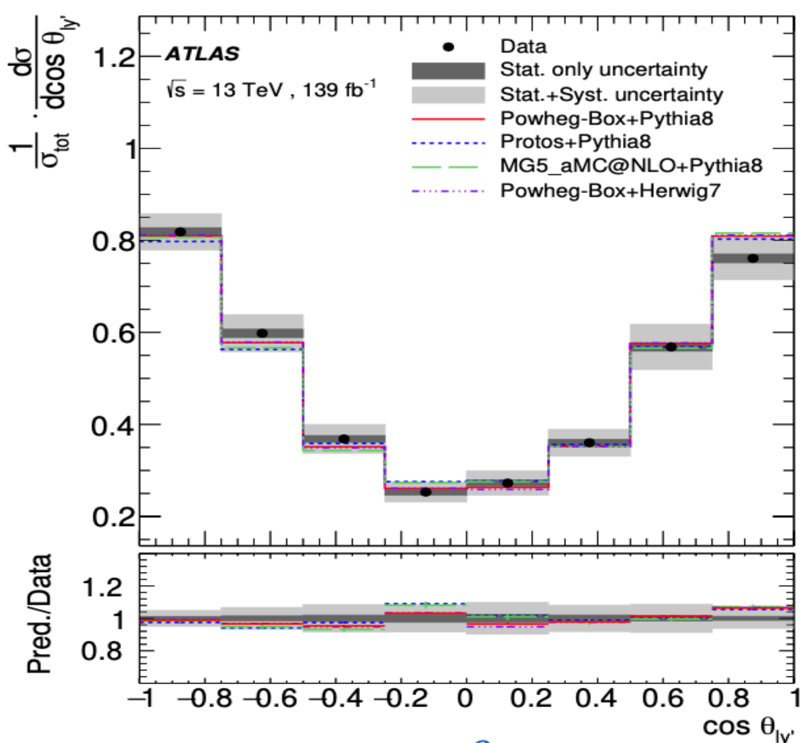


Template fit result: strong polarisation along z-axis

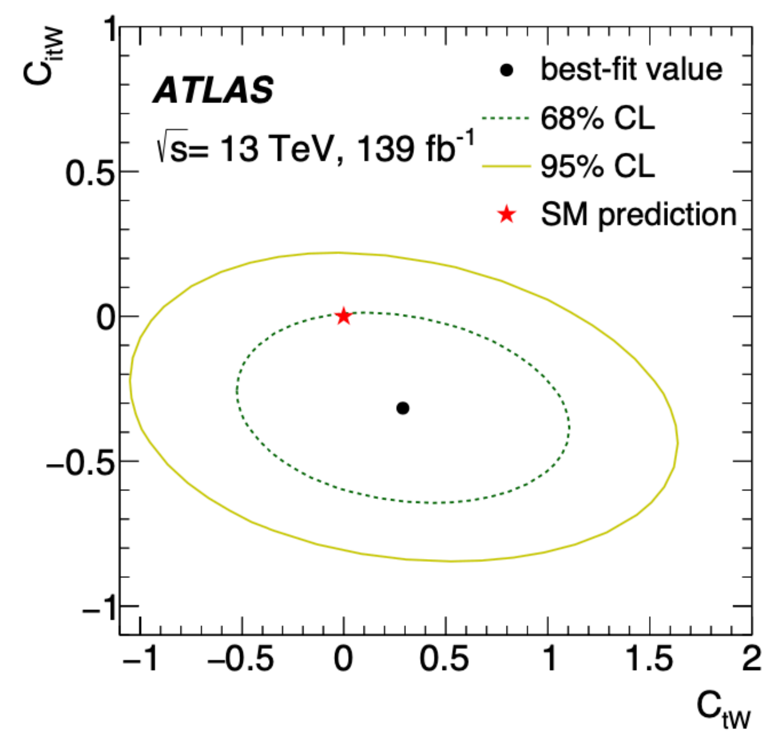
Top polarisation

M.Watson

- Unfolded angular distributions to particle level compared to MC predictions



$\cos \theta_{ly'}$



- Study of BSM effects in Wtb vertex
- Unfolded distributions give bounds on Wilson coefficients

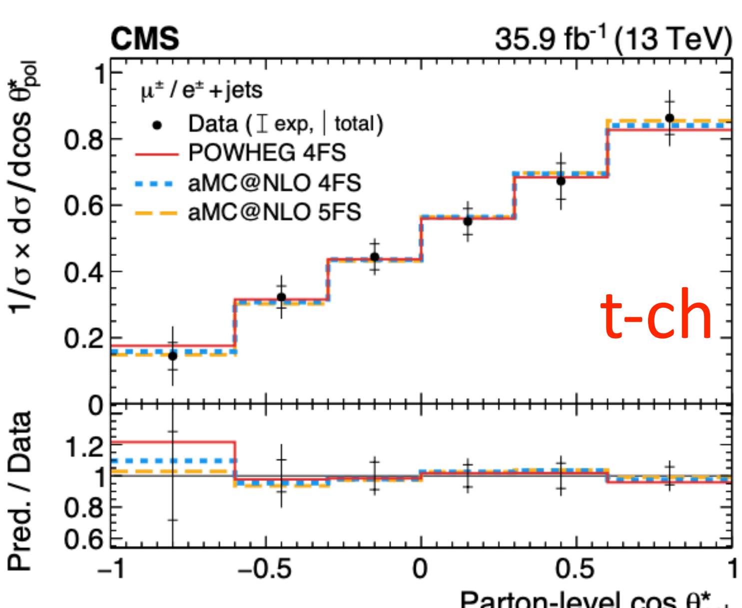
Consistent with SM prediction

- Spin asymmetry measurement

F.Lemmi

$$A_\ell = 0.440 \pm 0.031(\text{stat+exp}) \pm 0.062\,(\text{theo})$$

t-ch



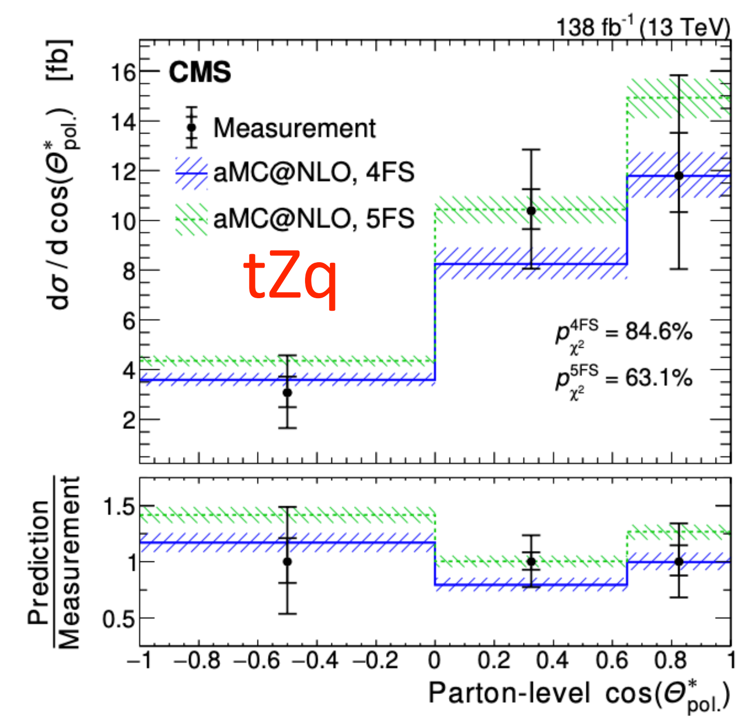
determined by parton level

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*_{pol}} \qquad \cos\theta^*_{pol} = \frac{\vec{p}^{\,*}_{q'} \cdot \vec{p}^{\,*}_{\ell}}{|\vec{p}^{\,*}_{q'}||\vec{p}^{\,*}_{\ell}|}$$

tZq

$$A_\ell = 0.54 \pm 0.16(\text{stat}) \pm 0.06\,(\text{syst})$$

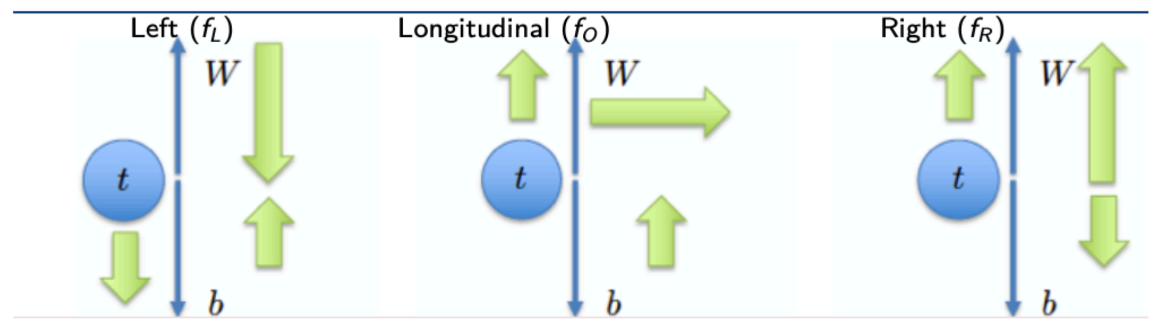
Statistically dominated



W polarisation in top events

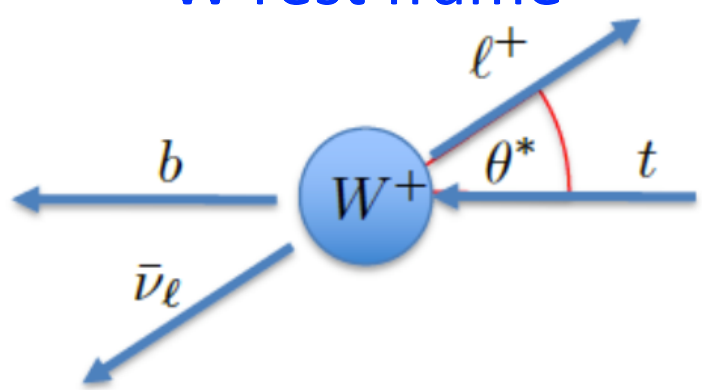
M.Watson

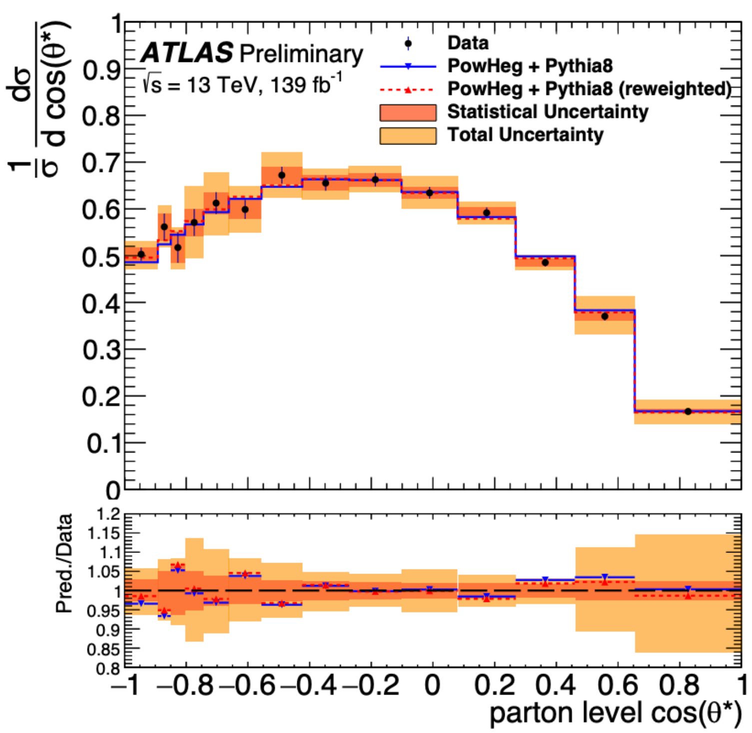
- Probe of Wtb vertex

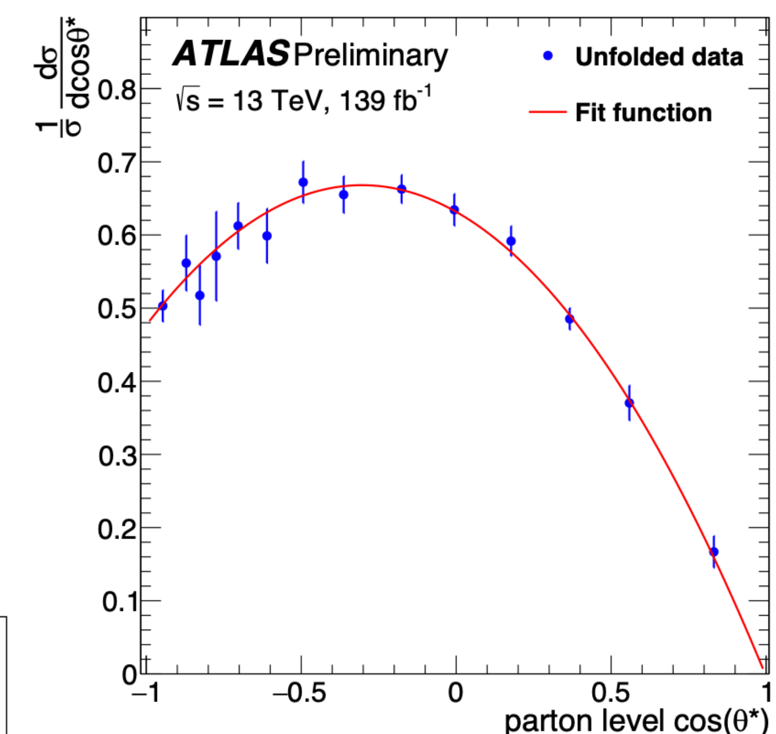


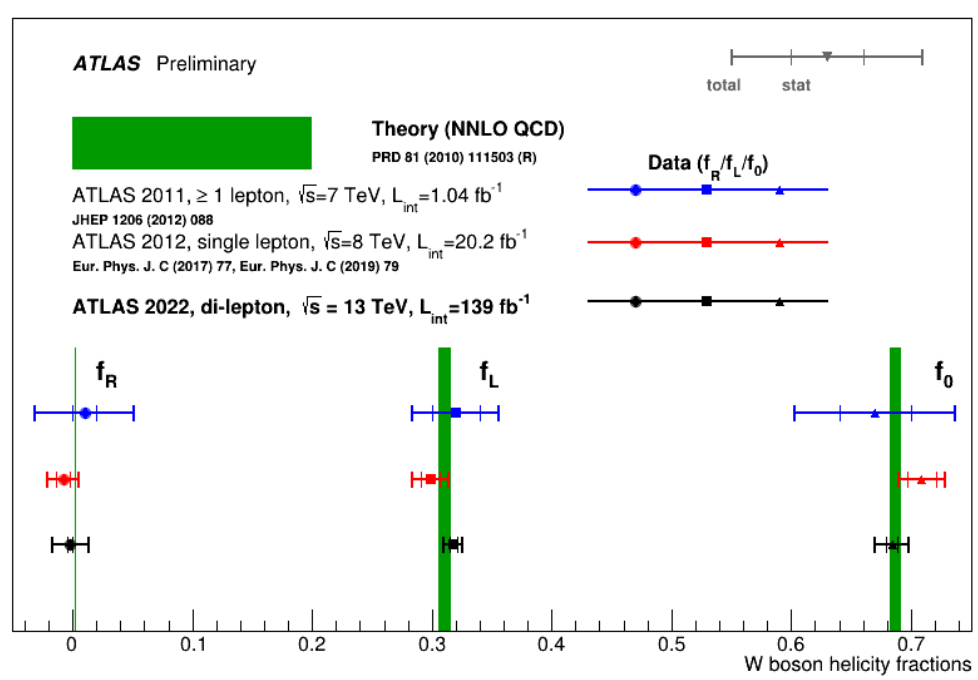
New method in dilepton channel: mesure absolute and normalised differential distributions in $\cos\theta^*$

W rest frame









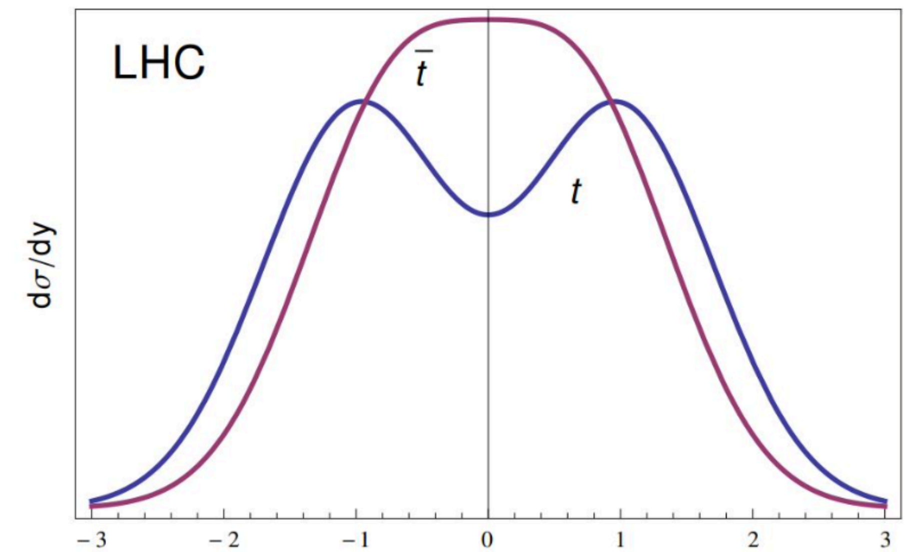
$$f_0 = 0.684 \pm 0.015\ (\text{stat.} + \text{syst.})$$
$$f_L = 0.318 \pm 0.008\ (\text{stat.} + \text{syst.})$$
$$f_R = -0.002 \pm 0.015\ (\text{stat.} + \text{syst.})$$

Systematically dominated measurement

Charge asymmetry in tt

D.Schwarz

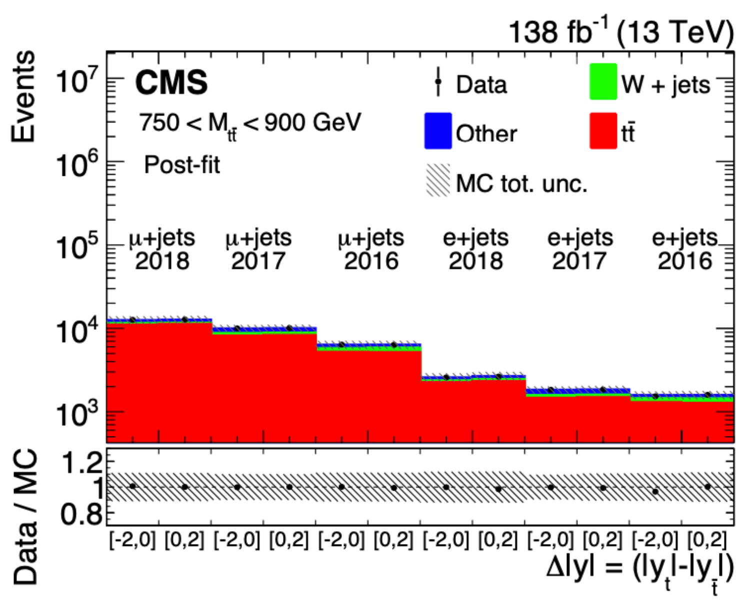
- Central-forward in ttbar events
- No asymmetry at LO
- Higher order effects in $q\bar{q} \rightarrow t\bar{t}$

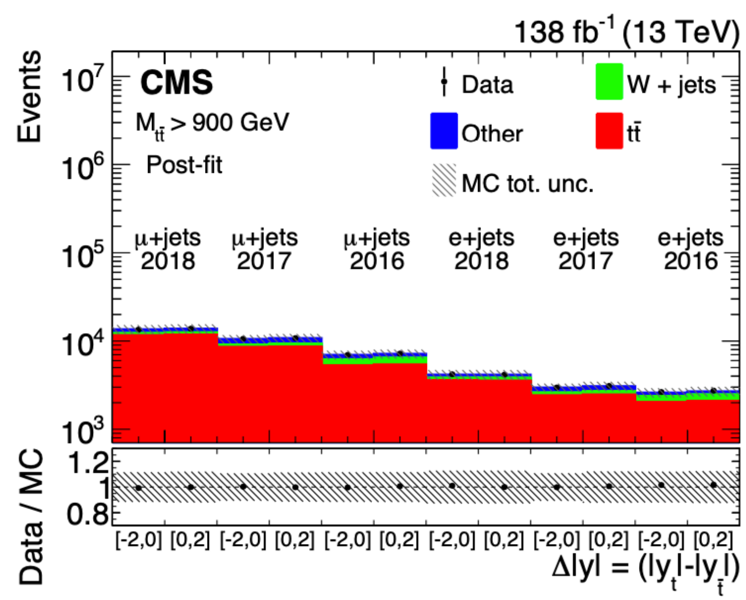


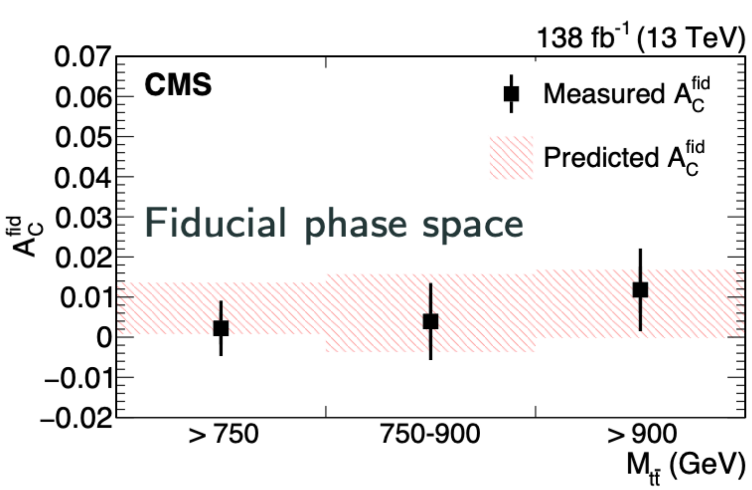
Boosted regime, two $M_{t\bar{t}}$ bins: [750, 900], [900, ∞]

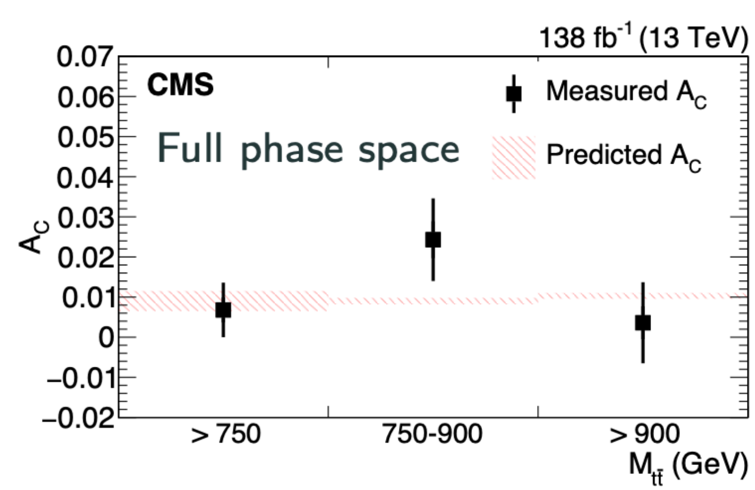
$$A_C = \frac{N(\Delta|y|>0) - N(\Delta|y|<0)}{N(\Delta|y|>0) + N(\Delta|y|<0)}$$

$$(\Delta|y| = |y_t| - |y_{\bar{t}}|)$$









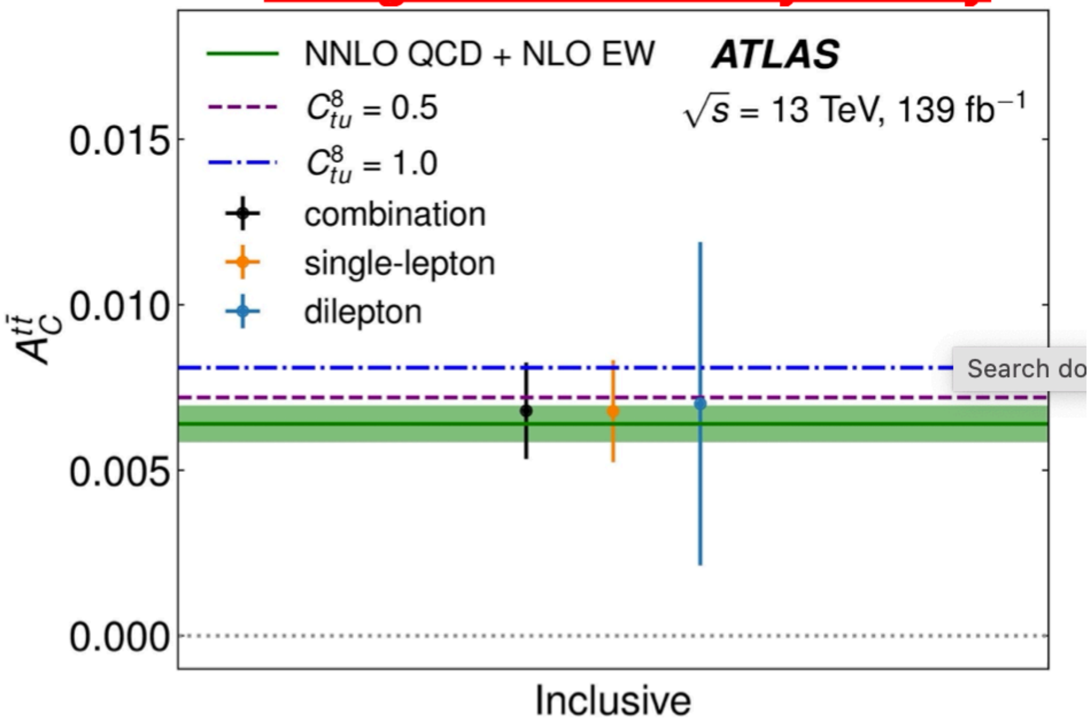
Good agreement with prediction

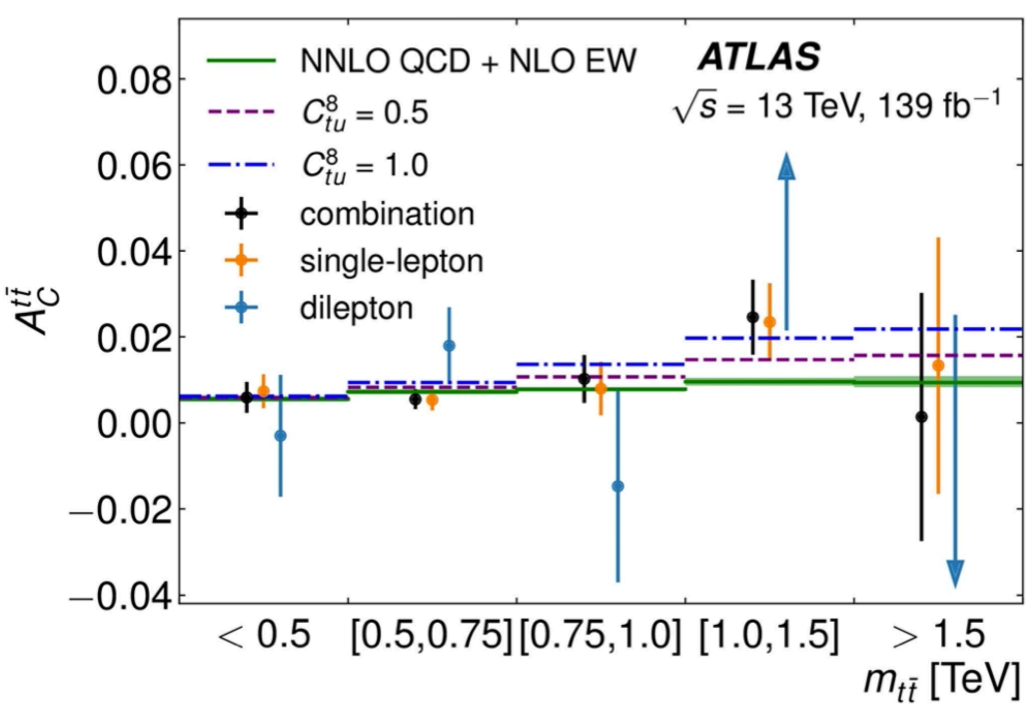
Charge asymmetry in tt

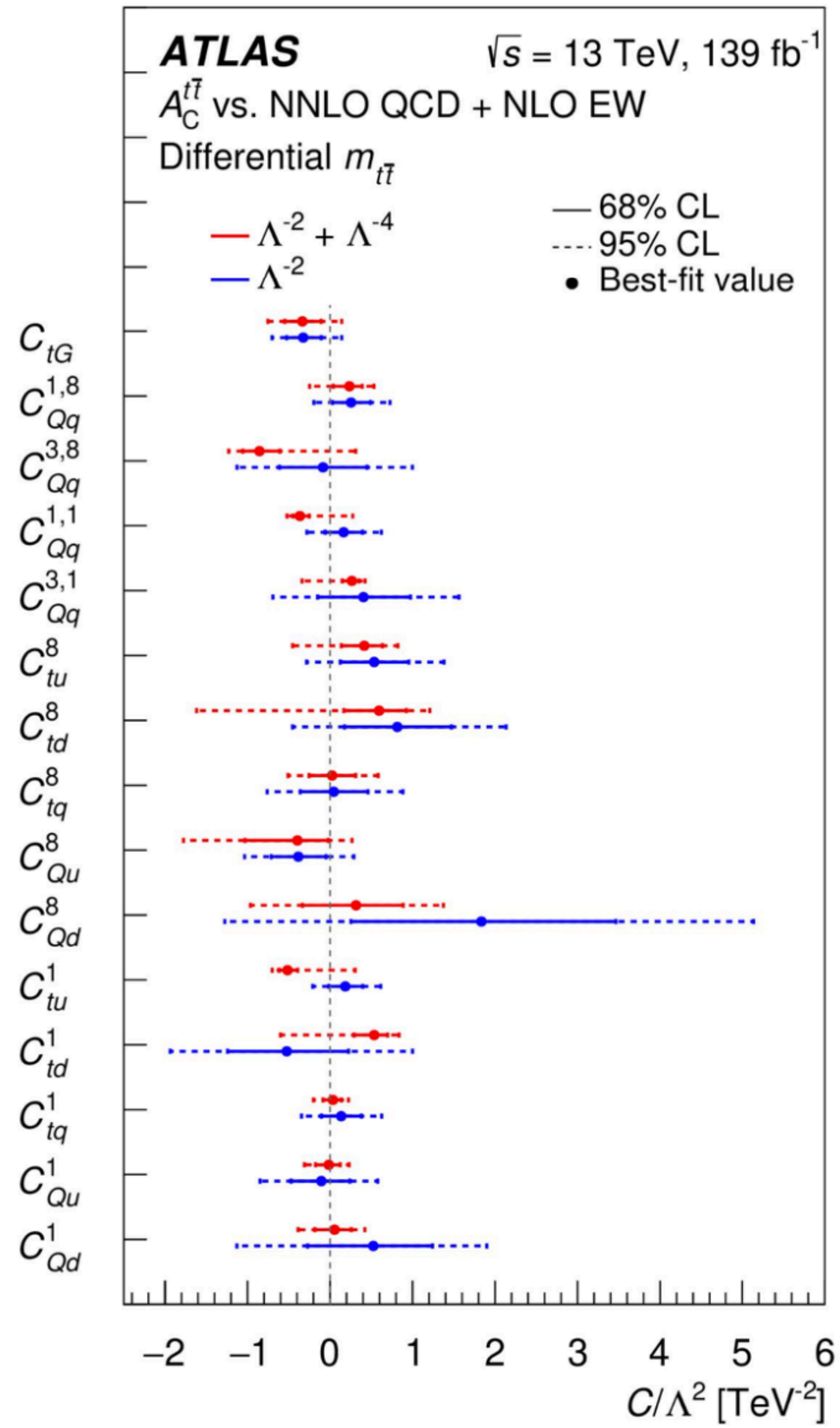
T.Dado
B.Eskerova
J.Keaveney

- Single and dilepton channels
- Resolved and boosted regime

- A_{tt} = 0.0068 ± 0.0015(stat+syst.).
  - 4.7 sigma from zero asymmetry







Best sensitivity at high mass
Expect improvement with additional data

Energy asymmetry in tt

T.Dado
J.Keaveney

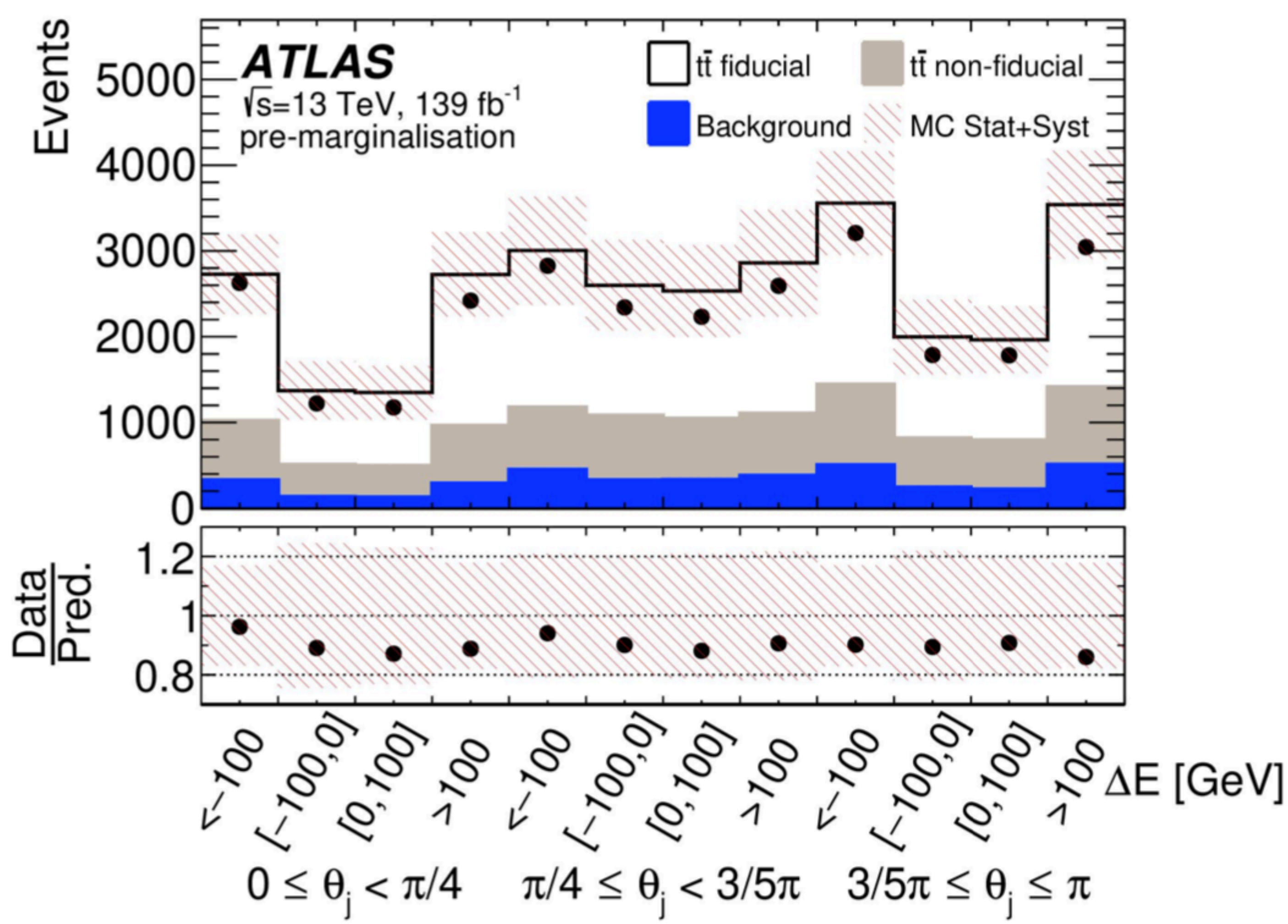
- Asymmetry between the energies of top and anti-top
- Measured in tt+j events in boosted regime

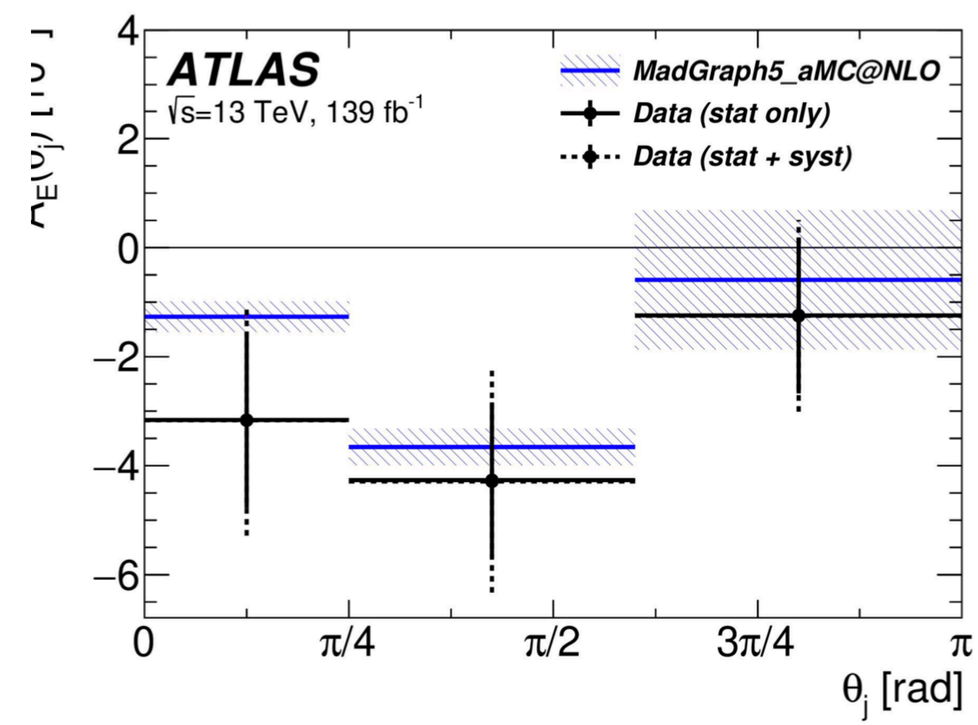
$$A_E(\theta_j) \equiv \frac{\sigma^{\text{opt}}(\theta_j|\Delta E > 0) - \sigma^{\text{opt}}(\theta_j|\Delta E < 0)}{\sigma^{\text{opt}}(\theta_j|\Delta E > 0) + \sigma^{\text{opt}}(\theta_j|\Delta E < 0)}$$

$$\sigma^{\text{opt}}(\theta_j) = \sigma(\theta_j|y_{t\bar{t}j} > 0) + \sigma(\pi - \theta_j|y_{t\bar{t}j} < 0)$$

Angle between the jet and z-axis

Effect increases with jet pT





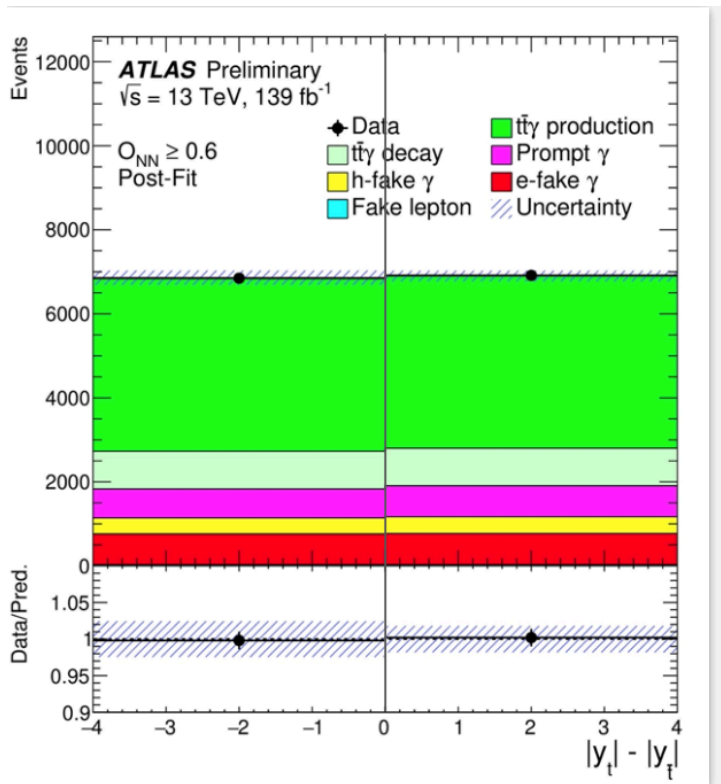
Unfolded distribution agrees with prediction

Statistically limited

Asymmetry in $t\bar{t}\gamma$ and $t\bar{t}W$

$t\bar{t}\gamma$ J. van der Linden, T.T.Tran, A.Rey, J.Keaveney $t\bar{t}W$

- Asymmetry from ISR/FSR interference
- Similar definition as in $t\bar{t}$
- Much lower statistics, 2 bins

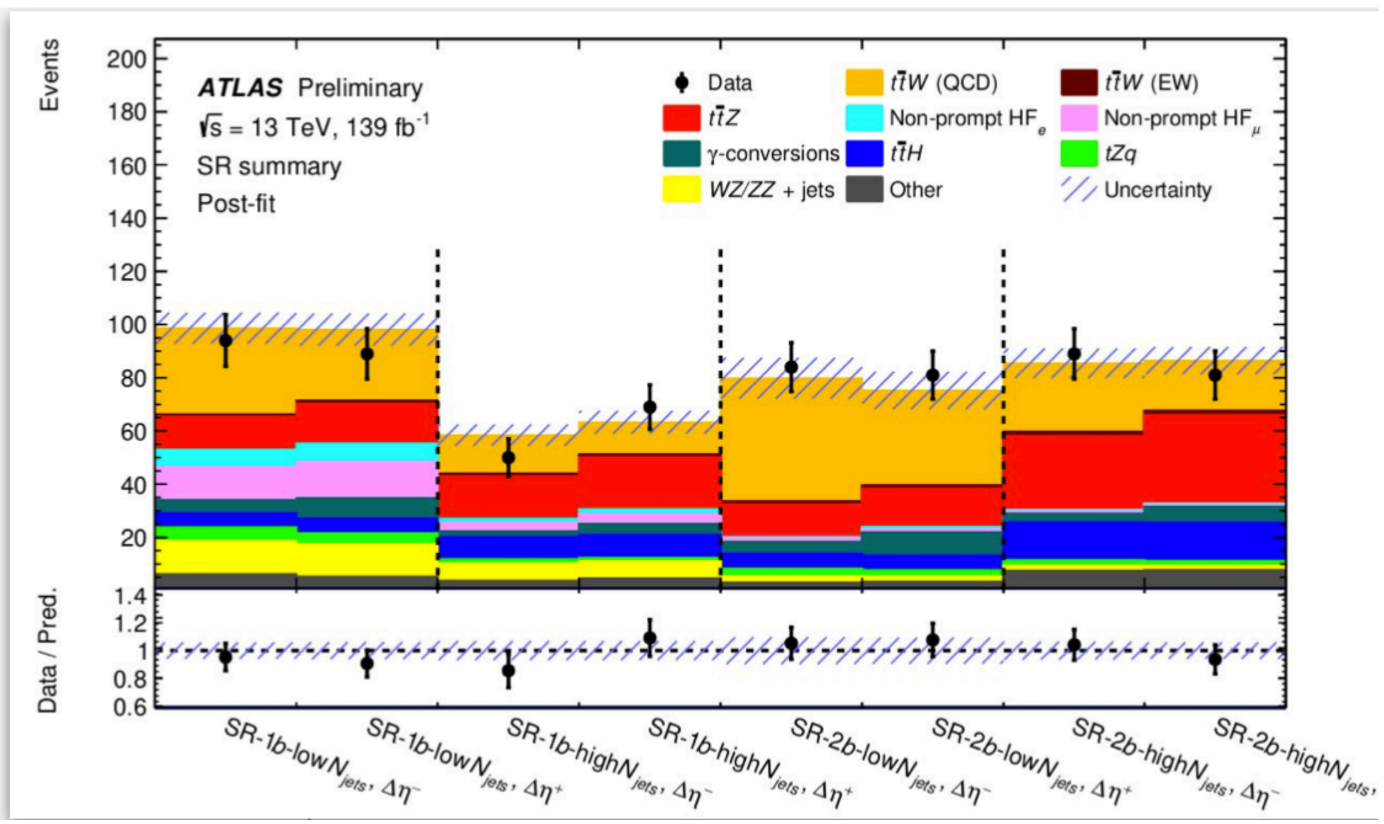


$A_C = -0.006 \pm 0.024(\text{stat}) \pm 0.018(\text{syst})$

in agreement with prediction from MG5aMC

$A_C = -0.014 \pm 0.001(\text{scale})$

- Expected to be larger than in $t\bar{t}$ due $q\bar{q}$ initial state
- 3-lepton channel, lepton as proxy for top



- Fiducial result unfolded to particle-level:

$A_C = -0.112 \pm 0.170\ (\text{stat}) \pm 0.055\ (\text{syst})$

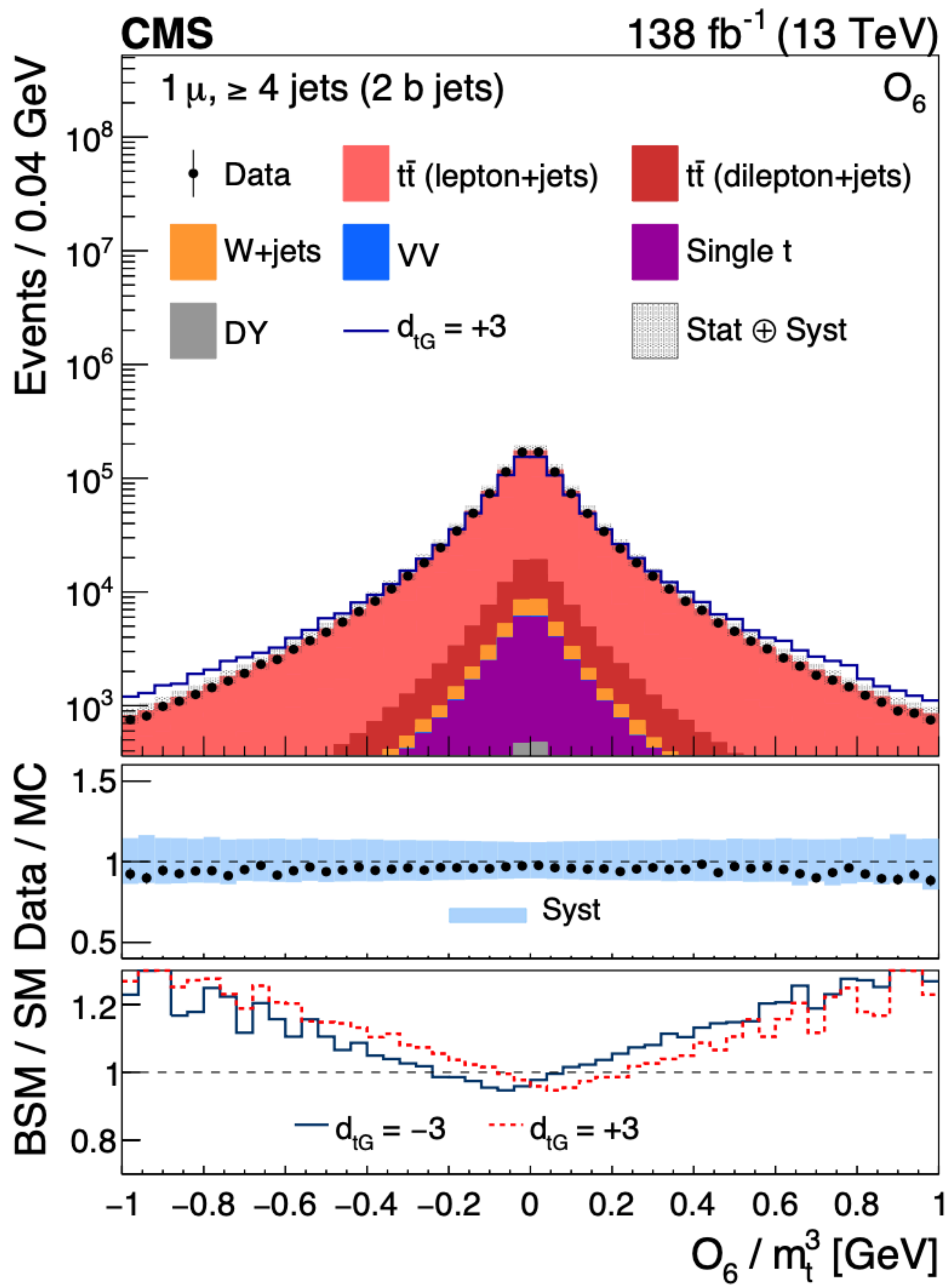
in agreement with Sherpa NLO+EW simulation

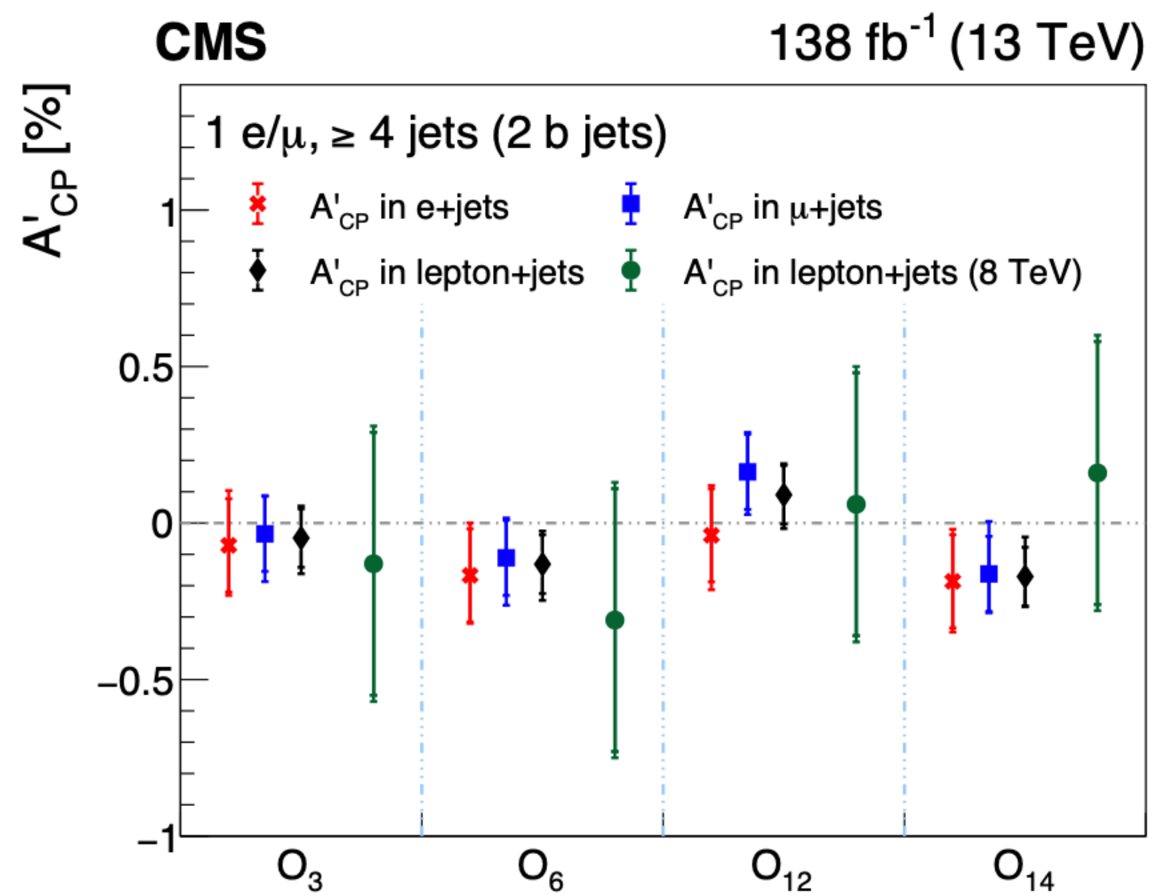
Statistically dominated analyses, Run 3 data will help

CP violation in ttbar

- Construct 4 CP-sensitive observables
- Define and measure asymmetry

$$A_{CP} = \frac{N(O_i>0)-N(O_i<0)}{N(O_i>0)+N(O_i<0)},$$
$$i = 3, 6, 12, 14$$



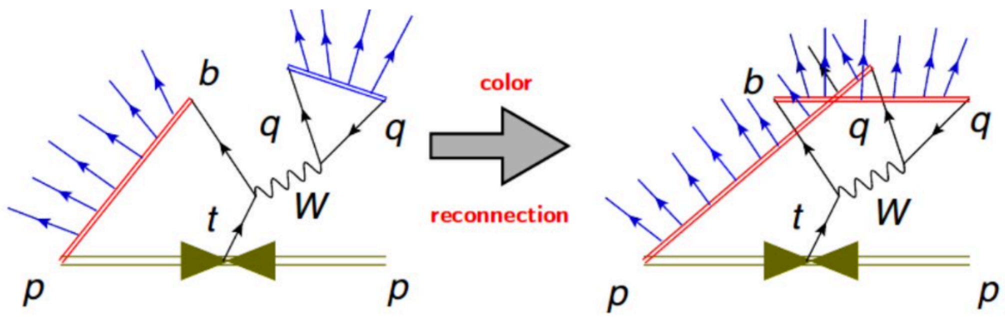


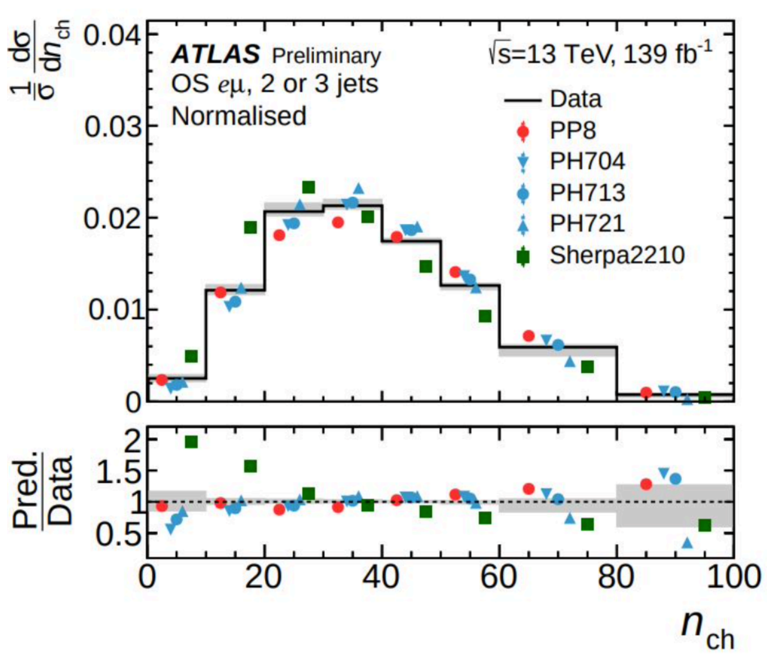
In agreement with SM value of zero
x3 improvement of precision

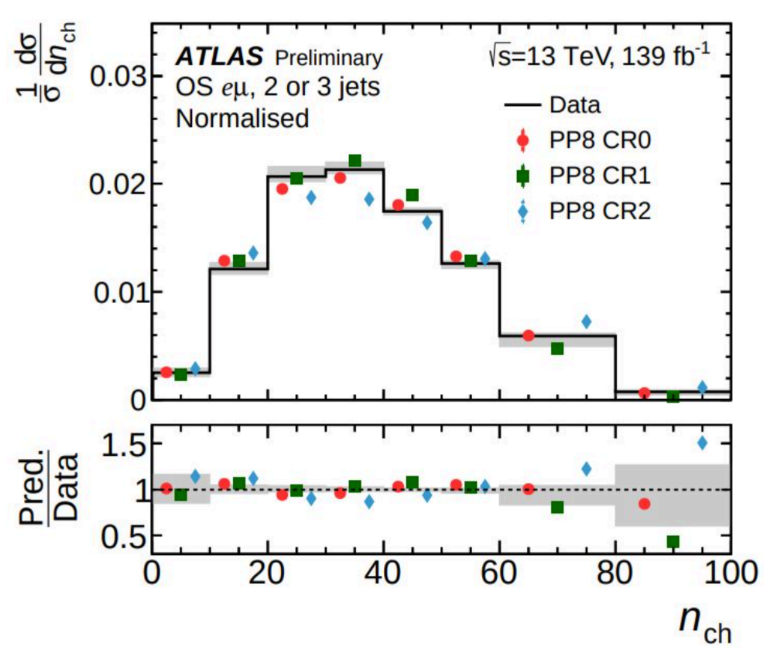
Properties for MC tuning

T.Dado
S.Wahdan

❑ Color reconnection







Good agreement for all MC simulations except Sherpa

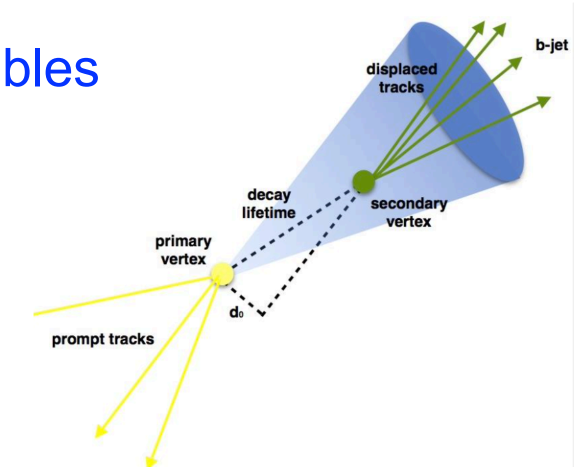
No ideal model

Shower returning including CR model is necessary

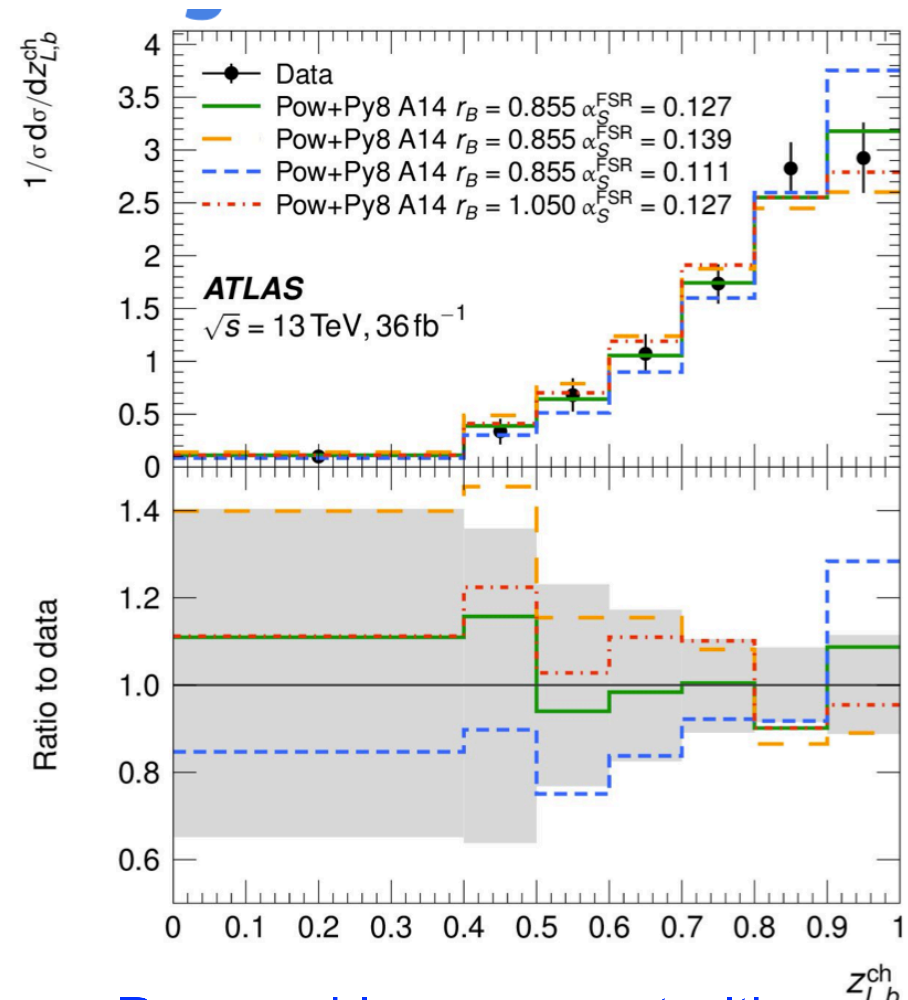
❑ B-fragmentation

Several sensitive variables

$$z^{\mathrm{ch}}_{\mathrm{L},b} = \frac{\vec{p}_b^{\,\mathrm{ch}} \cdot \vec{p}^{\,\mathrm{ch}}_{\mathrm{jet}}}{|p^{\mathrm{ch}}_{\mathrm{jet}}|^2}$$

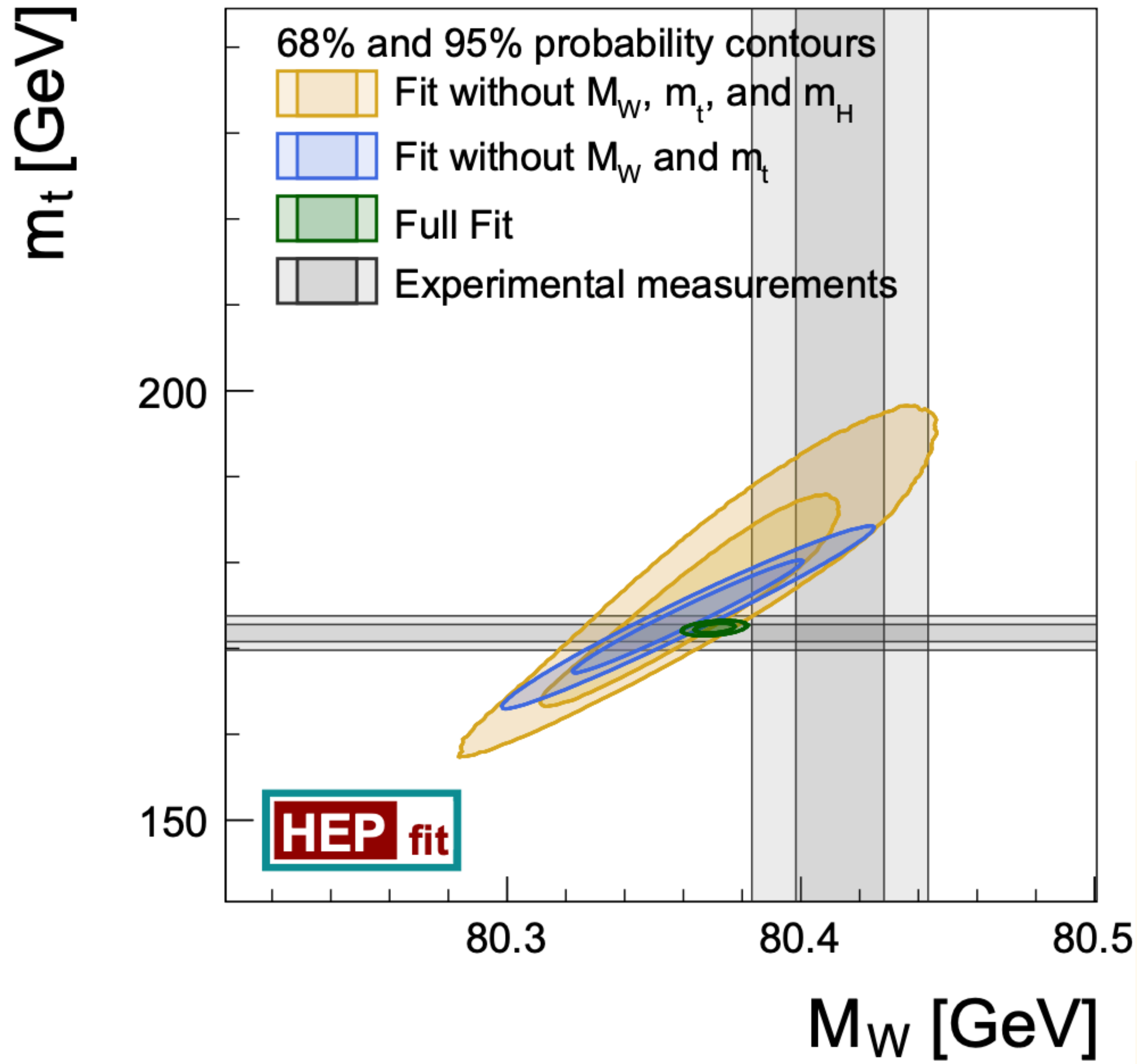


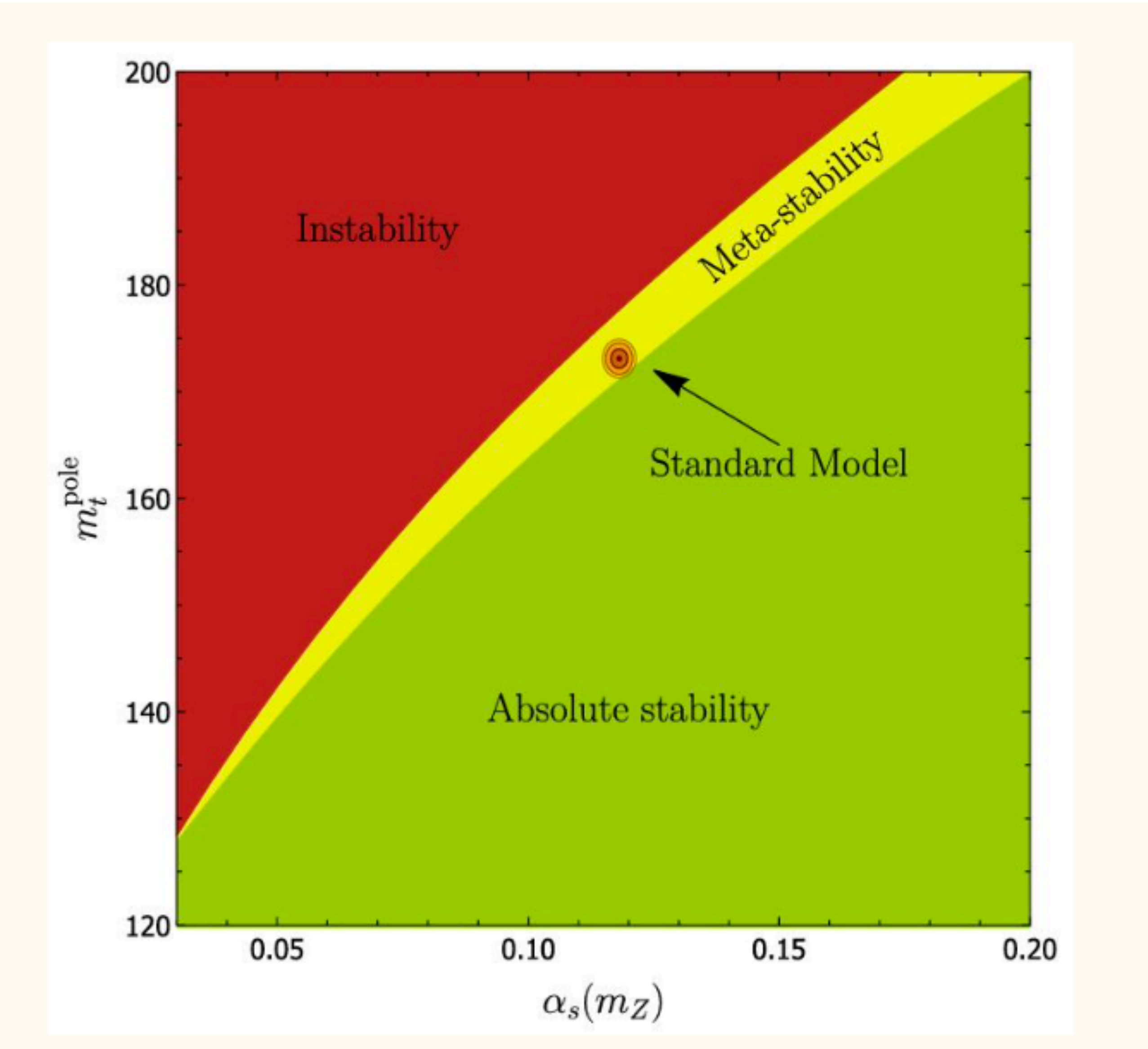
Unfolded to stable tracks



Reasonable agreement with Powheg+Pythia

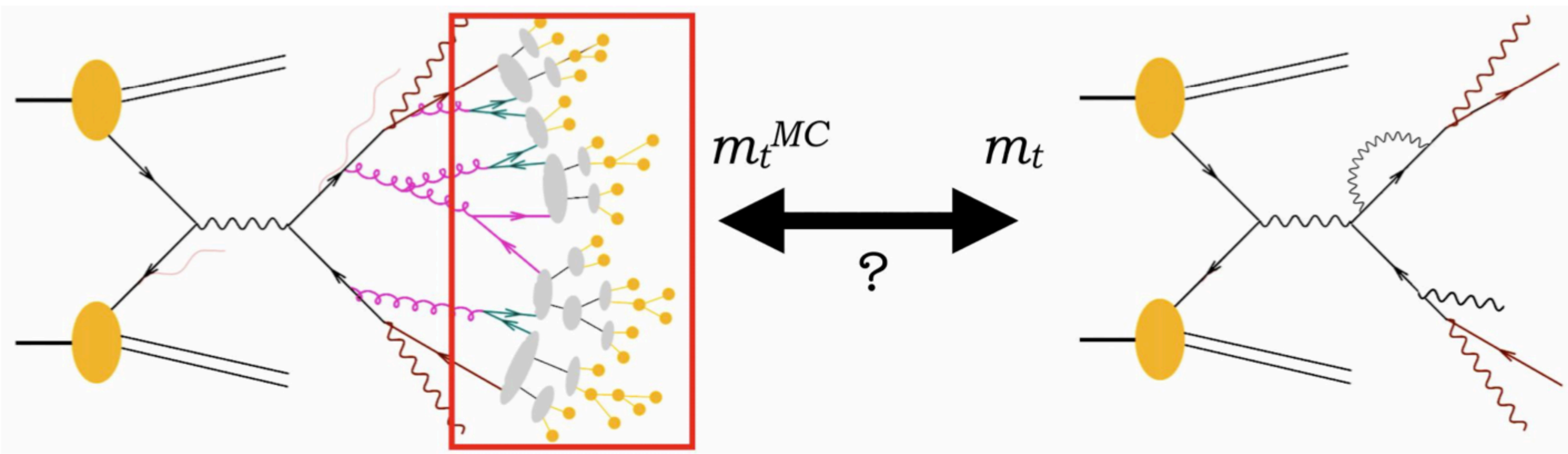
Top quark mass

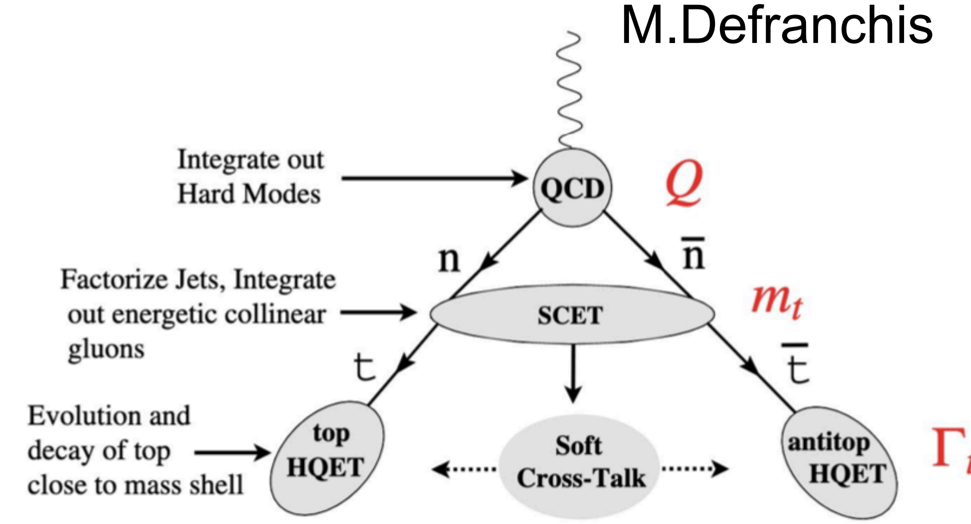




Top mass

M.Defranchis





Direct

from reconstruct invariant mass of top quark decay products

- Most precise (~0.3 GeV)
- Depends on the details of the MC simulation

- CMS: tt+jets (36/fb)
- CMS: single top t-channel
- ATLAS ttbar soft muon tagging
- ATLAS ttbar dilepton

Indirect

measure observable directly sensitive to m_t (e.g. σ_{tt})

- Compare to theory prediction in well-defined renormalisation **scheme** (pole, MS, MSR)
- Can be sensitive to soft-gluon effects at threshold, where mass sensitivity is the highest

- ATLAS+CMS: m_t pole from combined σ_{tt} 7+8 TeV
- CMS: mass from tt+1j invariant mass
- CMS: m_t running @NNLO revisited

"Third"

jet mass in boosted top decays can be calculated using SC-EFT

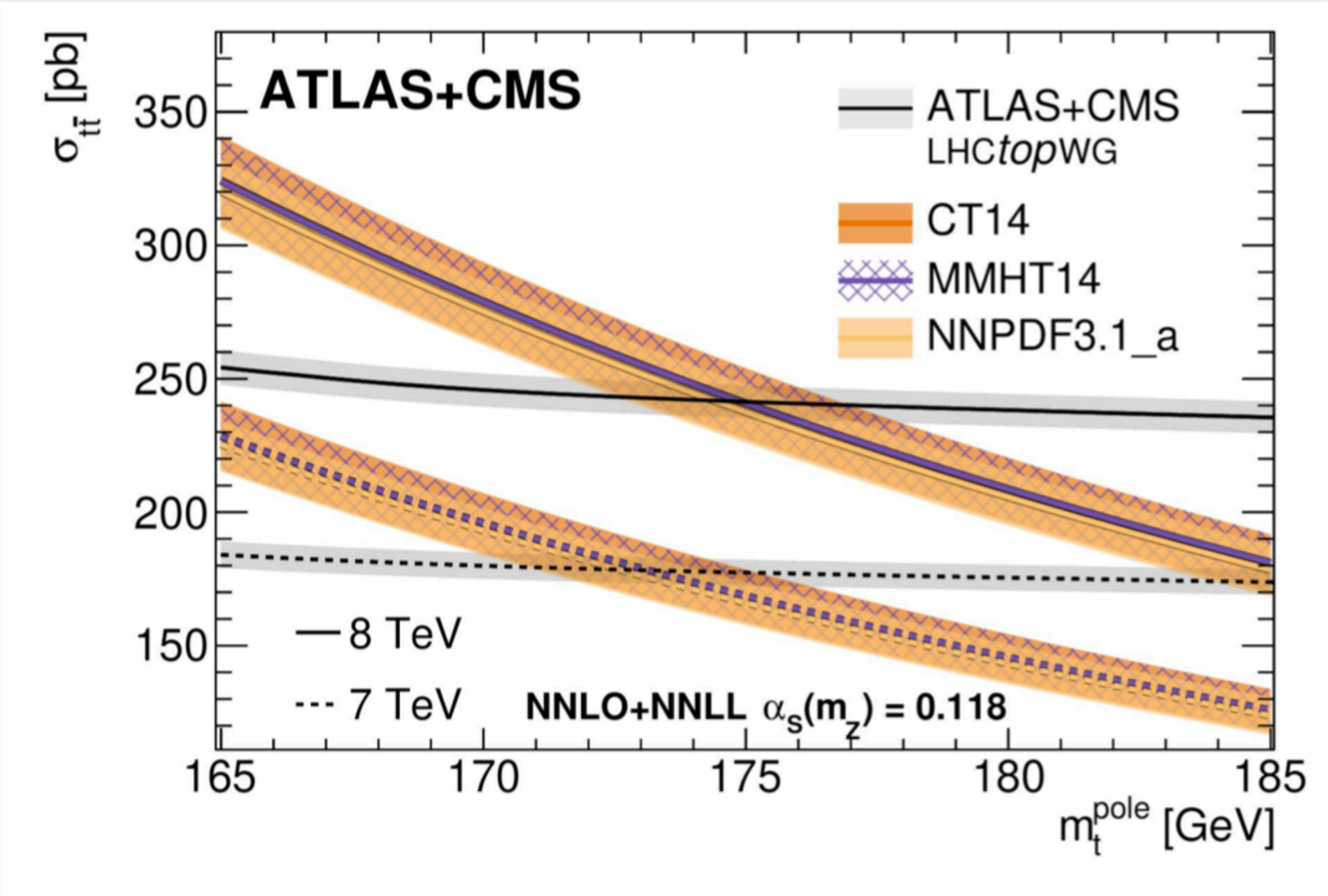
→ can provide info on relation between m ^{MC} and m (MSR)

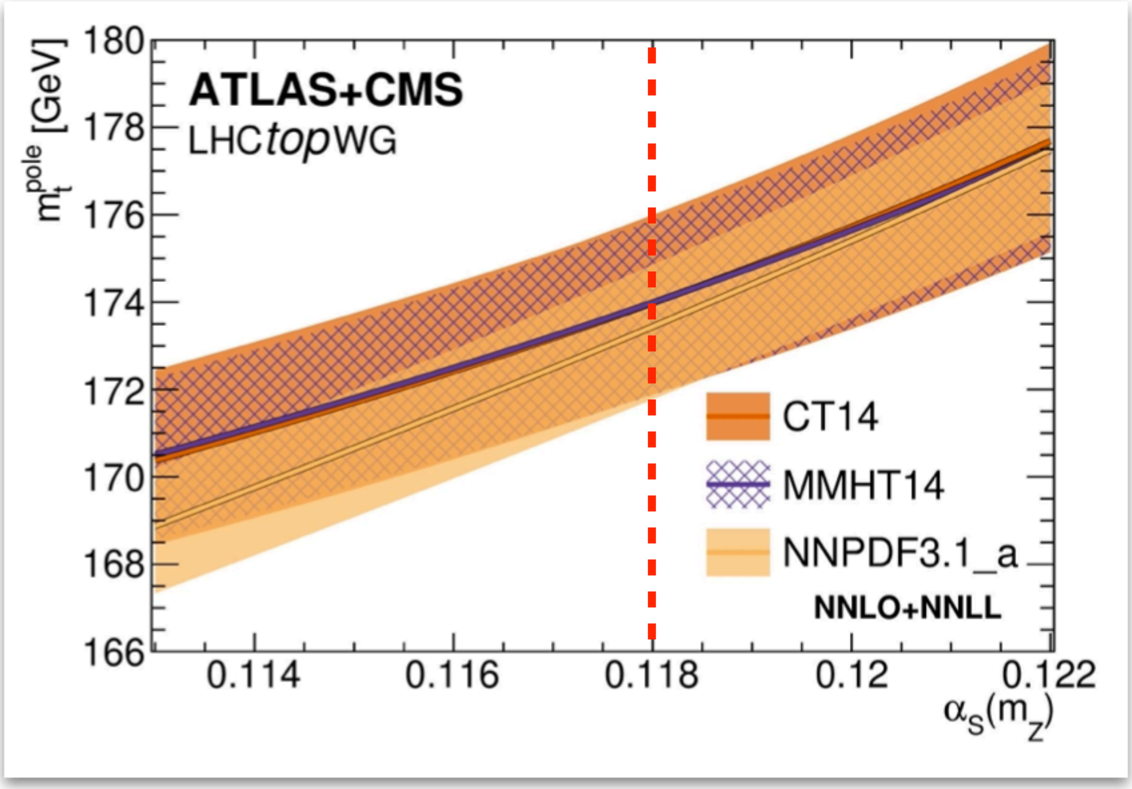
- CMS: top mass from boosted jet mass

Top mass from σ_{tt}

M.Defranchis

Simultaneous fit of NNLO+NNLL (Top++) prediction to combined 7+8 TeV σ_{tt}





Extracted values of m^{pole} crucially depends on assumed value of α_s

PDF set	m_t^{pole} ($\alpha_s = 0.118 \pm 0.001$)	$\alpha_s(m_Z)$ ($m_t = 172.5 \pm 1.0$ GeV)
CT14	$174.0^{+2.3}_{-2.3}$ GeV	$0.1161^{+0.0030}_{-0.0033}$
MMHT2014	$174.0^{+2.1}_{-2.3}$ GeV	$0.1160^{+0.0031}_{-0.0030}$
NNPDF3.1_a	$173.4^{+1.8}_{-2.0}$ GeV	$0.1170^{+0.0021}_{-0.0018}$

PDF does not contain top quark measurements

Earlier m^{pole} measurements from σ_{tt} at 13 TeV using dileptonic events are similar in terms of central values and systematics

Top mass from tt+jet events

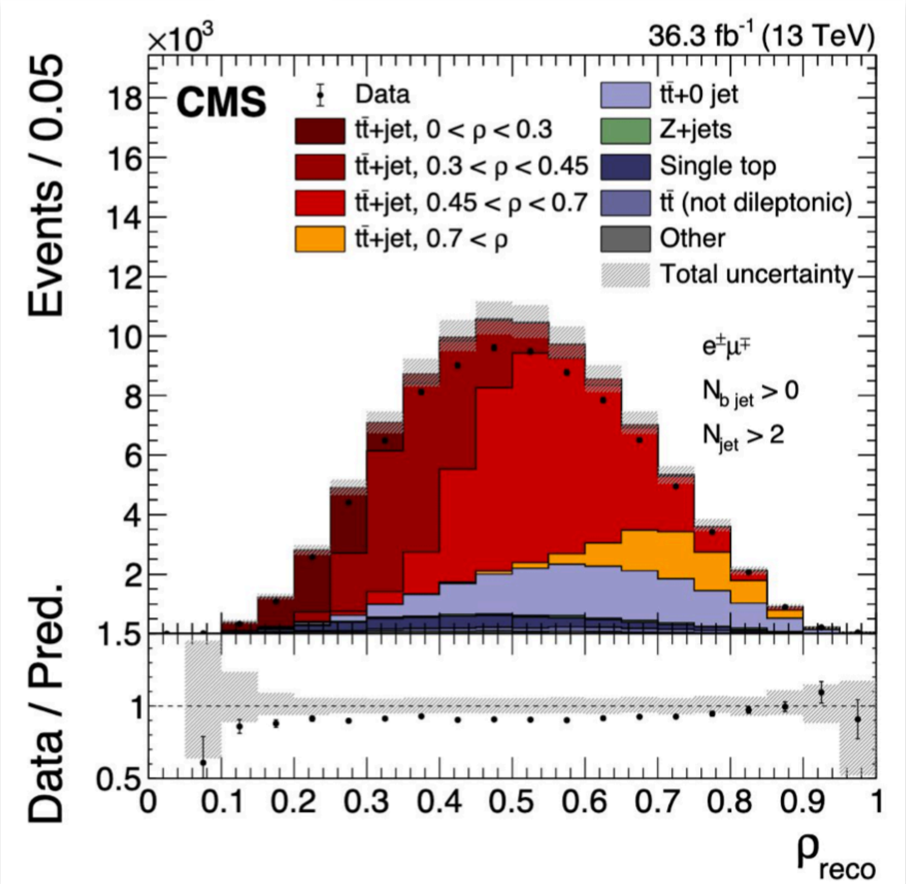
M.Defranchis
S.Wuchterl

- Invariant mass of tt+1jet system sensitive to value of m_t near the production threshold

$$\mathcal{R}(m_t^{\text{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \cdot \frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s},$$

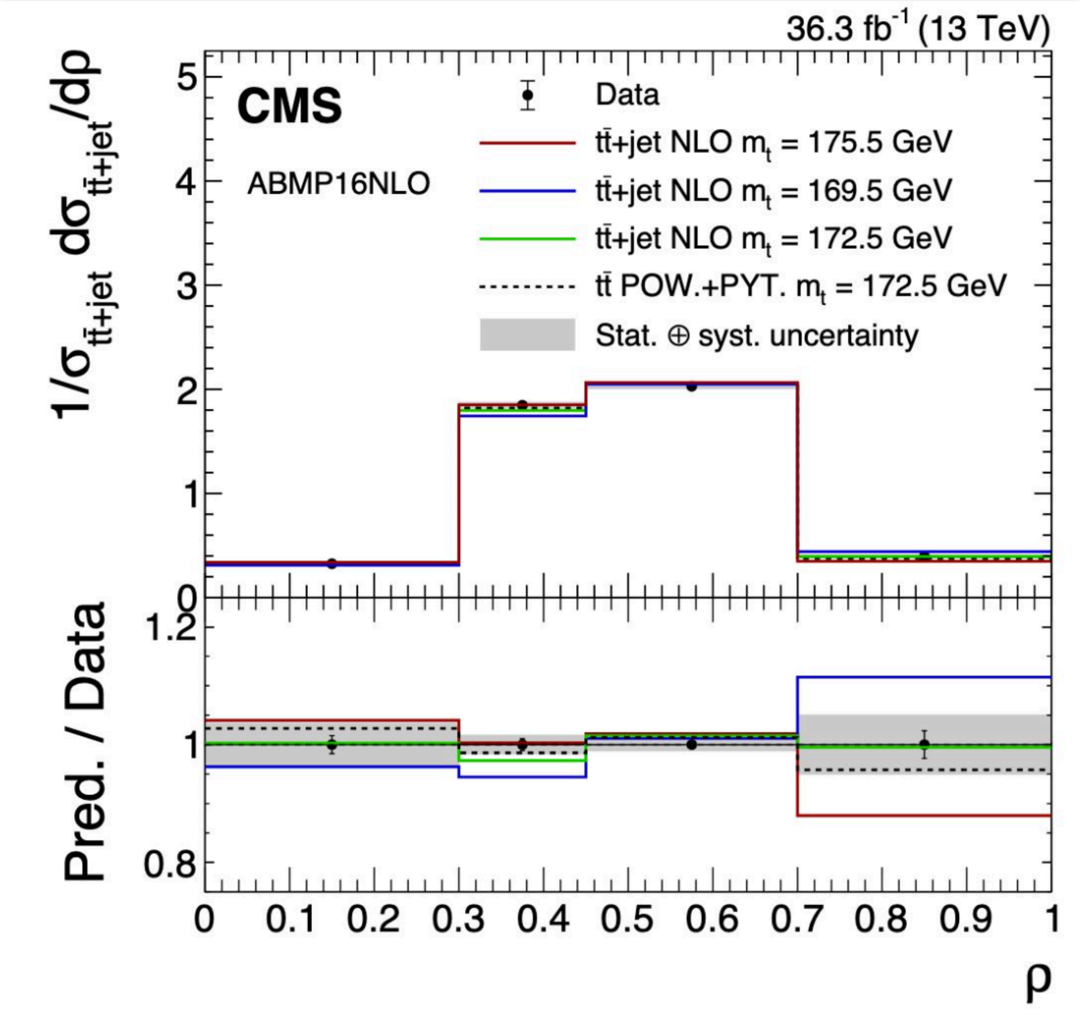
$$\rho_s = \frac{2m_0}{m_{t\bar{t}+1\text{-jet}}}$$

NN techniques to reconstruct ρ variable



Unfolding to parton level

fit NLO predictions to normalised differential cross section



ABMP16: $m_t^{\text{pole}} = 172.94 \pm 1.27\,(\text{fit})\,^{+0.51}_{-0.43}\,(\text{scale})\,\text{GeV}$

CT18: $m_t^{\text{pole}} = 172.16 \pm 1.35\,(\text{fit})\,^{+0.50}_{-0.40}\,(\text{scale})\,\text{GeV}.$

Similar precision as ATLAS 8 TeV result:

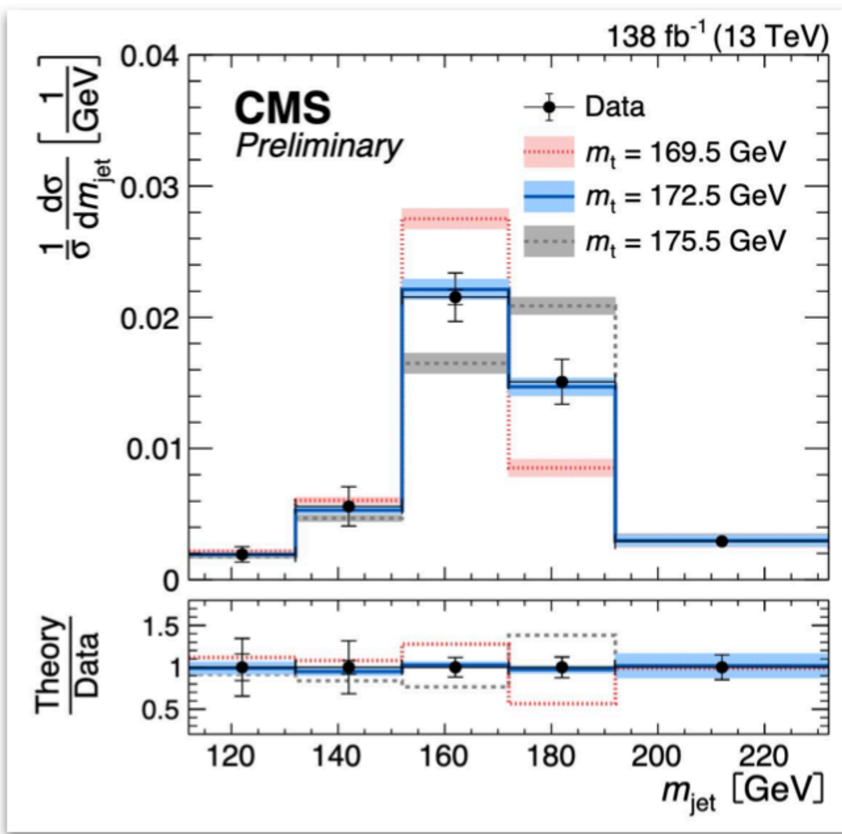
$$m_t^{\text{pole}} = 171.1 \pm 0.4\;(\text{stat}) \pm 0.9\;(\text{syst})\;^{+0.7}_{-0.3}\;(\text{theo})\;\text{GeV}$$

Boosted/running

Top mass from boosted jet mass

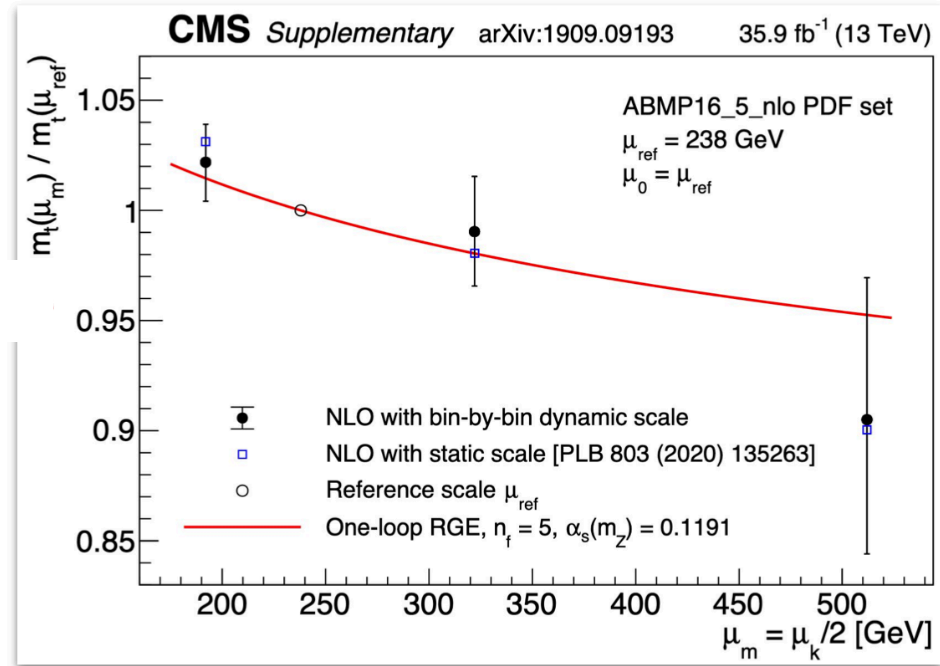
M.Defranchis
D.Schwarz

- XCone exclusive algorithm to reconstruct jets and sub-jets → improved resolution
- Dedicated calibration of FSR using substructure variables, and dedicated jet mass calibration
- x3 improvement over CMS 2016 analysis!
- Comparable precision to direct measurements

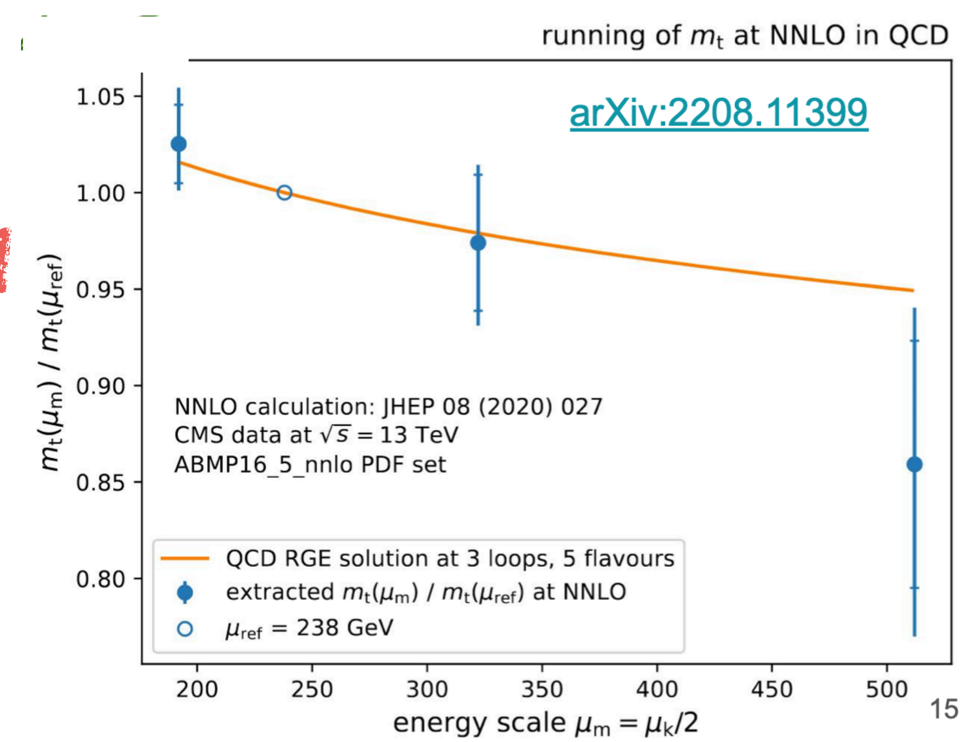


$$m_t = 172.76 \pm 0.22\,(\text{stat}) \pm 0.57\,(\text{exp}) \pm 0.48\,(\text{model}) \pm 0.24\,(\text{theo})\,\text{GeV} = 172.76 \pm 0.81\,\text{GeV}.$$

Running top mass @NNLO



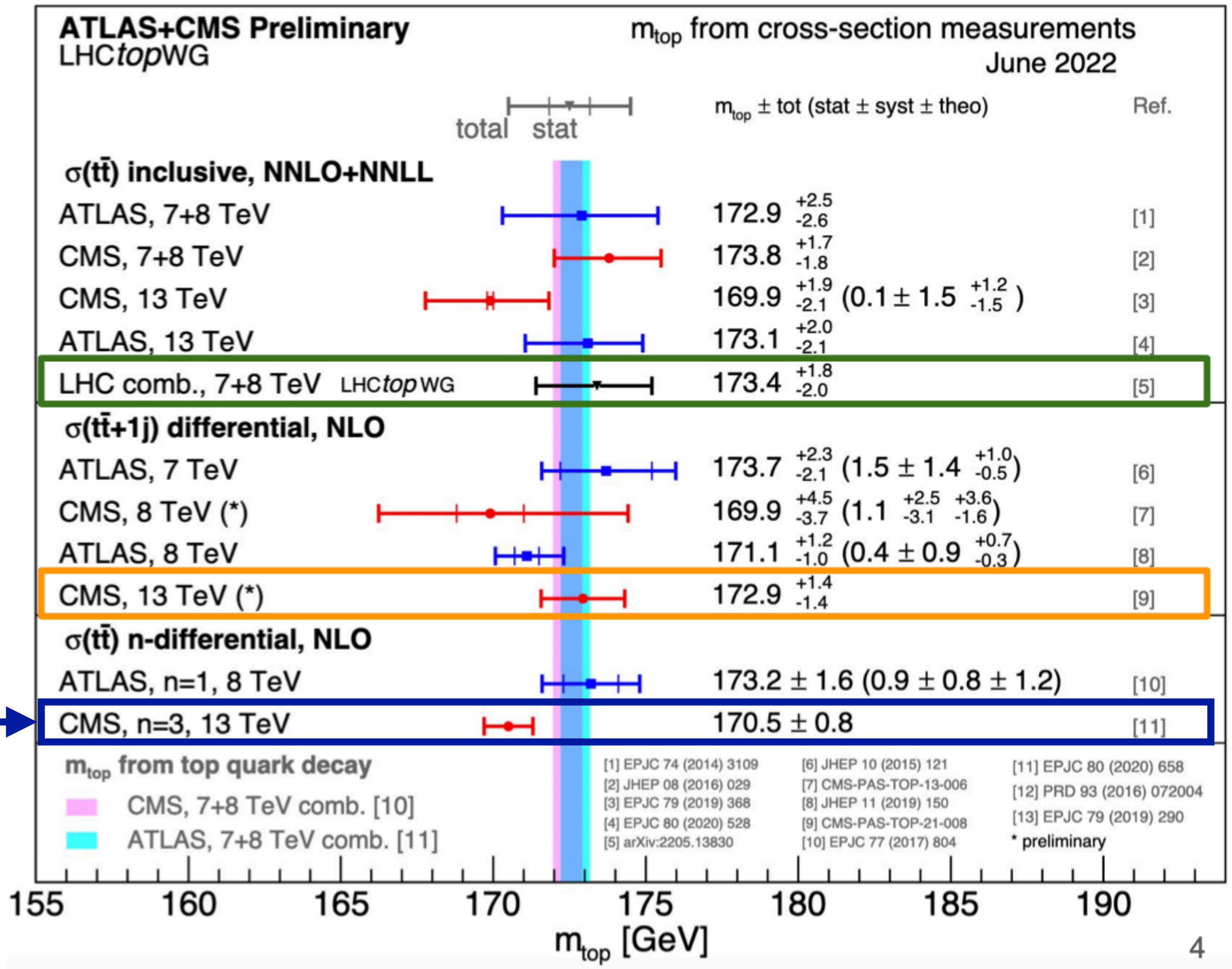
- NNLO prediction in MS scheme using using MATRIX
- Reduction of scale uncertainties
- Improved fit



Summary: indirect measurements

M.Defranchis

Results obtained with different methods overall in good agreement



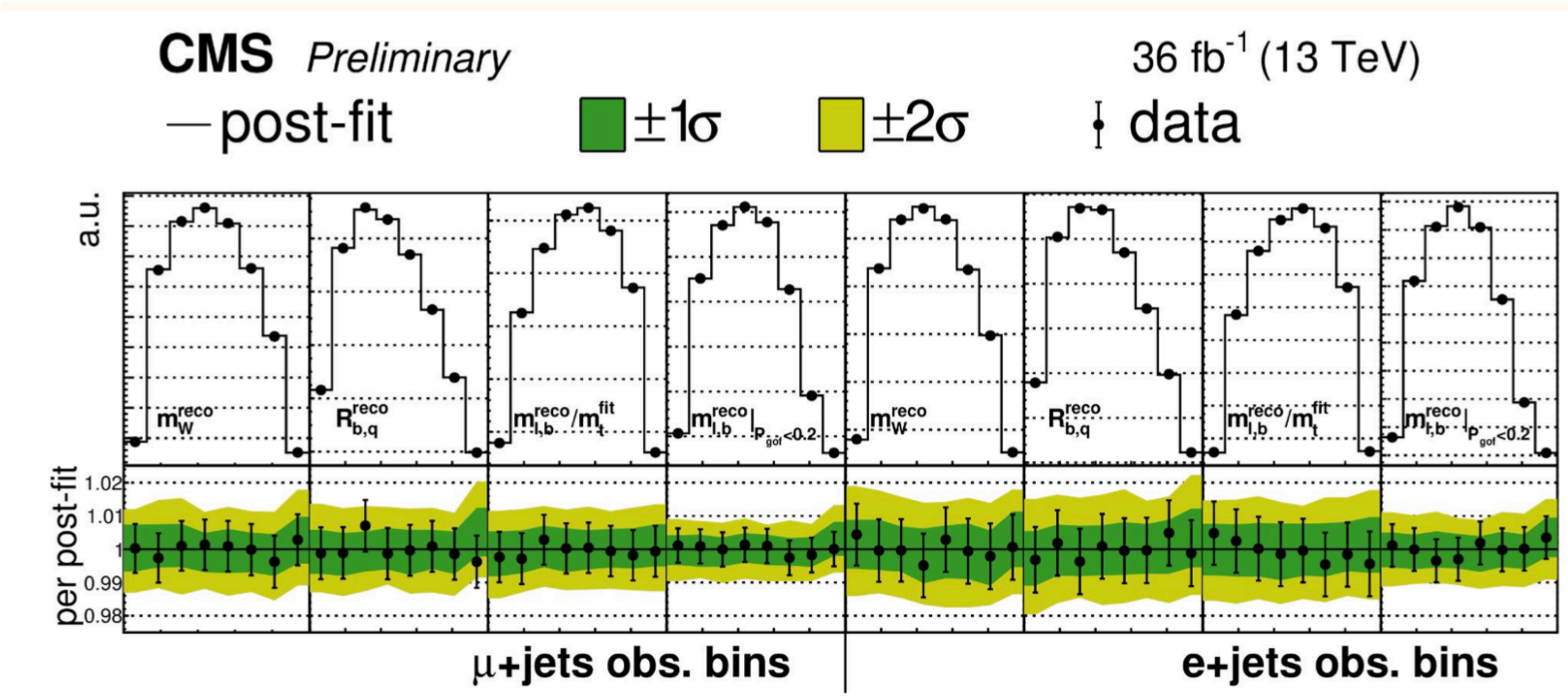
- CMS result from 3D cross section is the most precise result, to date, but may be significantly affected by threshold effects (can be 1.4 GeV).
- No consensus in theory community on the size of the effect

Theoretical advances needed in order to obtain accurate and unambiguous results

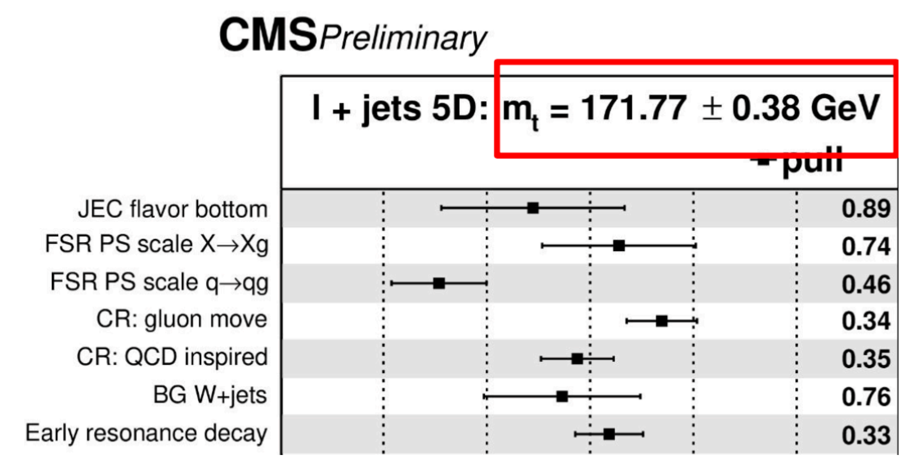
CMS measurements

M. Vanadia

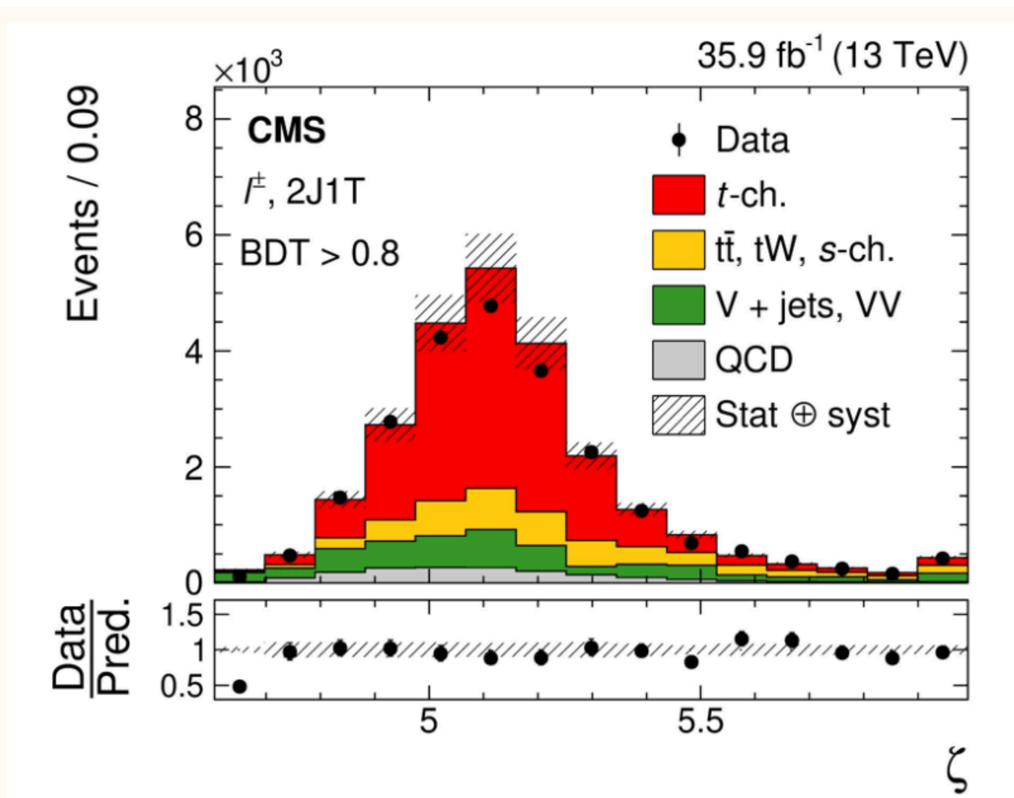
- tt l+jets: profile LH fit to 5 observables in different event categories



Most precise measurement to date with 0.38 GeV uncertainty



- Significant pull and constraint of FSR PS scale q->qg due to m_W^{reco}
- Alternative correlation scheme 172.14 ± 0.31 GeV



- t-channel single top: ML fit to $\zeta = \ln(m_t/1\text{ GeV})$

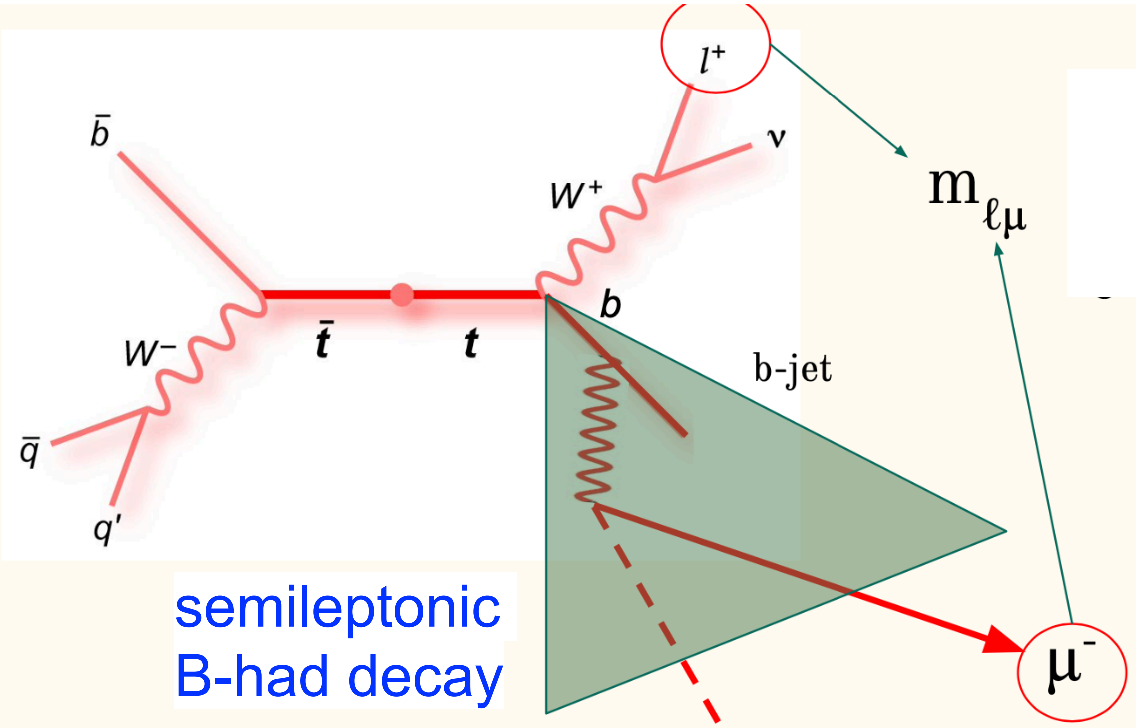
$$m_t = 172.13^{+0.76}_{-0.77}\text{ GeV}$$

$$R_{m_t} = \frac{m_{\bar{t}}}{m_t} = 0.9952^{+0.0079}_{-0.0104}$$

$$\Delta m_t = m_t - m_{\bar{t}} = 0.83^{+1.79}_{-1.35}\text{ GeV}$$

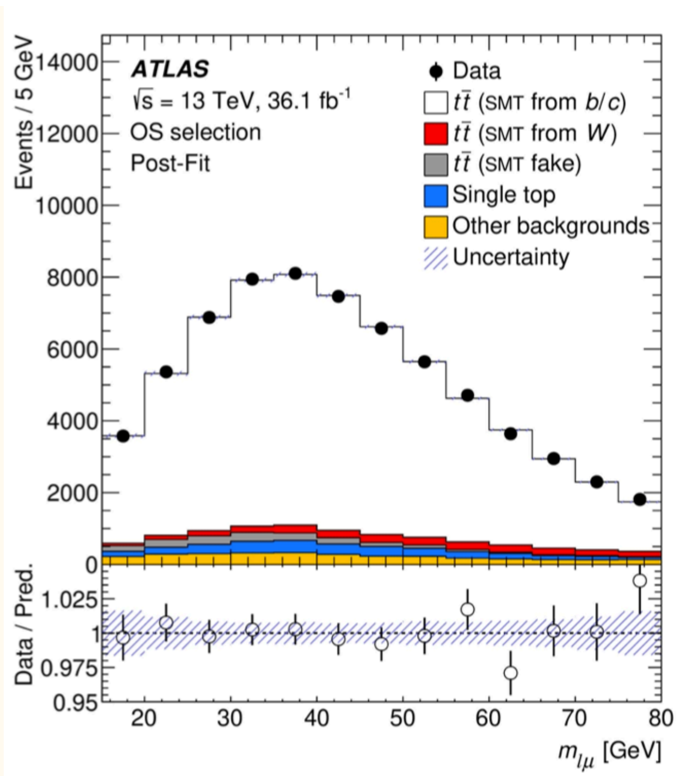
ATLAS SMT mass

M. Vanadia



semileptonic B-had decay

- Top mass using soft muon tag
  - Invariant mass $m_{l\mu}$ sensitive to m_t
  - reduced sensitivity to JES
  - sensitive to fragmentation modelling
  - preliminary result shown at Top2019



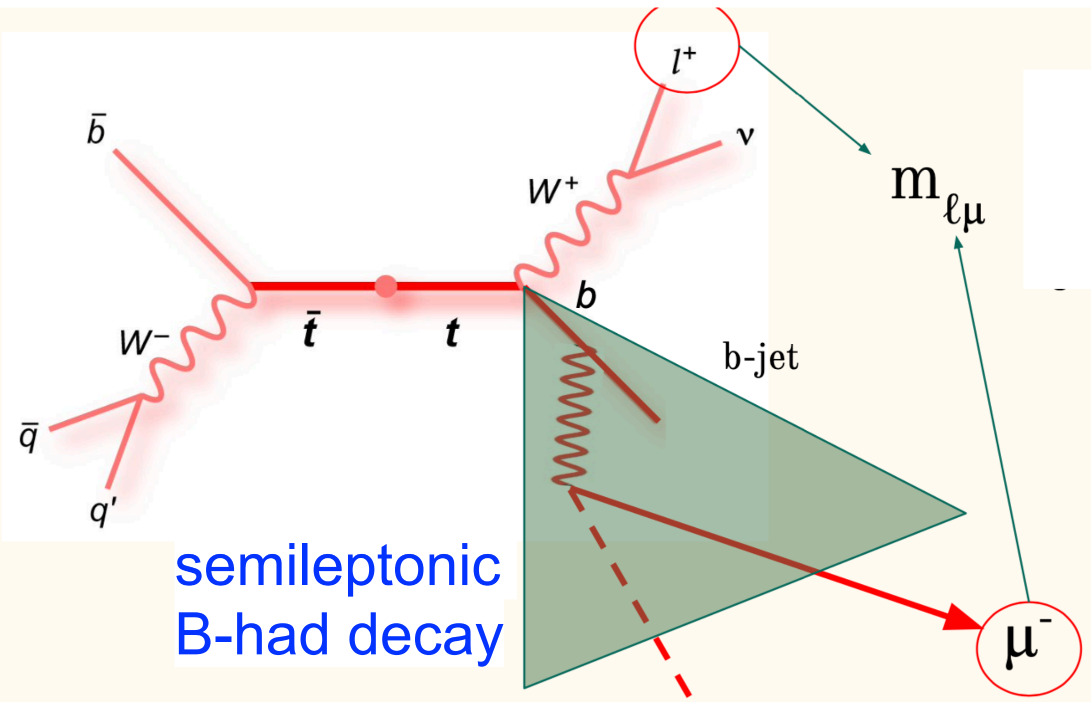
profiled LH fit of $m_{l\mu}$

$$174.41 \pm 0.39\ (\text{stat.}) \pm 0.66\ (\text{syst.}) \pm 0.25\ (\text{recoil})\ \text{GeV}$$

consistent at 2σ level with previous results

ATLAS SMT mass

M. Vanadia



❑ Top mass using soft muon tag

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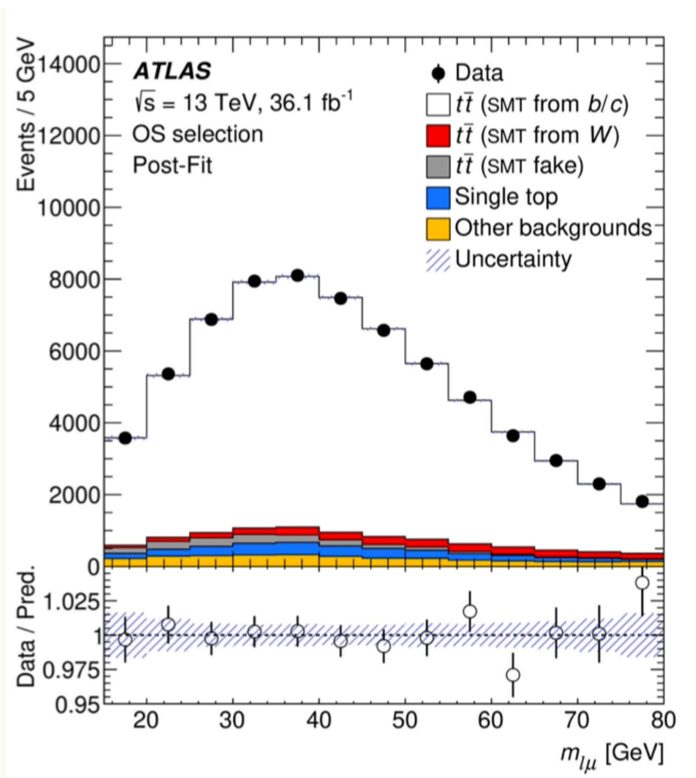
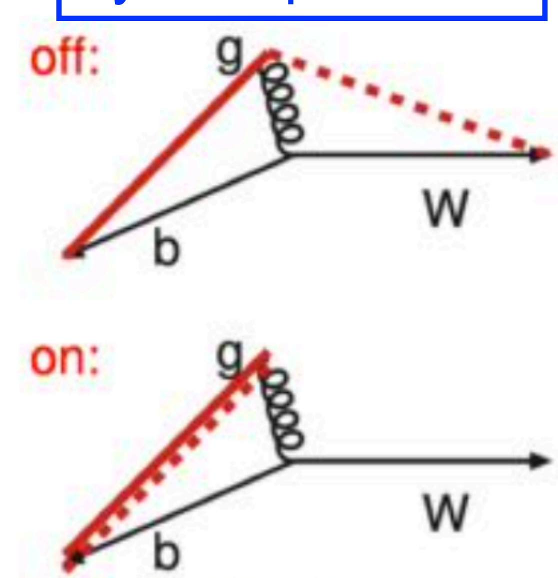


Uncertainty on gluon emission in t→Wb

- impacts PS modelling of gluons from b→gb
- changes energy distribution within jet
- changes jet p_T due to out-of-cone radiation → impacts jet-based measurement

recoilToColoured Pythia option



profiled LH fit of $m_{l\mu}$

$$174.41 \pm 0.39\ (\text{stat.}) \pm 0.66\ (\text{syst.}) \pm 0.25\ (\text{recoil})\ \text{GeV}$$

consistent at 2σ level with previous results

Re-tuning of Pythia is necessary for realistic estimate of the effect

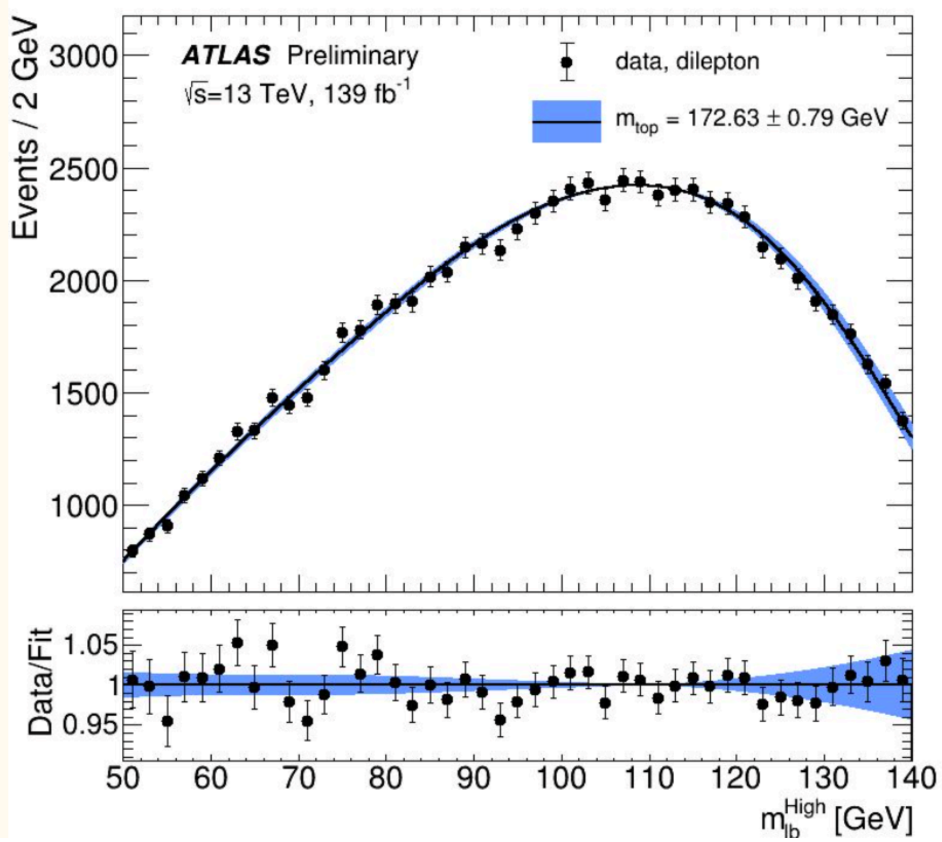
Theory input is welcome

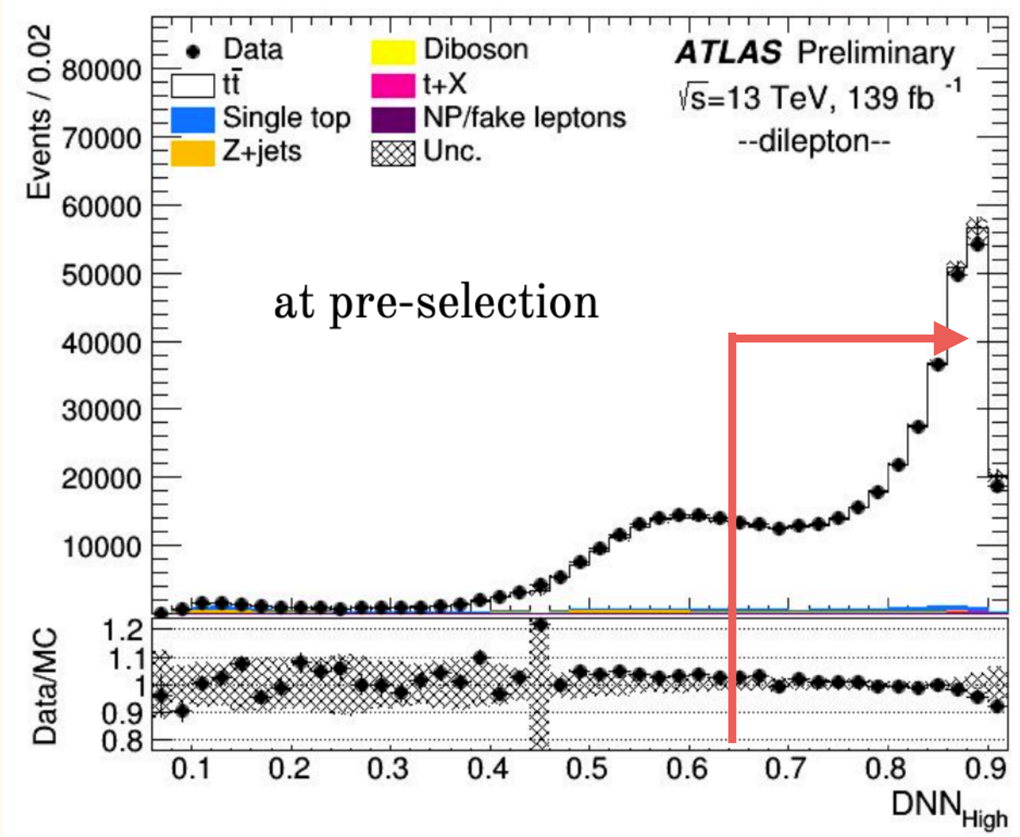
ATLAS mass in dilepton

M. Vanadia
D. Rafanoharana

Template method (similar to 8 TeV)

- DNN to select b/lepton pairings
- Select permutation with highest DNN score





- Optimised selection of lepton-b pair used to mass extraction to reduce uncertainties
- Invariant mass of this pair is used for measurement

$$m_{top}^{dilepton} = 172.63 \pm 0.20\,(\text{stat}) \pm 0.67\,(\text{syst}) \pm 0.37\,(\text{recoil})\ \text{GeV}$$

- Dominant uncertainties from modelling (ME algorithm, ISR/FSR, color reconnections) and JES
- Large effect of recoil uncertainty

Ttbar modelling is the largest challenge for future measurements

Require input from theory and experiments

Searches for FCNC

L.Cerrito

- Improved limit by factors 3.3 to 5.4 from previous analysis

Coupling	BR limits $[10^{-5}]$ Expected	BR limits $[10^{-5}]$ Observed
$t \to u\gamma$ LH	$0.88^{+0.37}_{-0.25}$	0.85
$t \to u\gamma$ RH	$1.20^{+0.50}_{-0.33}$	1.22
$t \to c\gamma$ LH	$3.40^{+1.35}_{-0.95}$	4.16
$t \to c\gamma$ RH	$3.70^{+1.47}_{-1.03}$	4.46

$\mathcal{B}(t \to Zq)\ [10^{-5}]$

tZu	LH	6.2
tZu	RH	6.6
tZc	LH	13
tZc	RH	12

- Improved limit by factors 3 to 5 from previous analysis

Improved limit by x2 from 8 TeV analysis

$\mathcal{B}(t \to u + g) < 0.61 \times 10^{-4}$

$\mathcal{B}(t \to c + g) < 3.7 \times 10^{-4}$

Large impact from systematics

$\mathcal{B}(t \to uH) < 0.94 \times 10^{-3}$ H →ττ
$\mathcal{B}(t \to cH) < 0.69 \times 10^{-3}$

$\mathcal{B}(t \to uH) < 0.79 \times 10^{-3}$ H →bb
$\mathcal{B}(t \to cH) < 0.94 \times 10^{-3}$

$\mathcal{B}(t \to uH) < 0.19 \times 10^{-3}$ H →γγ
$\mathcal{B}(t \to cH) < 0.73 \times 10^{-3}$

$t \to uZ$
$t \to u\gamma$
$t \to ug$
$t \to uH$

$t \to cZ$
$t \to c\gamma$
$t \to cg$
$t \to cH$

- All searches except tgq are statistically limited

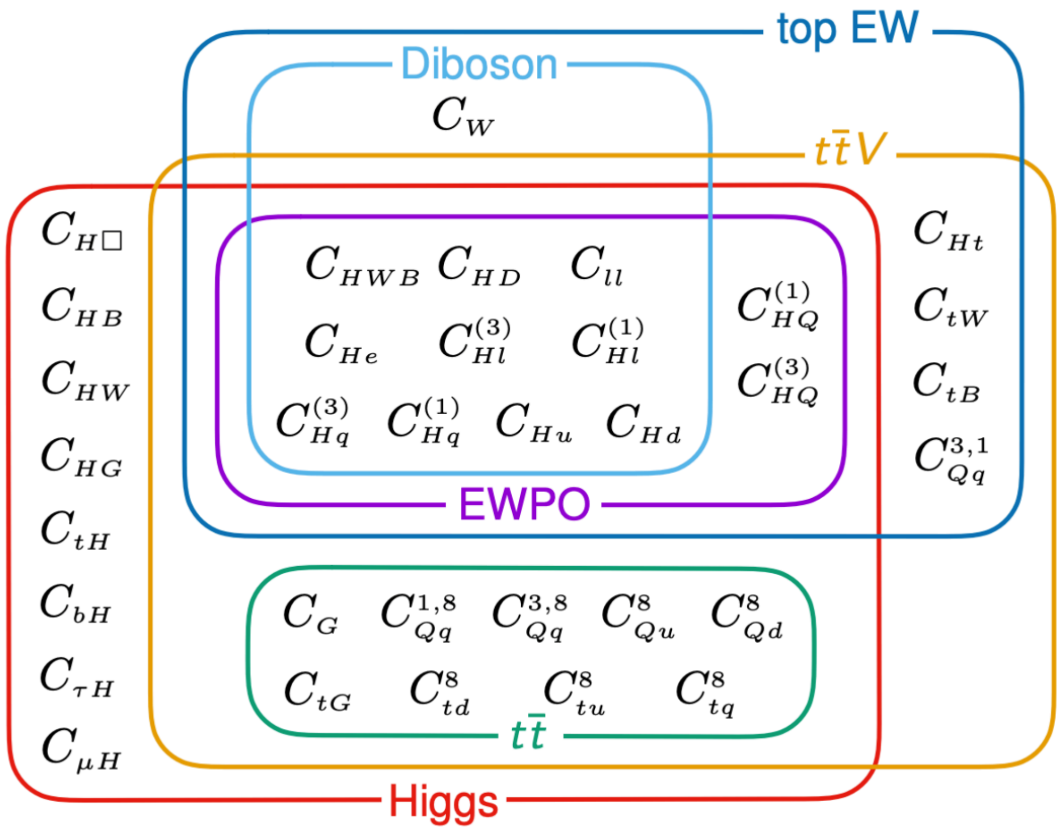
- gained sensitivity by including regions sensitive to couplings in top production and decay

EFT

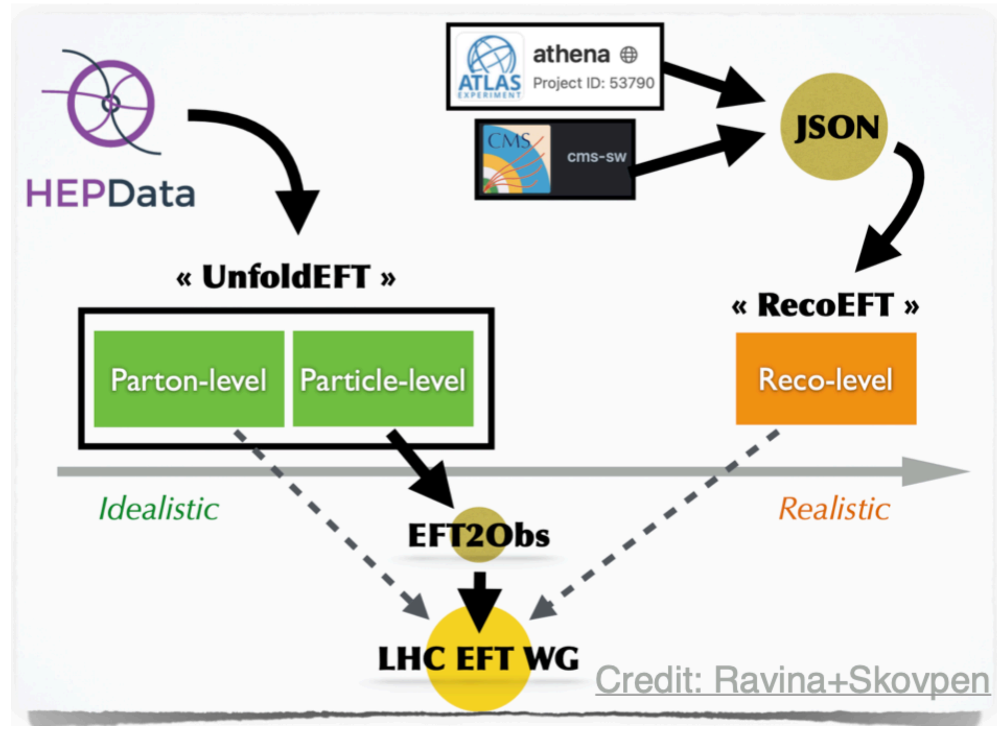
J.McFayden

EFT fits: multidimensional management problem

- Many Top analysis include and even designed to provide EFT interpretations
- Global fit is the goal but there are many steps to go and
- Practical difficulties
  - Different statistical methods (IBU vs FBU, PL vs toys, …)
  - Proper treatment of statistical and systematic correlations
  - Measurements delivered on different timelines
  - Interpretations: different assumptions on "backgrounds" → EFT effects - Hard without coordination!



- Signal model :
  - SMEFT@LO or @NLO?
  - Which operators?
  - Linear/quadratic terms?
  - EFT uncertainties and validity constraints



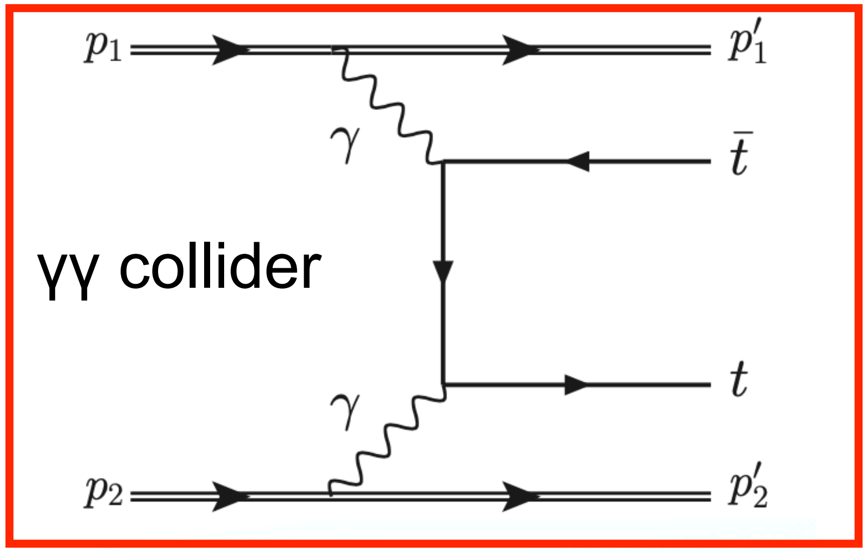
- Run 3 is a good opportunity to solve these issues and perform a global fit across different physics groups and experiments

New ideas: γγ collider

B.Lopez
M.Pitt

Exclusive tt production

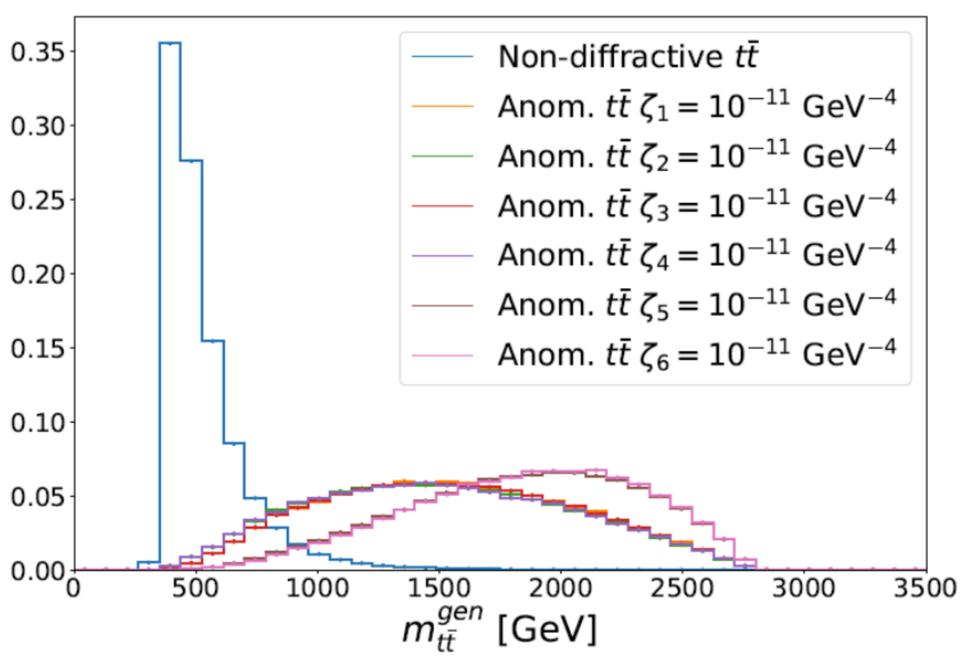
- tγ coupling, BSM
- complementary to traditional ways



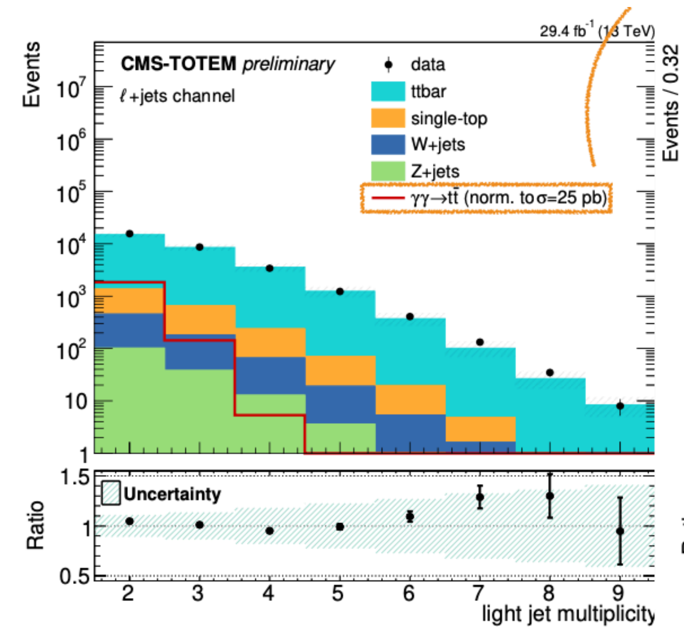
Proton intact

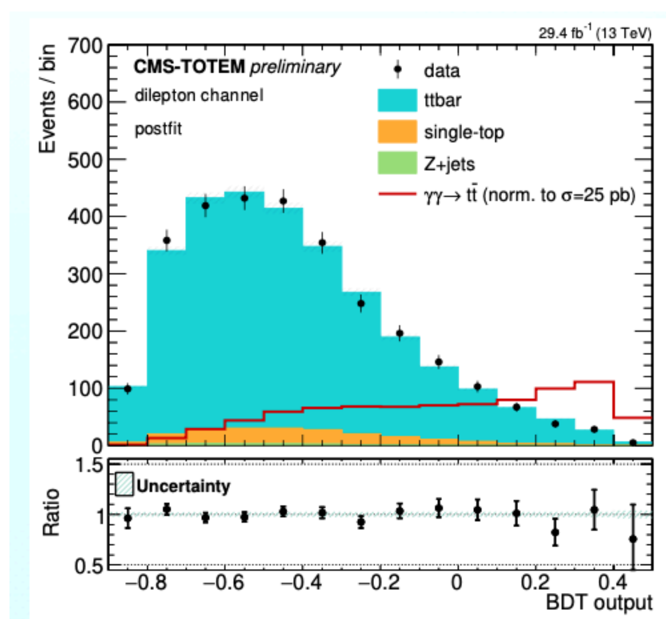
Precision Proton Spectrometer to tag protons

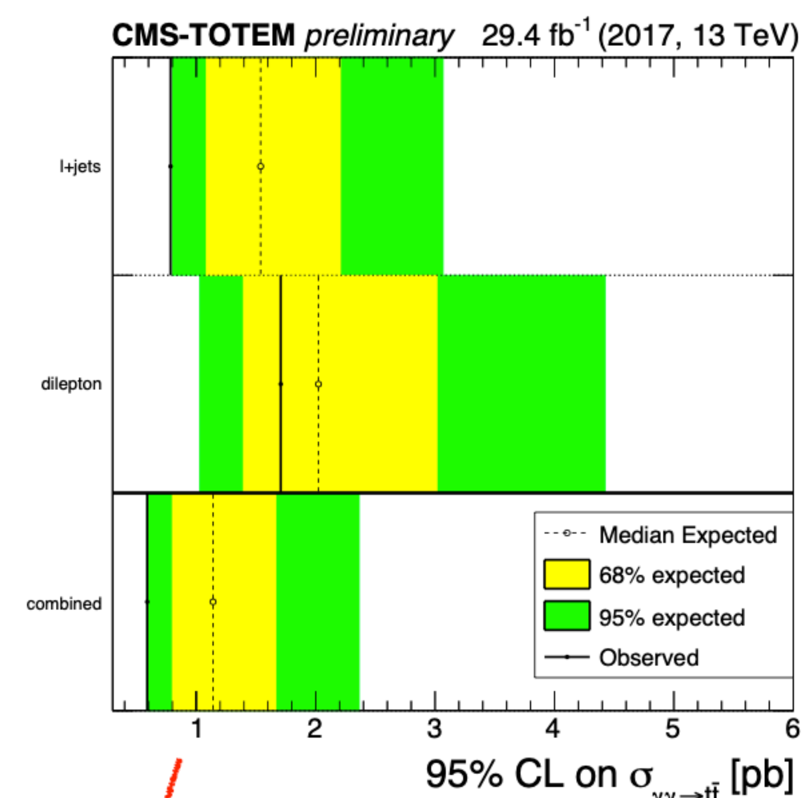
Can be used to probe tγ anomalous



Good sensitivity at high invariant mass





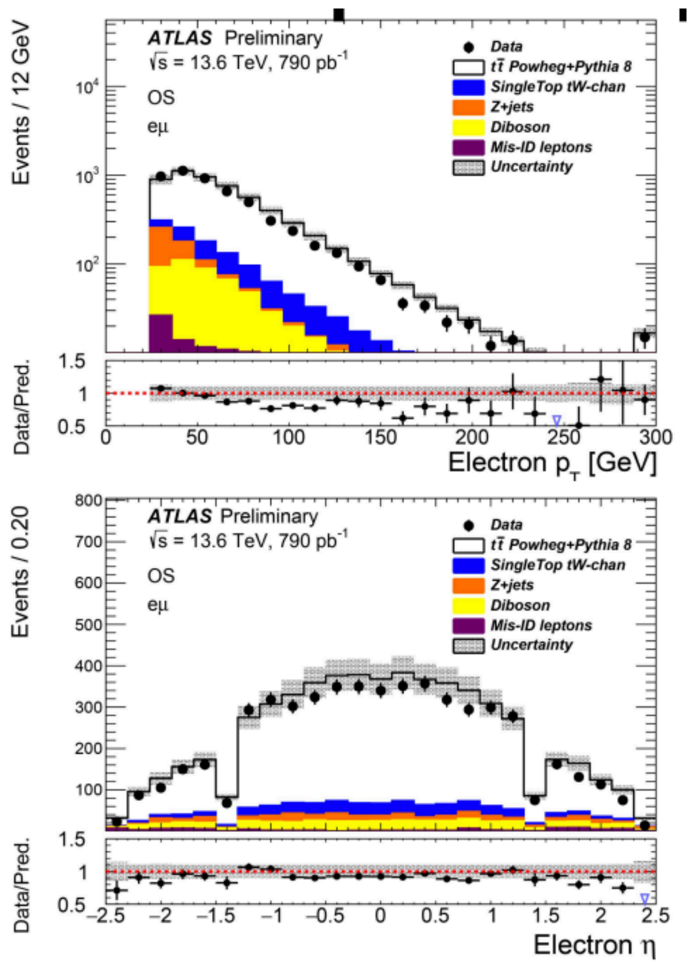


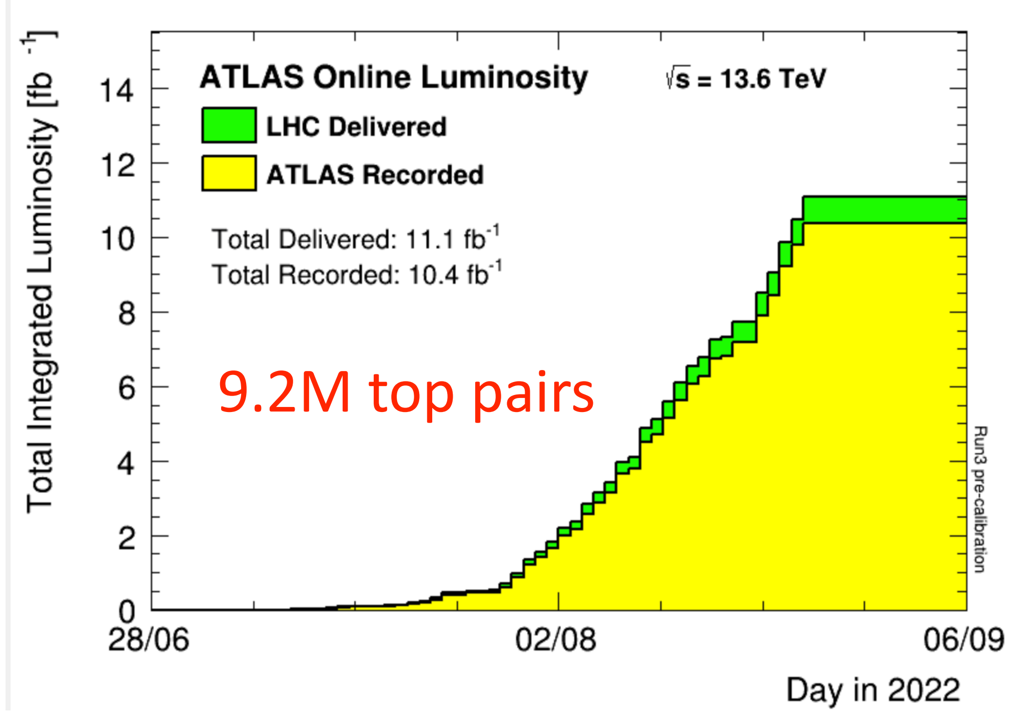
observed 0.59 pb (expected 1.14 pb)

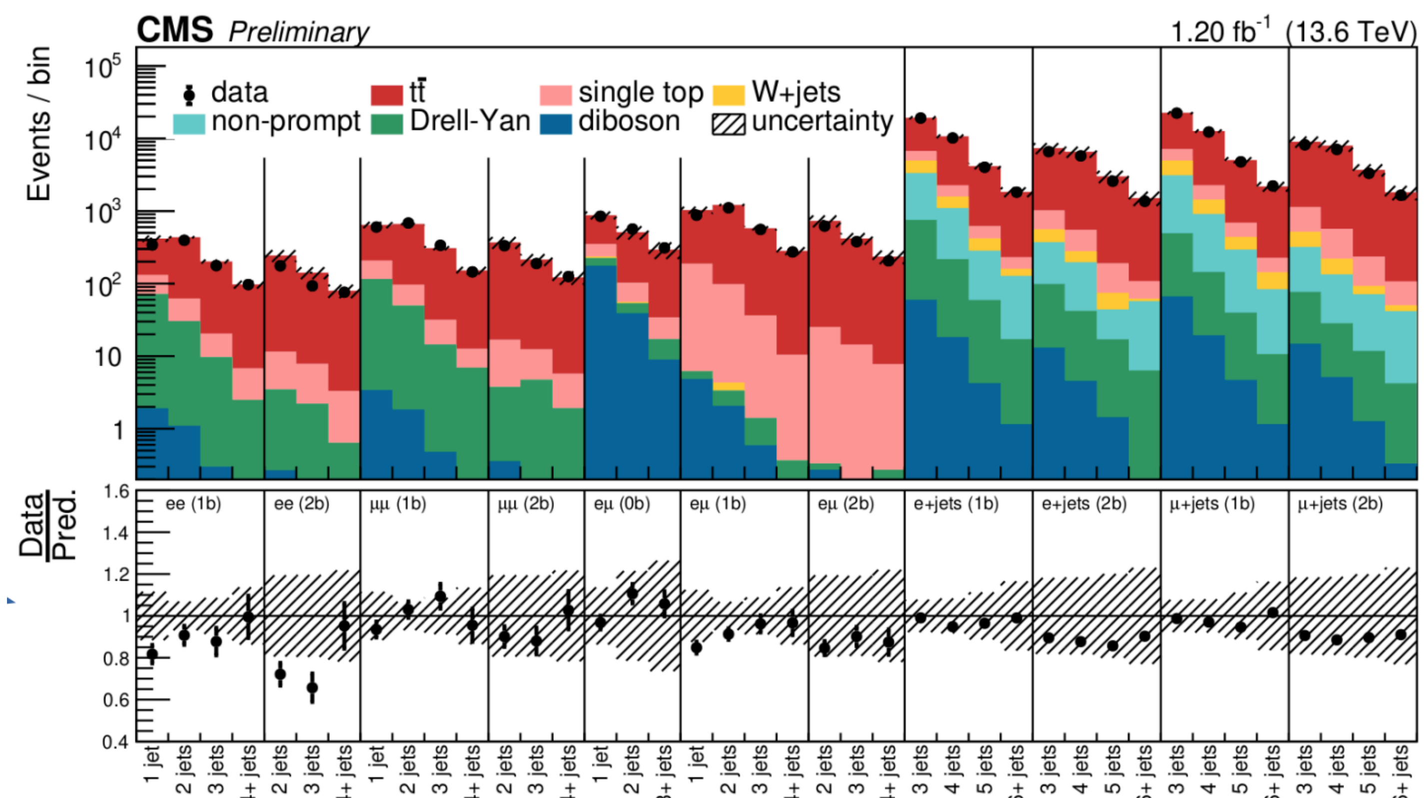
Run 3 started!

- LHC will resume running in 2 weeks
- Top quark is still there!
- Allows to exercise the analysis chain and validate the performance of all components

B.Pavina. L.Jeppe, E.Ranken, G.Guerrieri







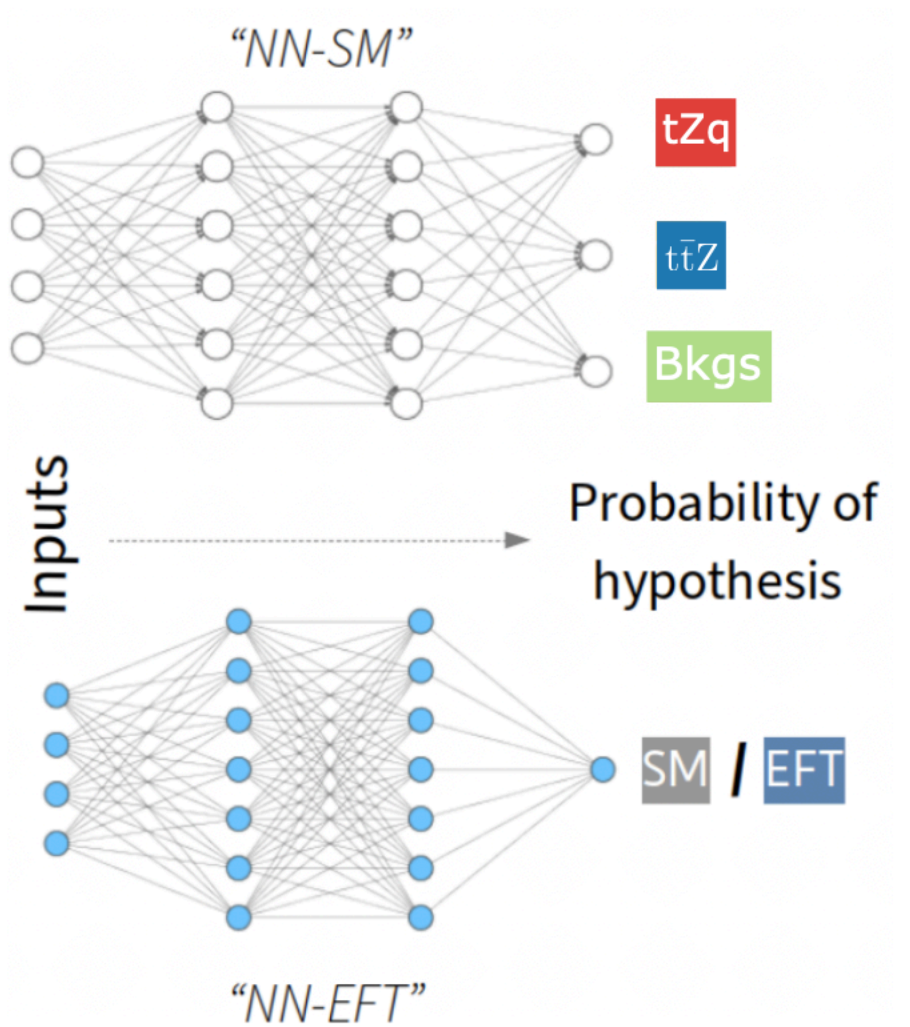
Assuming ~250/fb per experiment at 13.6 TeV and cross section ~920 pb (tt) + ~330 pb (t) run 3 will provide twice more ttbar and single top data sets

$$\sigma_{t\bar{t}} = 887^{+43}_{-41}(\mathrm{stat+sys}) \pm 53(\mathrm{lumi})\ \mathrm{pb}$$

F.Kiecher

Conclusions

- ML has **significant role** in top physics!
- Wide array of strategies and applications, very **active field of research**
  - CMS example [CMS-TOP-21-001]
  - ATLAS example [ATLAS-CONF-2022-049]
- Many **new developments** on-going
  - **DCTR** [PhysRevD.101.091901]
  - But also **much more**! E.g. [TOP22, M. Fenton]



Conclusions

- Many results with full run 2 data set have been presented
- What do we expect from run 3?
  - Measurements in t(t)+X final states and FCNC searches are statistically limited
  - More data will allow for reaching higher jet pT or higher masses sensitive to BSM and EFT parameters
- Global EFT fit should be the goal of run 3
  - from one parameter one analysis to many analysis/parameters/experiments
  - given the complexity of the task we have to put together a plan now
- and MC, MC, MC…. we have huge number of precisely measured differential distributions
  - when and how we will benefit from this information?
- Theoretical advancements are still necessary to improve simulation and to understand / reduce uncertainties

Thank you !

See you next year at Top 2023

Backup

3D mass and threshold effect

How big are threshold effects?

JHEP 06 (2020) 158

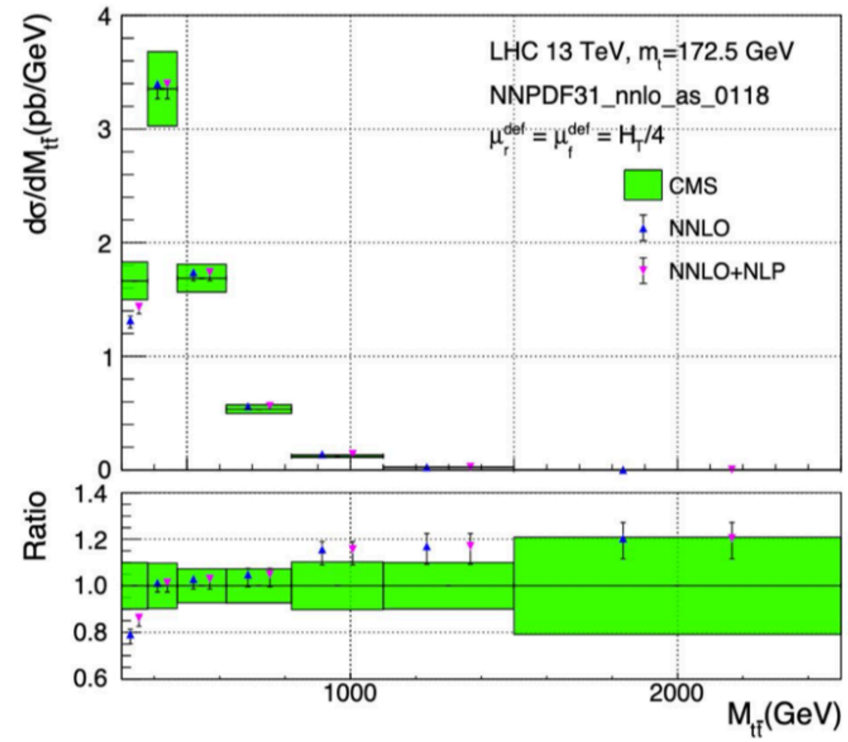
Short answer: we don't really know

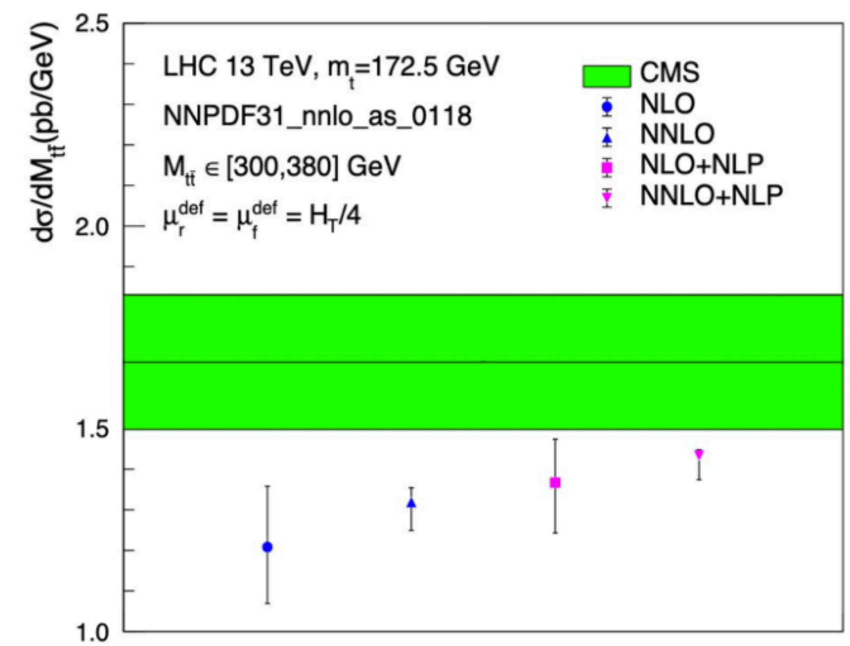
A study by Li Lin Yang et. al. based on next-to-leading power resummation suggests that the effect in the CMS 3D analysis (previous slide) can be as large as +1.4 GeV

This would lead to m_t^{pole} = 171.9 ± 0.8 GeV, in better agreement with other pole mass measurement

However, there is no consensus in the theory community on the presented NNLO+NLP results, and therefore we do not have a conclusive answer on the issue

- This is currently the **limiting factor** of indirect m_t measurement at threshold at the LHC
- Hard to think of consistent ways to assess the size of such uncertainty in the absence of a calculation





Matteo M. Defranchis (CERN)