Top quark production at the LHC

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on behalf of the ATLAS and CMS Collaborations

15TH MARCH 2016

Outlook

- The talk is organised as follows
  - Rates and dynamics of top quark pair production
  - Testing the EW couplings through single top production
  - Conclusions

- A review of the latest results on top production at the LHC is given
  - emphasis is put on 13 TeV results and latest "legacy" LHC Run I results
  - attempt for a summary of what have we learnt so far and what lies ahead

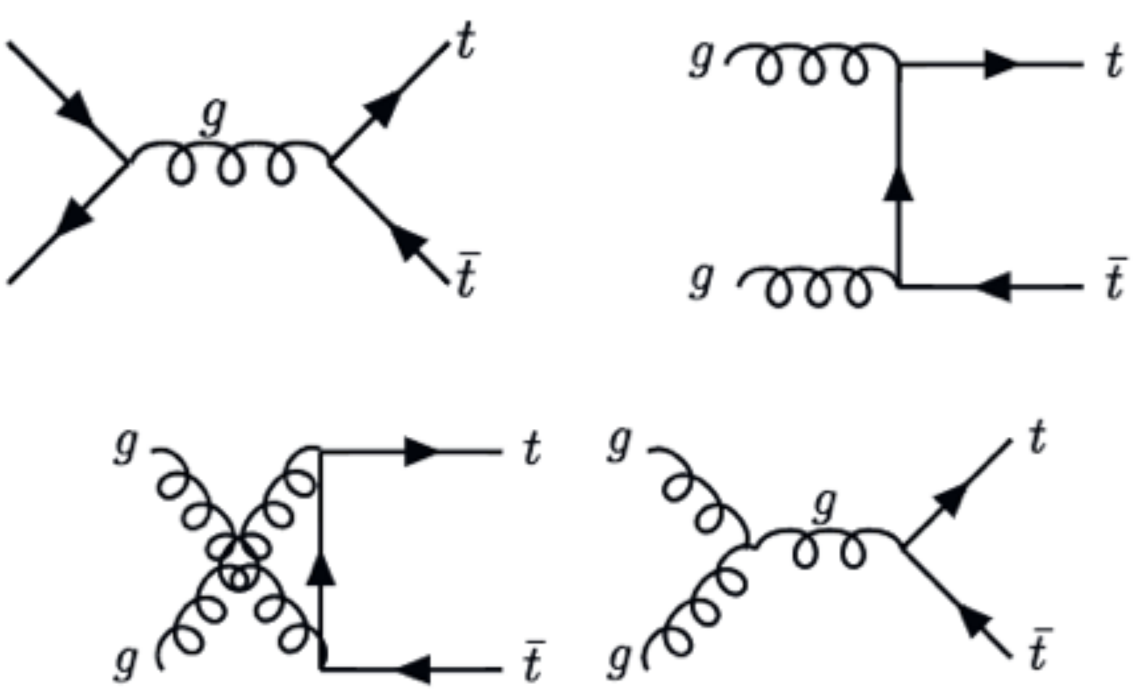
- Many more results can be found in
  - ATLAS public page https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
  - CMS public page https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Rates and dynamics of top quark pair production

Latest results on inclusive and differential $pp \to tt$ measurements:

interplay with fundamental parameters (m_t, α_S) and searches for new physics;

testing perturbative QCD predictions.



$$\sigma(7\ \mathrm{TeV}) = 177\ \mathrm{pb} \pm 7\%$$

$$\sigma(8\ \mathrm{TeV}) = 253\ \mathrm{pb} \pm 6\%$$

$$\sigma(13\ \mathrm{TeV}) = 832\ \mathrm{pb} \pm 5\%$$

$$R_{13/8} = 3.28$$

NNLO+NNLL predictions (arXiv:1112.5675)

Why is top quark pair production (still) interesting?

- Pair production is dominated by strong interactions
  - sensitivity to mass[4] : $\hat{\sigma} \propto (\frac{\alpha_S}{m_t})^2 f(\alpha_S, \beta)$
  - furthermore **differential distributions are sensitive to the width and to EW corrections**

Precise cross section measurements open the door to measure fundamental constants and test new physics

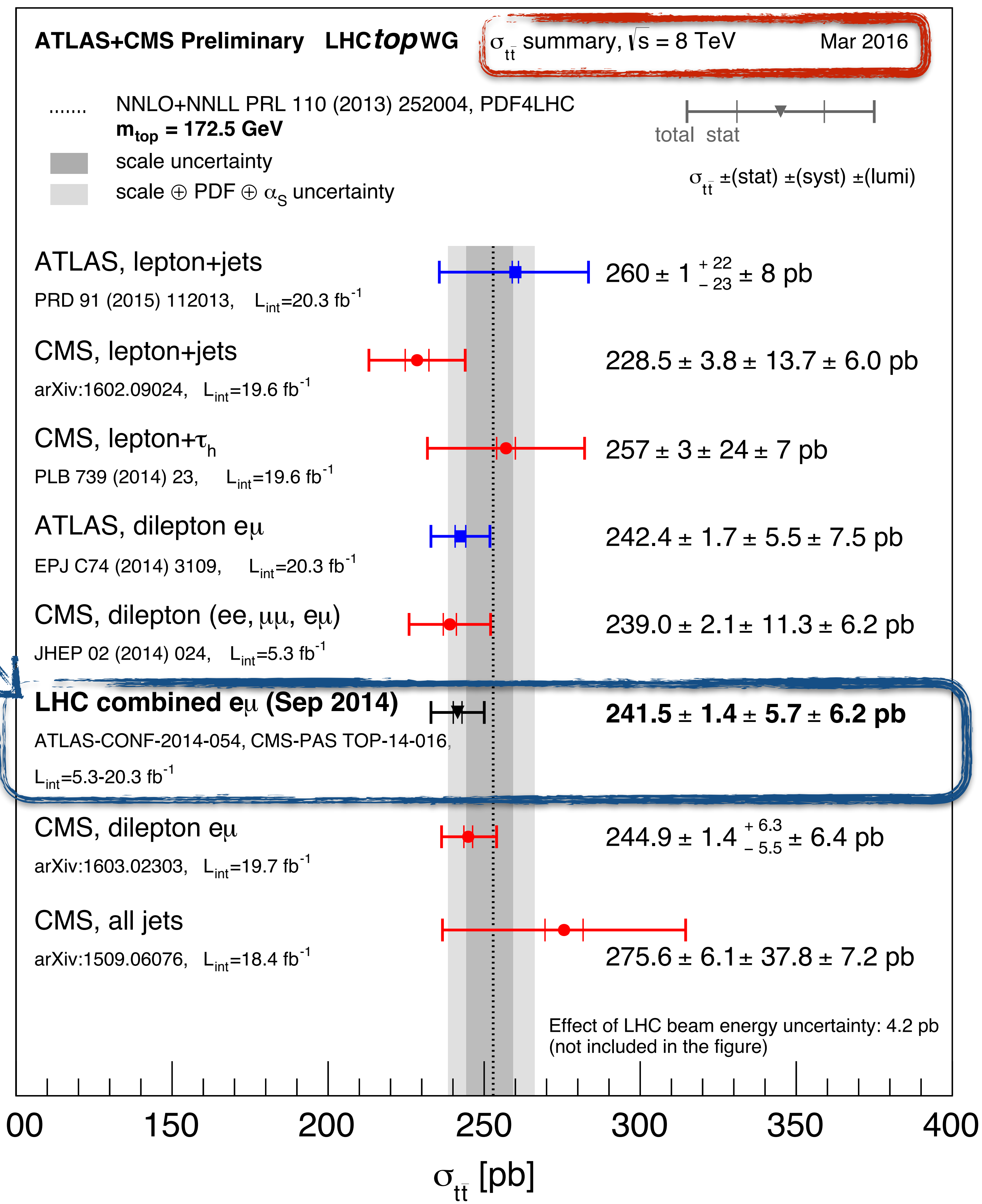
- Typical time scales allow to study the properties of a bare quark

$$\underbrace{\frac{1}{m_t}}_{\substack{\text{production} \\ 10^{-27}\ \text{s}}} < \underbrace{\frac{1}{\Gamma_t}}_{\substack{\text{lifetime} \\ 10^{-25}\ \text{s}}} < \underbrace{\frac{1}{\Lambda_{QCD}}}_{\substack{\text{hadronization} \\ 10^{-24}\ \text{s}}} < \underbrace{\frac{m_t}{\Lambda^2}}_{\substack{\text{spin-flip} \\ 10^{-21}\ \text{s}}}$$

- Top quarks couple to all interactions
  - privileged coupling to the Higgs - $Y_t \approx 1$ to be established directly by experiments
  - decays ruled by EW interactions: **$t \rightarrow Wb$ dominates as $V_{tb} \approx 1$**
  - W decay chain generates a **plethora of final states: all jets, lepton+jets, dileptons**

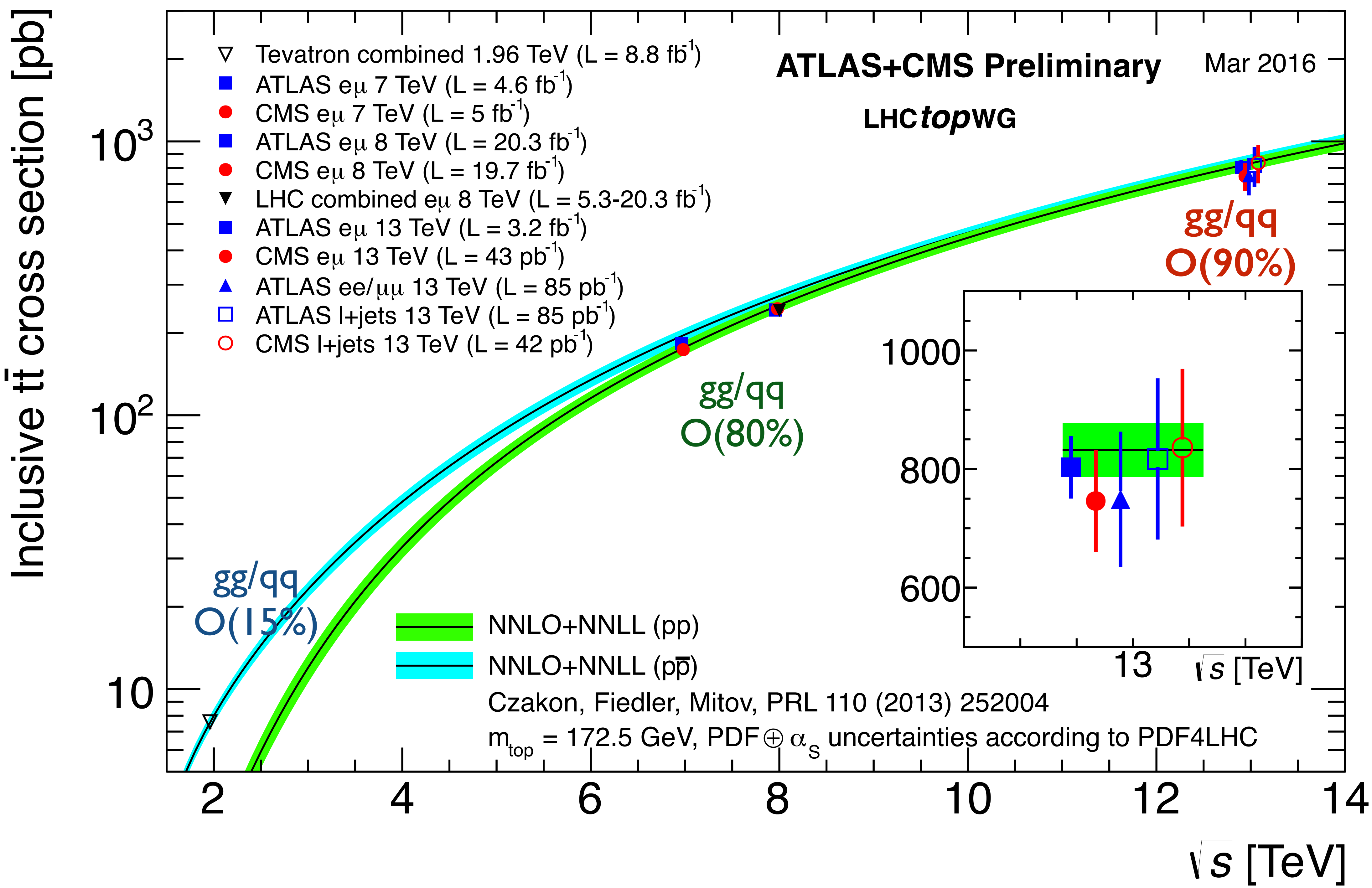
σ(tt) : status after Run I

- **All final states covered**
  - fair agreement for different analysis
  - no tension with respect to the SM
    NNLO+NNLL prediction for m_t=172.5 GeV
- **Dilepton analyses lead in precision**
  - electron+muon + jets final state
  - high purity sample (~90%)
  - large acceptance due to loose cuts
- **LHCb has also observed top production in the forward region**
  PRL 115, 112001 (2015)
  (won't cover in this talk)



σ(tt) has been promptly measured at 13 TeV

- **Re-established tt production at 13 TeV with very early data : <100 pb^{-1}**
- Evolution as function of $s^{1/2}$ seems well understood: tt can be used as a "gluon luminometer"



Early cross section measurements I

PRL 116, 052002 (2016)

- Focused on **counting high purity eμ events**
- **Typical requirements:** 2 op. sign leptons (p_T>20 GeV |η|<2.5)

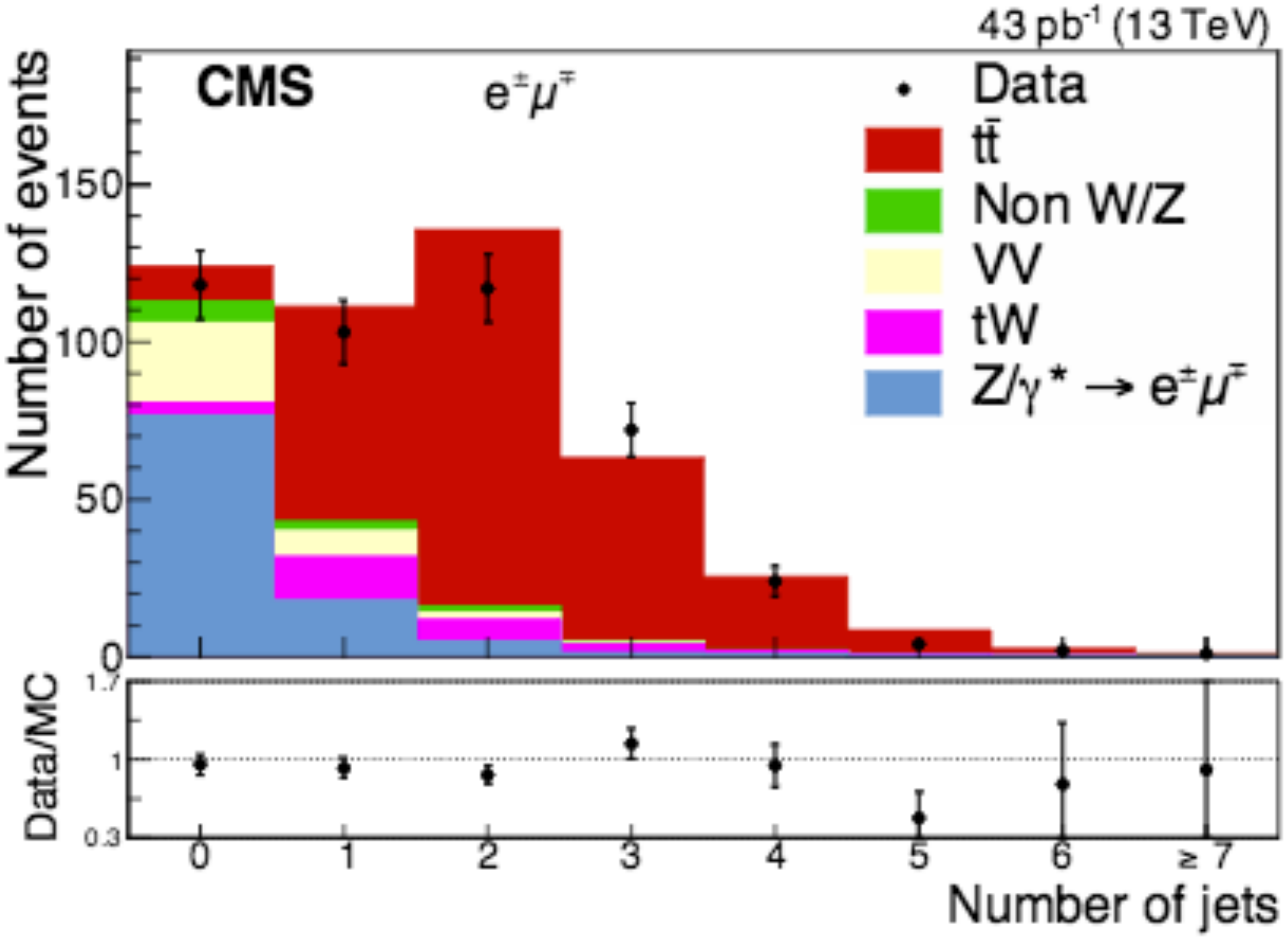
  at least two jets (p_T>30 GeV |η|<2.5)

- **Backgrounds**
  - **single resonant production tW** dominates
  - Drell-Yan/fake leptons : estimated in data
- **Main uncertainties:**

Source	Δσ/σ (%)
Statistics	7.8
Luminosity	4.8
Trigger/selection	5.6
Signal modelling	2.6
PDF	2.4
Backgrounds	2.1

$$\sigma_{t\bar{t}} = 746 \pm 58_{\text{stat}} \pm 53_{\text{syst}} \pm 36_{\text{lumi}}\ \text{pb}$$

Δσ/σ≈11%



Expect partial scaling of exp. with more data: integ. luminosity/efficiencies/energy scales

Early cross section measurements II

NEW ATLAS-CONF-2016-005

- Beyond counting : **profit from statistics to constraint in-situ some systematics**
  - count jets identified as coming from the hadronization of a b quark
  - counts in each category are related by the **b-identification efficiency ($\varepsilon_b \approx 70\%$)**

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

$$N_2 = L\sigma_{t\bar{t}}\, \epsilon_{e\mu} C_b \epsilon_b^2 + N_2^{\mathrm{bkg}}$$

- **Extrapolation to full phase space volume yields**

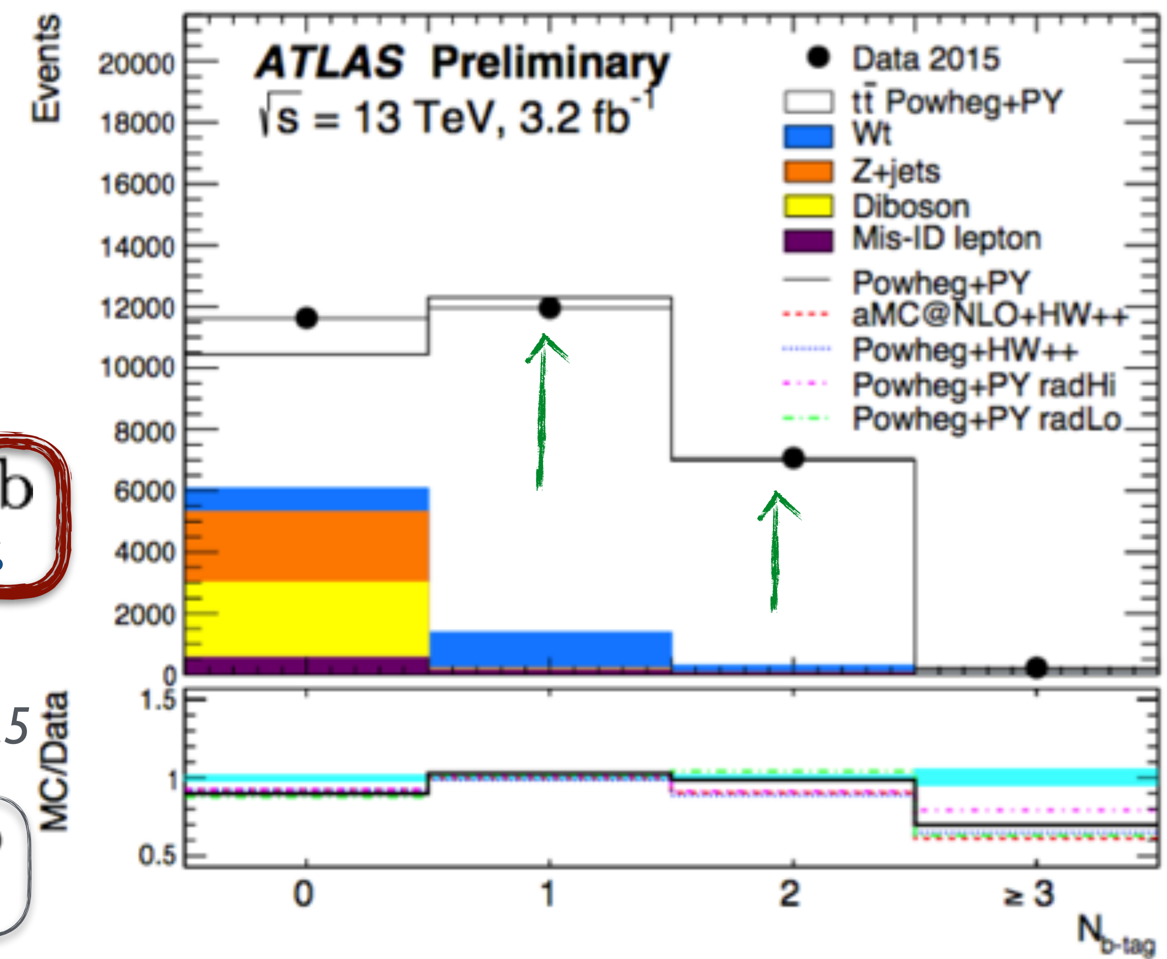
$$\sigma_{t\bar{t}} = 803 \pm 7_{\mathrm{stat}} \pm 27_{\mathrm{syst}} \pm 45_{\mathrm{lumi}} \pm 12_{\mathrm{beam}}\ \mathrm{pb}$$

$\Delta\sigma/\sigma \approx 6.7\%$

- Measurement in the fiducial volume *1e+1μ with $p_T(\ell)>25$ GeV $|\eta|<2.5$*

$$\sigma_{t\bar{t}}^{\mathrm{fid}} = 11.12 \pm 0.10_{\mathrm{stat}} \pm 0.28_{\mathrm{syst}} \pm 0.62_{\mathrm{lumi}} \pm 0.17_{\mathrm{beam}}\ \mathrm{pb}$$

$\Delta\sigma/\sigma \approx 6.3\%$



Main uncertainties:

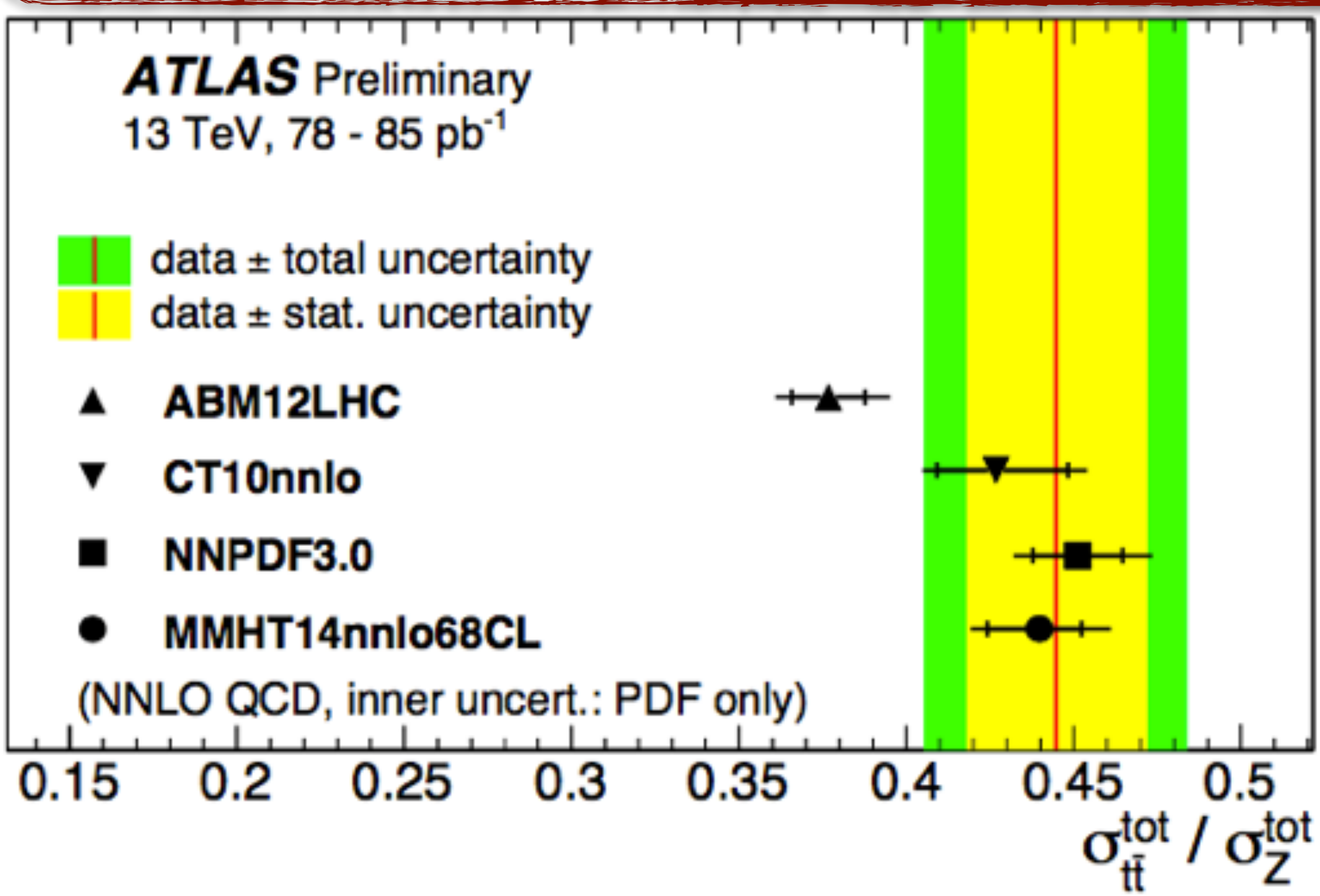
Δσ/σ (%)	Statistics	Luminosity	Trigger/ selection	Signal modelling	Backgrounds
fiducial / total	0.9	5.5	0.7	2.0 / 2.9	0.9

Using top quarks as gluon luminometers

ATLAS-CONF-2015-049

- Ratios of cross sections are expected to cancel out some of the systematic uncertainties
  - compare to SM predictions : test parton luminosities, search for new physics effects
- Ratio to Z production tests qq/gg ratio
  - improves on luminosity (1%), trigger/lepton selection efficiencies (2.2%)
  - uncertainties in Z/tt modelling and backgrounds are similar

$$R^{\mathrm{CT10nnlo}}_{t\bar{t}/Z} = 0.427^{+0.022}_{-0.013}\ (\mathrm{PDF})\ ^{+0.012}_{-0.016}\ (\mathrm{QCD\ scale})\ ^{+0.005}_{-0.004}\ (\alpha_s)$$



- **PDF predictions tested mostly compatible with data**
  - 2σ tension with prediction based on ABM12LHC (smaller gg density)

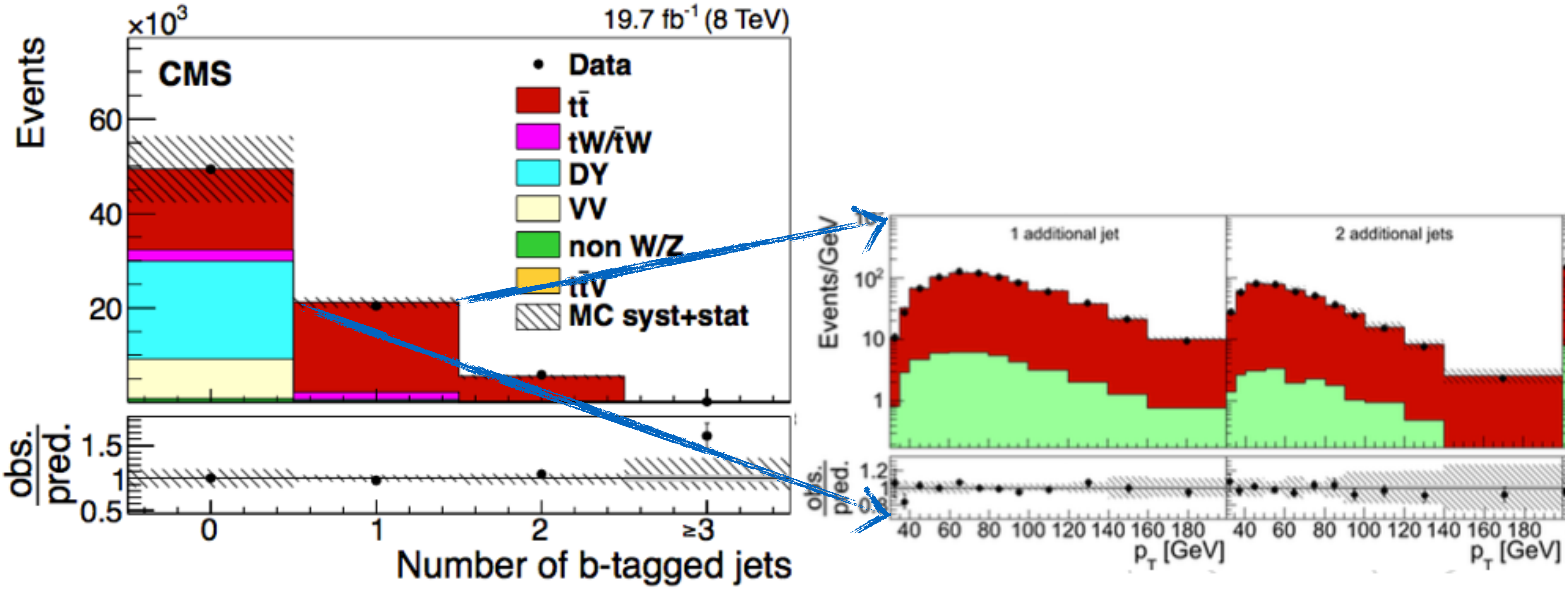
Still large room to explore different ratios in Run 2, also at different $s^{1/2}$, to constraint further PDFs

Eroding the systematics wall

NEW arXiv:1603.02303 *sub to JHEP*

see also arXiv:1602.09024

- Measurements are **systematics limited but can improve with larger datasets**
  - study differentially event categories in eμ for signal/background discrimination / modelling sensitivity
  - **statistical analysis constraints backgrounds and main systematic uncertainties (visible phase space)**



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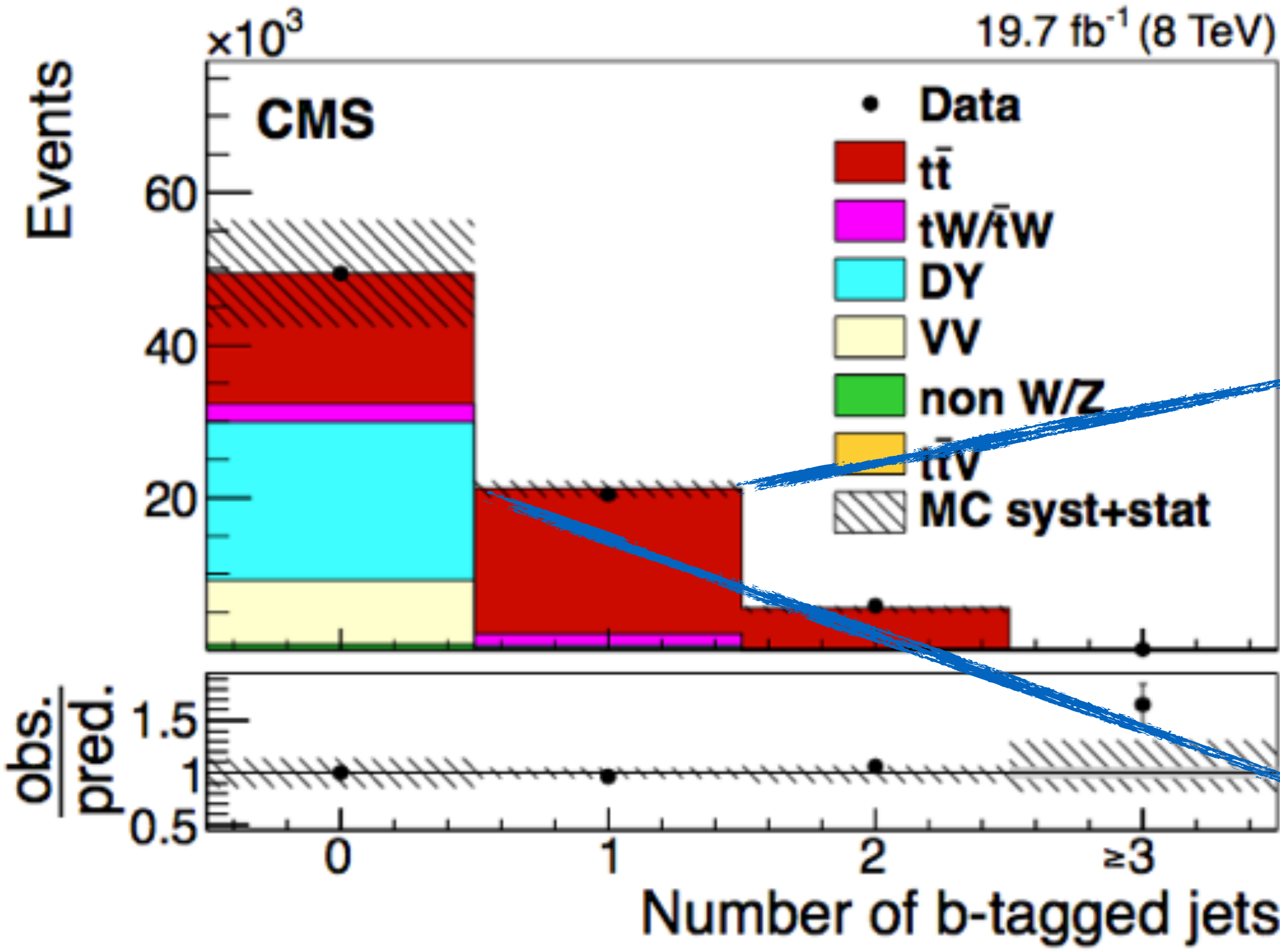
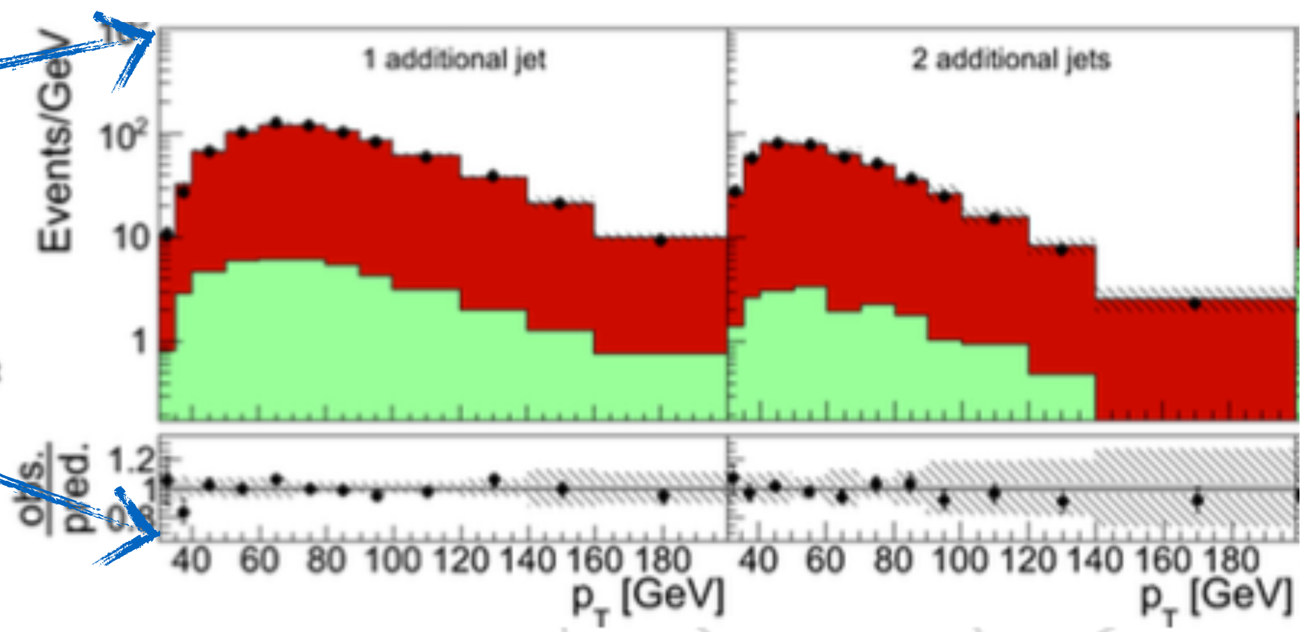


$$\sigma_{t\bar{t}}^{7\,\mathrm{TeV}} = 173.6 \pm 2.1\,(\mathrm{stat})^{+4.5}_{-4.0}\,(\mathrm{syst}) \pm 3.8\,(\mathrm{lumi})\,\mathrm{pb}$$
$$\sigma_{t\bar{t}}^{8\,\mathrm{TeV}} = 244.9 \pm 1.4\,(\mathrm{stat})^{+6.3}_{-5.5}\,(\mathrm{syst}) \pm 6.4\,(\mathrm{lumi})\,\mathrm{pb}$$

Δσ/σ=3.7%



Main uncs.

Source	Stats	Luminosity	Trigger/ selection	Signal modelling	Backgrounds	Extrapolation (signal model)
Δσ/σ (%)	0.6	2.6	2.0	1.1	1.6	0.7

Expect methods to evolve and benefit from higher statistics in Run II

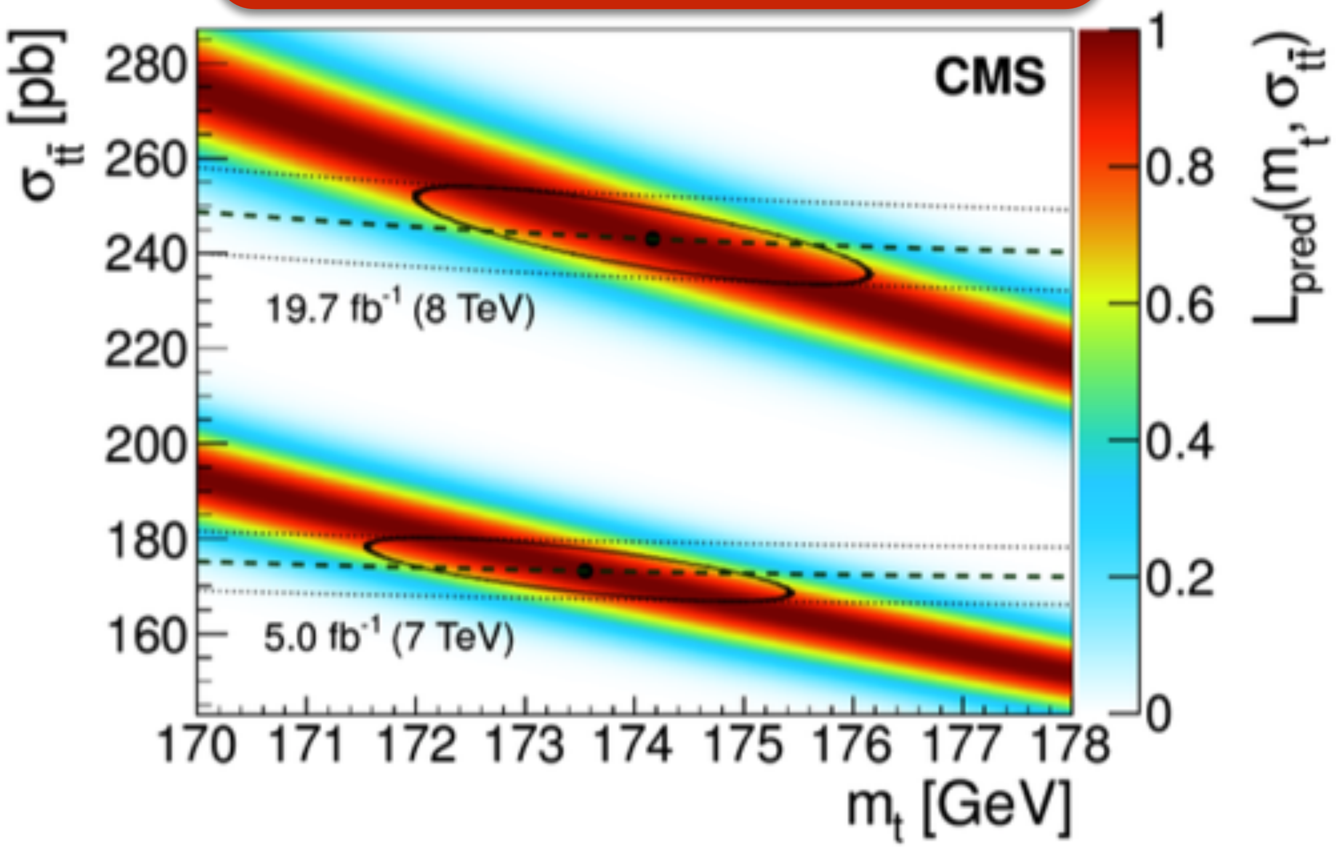
Pole mass extraction

- **Top mass extraction at fixed order scheme**
  - need full phase space extrapolation
  - benefits from loose selections ⇒ flat acceptance
  - assume α_s and PDF and compare to theory

$$m_t^{\mathrm{pole}} = 173.8^{+1.7}_{-1.8}\ (\mathrm{GeV})$$

Δm/m=1%

NEW arXiv:1603.02303 *sub to JHEP*



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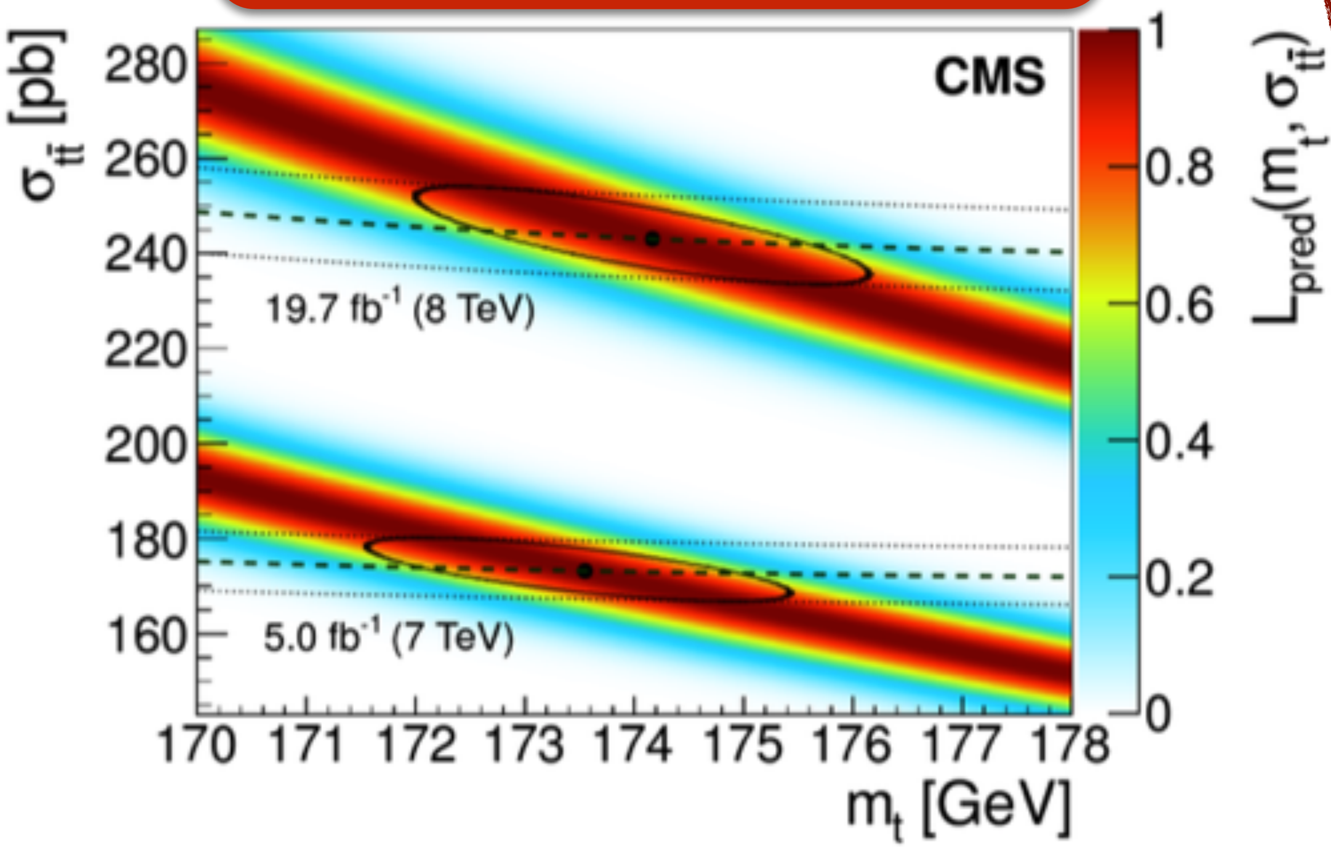
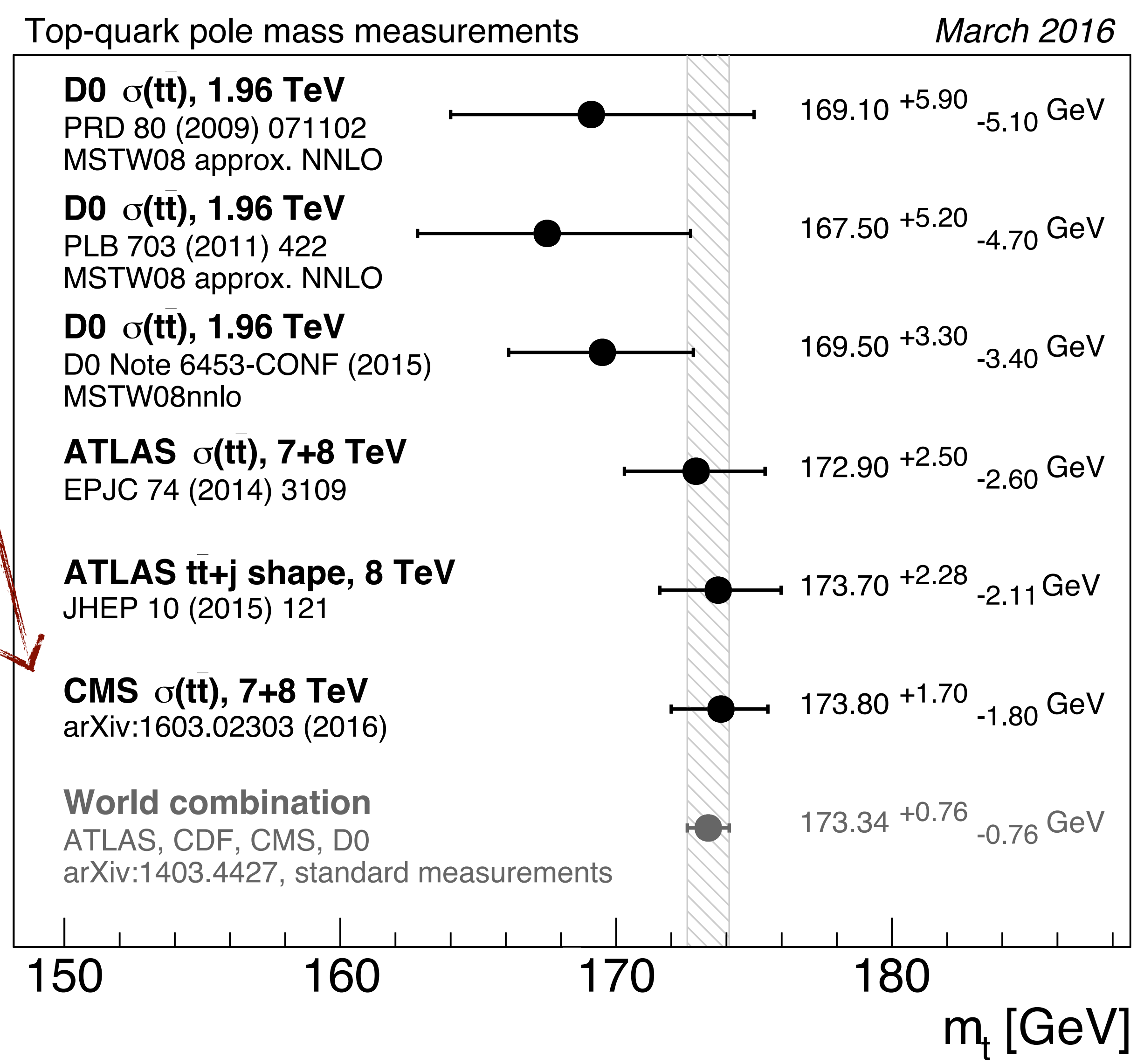


- **How far do we need go experimentally?**
  - assuming current $\delta\sigma_{th}^{NNLO} \approx 5.5\%$ PRL110 (2013) 252004
  - may reach **$\delta m_t^{pole} \approx 0.5\%$ if $\delta\sigma_{exp} \approx 2\%$**

For more details on top mass see - B. Stieger's talk

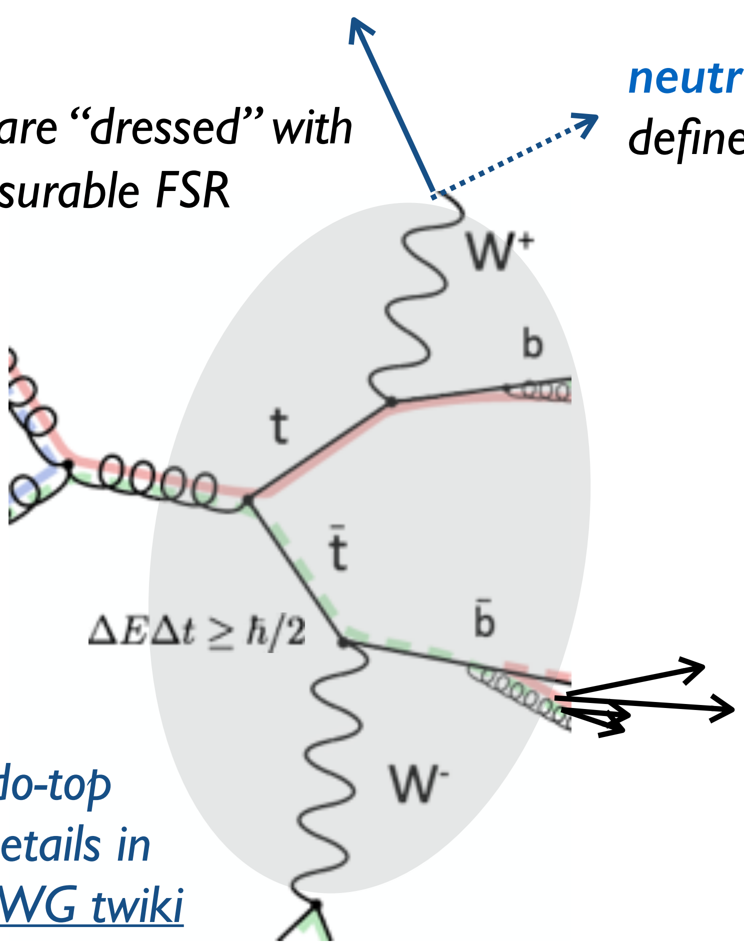


Differential cross section measurements

- **Provide additional constraints on m_t, α_S, PDF, pQCD, new physics**
  - use final state products to reconstruct top quark candidates
  - compare to theory ⇒ "unsmear" data for reconstruction, resolution, parton shower effects
- **Whenever possible find theory-safe definitions** (pseudo-top)
  - mimic at particle level the selections and reconstruction algorithms
- **Comparisons to fixed order computations require "unsmearing" to parton level**

leptons are "dressed" with non-measurable FSR

neutrinos are used to define missing E_T

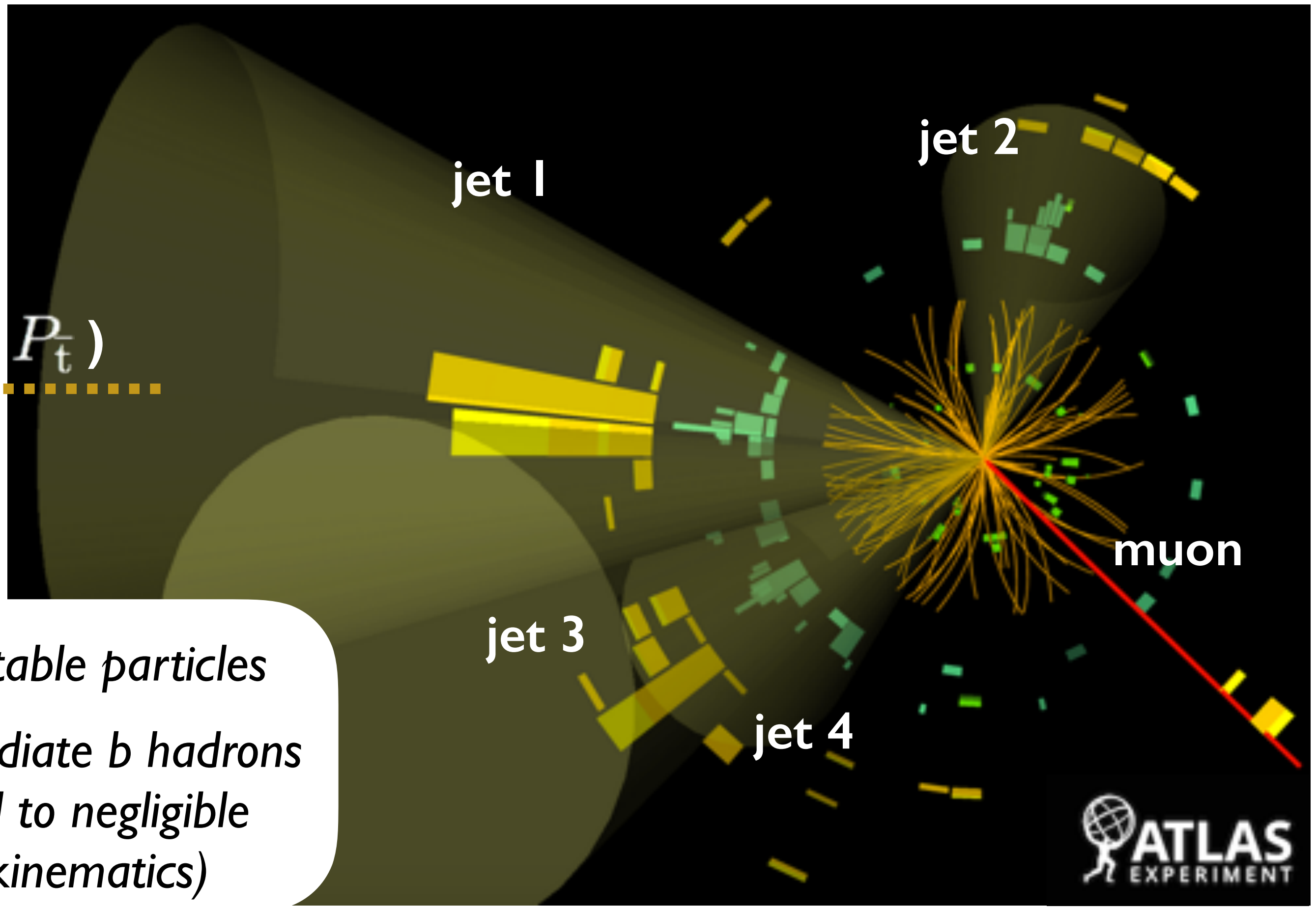


Jets clustered from stable particles

b jets cluster intermediate b hadrons (momentum re-scaled to negligible value to preserve jet kinematics)

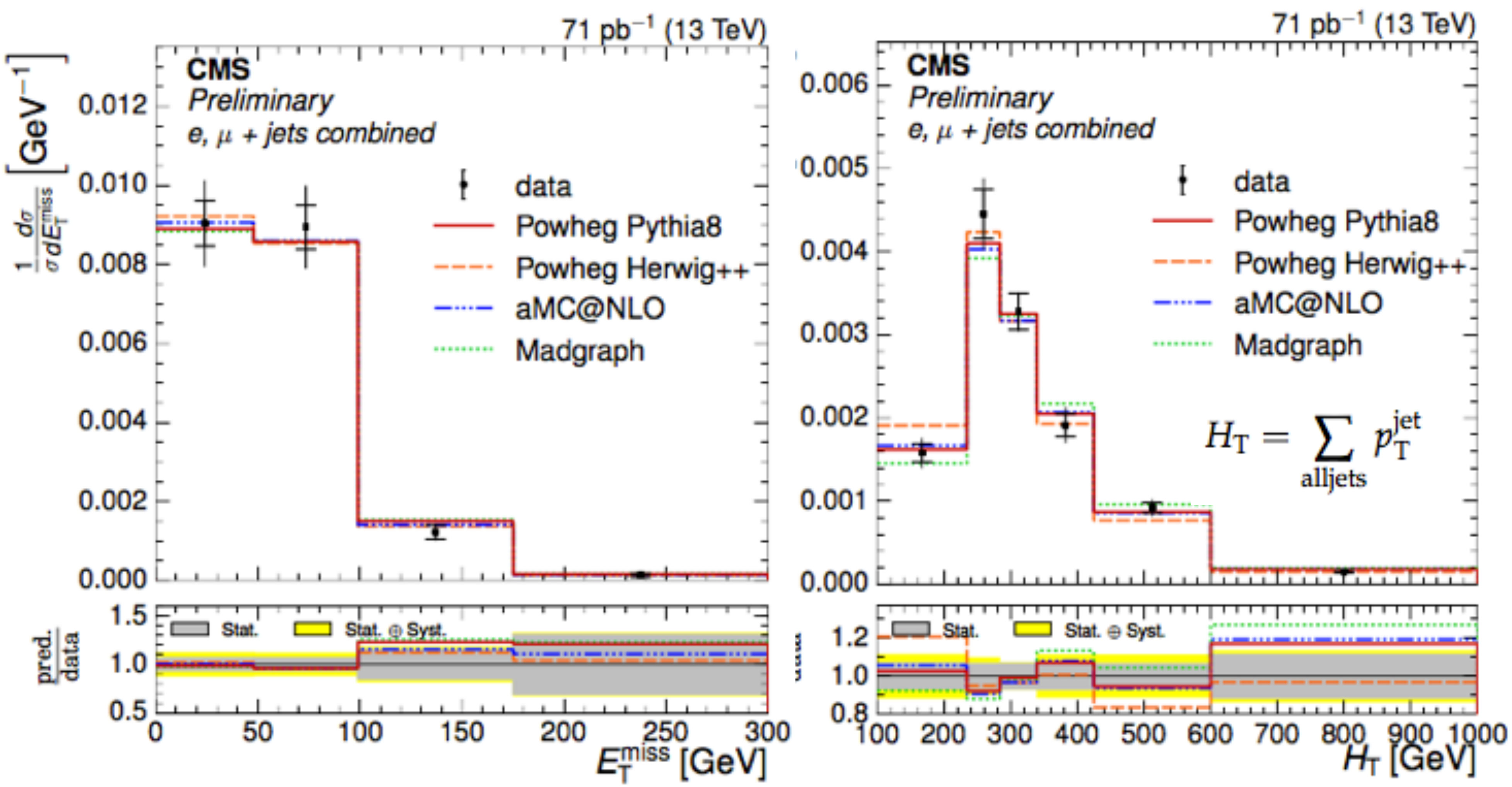
Pseudo-top more details in LHCTOPWG twiki

$f^{-1}(P_t, P_{\bar{t}})$



Global event description I

- **Impacts searches e.g. ttH→invisible/bb / SUSY** which are produced in the bulk/tails of tt events
- **Early analysis** using lepton+jets final state indicates **no significant deviation from predictions**
  - corrections are made to particle level (no kinematics reconstruction involved)
  - statistics dominated, main systematics from signal model used to derive unfolding corrections
  - **test NLO + Parton Shower (PS) generators and tunes used in Run 2**

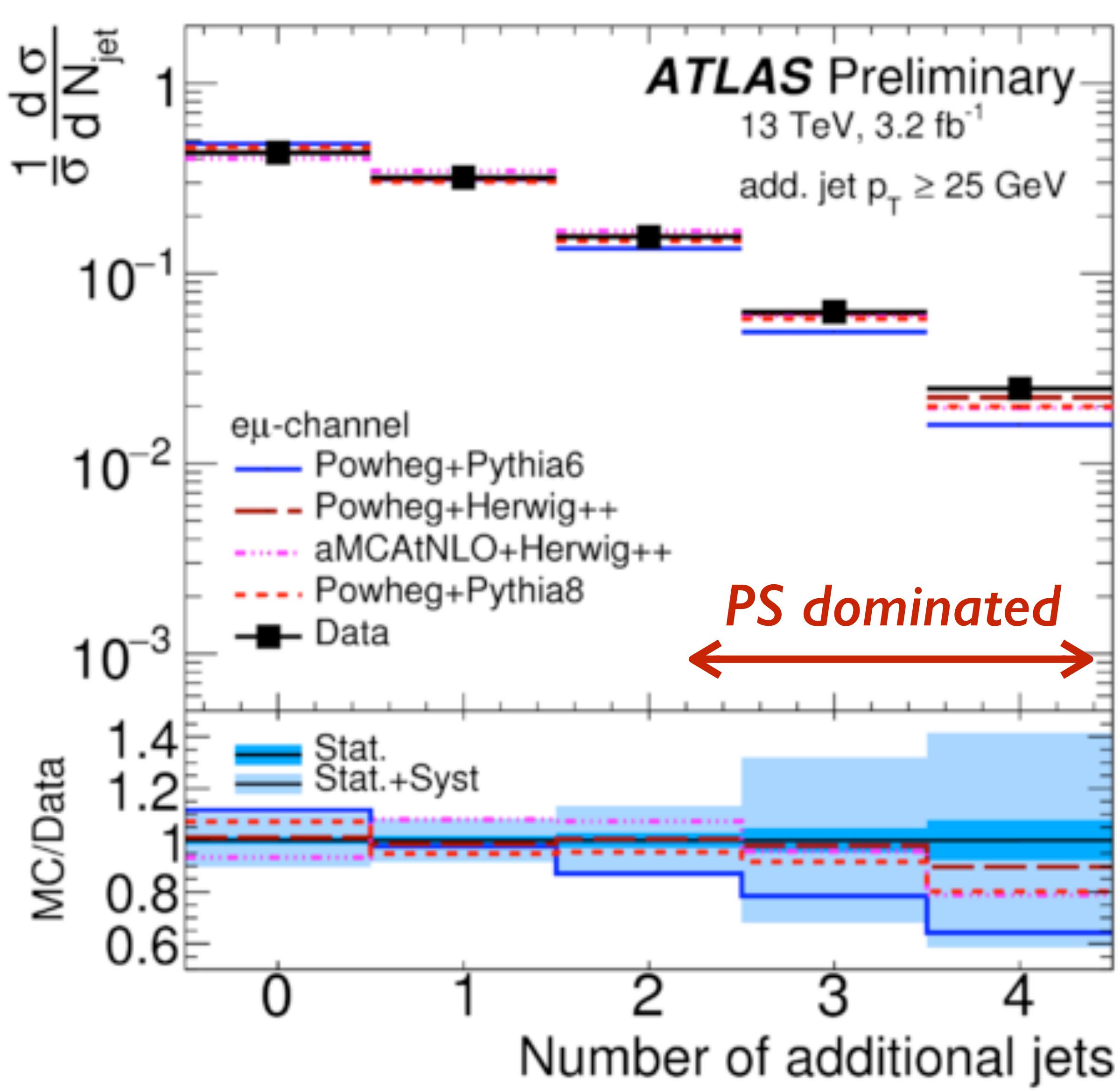


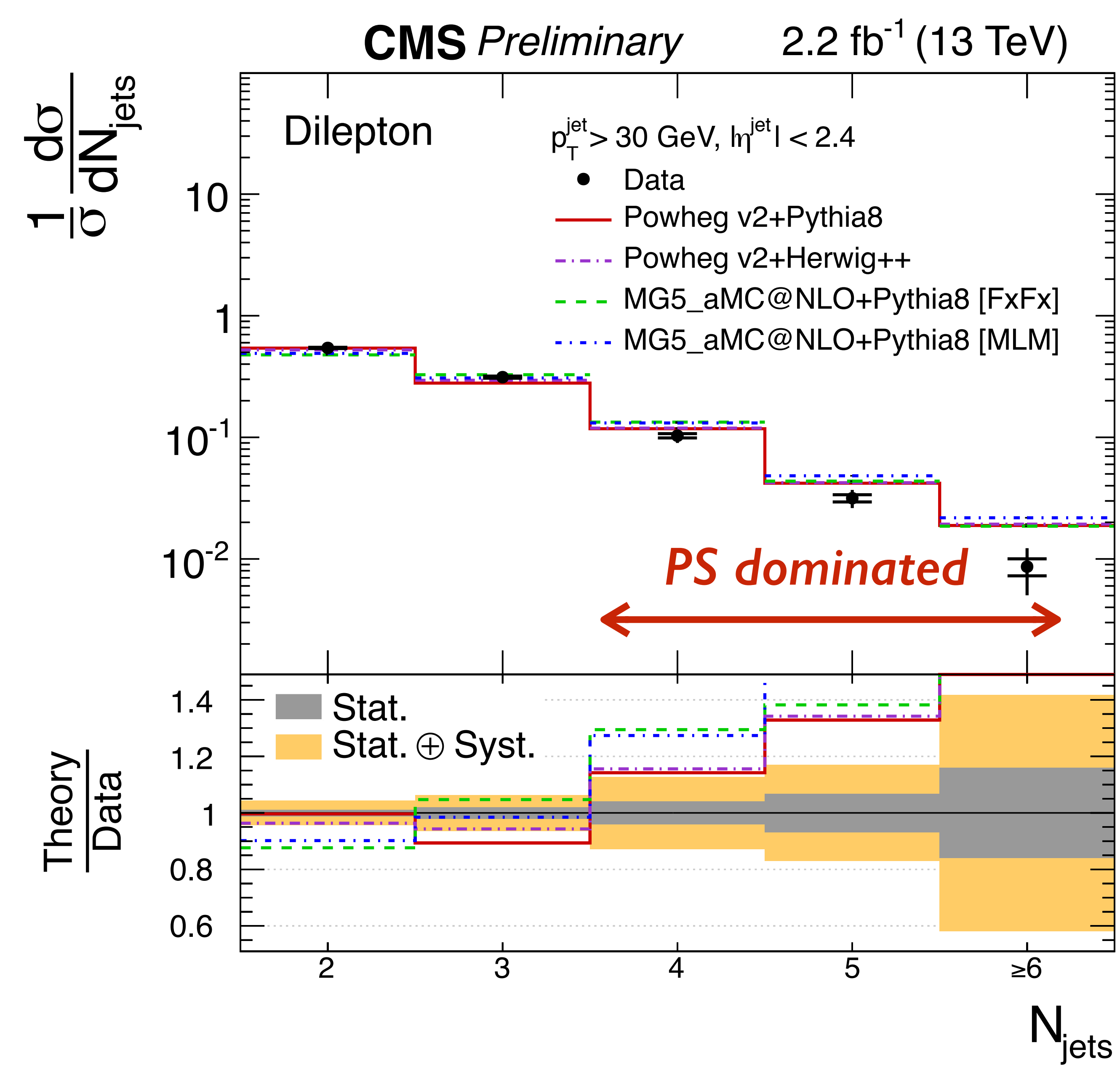
Main uncertainties

Source	Median unc. (%)
Statistics	5-25
Hadronizer	1.1
NLO generator	3.2
QCD multijet backgrond	1.6

Global event description II

- **Extra jet emissions are mostly regulated by the Parton Shower generators**
  - sensitive to matching to matrix-element generators and to shower model
  - predictions from modern generators in agreement with each other within <15%
  - however in extreme regions observe discrepancies which need to be tuned further

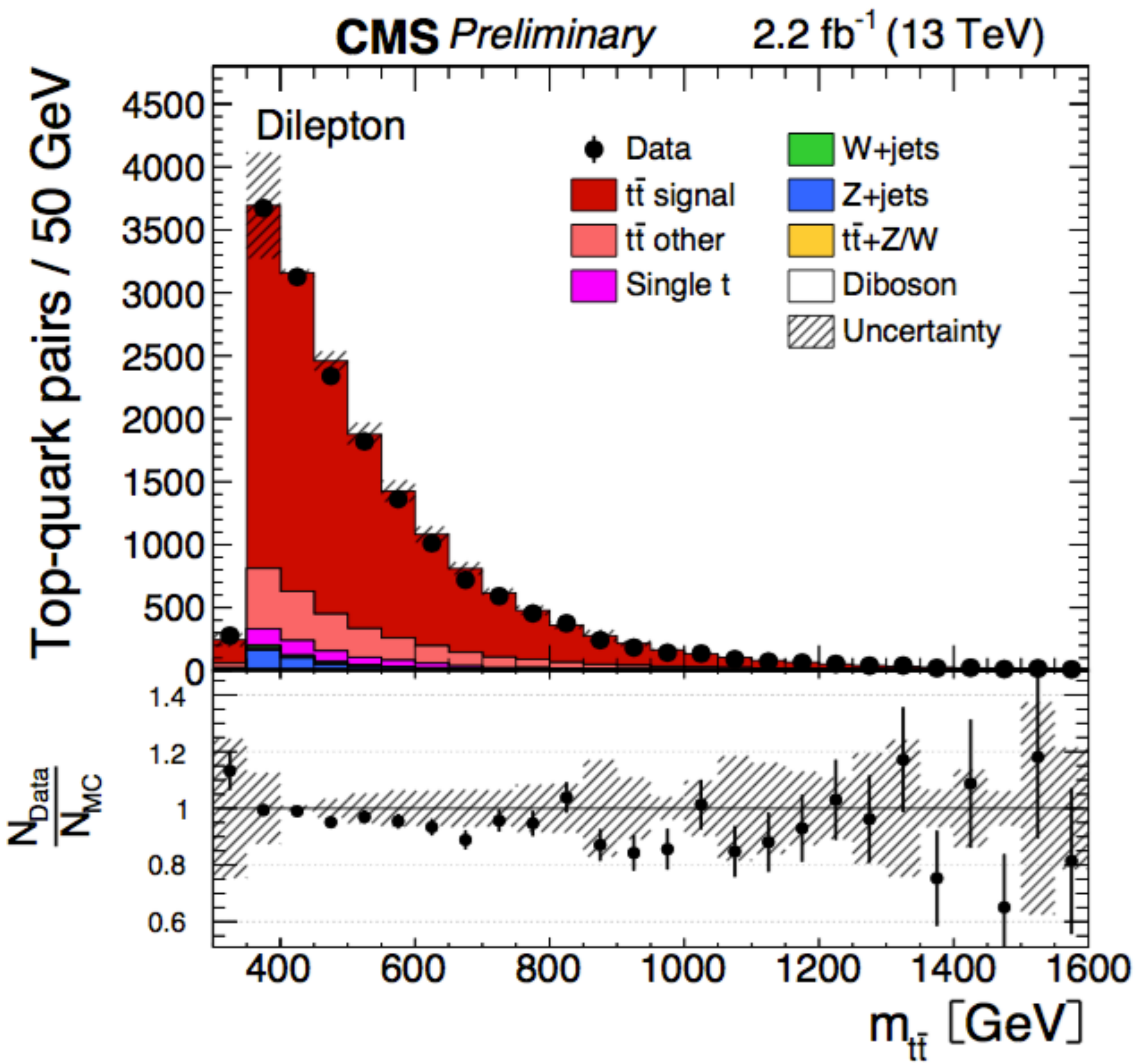




the measured tt invariant mass

NEW PAS-TOP-16-011

Rate/shape reproduced within uncertainties



Towards probing precisely the measured tt invariant mass

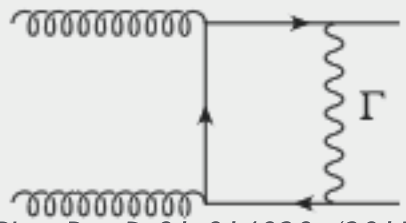
NEW PAS-TOP-16-011

Rate/shape reproduced within uncertainties

Test QCD production modes near threshold

JHEP 1009:034,2010

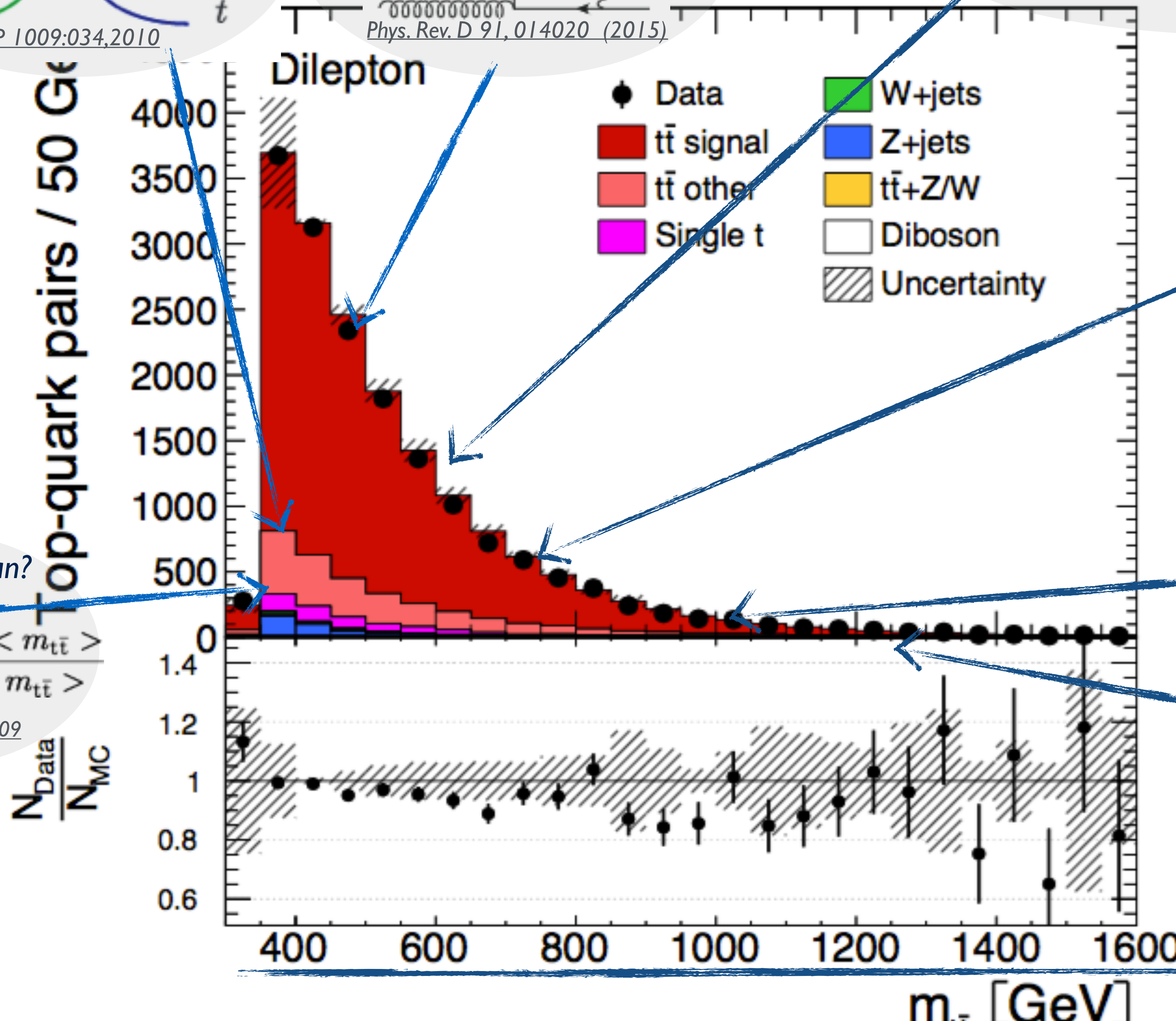
Test EW corrections (Z,γ,H)



Phys. Rev. D 91, 014020 (2015)

Elusive signs of new physics

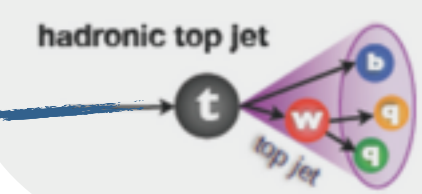
PRD 90, 014008 (2014) 10.1007/JHEP01(2015)092



Bump hunting

X→tt

Entering the boosted regime



Pole mass scan?

$$\frac{\Delta m_t}{m_t} \sim 1.2 \cdot \frac{\Delta < m_{t\bar{t}} >}{< m_{t\bar{t}} >}$$

JHEP 0901:047,2009

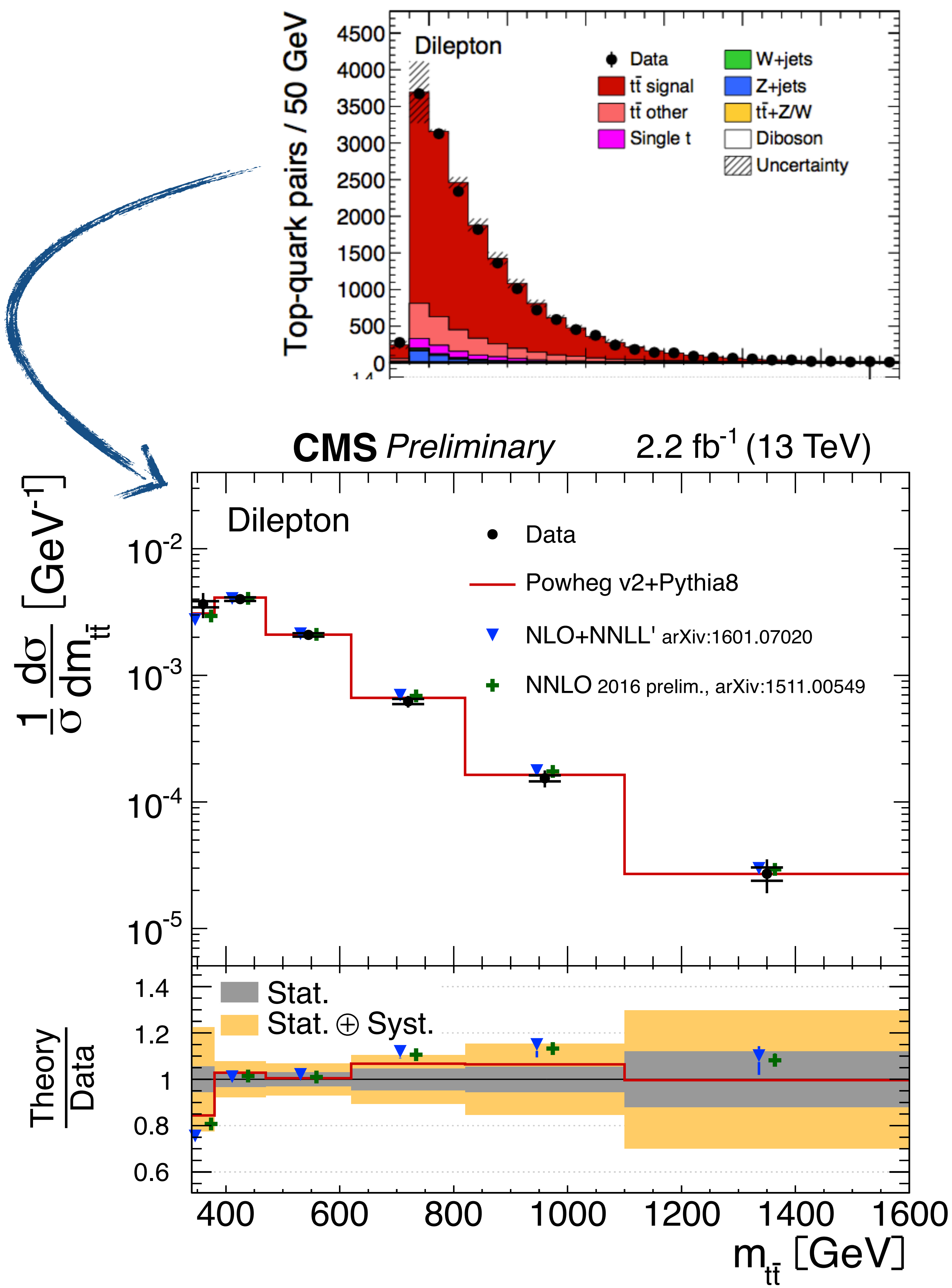
PDFs, α_S at high x

Top mass running?

$$m_t = m_t(\mu)$$

Probing the measured tt invariant mass

NEW PAS-TOP-16-011



Rate/shape reproduced within uncertainties

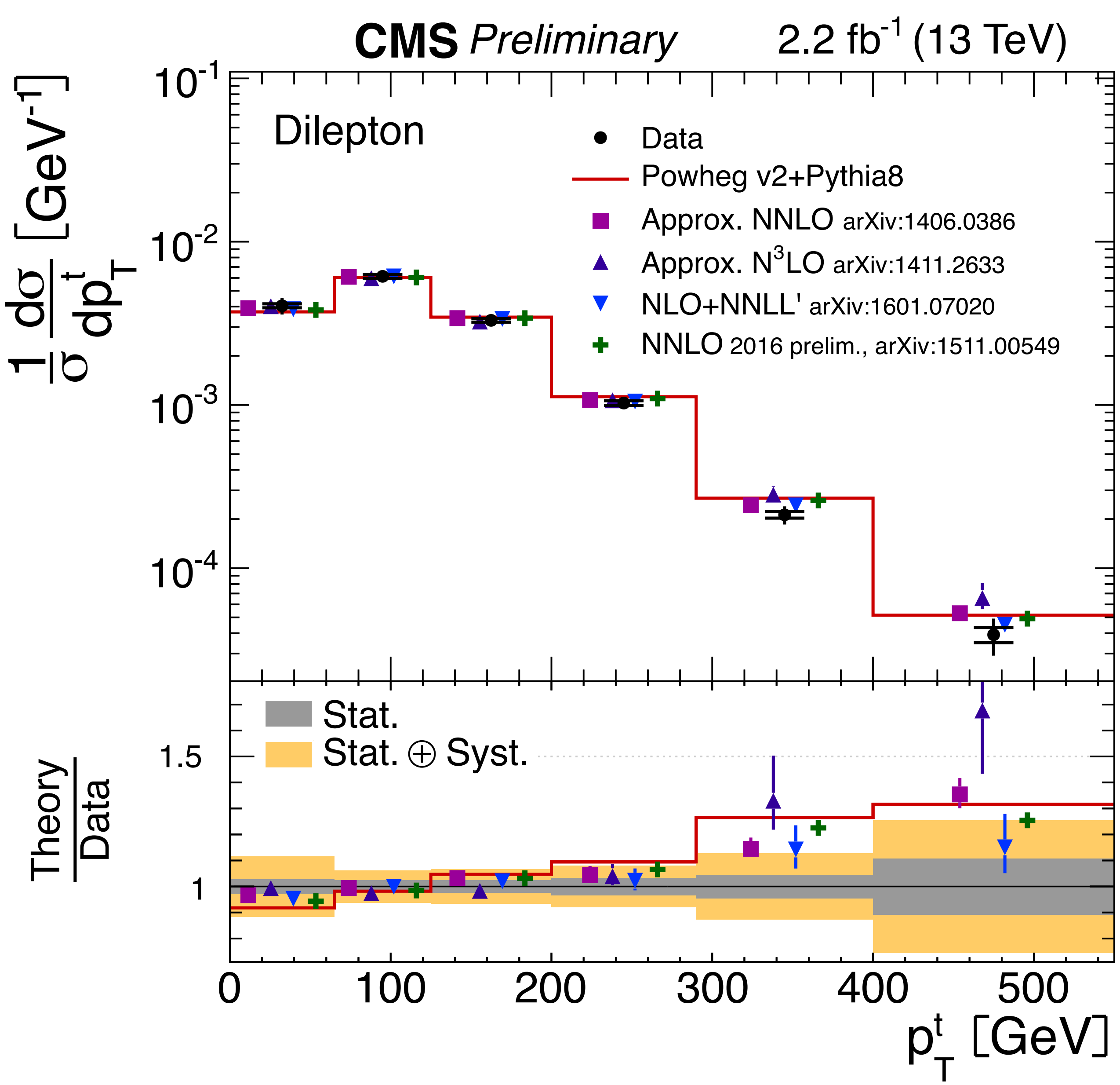
- **Precise measurements** of M(tt) and others **depends crucially on the understanding of ME+PS-based predictions**
- Current uncertainty at the level of 5-20%
  - ambiguity in data shape corrections
  - dominated by different MC models
- **Largest contributions** from choice of
  - hadronizer (Pythia8 vs Herwig++)
  - NLO generator (aMC@NLO vs Powheg)

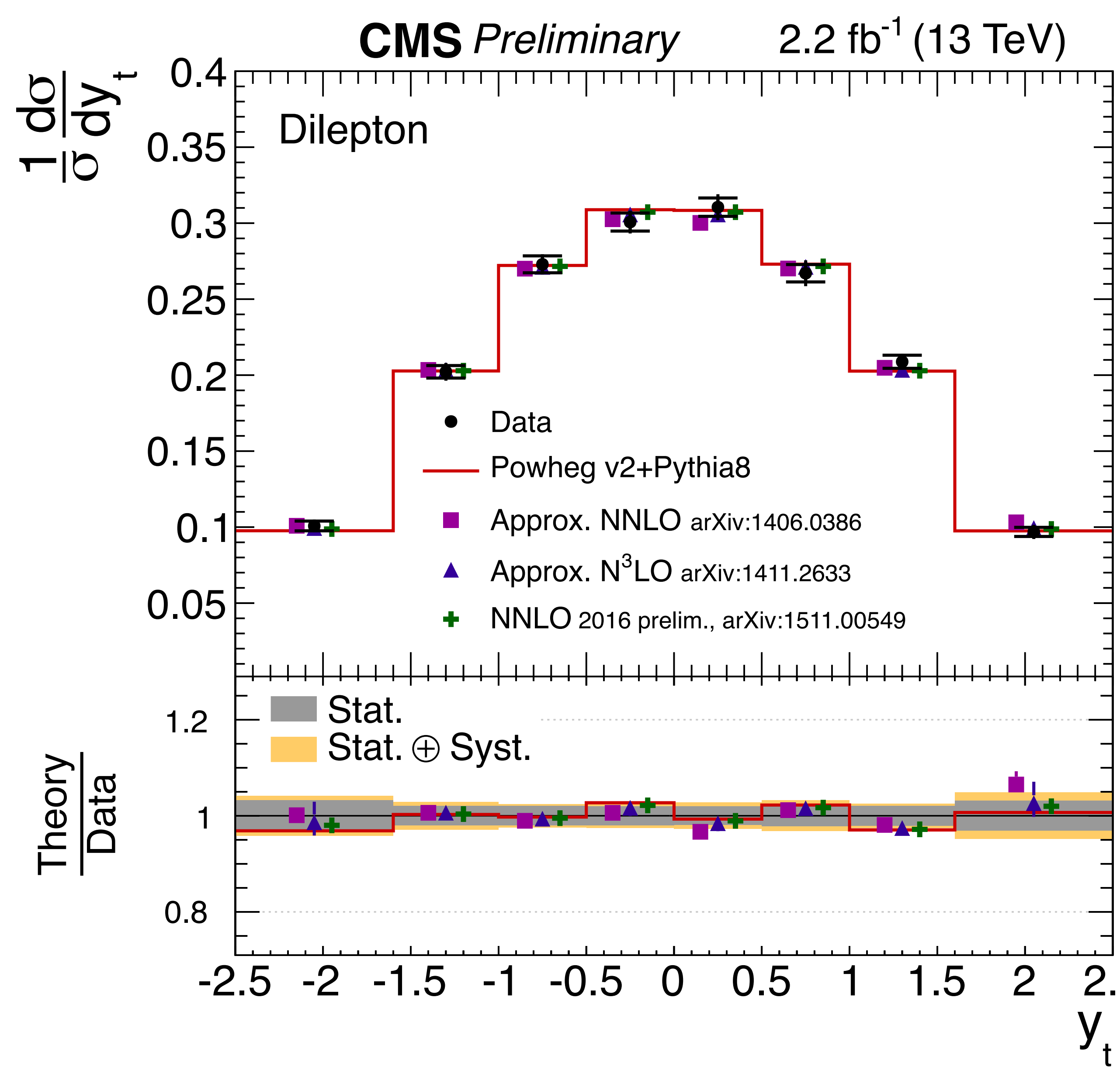
  ⇒ complement with alternative measurements to constrain PS related uncertainties (e.g. underlying event, jet activity, etc.)
- Experimentally jet energy scale unc. dominant

Probing individual top quark kinematics

NEW PAS-TOP-16-011

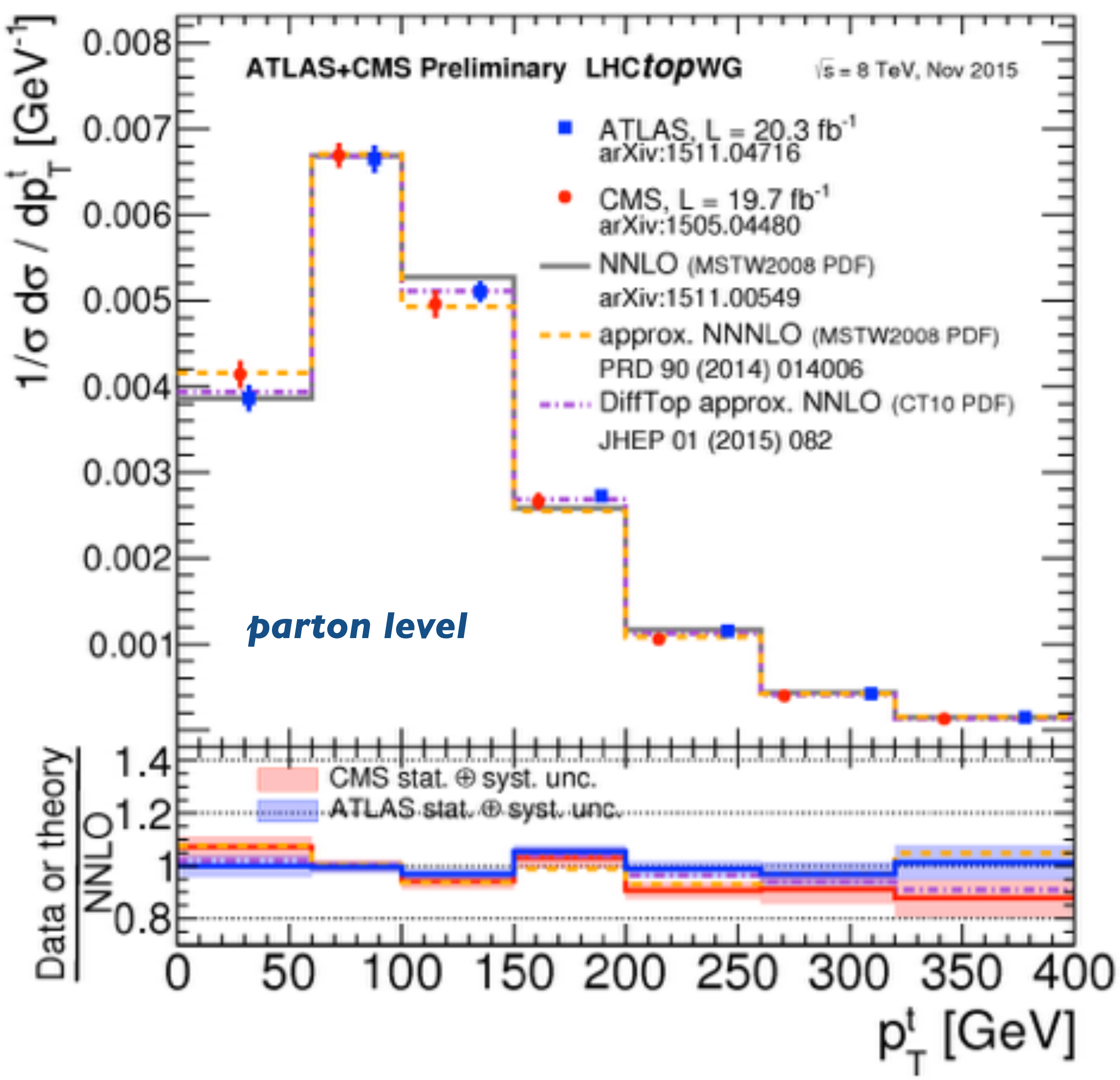
- **Comparison to fixed-order calculations**
  - need to unfold to parton level
  - cancel main systematics by normalizing by σ(tt) (shape only)
- **Top p_T better described at NNLO** (softer in data with respect to NLO+PS predictions)

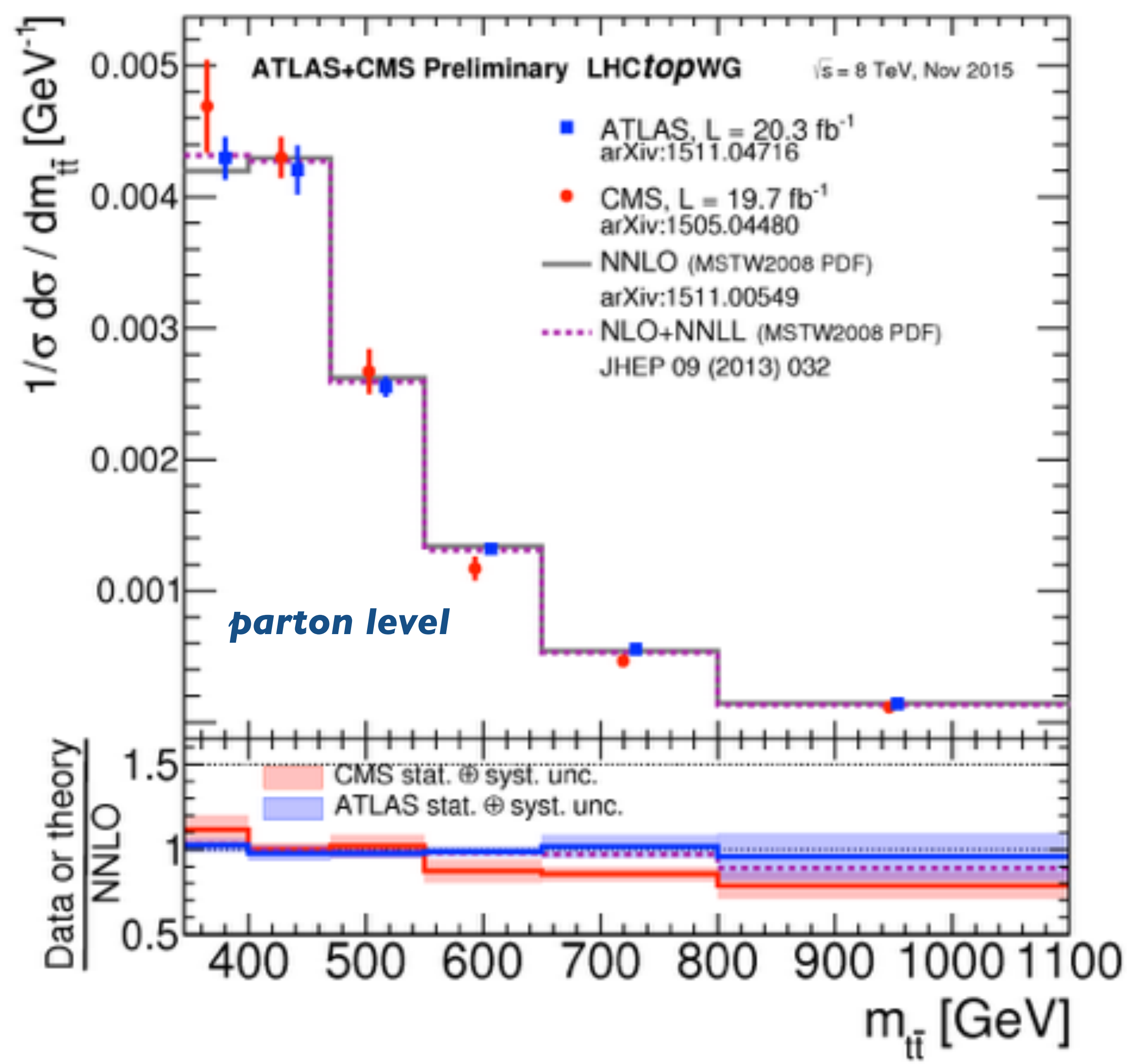




Further comparisons to NNLO at 8 TeV

- **Legacy Run I results compared to fixed order calculations**
  - fair agreement between experiments, CMS tends to observe slightly softer $p_T(t)$ and m(tt)
    (note that bin-to-bin correlations need to be taken into account for a proper χ^2 evaluation)
  - **overall good agreement with the NNLO predictions**
    (data is softer than NLO+PS predictions)

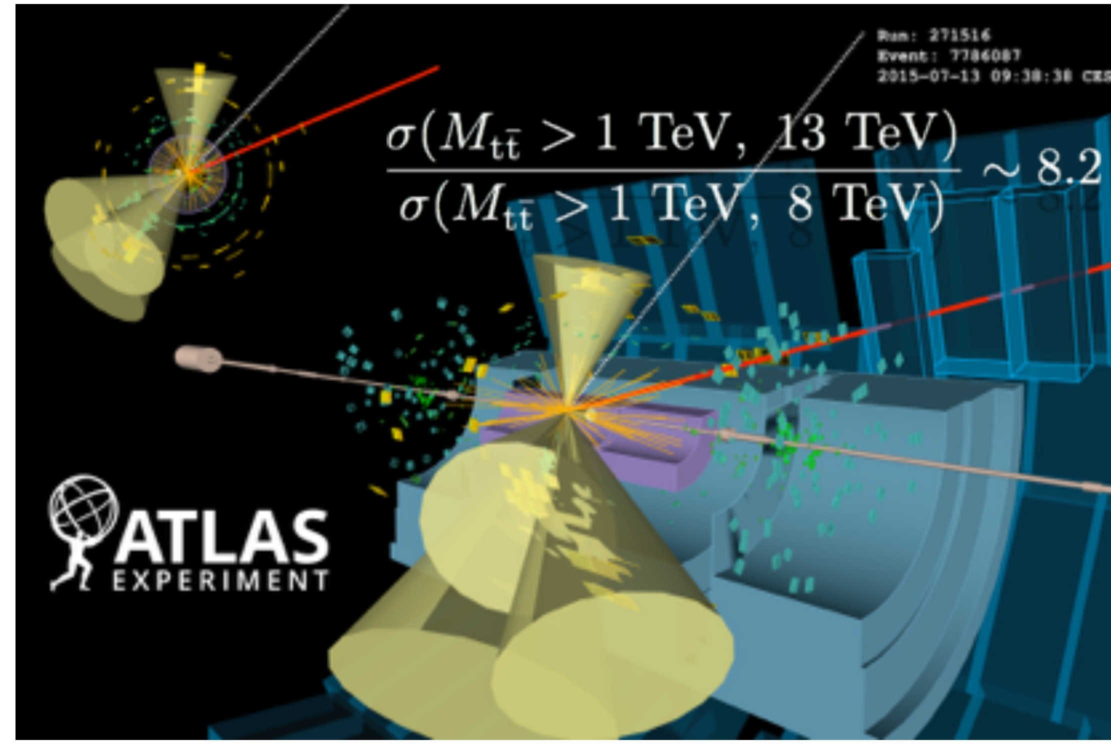


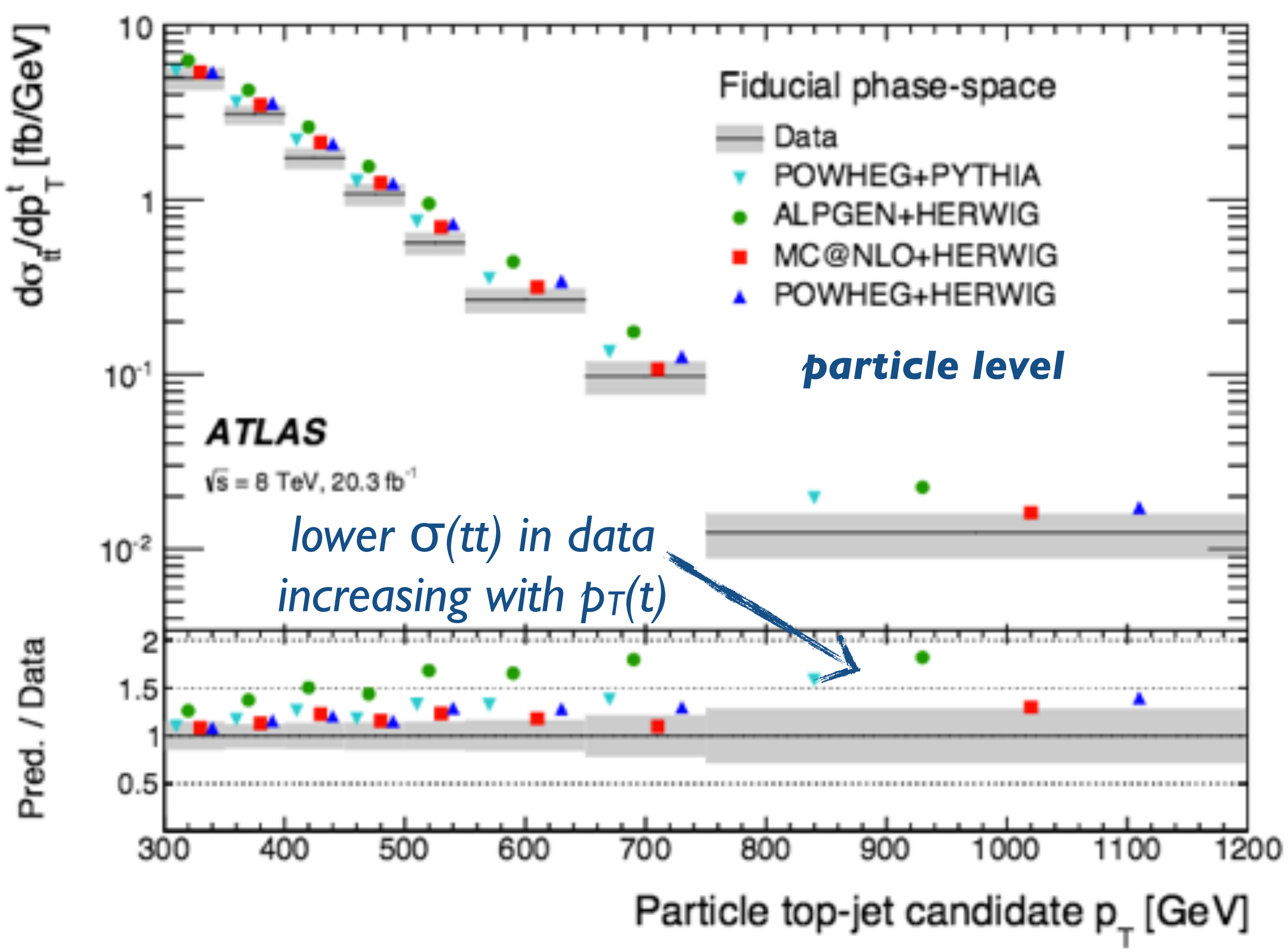


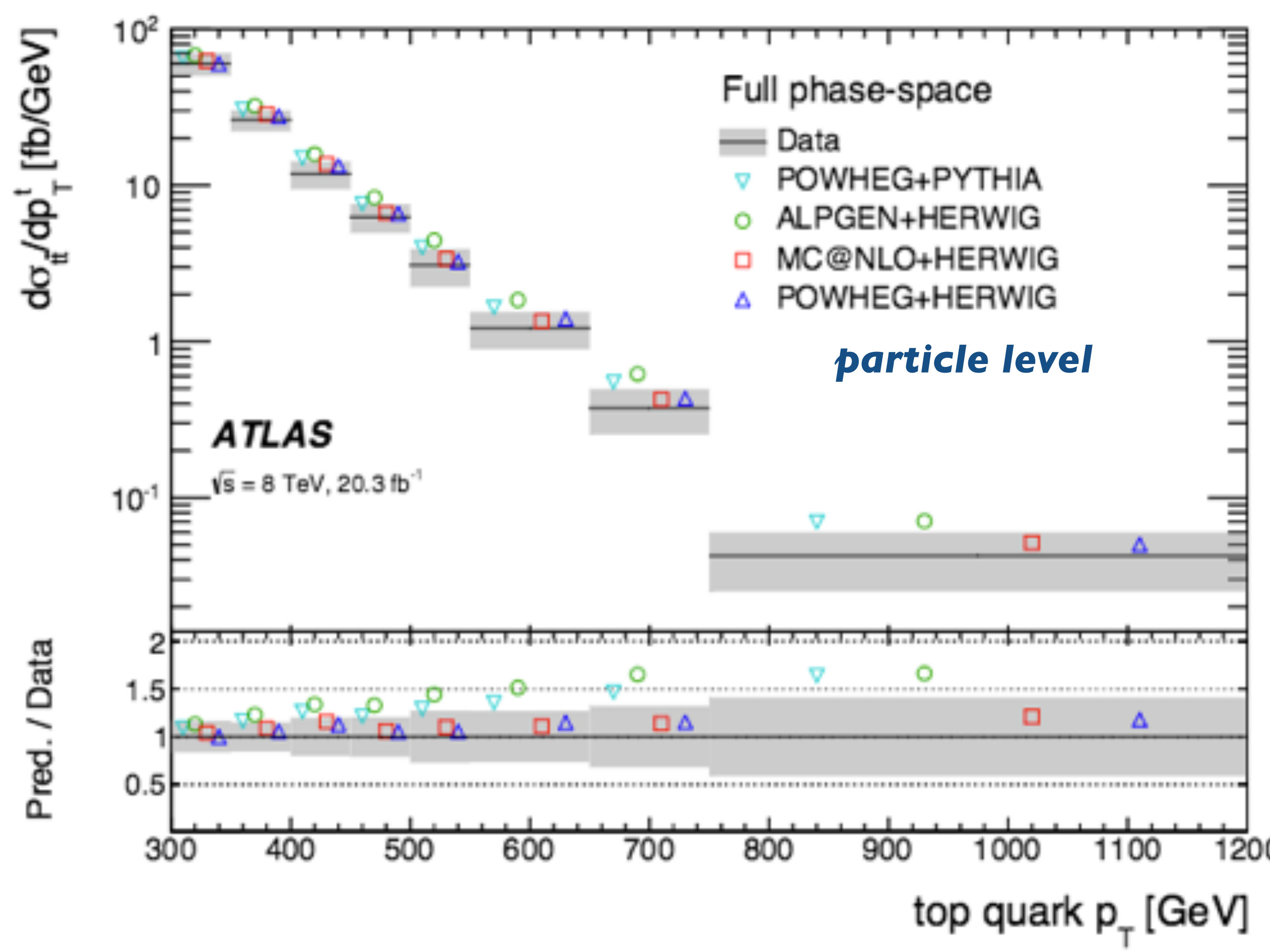
Probing the boosted top quark regime

Phys. Rev. D93 (2016) 032009
see also CMS-PAS-TOP-14-012

- **Extension to higher p_T**/m(tt) leads to objects merging
  - lepton isolation in a p_T-dependent cone
    (remove if overlapping with jet $\Delta R(\mu, \mathrm{jet}_{R=0.4}) < 0.04 + 10\ \mathrm{GeV}/p_{\mathrm{T},\mu}$)
  - require 1 small (R=0.4) jet close to the lepton DR<1.5
  - require 1 large jet (R=1.0) away from other objects
    ($M_{trimmed}$>100 GeV, splitting scale >40 GeV)
- **Largest uncertaintyies: stats and jet energy scale for R=1.0**

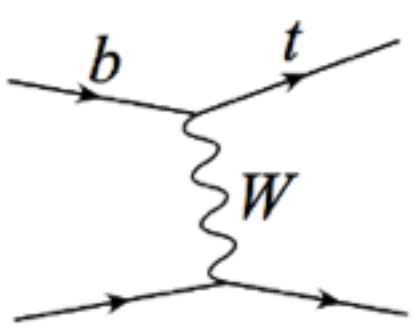






Testing the EW couplings through single top production

Latest results on single top quark production: is $V_{tb} \approx 1$?



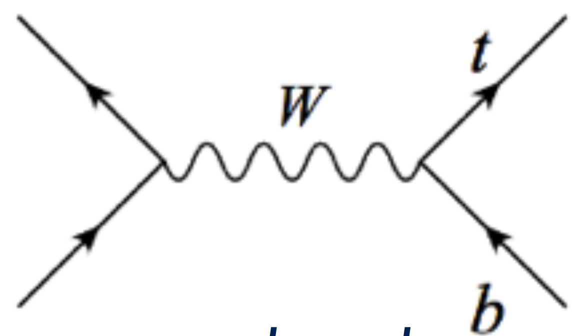
t-channel

$\sigma(7\text{ TeV}) = 64\text{ pb} \pm 4.5\%$

$\sigma(8\text{ TeV}) = 85\text{ pb} \pm 4.4\%$

$\sigma(13\text{ TeV}) = 217\text{ pb} \pm 4.1\%$

$R_{13/8} = 2.6$



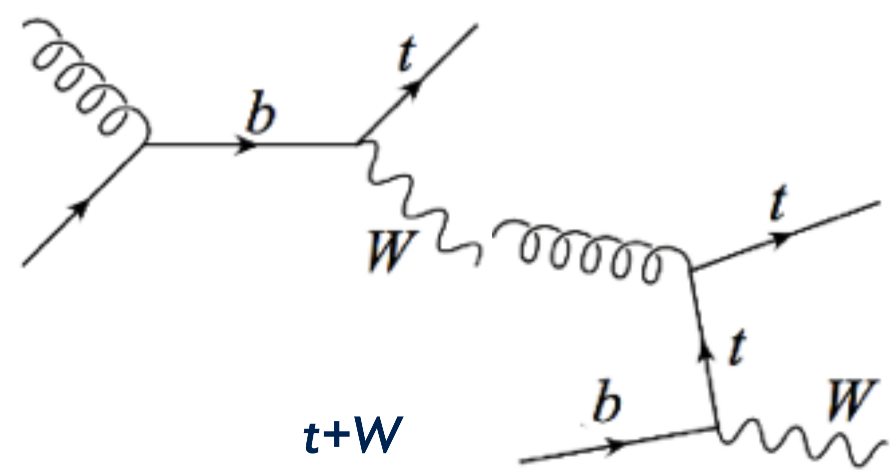
s-channel

$\sigma(7\text{ TeV}) = 4.3\text{ pb} \pm 4.4\%$

$\sigma(8\text{ TeV}) = 5.2\text{ pb} \pm 4.2\%$

$\sigma(13\text{ TeV}) = 10.3\text{ pb} \pm 3.9\%$

$R_{13/8} = 1.9$



t+W

$\sigma(7\text{ TeV}) = 15.7\text{ pb} \pm 7.6\%$

$\sigma(8\text{ TeV}) = 22.4\text{ pb} \pm 6.8\%$

$\sigma(13\text{ TeV}) = 71.7\text{ pb} \pm 5.3\%$

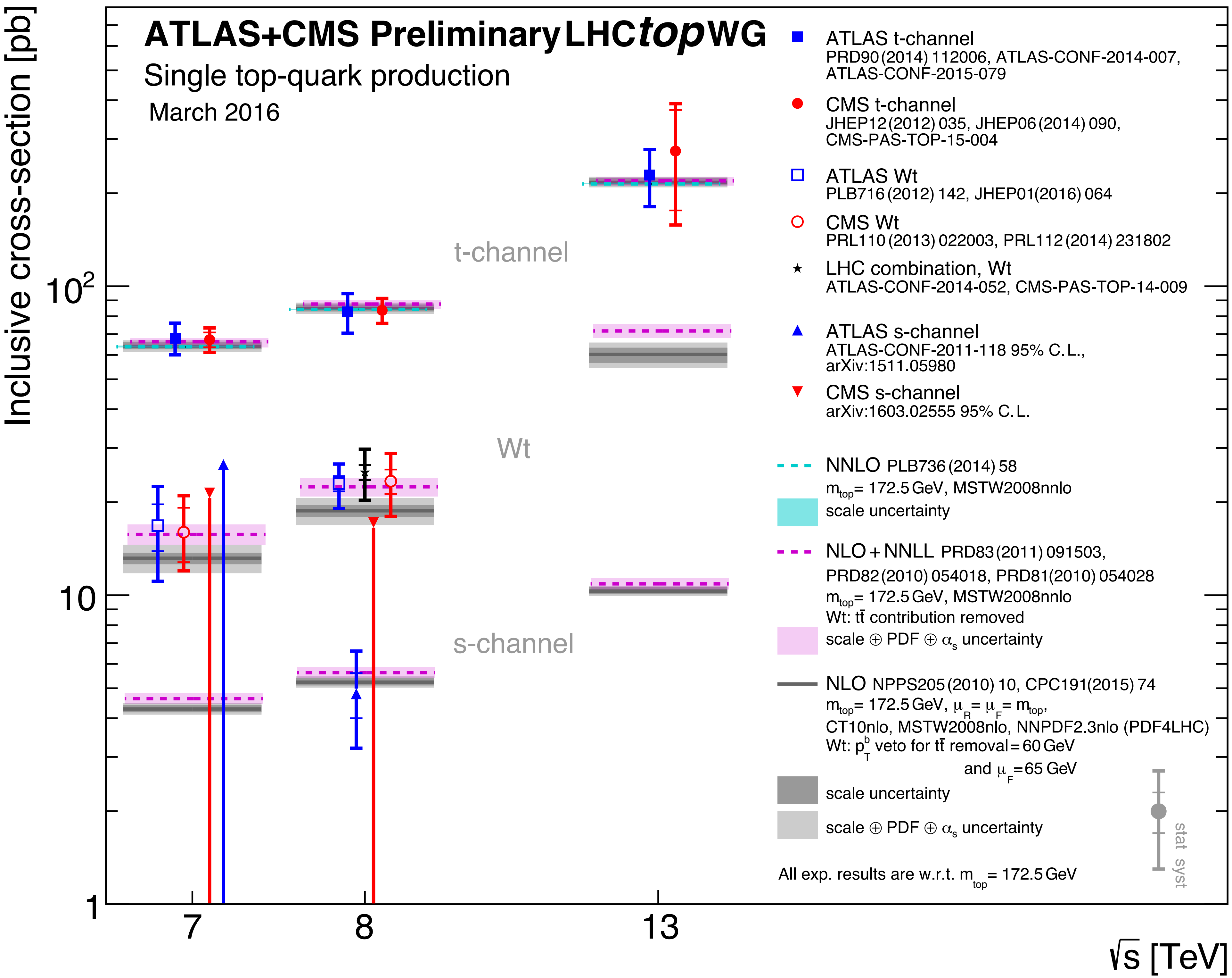
$R_{13/8} = 3.2$

NLO predictions (arXiv:1406.4403,arXiv:1007.1327)

NLO+NNLL predictions (arXiv:1311.0283)

Single top quarks measured in different production modes

- **All in agreement with SM predictions:** **testing directly PDFs and V_{tb}**
- t-channel : spans all the energy ranges probed at the LHC

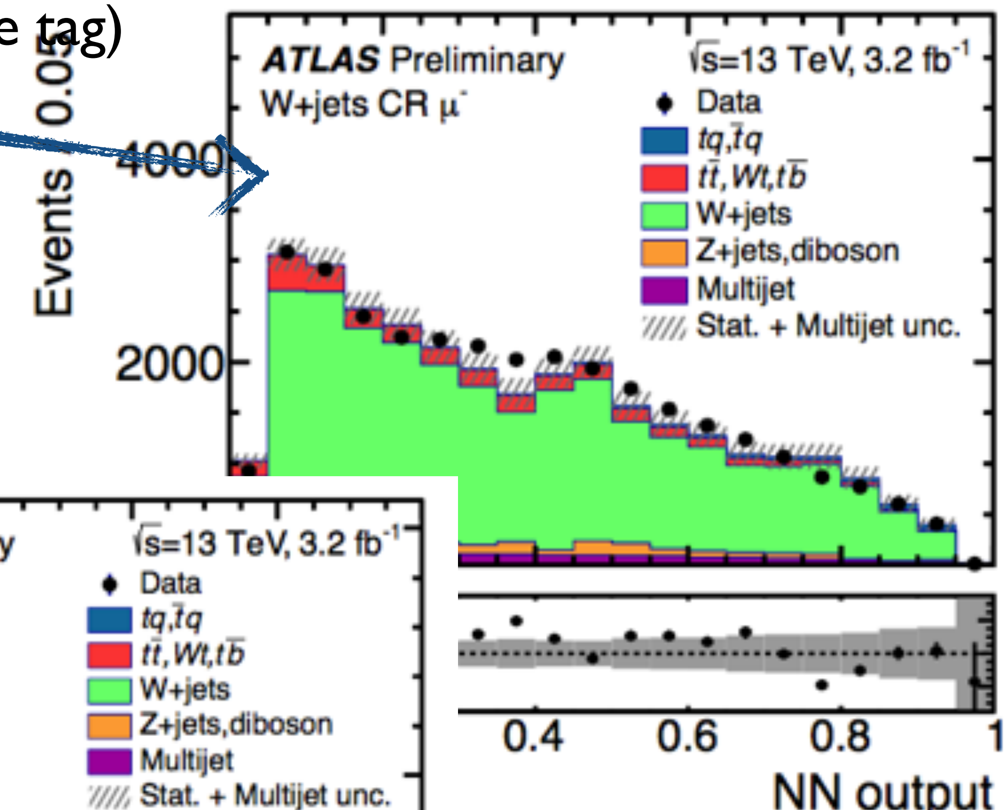


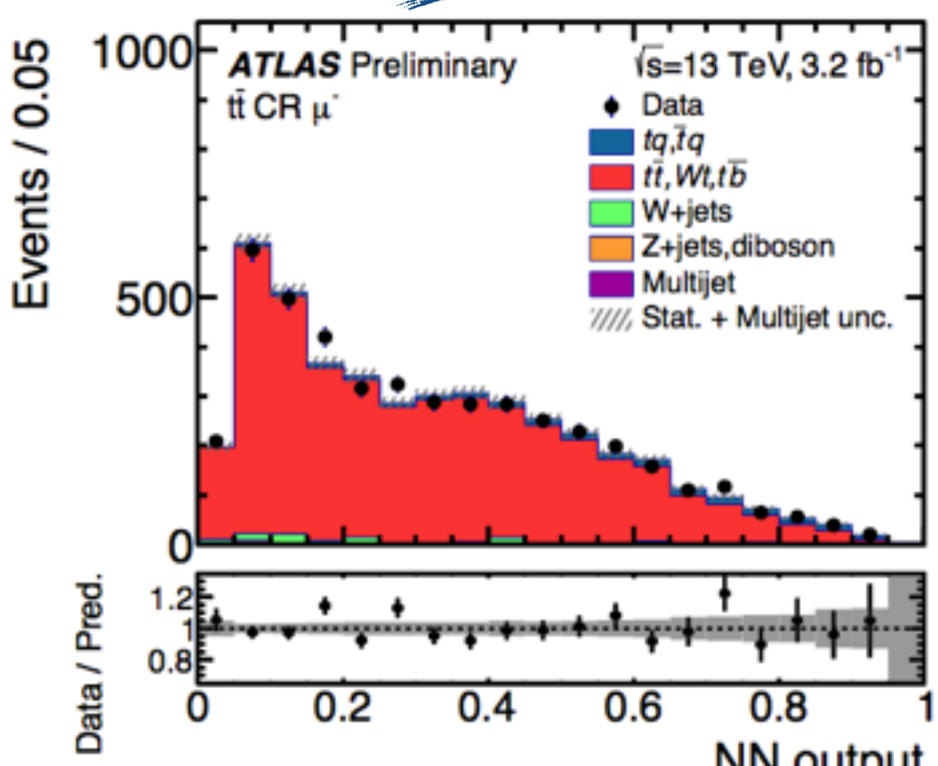
t-channel cross section measurement at 13 TeV I

ATLAS-CONF-2015/079 *see also* CMS-PAS-TOP-15-004

- **t-channel exchange leads to large angular separation between top and light jet**
  - pre-selection dominated by tt/W+jets: 1 lepton $m_T(W)$>50 GeV, 1 b-tagged jet + 1 jet ($|\eta|$<3.5)
  - improve discrimination with a multivariate analysis: m_t, m_{jb}, $m_T(W)$, η(j') are the most relevant
  - use control regions for tt (3jets-2tags) W+jets (1jet-1loose tag)

Process	μ^+-channel	μ^--channel
tq	$2\,200 \pm 47$	< 1
$\bar{t}q$	< 1	$1\,380 \pm 37$
$t\bar{t}$	$6\,390 \pm 80$	$6\,510 \pm 81$
Wt	818 ± 29	825 ± 29
$t\bar{b}$+$\bar{t}b$	155 ± 12	105 ± 10
W+jets	$5\,330 \pm 73$	$4\,320 \pm 66$
Z+jets/diboson	781 ± 28	628 ± 25
Multijets	280 ± 140	330 ± 160
Total expected	$16\,000 \pm 190$	$14\,100 \pm 200$
Data	16 865	15 110

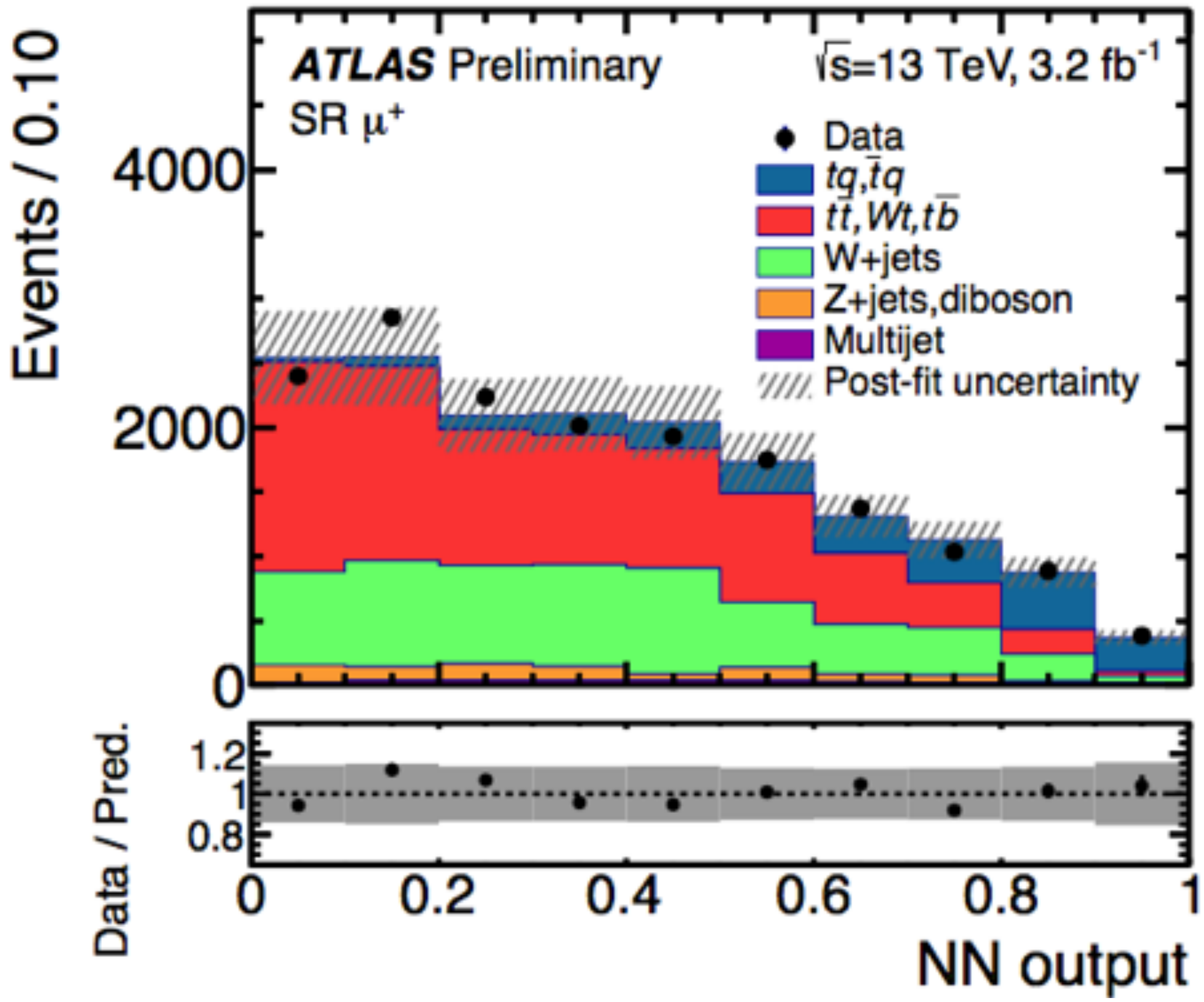


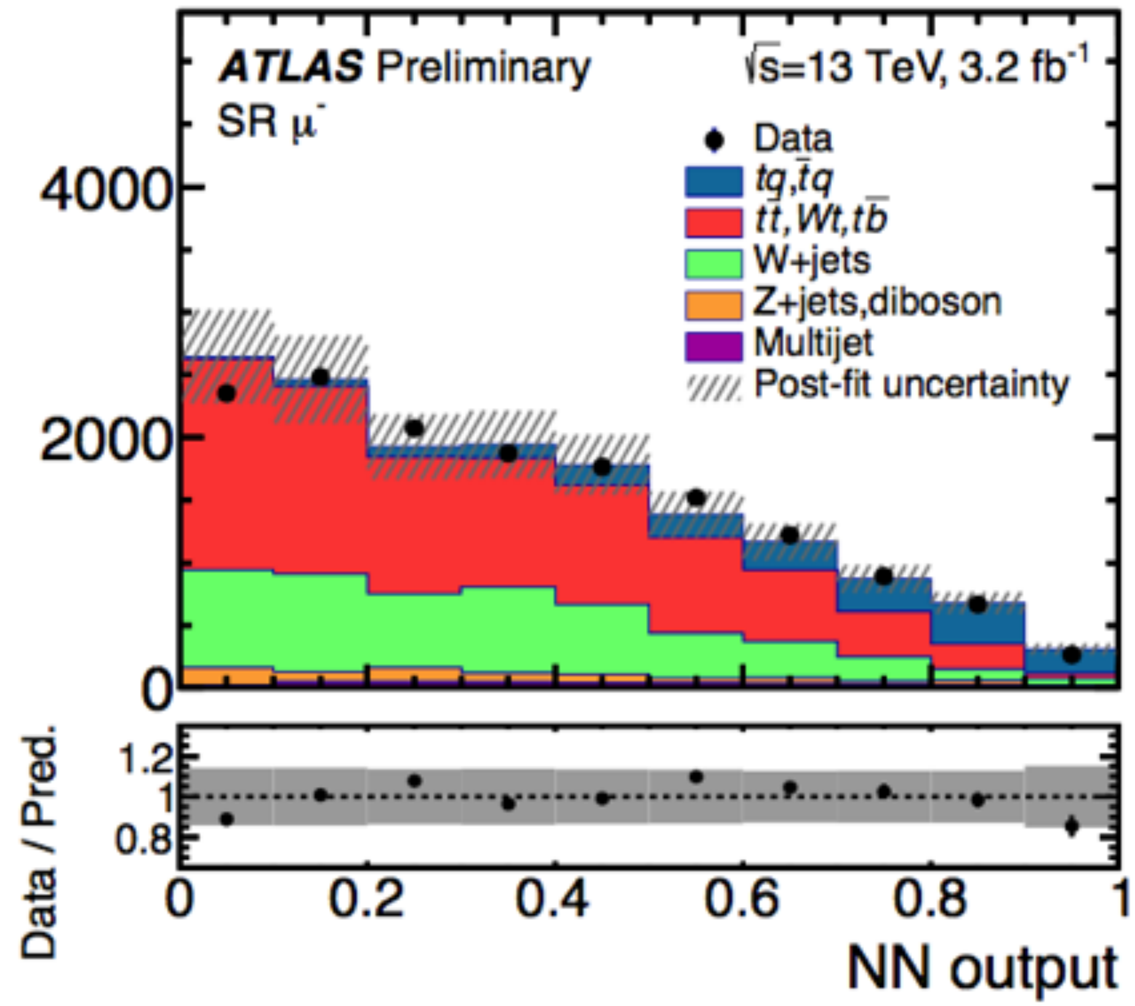


Fair description of the main backgrounds in the control regions

t-channel cross section measurement at 13 TeV II

ATLAS-CONF-2015/079 *see also* *CMS-PAS-TOP-15-004*





- **Fit the multivariate discriminator** for signal strength $\beta=\sigma/\sigma_{th}$
  - background normalization is left to float constrained
  - systematics determined from pseudo-experiments

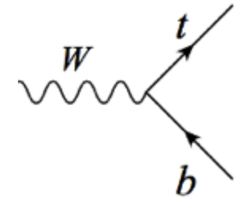
$$\sigma(\mathrm{tq}) = 133 \pm 25\ \mathrm{pb}$$
$$\sigma(\bar{\mathrm{t}}\mathrm{q}) = 96 \pm 24\ \mathrm{pb}$$
$$\sigma(\mathrm{tq}+\bar{\mathrm{t}}\mathrm{q}) = 229 \pm 48\ \mathrm{pb}$$

$\Delta\sigma/\sigma$=20%

Source	$\Delta\sigma_{t(\bar{t})}/\sigma$ (%)
Statistics	5 (5)
Luminosity	5 (5)
MC statistics	6 (6)
Jet/MET	8 (6)
b-tagging	7 (8)
single top model (t/tW,s)	13 (18)

Run I legacy

s-channel production



arXiv:1511.05980 *sub to PLB*

NEW arXiv:1603.02555 *sub. to JHEP*

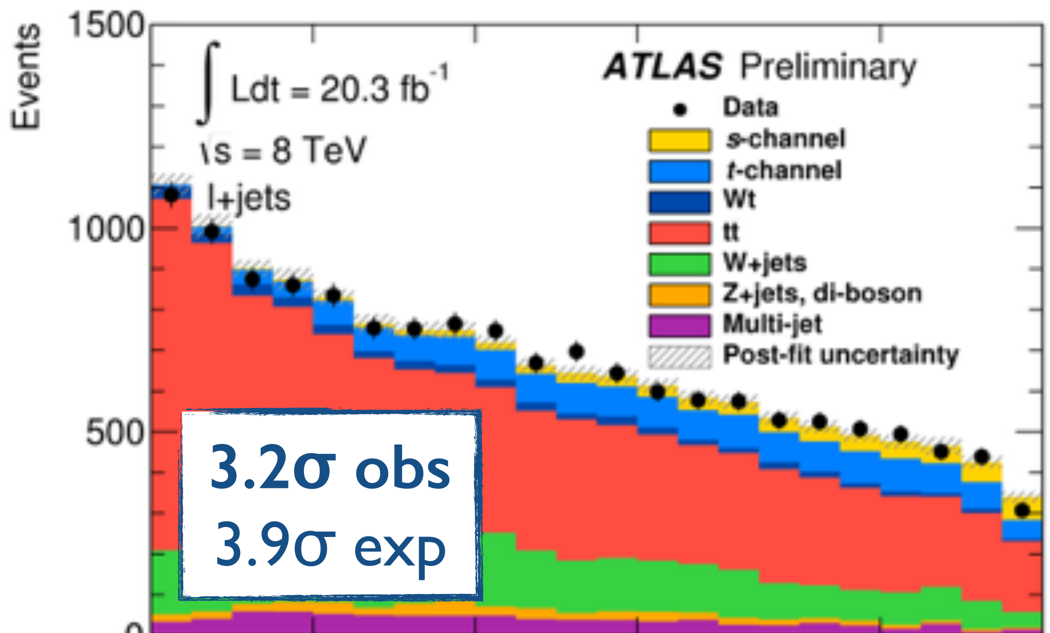
- **Rare in pp collisions - grows much slower with $s^{1/2}$ than other top production modes**
- Use multivariate discriminator (CMS) or matrix element approach (ATLAS) to discriminate signal

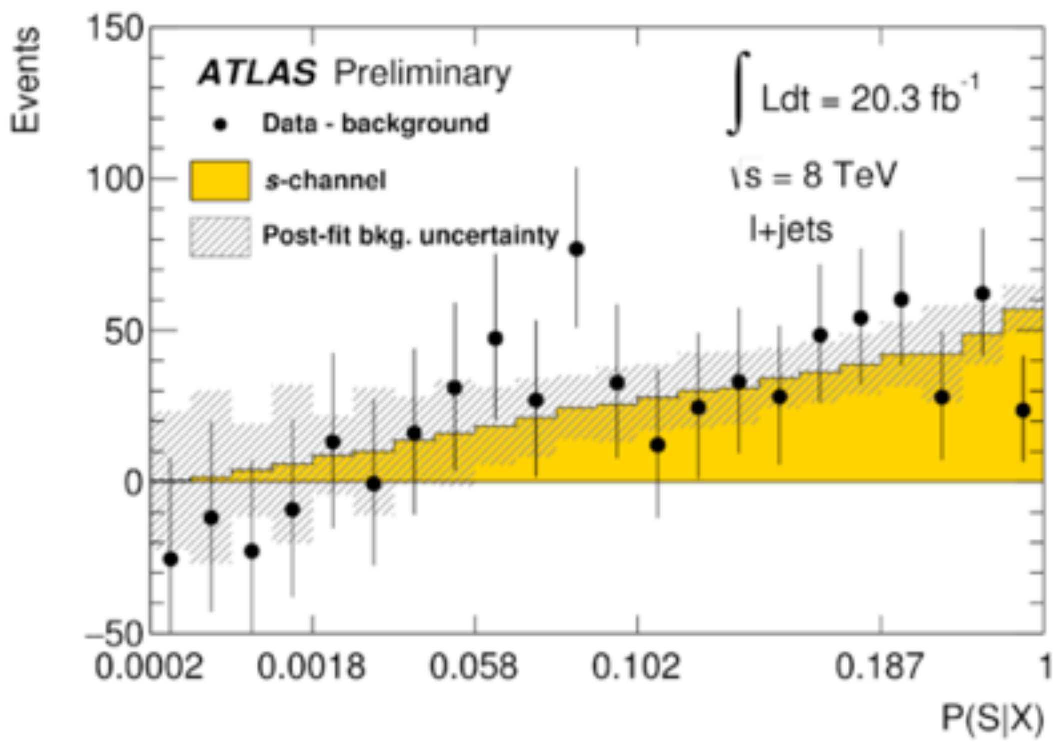
$$\sigma_s = 4.8 \pm 0.8(\text{stat})^{+1.6}_{-1.3}(\text{syst})\ \text{pb}$$

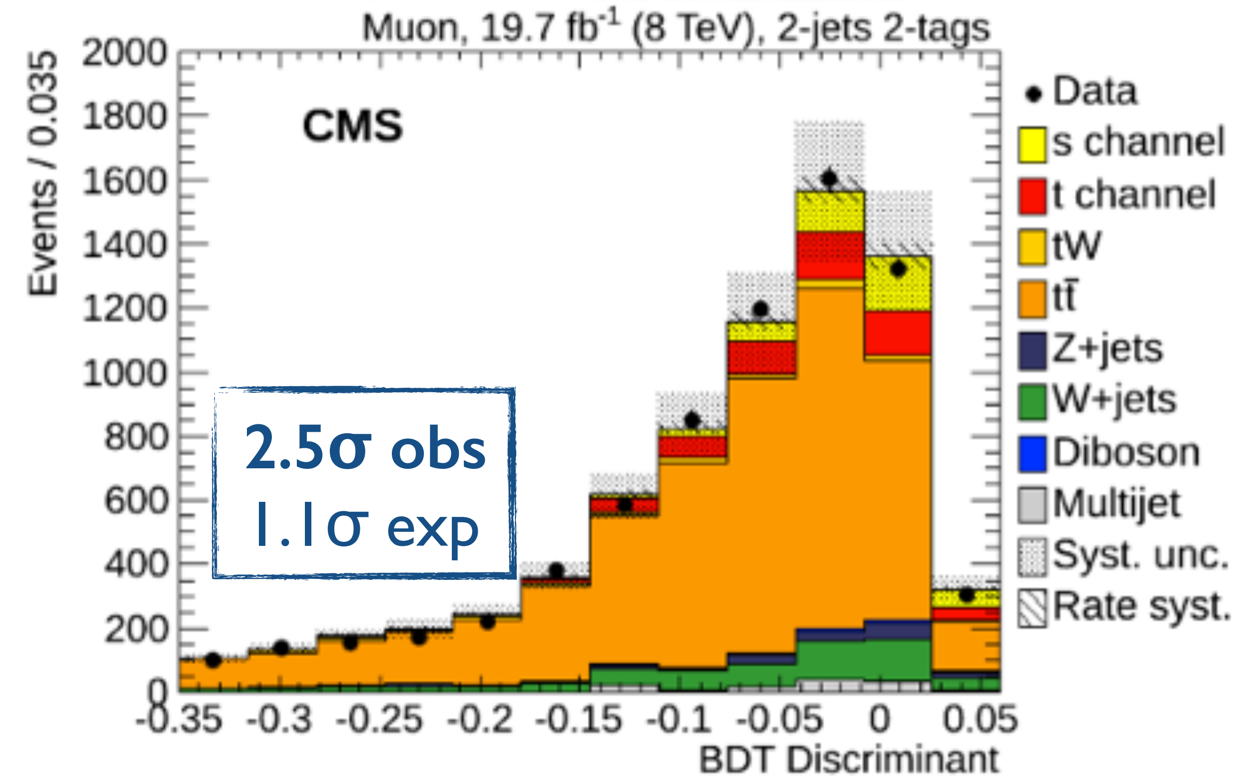
Δσ/σ=37%

$$\sigma_s = 13.4 \pm 7.3_{\text{total}}\ \text{pb}$$

Δσ/σ=54%





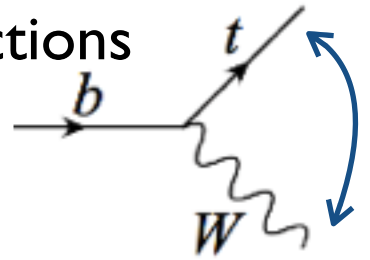


Source	Δσ/σ (%) ATLAS	CMS
Statistics	12	11
Luminosity	5	6
MC statistics	12	-
Jet/MET	13	19
b-tagging	8	16
Backgrounds	8	19
tt/single top (t,s) models	13	33

Associated t+W production

JHEP 01 (2016) 064
see also PRL 112 (2014) 231802

- **Process can't be isolated beyond NLO**
  - competing with no-resonant (WWbb/WWb), and double resonant (tt) productions



- **Explore cleanest final state** leading to 2 leptons, E_T^{miss}, 1 b-jet
  - at LO top recoils against a W boson ($p_T^{system} \rightarrow 0$), harder lepton p_T spectrum from $W \rightarrow \ell\nu$
  - combine different variables in a multivariate discriminator optimised depending on #jets #b-jets

$$\sigma_{tW} = 23.0 \pm 1.3_{stat}\ {}^{+3.2}_{-3.5}{}_{syst} \pm 1.1_{lumi}\ \text{pb}$$

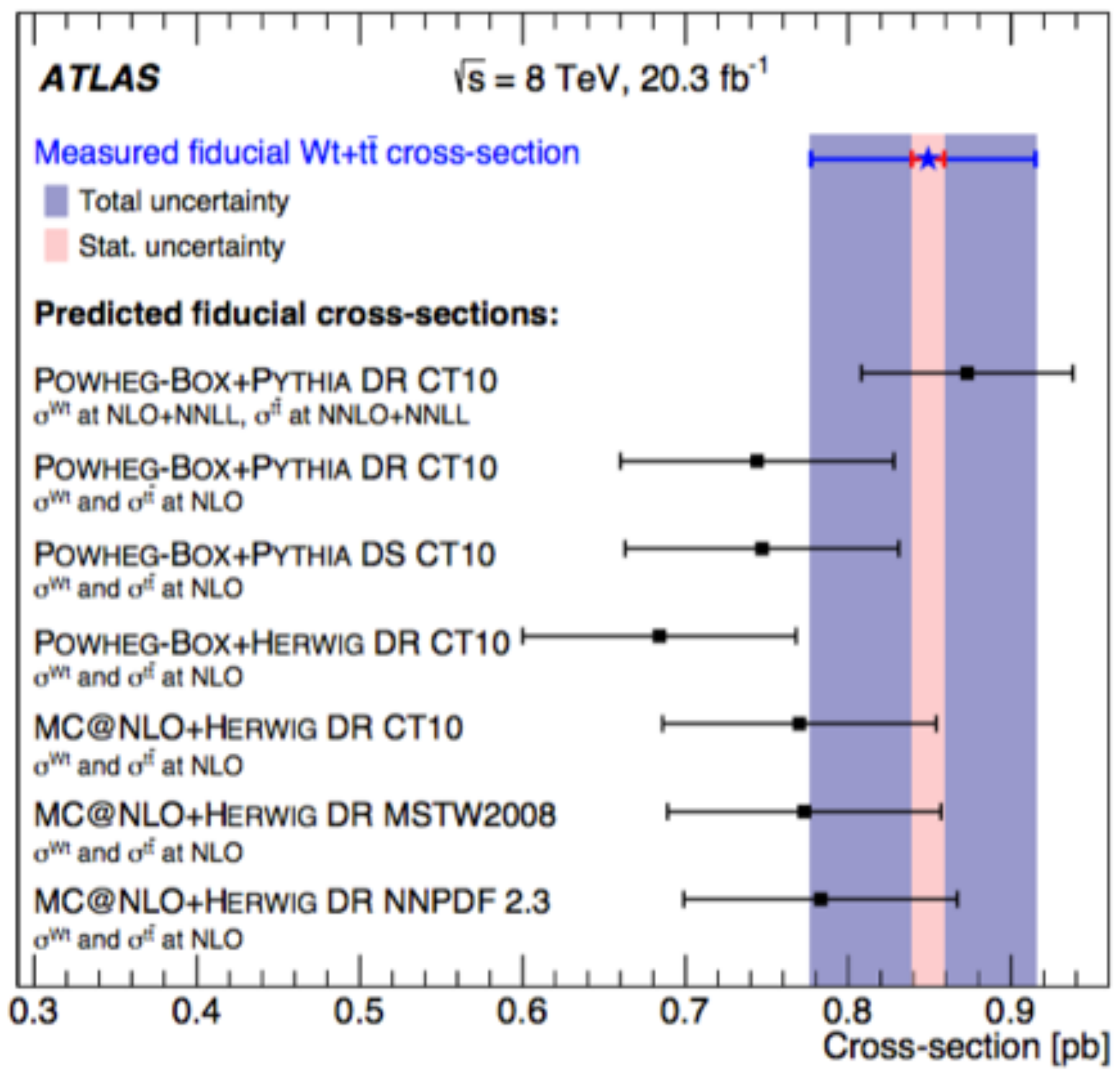
Δσ/σ=16%

- Explore fiducial phase space for combined tt+tW

$$\sigma^{fid}_{t\bar{t}+tW} = 0.85 \pm 0.01_{stat}\ {}^{+0.06}_{-0.07}{}_{syst} \pm 0.03_{lumi}\ \text{pb}$$

Δσ/σ=8.5%

Source	Impact on σ (%) inclusive	Impact on σ (%) fiducial
Statistics	5.8	1
Luminosity	4.7	3.1
Theory modelling	9.9	4.9
Jet/MET	10.9	5.2
b-tagging	3	2.3
Lepton efficiencies	1	2.3



From signal strengths to EW coupling

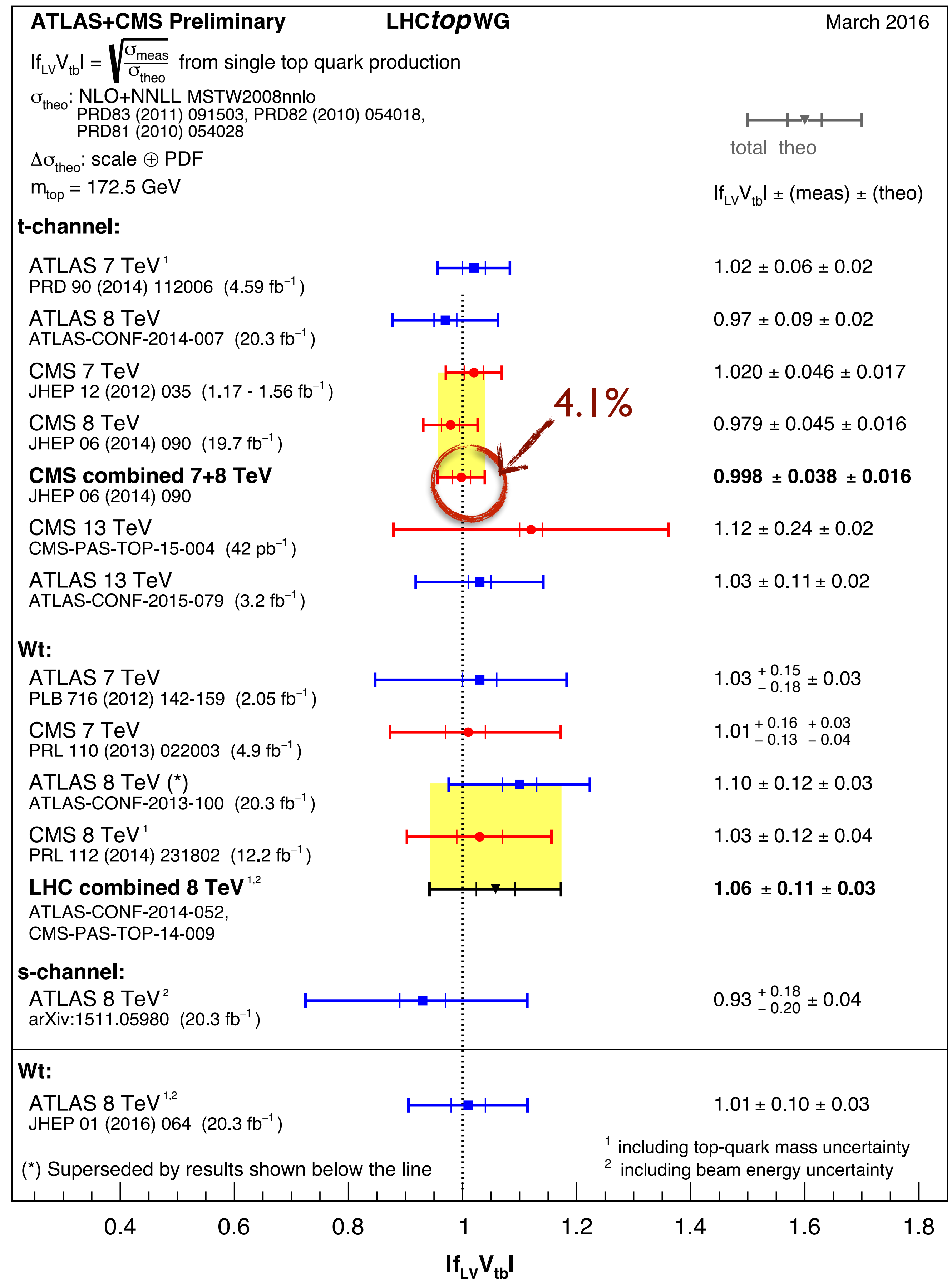
- The CKM matrix elements V_{tq} enter in production and decay vertices

$$\sigma(\mathrm{tj}+\bar{\mathrm{t}}\mathrm{j}) = \sum_{q=b,d,s} \alpha_{tq} \cdot |V_{tq}|^2 \cdot \mathcal{B}(t \to Wq)$$

  - approximate assuming $|V_{tb}| \gg V_{tq}$ and full left-handed decays to Wb

- Expect to improve slowly
  - limited by theory (~3% at NNLO)
  - experimental uncertainties (~10% in Run I)

$$\frac{\Delta V_{tb}}{V_{tb}} = \frac{1}{2}\left(\frac{\Delta\sigma^{obs}}{\sigma^{obs}} \oplus \frac{\Delta\sigma^{th}}{\sigma^{th}}\right)$$



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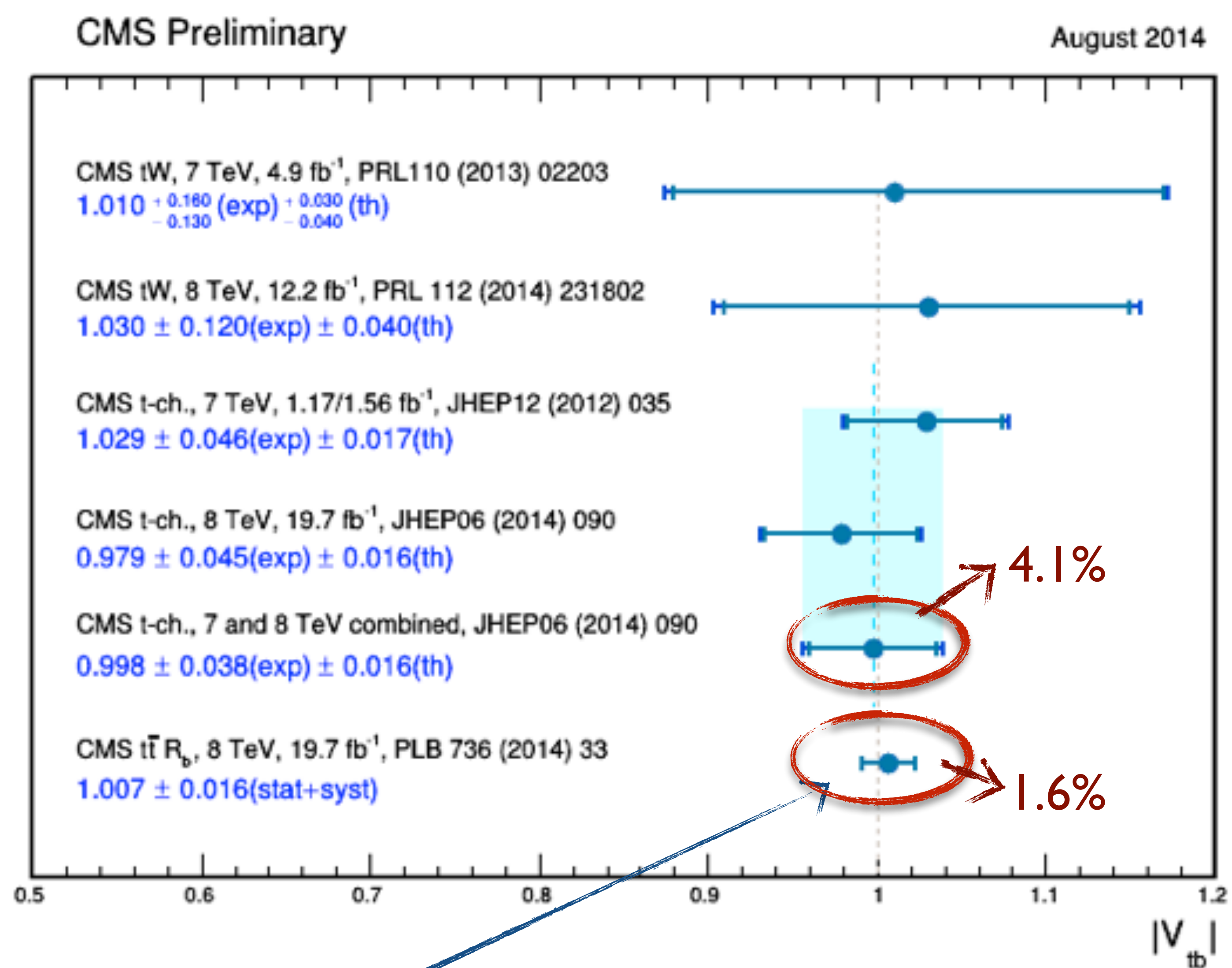
$$\frac{\Delta V_{\mathrm{tb}}}{V_{\mathrm{tb}}} = \frac{1}{2}\left(\frac{\Delta\sigma^{\mathrm{obs}}}{\sigma^{obs}} \oplus \frac{\Delta\sigma^{\mathrm{th}}}{\sigma^{th}}\right)$$

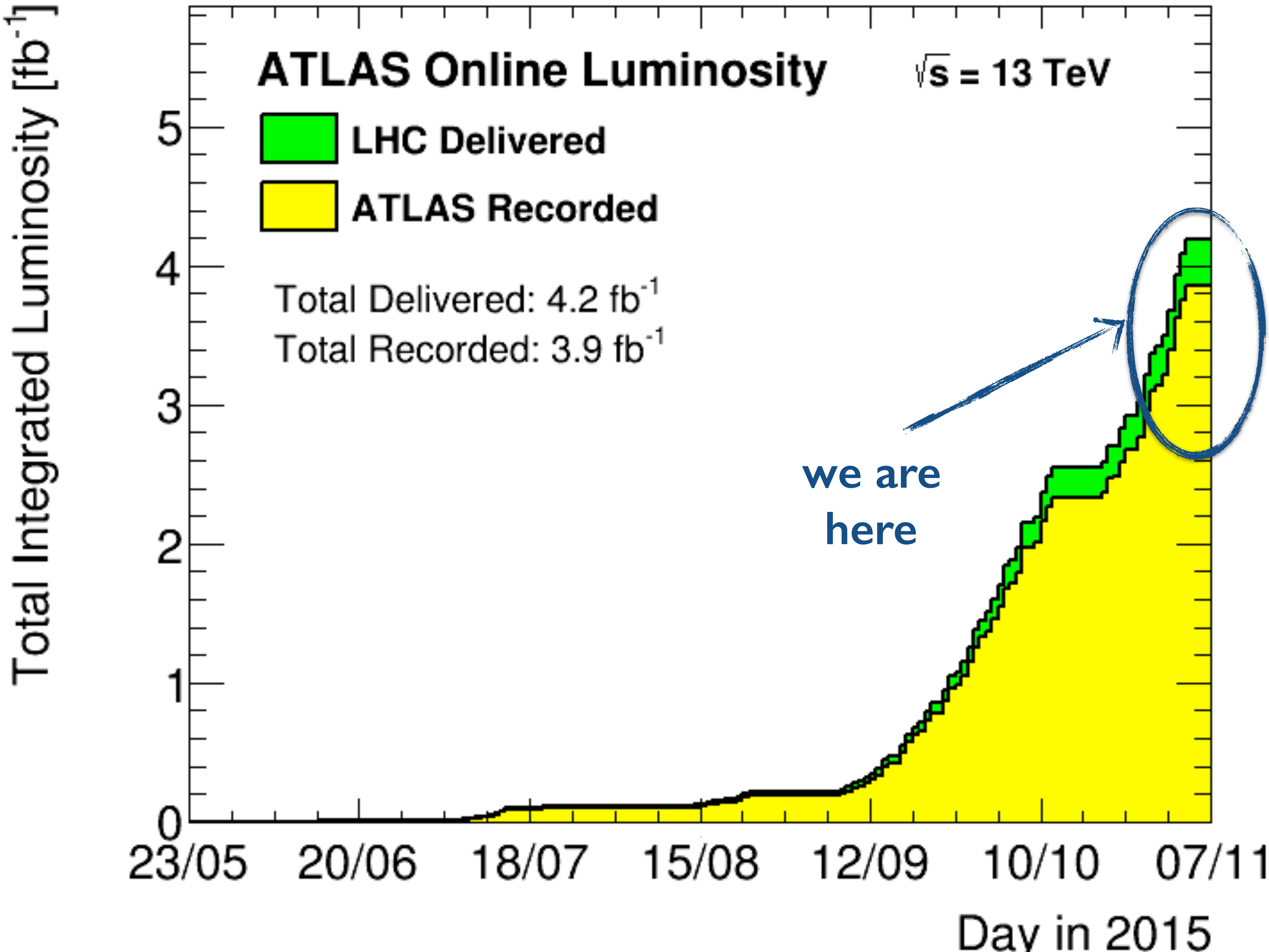
- Complemented by direct measurement of B(t→Wb) in tt decays assuming CKM unitarity and no sequential quark generation
  - limited by b-tagging efficiency (2% in Run I)

$$\frac{\Delta V_{\mathrm{tb}}}{V_{\mathrm{tb}}} = \frac{1}{2}\frac{\Delta\varepsilon_{\mathrm{b}}}{\varepsilon_{\mathrm{b}}}$$

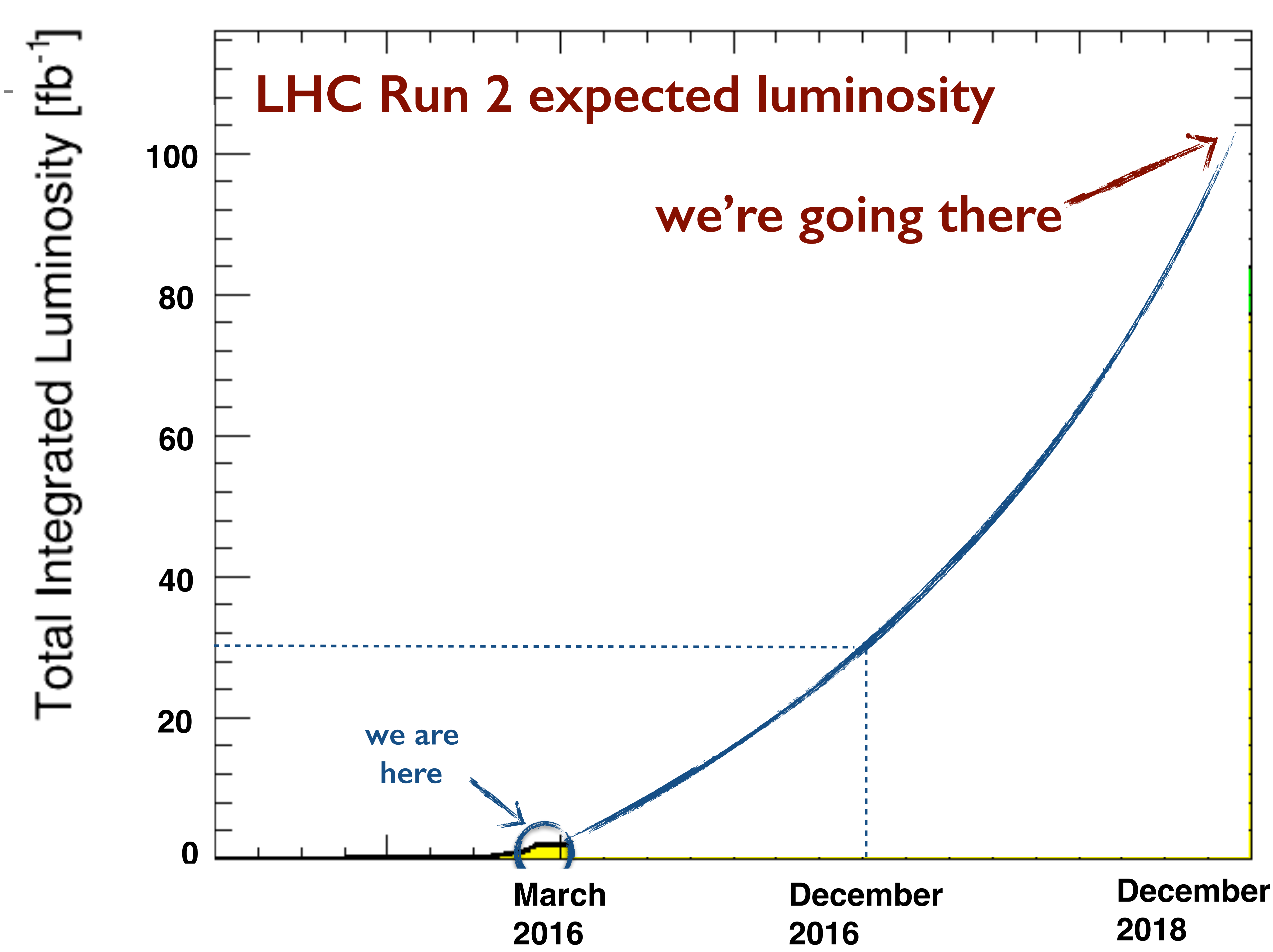


more on Top Properties at the LHC in E. Monnier's talk

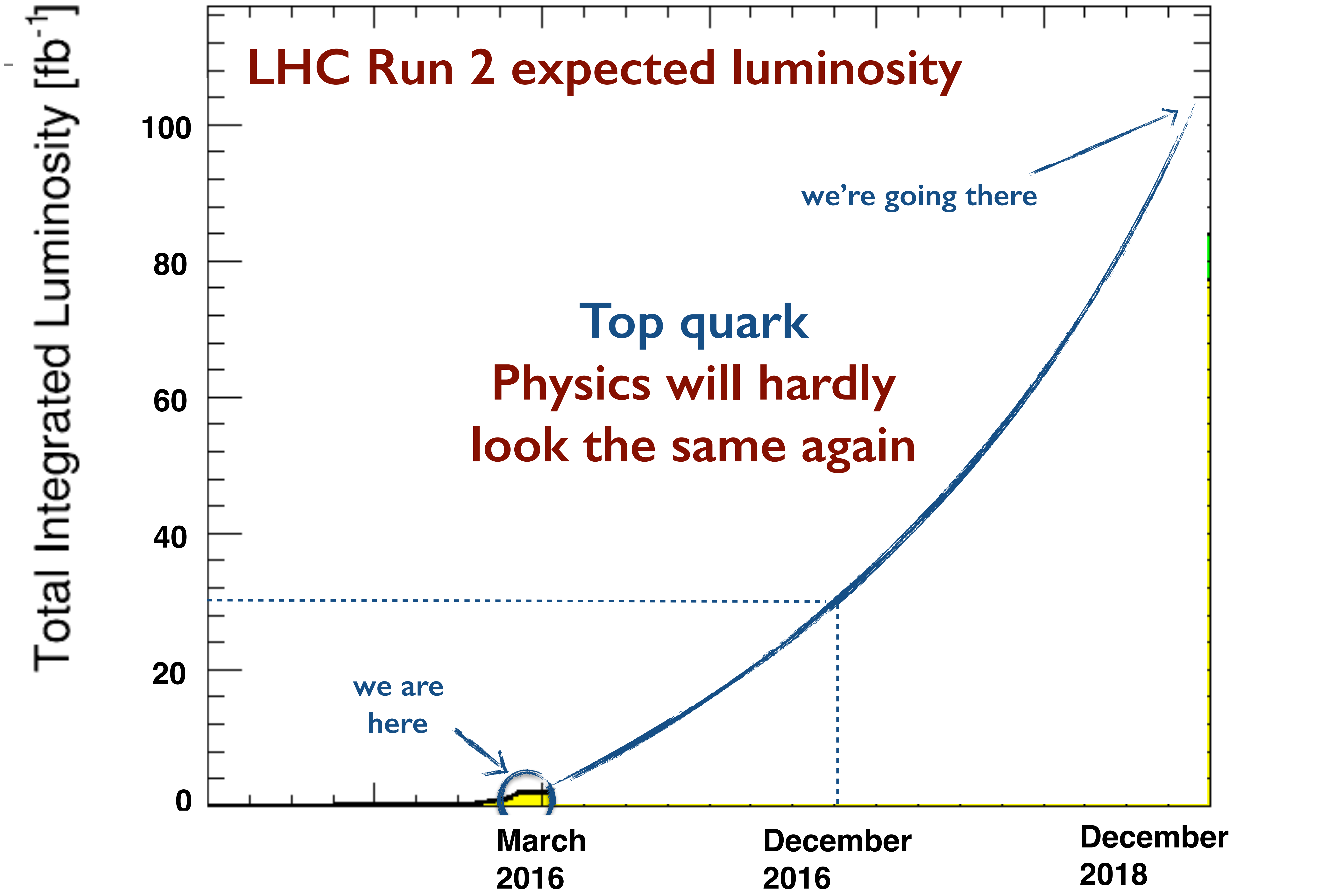
Conclusions and outlook



ATLAS Online Luminosity
√s = 13 TeV
LHC Delivered
ATLAS Recorded
Total Delivered: 4.2 fb⁻¹
Total Recorded: 3.9 fb⁻¹
we are here
Total Integrated Luminosity [fb⁻¹]
0
1
2
3
4
5
23/05
20/06
18/07
15/08
12/09
10/10
07/11
Day in 2015



LHC Run 2 expected luminosity
we're going there
we are
here
Total Integrated Luminosity [fb^{-1}]
100
80
60
40
20
0
March
2016
December
2016
December
2018



LHC Run 2 expected luminosity
Top quark
Physics will hardly
look the same again
we're going there
we are
here
Total Integrated Luminosity [fb-1]
100
80
60
40
20
0
March
2016
December
2016
December
2018

Summary

- **Latest top production results are showing overall good agreement with SM**
  - NLO+PS is in common usage by experiments
  - evidence that needs further tuning aiming to great measurements in Run II
  - comparison to fixed-order computations possible : good agreement with NNLO
  - nota bene : relying so far on MC-based models, be careful for BSM-like re-interpretations
  - probing further single top production in Run II will require further (this year's) statistics
- **Re-interpretation of the production cross-sections for:**
  - precise determination of fundamental parameters: m_t, α_S, EW couplings of the top quark
  - constraining further PDFs
  - search for new physics

To erode the systematics wall in Run II work is required

from both experiment and theory communities

Backup

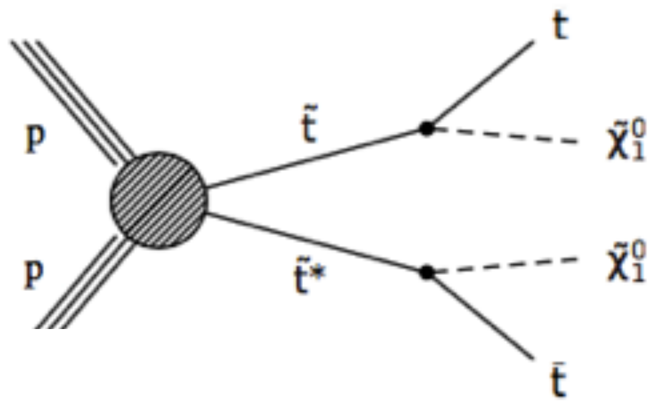
Limits on compressed SUSY spectra

NEW arXiv:1603.02303 *sub to JHEP*

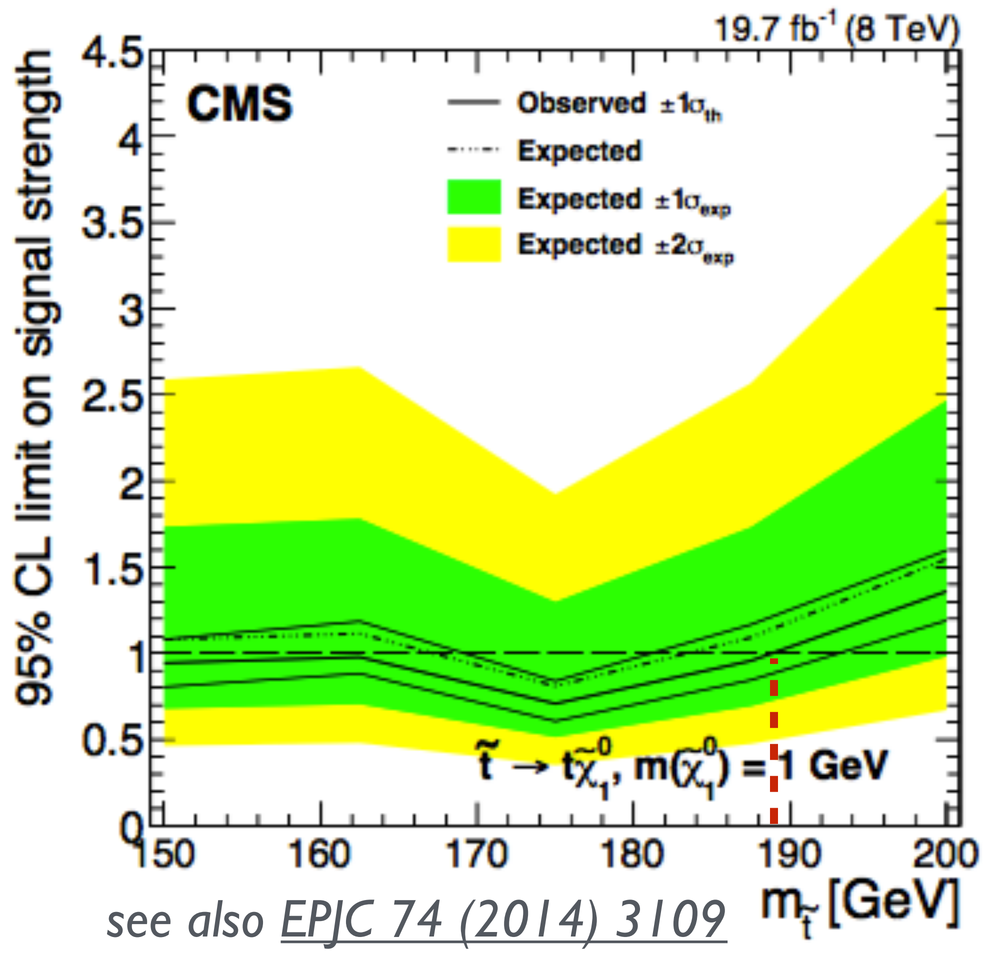
PRL 114, 142001 (2015)

see also EPJC 74 (2014) 3109

- **Complement direct stop production with precision**
  - compressed SUSY spectra mimicking tt

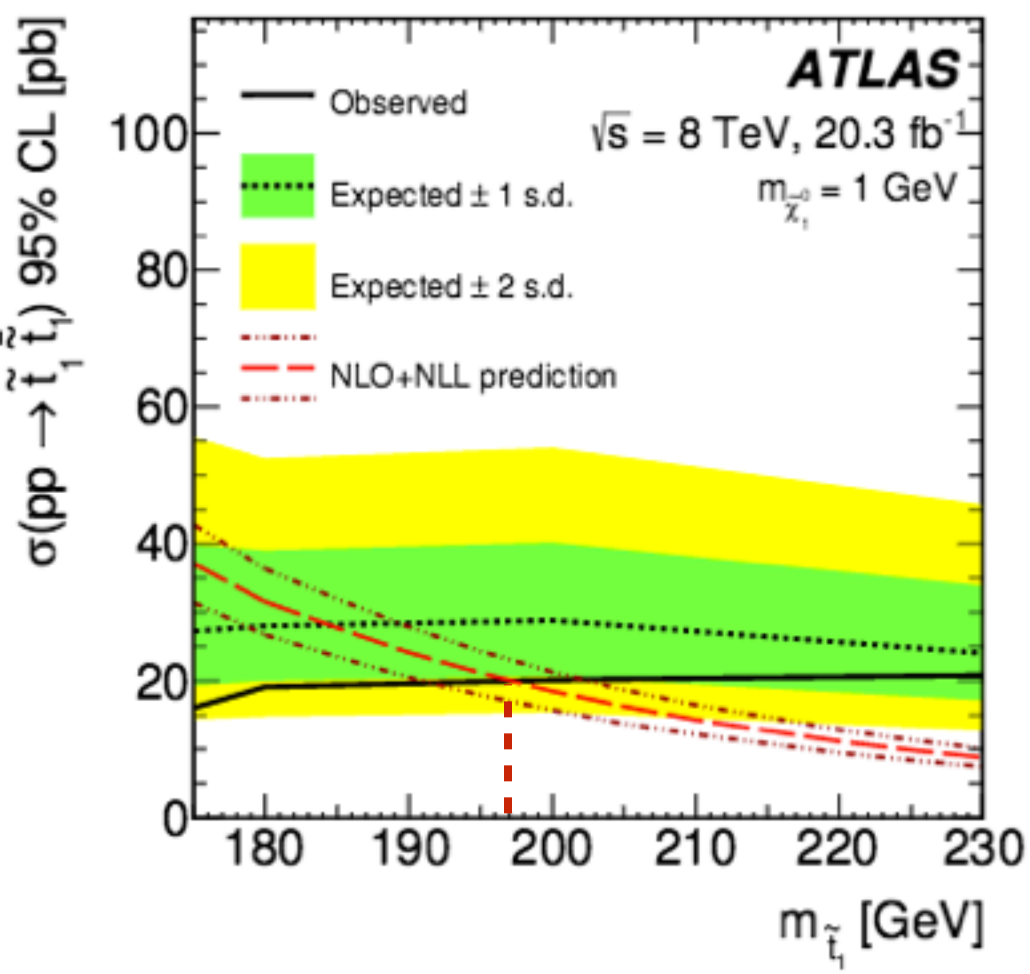


using rate information



see also EPJC 74 (2014) 3109

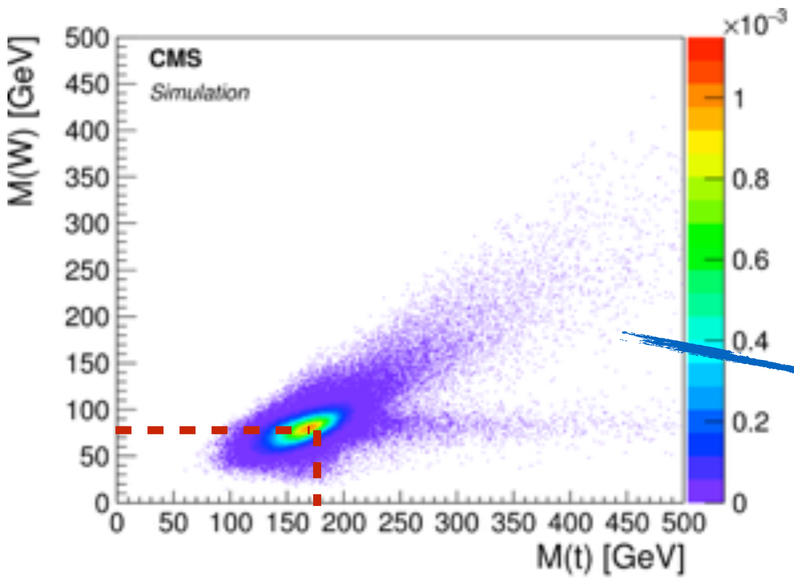
using shape information - Δϕ(ℓ,ℓ')



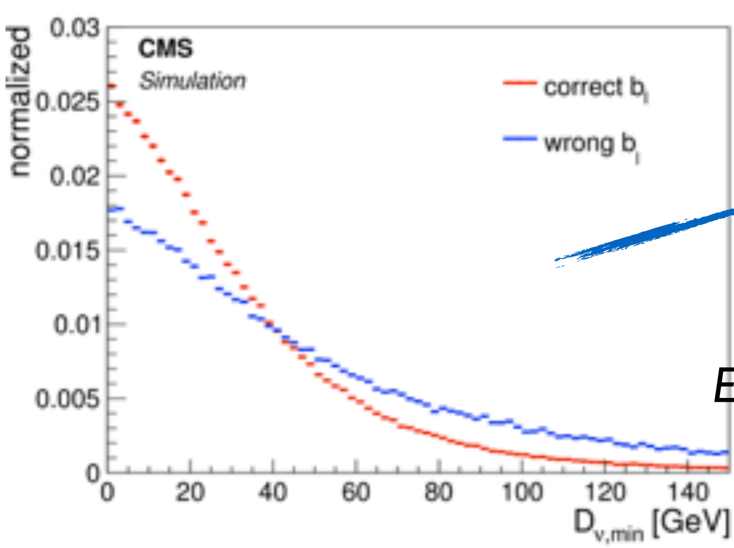
- **Expect further improvements if top mass or polarisation information is used**
  - benefit from "infinite" Run 2 statistics to probe new physics in top sector

Probing the top kinematics

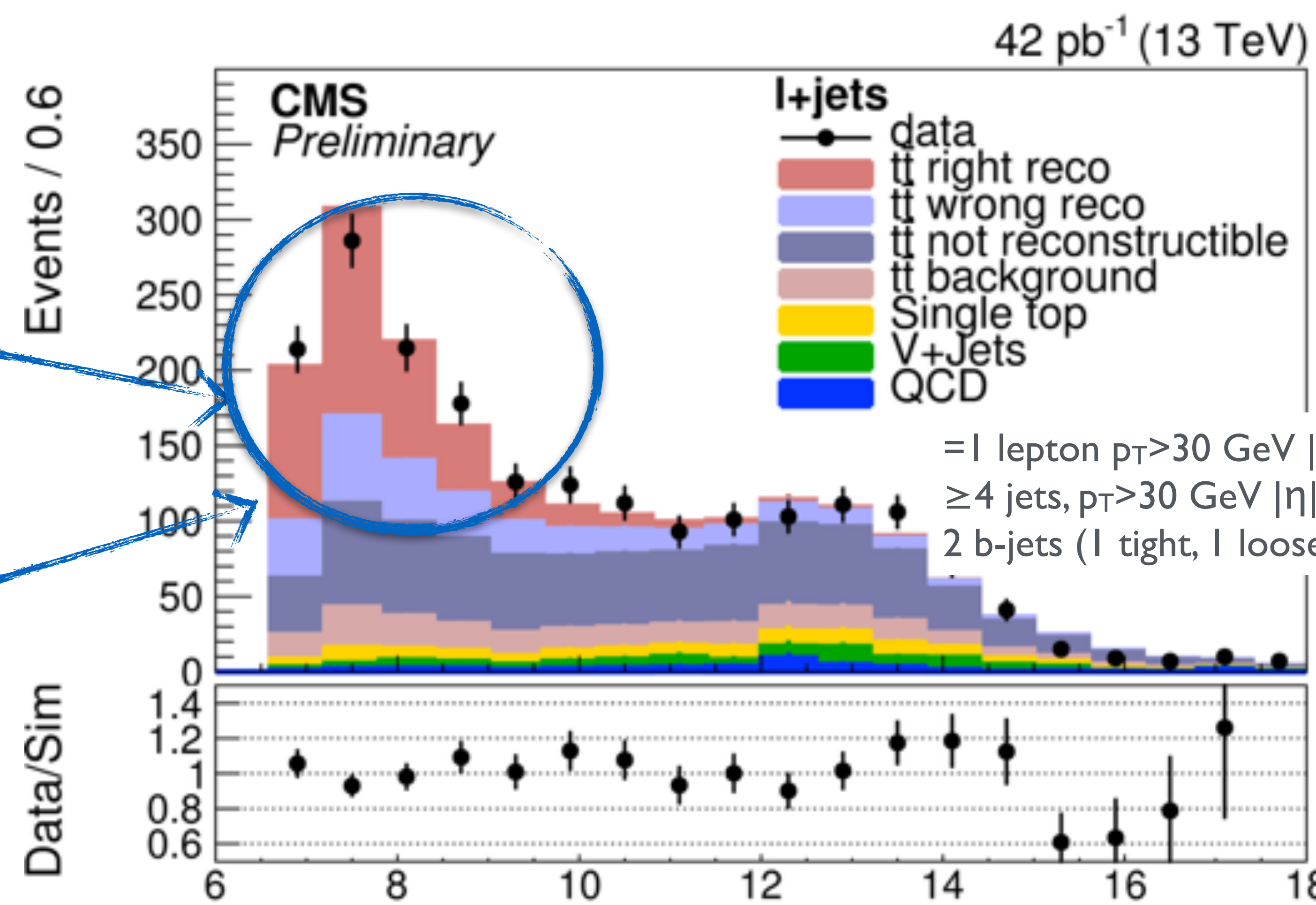
- **Different algorithms can be employed to reconstruct the top kinematics**
  - missing degrees of freedom (neutrinos), completed imposing mass constraints
  - pair objects by giving preference to b-tagged jets and using m_W, m_T, E_T^{miss} constraints
  - minimize combinatorial misassignments from simulated expectations
- Nota bene: normally, **underlying hypotheses** used in reconstruction **are SM tt-oriented**



maximize (m_t,m_W)

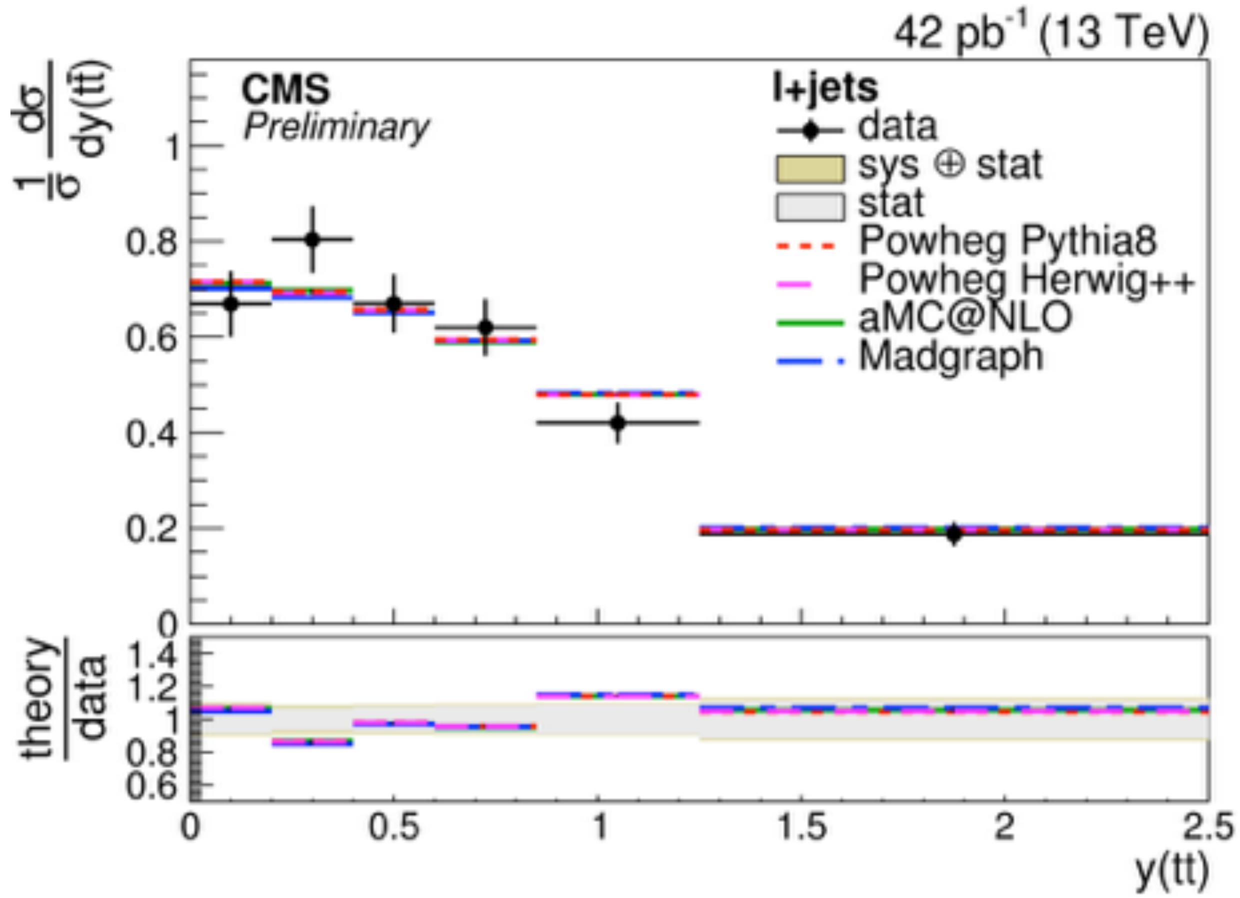


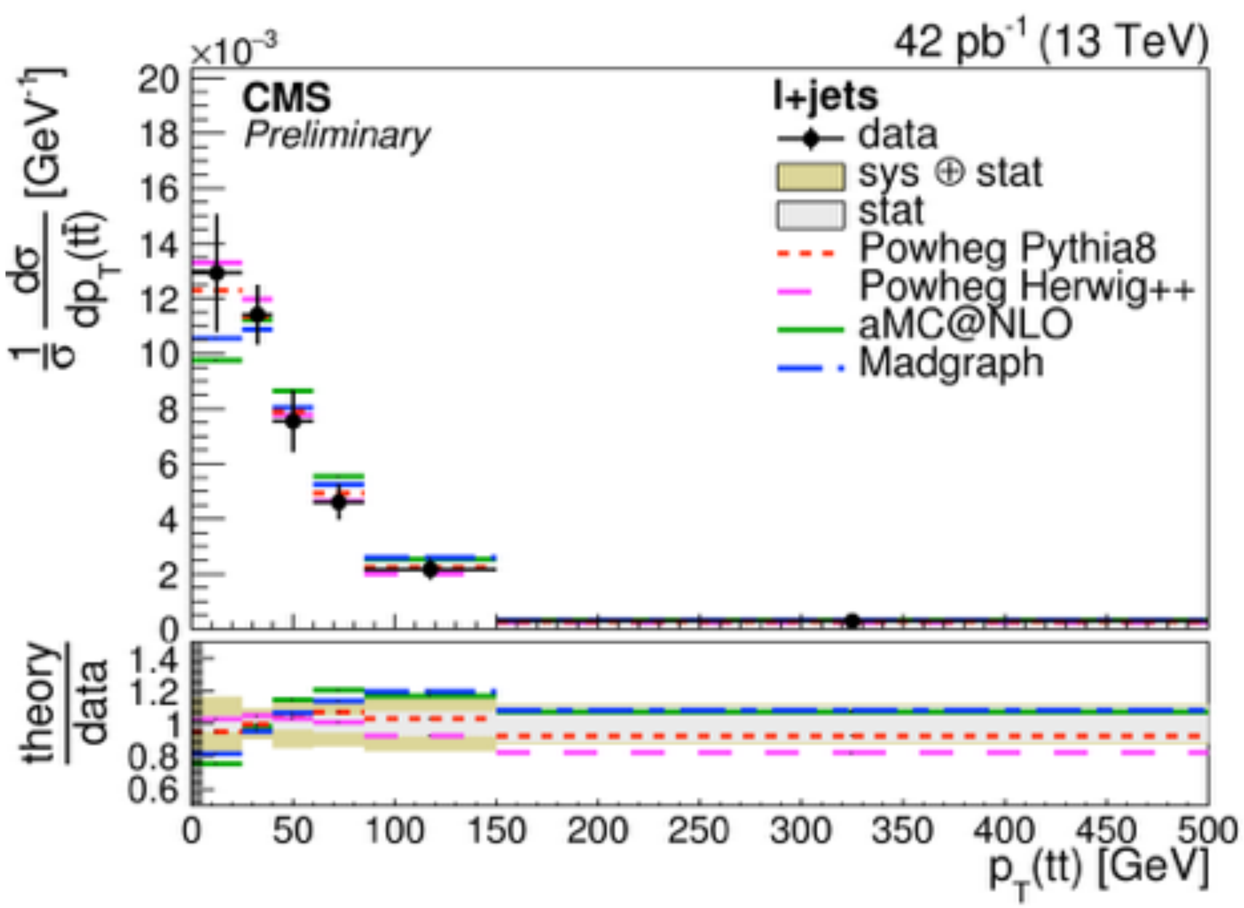
minimize neutrino solution with respect to E_T^{miss} measurement



Combination rank: $-\log(\lambda_m)$

tt system kinematics





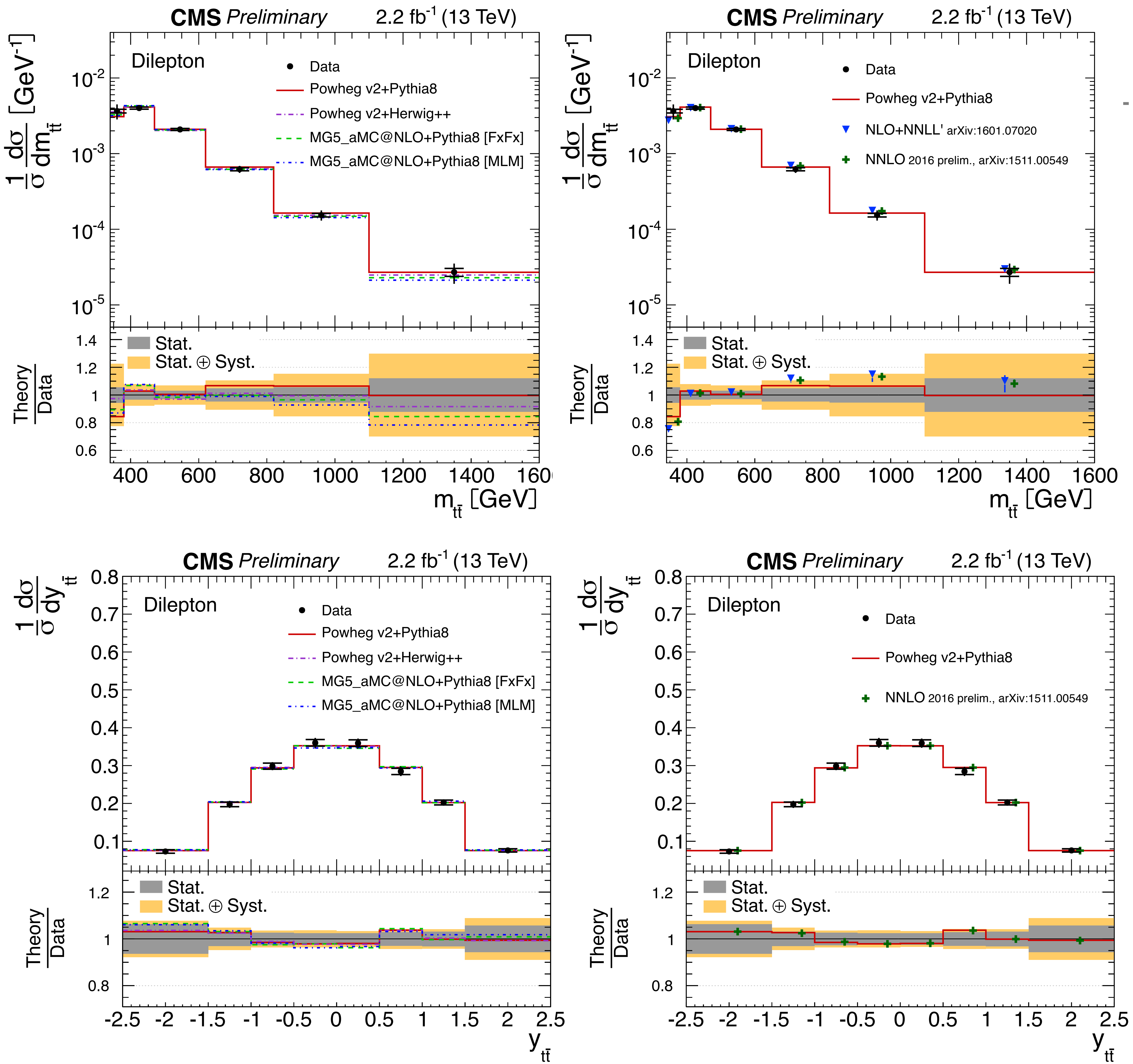
- **Semileptonic final states used**
  - at least 4 jets p_T>25 GeV (at least 1 b-tagged)
  - 1 b-jet and 1 light jet with p_T>35 GeV
  - require minimum reconstruction quality
- **Background are estimated from simulation**
  - used to subtract data before unfolding
- Fair agreement between data and nominal MC
  - **rate and shapes fairly well described**
- **Non-negligible interplay between PS and ME**
  - currently one of the limiting uncertainties
  - dependency increases for parton level extrapolation
  - can limit uncertainty up to 25% in p_T(t), p_T(tt), M(tt)

Fixed order theory predictions

- **approx. NNLO - DiffTop**, *S.Moch et al*
  - the uncertainty is the full theory uncertainty, obtained by adding in quadrature PDF and α_S uncertainties
  - scale uncertainty (simultaneous variation of ren. and fact. scales by factors 2 and 0.5; the scale is set to m_t= 172.5 GeV)
  - variation of m_t by +-1 GeV
- **approx. N^3LO** *N.Kidonakis*
  - the uncertainty is only the scale uncertainty - simultaneous variation of ren. and fact. scales by factors 2 and 0.5
  - the scale is set to m_t = 172.5 GeV).
- **NLO+NNLL'** , *B.Pecjak et al.*
  - the uncertainty is only the scale uncert, where the factorization scale μ_F is:
  - for pT(top): $\mu_F = m_T = \text{sqrt}(m_t^2 + p_T(\text{top})^2)$, and it is varied by factors 2 and 0.5
  - for m(ttbar): μ_F = m(ttbar)/2, and it is varied by factors 2 and 0.5
- **NNLO**, *A.Mitov et al.*
  - the uncertainty is only the scale uncertainty. The scale (dynamic) is:
  - for p_T(top): $\mu = m_T/2$ (varied by factors 2 and 0.5)
  - for y(top), pT(ttbar), m(ttbar), y(ttbar): $\mu = H_T/4$

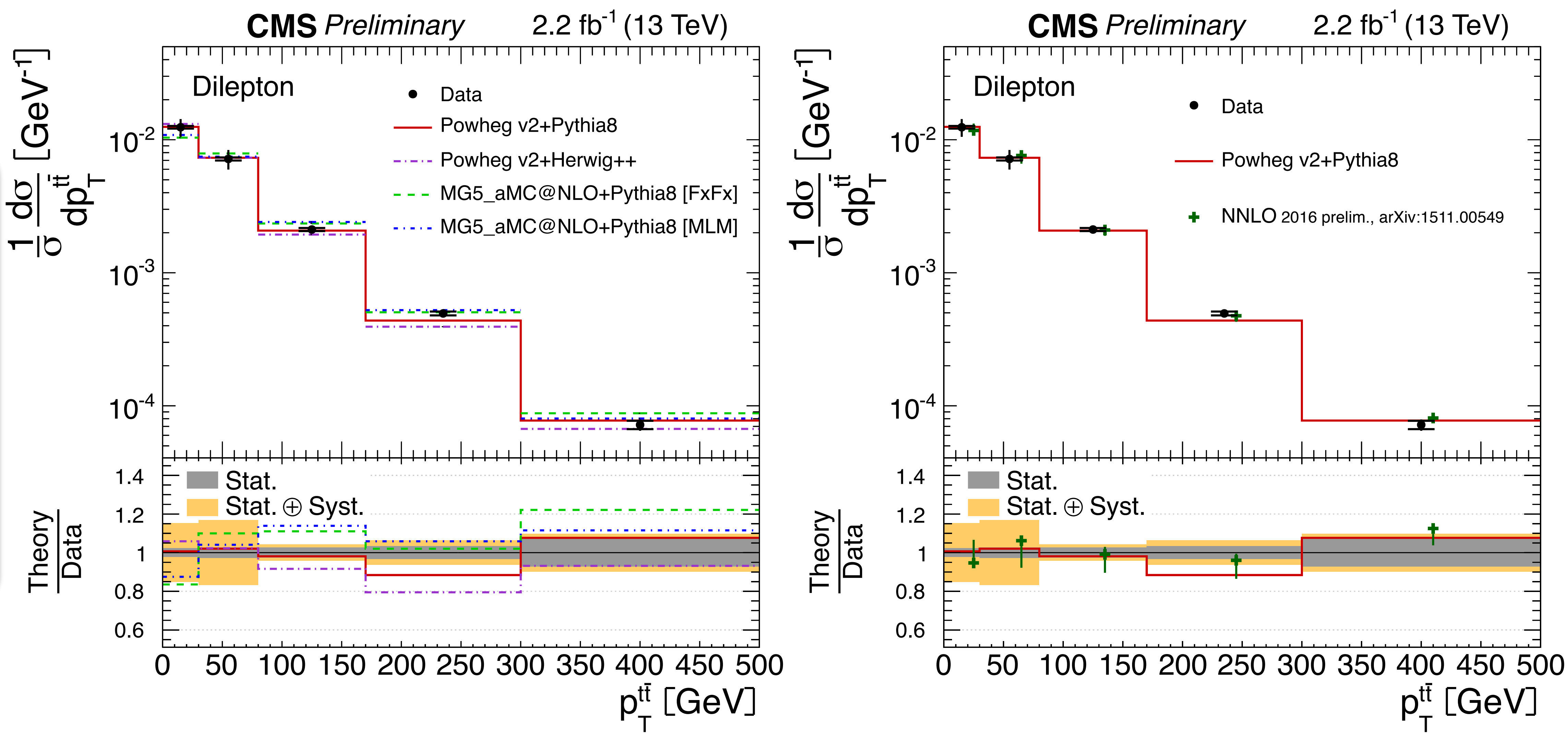
tt distributions I

NEW PAS-TOP-16-011



tt distributions II

NEW PAS-TOP-16-011



top dynamics

NEW PAS-TOP-16-011