Update on top-quark pair production results

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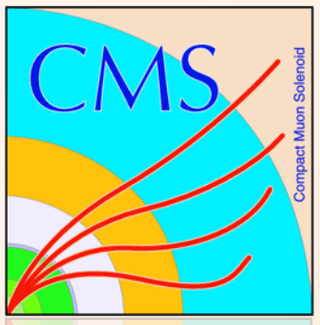
LHC*top*WG

16.05.2016



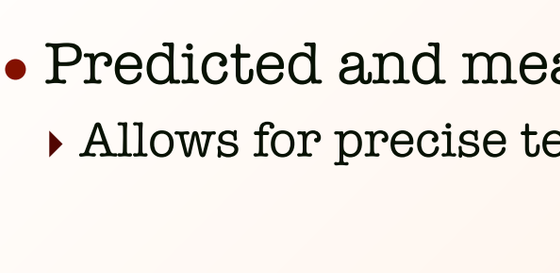
- Status
- Combination plans

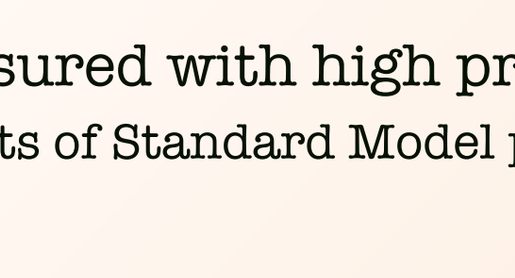
Top-quark-pair production cross sections

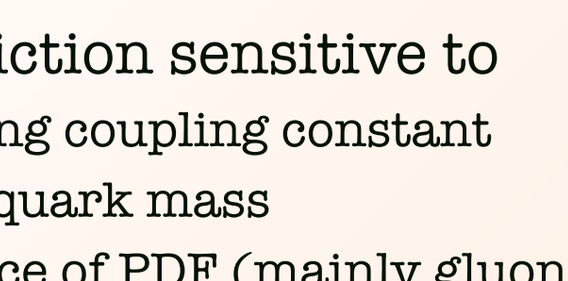
- Predicted and measured with high precision
  - Allows for precise tests of Standard Model predictions

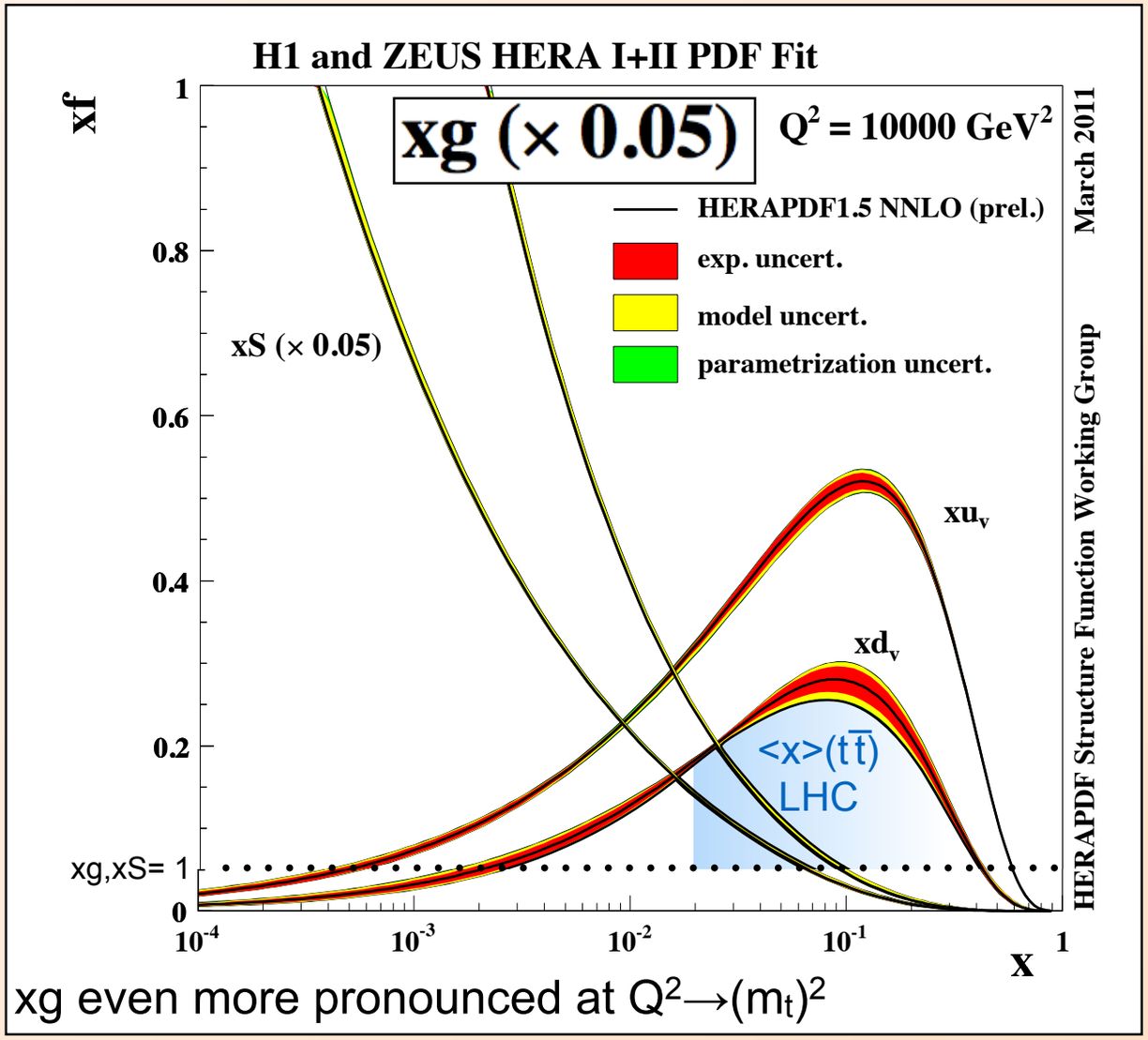
- Prediction sensitive to
  - Strong coupling constant
  - Top quark mass
  - Choice of PDF (mainly gluon density)

➡Power to extract parameters and differentiate between or constrain PDF sets









xg even more pronounced at $Q^2 \rightarrow (m_t)^2$

PDF4LHC recommendations

1. **Comparisons between data and theory for Standard Model measurements**

   Recommendations: Use *individual PDF sets*, and, in particular, as many of the modern PDF sets [5–11] as possible.

   Rationale: Measurements such as jet production, vector-boson single and pair production, or top-quark pair production, have the power to constrain PDFs, and this is best utilized and illustrated by comparing with many individual sets.

   As a rule of thumb, *any measurement that potentially can be included in PDF fits* falls in this category.

PDF4LHC recommendations for LHC Run II, arXiv:1510.03865

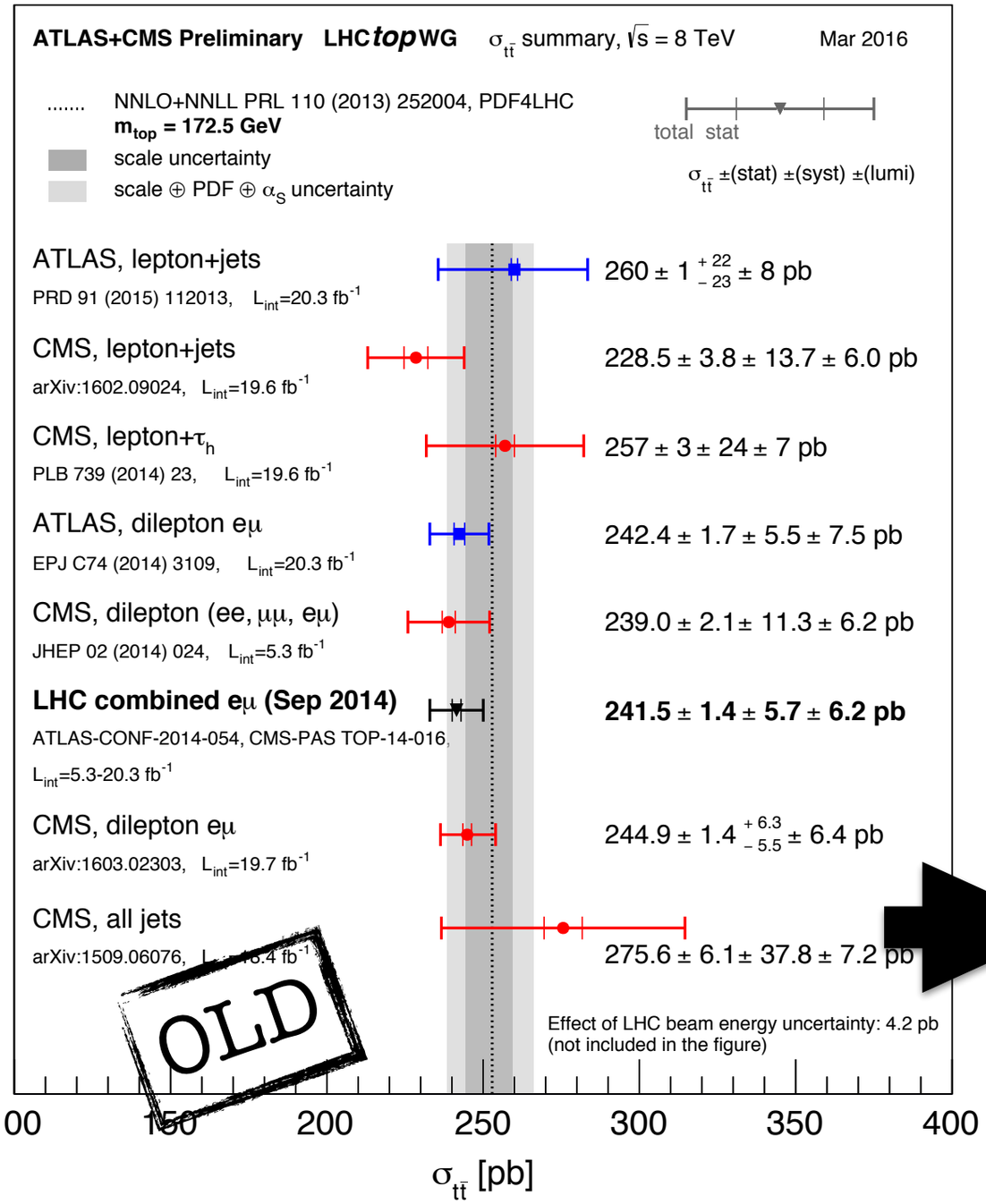
"In case (i) [the above 1.] the recommendation is to use individual PDF sets […] for comparison between data and theory for SM measurements."

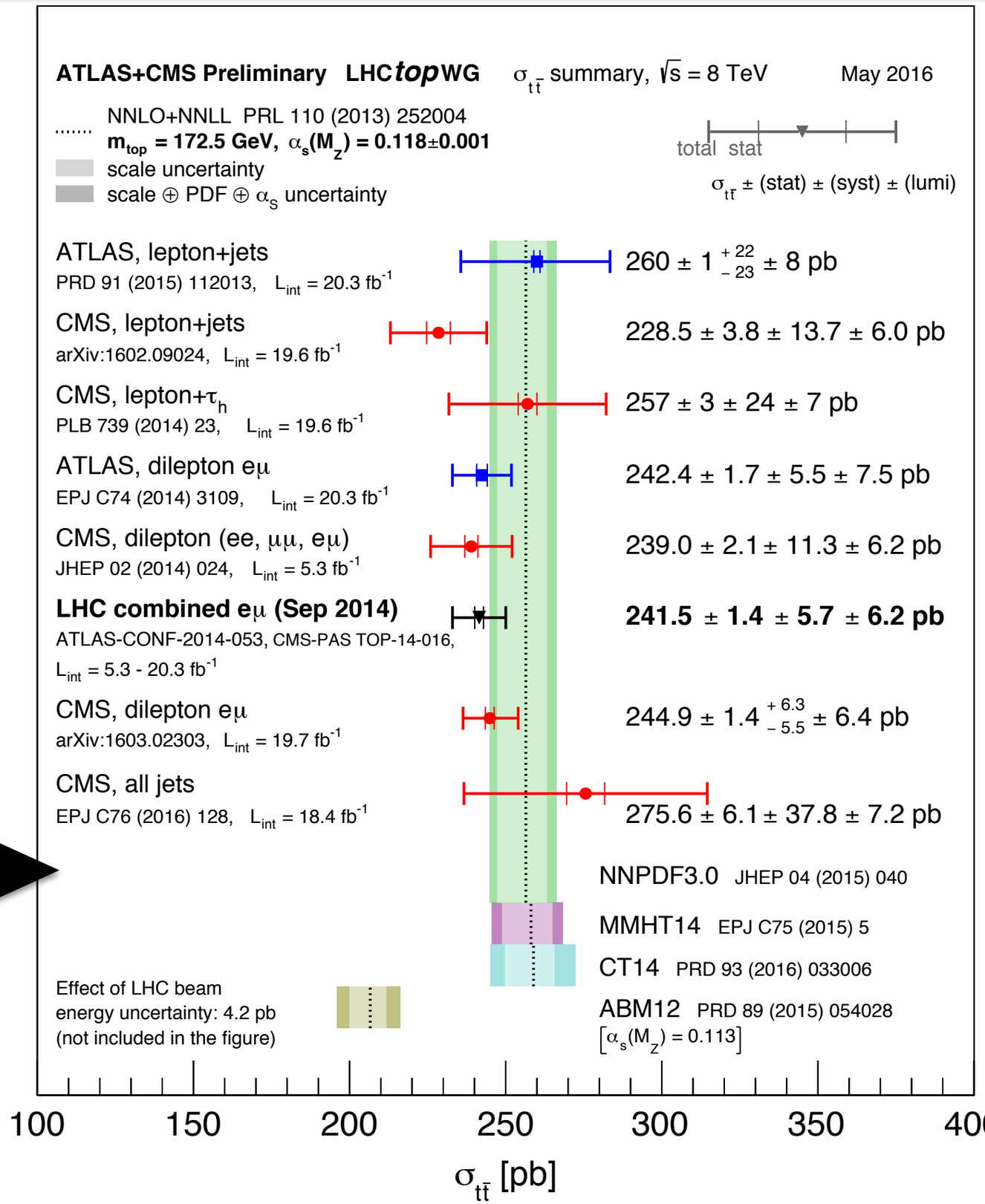
Recommendations for PDF usage in LHC predictions, arXiv:1603.08906

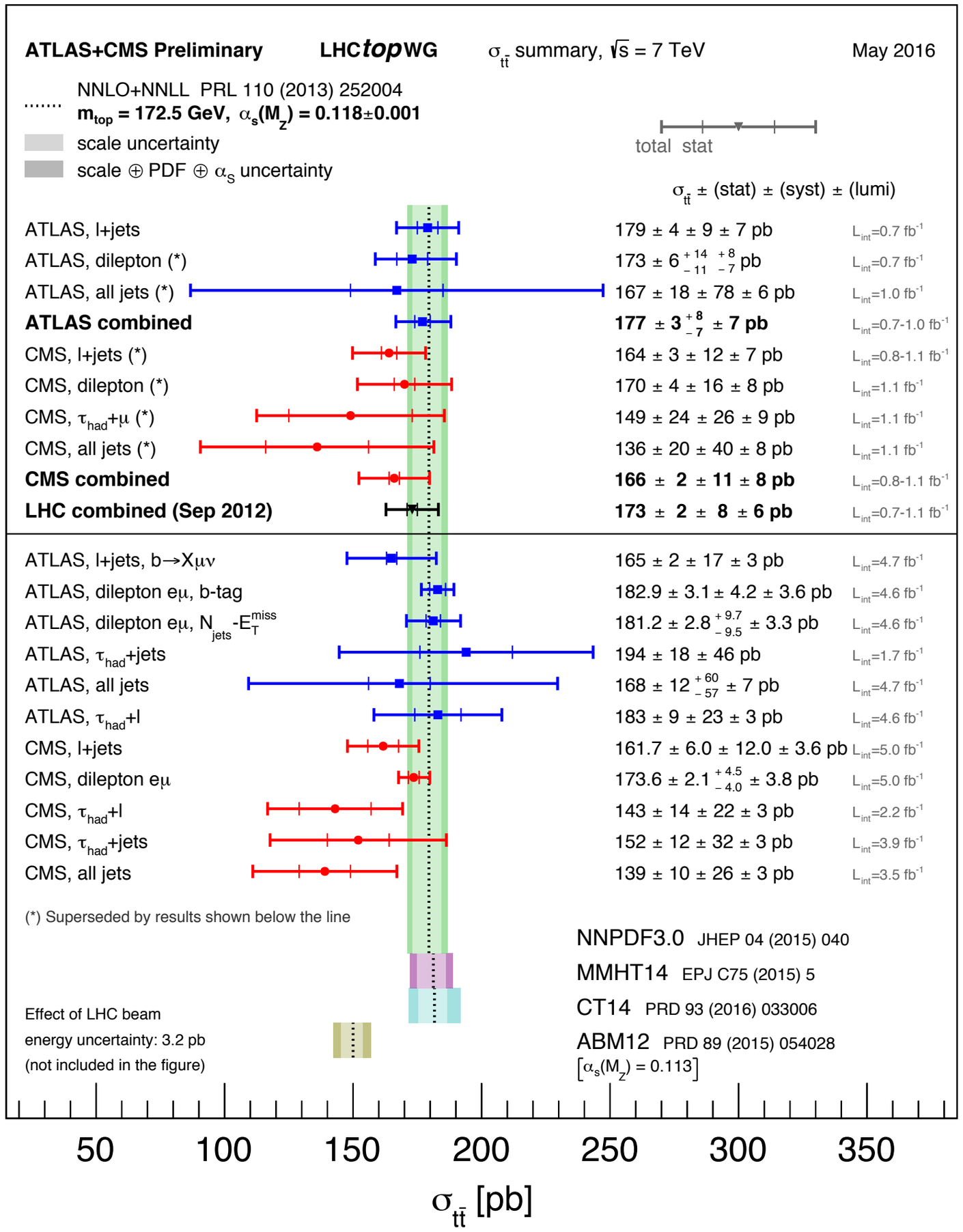
➡ Update of the summary plots

- Use 4 recent PDF sets for NNLO+NNLL prediction
  - ABM12 PRD 89 (2015) 054028
  - CT14 PRD 93 (2016) 033006
  - MMHT14 EPJ C 75 (2015) 5
  - NNPDF3.0 JHEP 04 (2015) 040
- Compare individual PDF sets

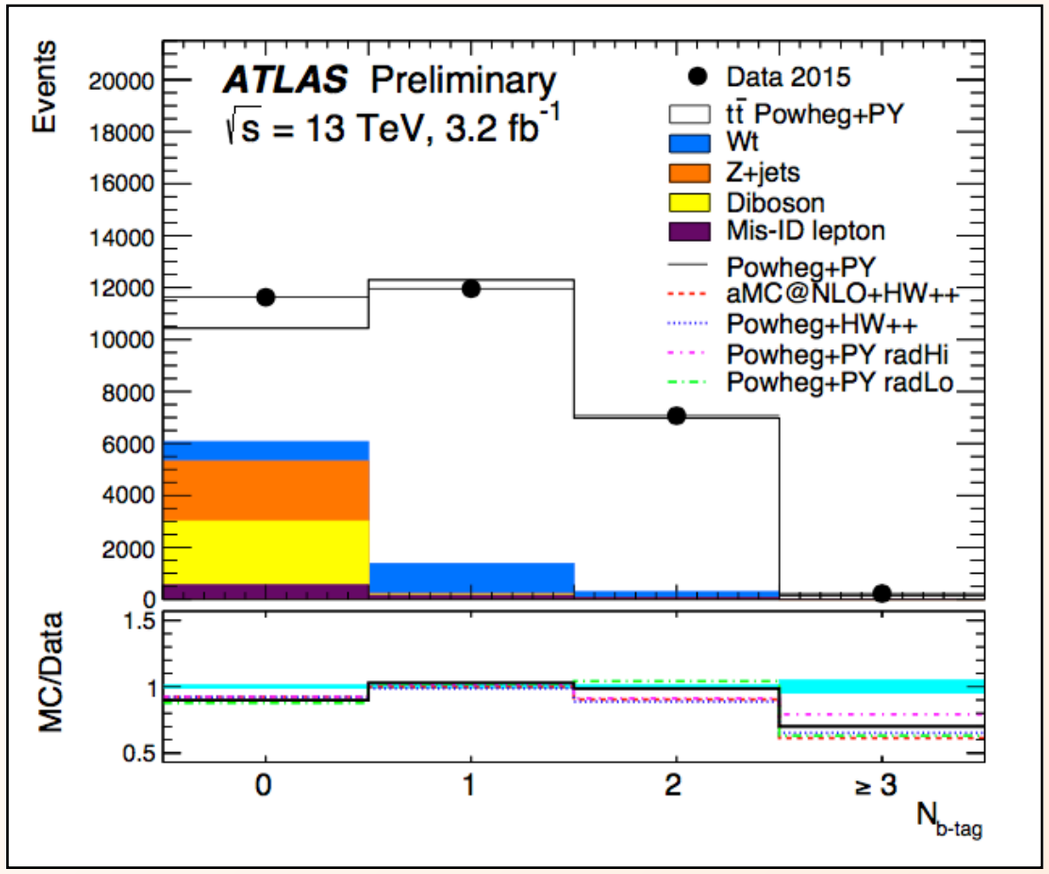
New summary plots






ATLAS+CMS Preliminary
LHC top WG
σtt̄ summary, √s = 7 TeV
May 2016
NNLO+NNLL PRL 110 (2013) 252004
mtop = 172.5 GeV, αs(MZ) = 0.118±0.001
scale uncertainty
scale ⊕ PDF ⊕ αS uncertainty
total stat
σtt̄ ± (stat) ± (syst) ± (lumi)
ATLAS, l+jets 179 ± 4 ± 9 ± 7 pb Lint=0.7 fb-1
ATLAS, dilepton (*) 173 ± 6 +14 −11 +8 −7 pb Lint=0.7 fb-1
ATLAS, all jets (*) 167 ± 18 ± 78 ± 6 pb Lint=1.0 fb-1
ATLAS combined 177 ± 3 +8 −7 ± 7 pb Lint=0.7-1.0 fb-1
CMS, l+jets (*) 164 ± 3 ± 12 ± 7 pb Lint=0.8-1.1 fb-1
CMS, dilepton (*) 170 ± 4 ± 16 ± 8 pb Lint=1.1 fb-1
CMS, τhad+μ (*) 149 ± 24 ± 26 ± 9 pb Lint=1.1 fb-1
CMS, all jets (*) 136 ± 20 ± 40 ± 8 pb Lint=1.1 fb-1
CMS combined 166 ± 2 ± 11 ± 8 pb Lint=0.8-1.1 fb-1
LHC combined (Sep 2012) 173 ± 2 ± 8 ± 6 pb Lint=0.7-1.1 fb-1
ATLAS, l+jets, b→Xμν 165 ± 2 ± 17 ± 3 pb Lint=4.7 fb-1
ATLAS, dilepton eμ, b-tag 182.9 ± 3.1 ± 4.2 ± 3.6 pb Lint=4.6 fb-1
ATLAS, dilepton eμ, Njets-ETmiss 181.2 ± 2.8 +9.7 −9.5 ± 3.3 pb Lint=4.6 fb-1
ATLAS, τhad+jets 194 ± 18 ± 46 pb Lint=1.7 fb-1
ATLAS, all jets 168 ± 12 +60 −57 ± 7 pb Lint=4.7 fb-1
ATLAS, τhad+l 183 ± 9 ± 23 ± 3 pb Lint=4.6 fb-1
CMS, l+jets 161.7 ± 6.0 ± 12.0 ± 3.6 pb Lint=5.0 fb-1
CMS, dilepton eμ 173.6 ± 2.1 +4.5 −4.0 ± 3.8 pb Lint=5.0 fb-1
CMS, τhad+l 143 ± 14 ± 22 ± 3 pb Lint=2.2 fb-1
CMS, τhad+jets 152 ± 12 ± 32 ± 3 pb Lint=3.9 fb-1
CMS, all jets 139 ± 10 ± 26 ± 3 pb Lint=3.5 fb-1
(*) Superseded by results shown below the line
Effect of LHC beam
energy uncertainty: 3.2 pb
(not included in the figure)
NNPDF3.0 JHEP 04 (2015) 040
MMHT14 EPJ C75 (2015) 5
CT14 PRD 93 (2016) 033006
ABM12 PRD 89 (2015) 054028
[αs(MZ) = 0.113]
50
100
150
200
250
300
350
σtt̄ [pb]

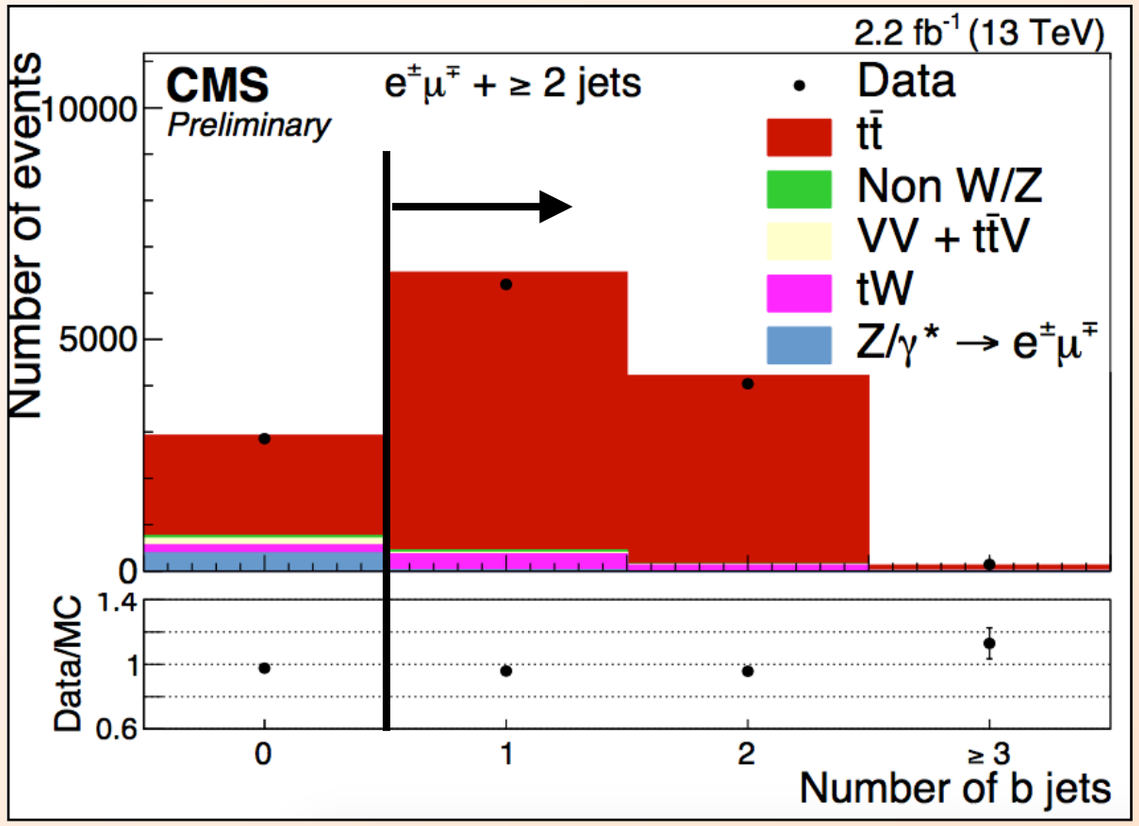
13 TeV: New results since Nov. 2015



ATLAS: ATLAS-CONF-2016-005

- Isolated, high p_T $e^{\pm}\mu^{\mp}$ pair
- Exploit expected $t\bar{t}$ event topology
  - simultaneously determine σ_{tt} and b-tagging efficiency*
- Dominant uncertainties: luminosity, hadronisation modelling

*N.B.: efficiency to reconstruct and b-tag a jet from a top quark decay

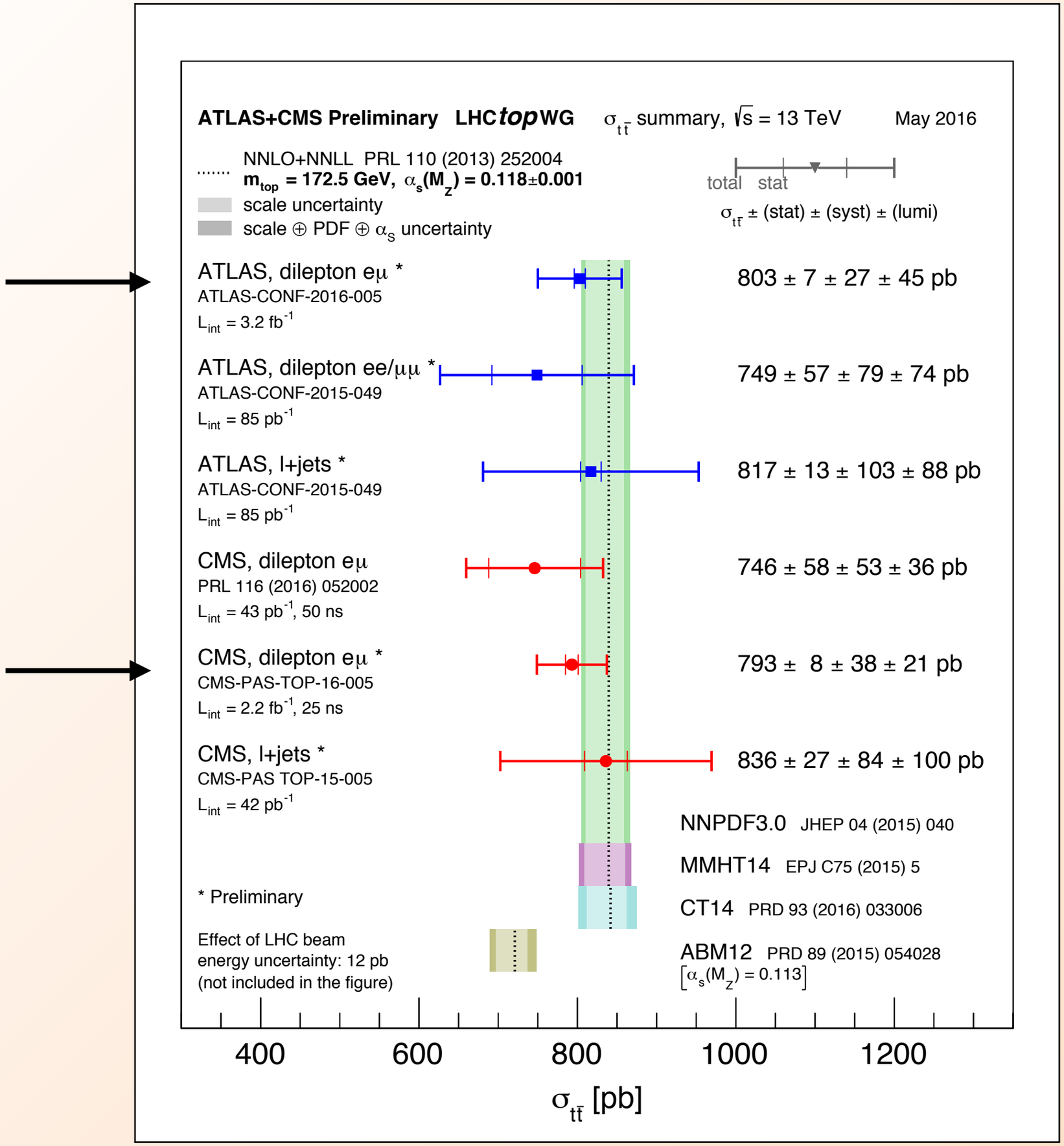


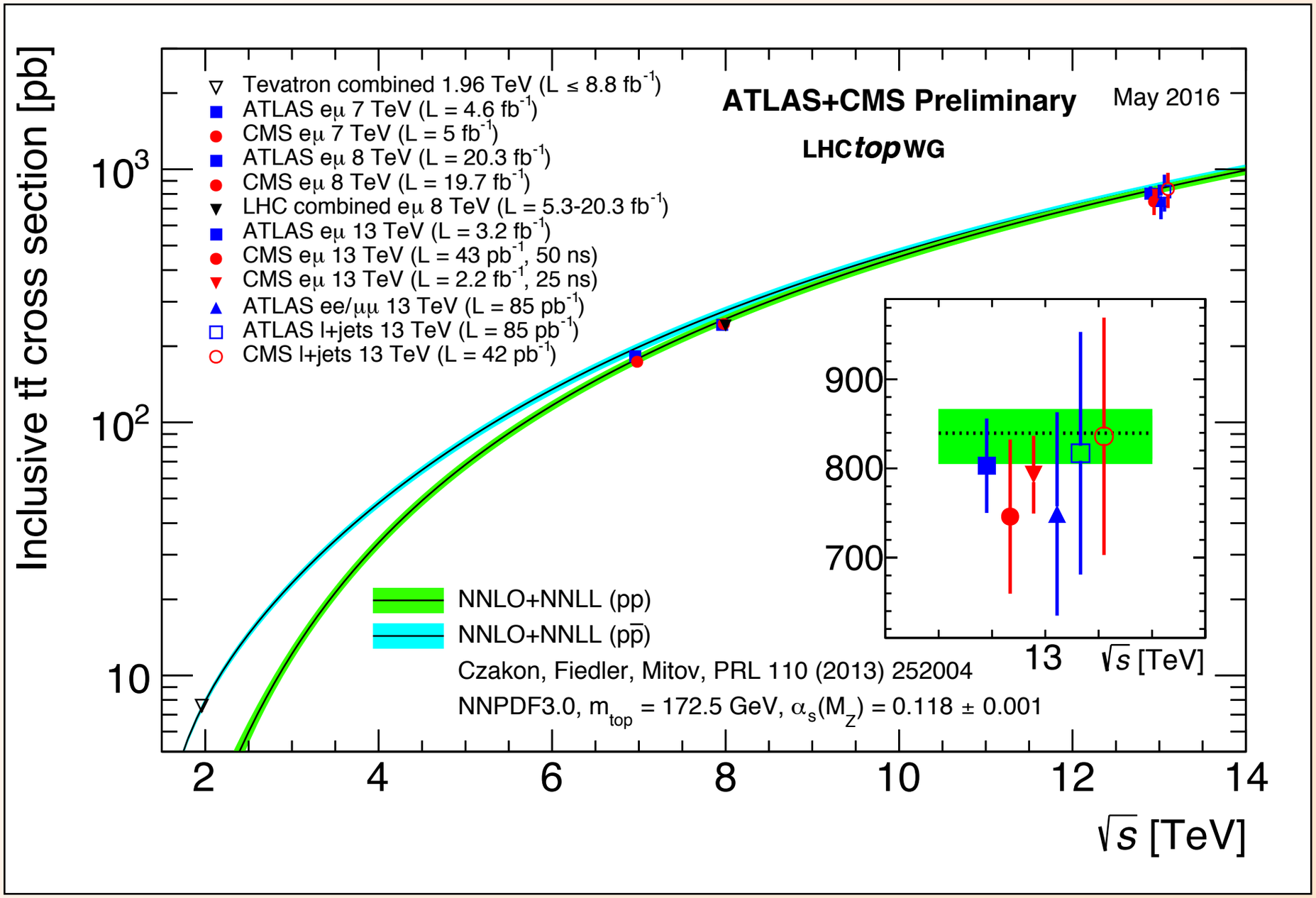
CMS: CMS PAS TOP-16-005

- Isolated, high p_T $e^{\pm}\mu^{\mp}$ pair
- 2 high energetic jets
- At least one b-tagged jet
- Cut and count
  - Z/γ^*, non W/Z backgrounds from data

$$\sigma_{t\bar{t}} = \frac{N - N_B}{\mathcal{A} \cdot \mathcal{L}}$$

- Dominant uncertainties: luminosity, lepton efficiencies, jet energy scale


ATLAS+CMS Preliminary LHCtopWG
$\sigma_{t\bar{t}}$ summary, $\sqrt{s}$ = 13 TeV
May 2016
NNLO+NNLL PRL 110 (2013) 252004
m_{top} = 172.5 GeV, $\alpha_s(M_Z)$ = 0.118±0.001
scale uncertainty
scale ⊕ PDF ⊕ α_S uncertainty
total stat
$\sigma_{t\bar{t}}$ ± (stat) ± (syst) ± (lumi)
ATLAS, dilepton eμ *
ATLAS-CONF-2016-005
L_{int} = 3.2 fb^{-1}
803 ± 7 ± 27 ± 45 pb
ATLAS, dilepton ee/μμ *
ATLAS-CONF-2015-049
L_{int} = 85 pb^{-1}
749 ± 57 ± 79 ± 74 pb
ATLAS, l+jets *
ATLAS-CONF-2015-049
L_{int} = 85 pb^{-1}
817 ± 13 ± 103 ± 88 pb
CMS, dilepton eμ
PRL 116 (2016) 052002
L_{int} = 43 pb^{-1}, 50 ns
746 ± 58 ± 53 ± 36 pb
CMS, dilepton eμ *
CMS-PAS-TOP-16-005
L_{int} = 2.2 fb^{-1}, 25 ns
793 ± 8 ± 38 ± 21 pb
CMS, l+jets *
CMS-PAS TOP-15-005
L_{int} = 42 pb^{-1}
836 ± 27 ± 84 ± 100 pb
* Preliminary
Effect of LHC beam energy uncertainty: 12 pb (not included in the figure)
NNPDF3.0 JHEP 04 (2015) 040
MMHT14 EPJ C75 (2015) 5
CT14 PRD 93 (2016) 033006
ABM12 PRD 89 (2015) 054028
[$\alpha_s(M_Z)$ = 0.113]
400
600
800
1000
1200
$\sigma_{t\bar{t}}$ [pb]



- Precision already increased w.r.t previous results
- Precision of prediction increases with higher √s (smaller PDF uncertainties)

➡Stay tuned

Combination plans

- Last combination of σ_{tt} at 8 TeV CMS-PAS TOP-14-016 / ATLAS-CONF-2014-054
  - Using most precise measurements in the dilepton (eμ) channel
  - Many correlations between uncertainties (ATLAS/CMS) studied in detail [1]
  - Dominated by significantly more precise result from ATLAS
  - Achieved precision of 3.5%

EPJ C74 (2014) 3109

- Now: very precise 'legacy' measurements at 7 and 8 TeV from ATLAS and CMS
  arxiv:1603.02303
  - Both in the eμ channel
  - Equally precise with < 4% total uncertainty, significantly more precise than other channels
  - Similar (CMS) or same (ATLAS) sources of uncertainties that were already studied

- Gain in precision from combination of both

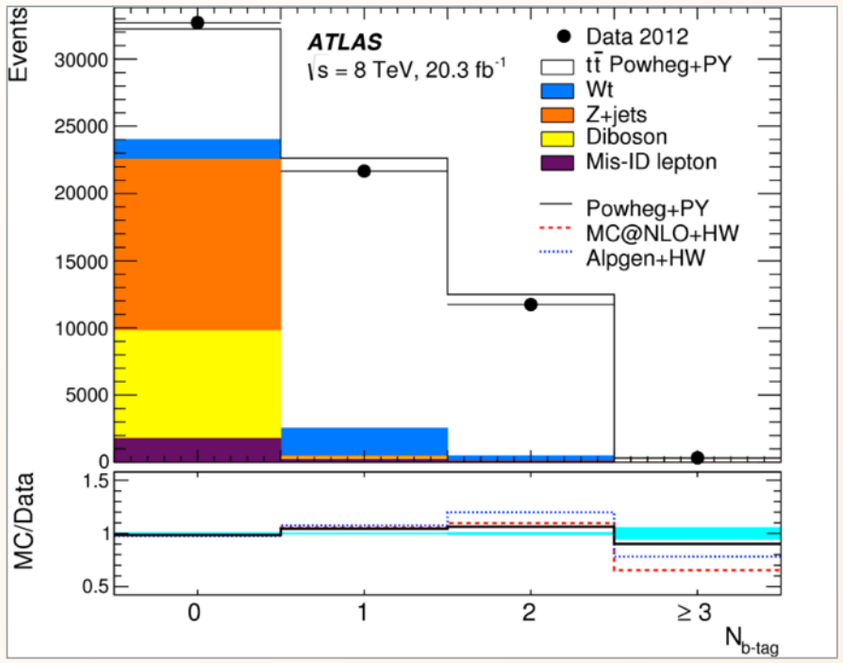
  a) Large contribution of uncorrelated uncertainties:
  - Lepton ID/isolation
  - Trigger
  - Jet resolution/ID
  - Significant part of luminosity uncertainty
  - Statistics

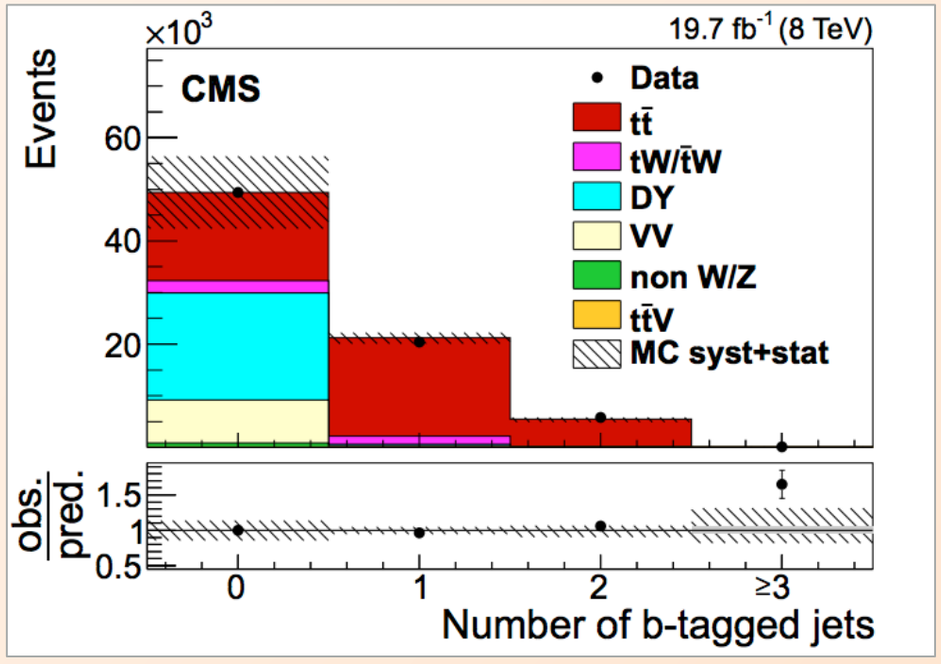
  examples

  b) Large difference in contribution of uncertainties

[1] https://indico.cern.ch/event/340357/contributions/1733547/attachments/667579/917606/LHC_xsec_ttbar_120115.pdf

Selection of dominant uncertainties





- **ATLAS**:
  - Luminosity
  - Statistics (7 TeV only)
  - Signal modelling
  - PDF
  - tW background

Uncorrelated

Part of luminosity

Statistics

Lepton ID/isolation

Trigger

Jet resolution/ID

- **CMS**:
  - Luminosity
  - Lepton ID/Isolation
  - Z+jets background
  - Trigger
  - Statistics (7 TeV only)

➡Most dominant uncertainties uncorrelated

➡Contribution different for others

➡**Expect gain in precision from combination**

Measurement strategies in a nutshell

ATLAS

- Simultaneous determination of fiducial σ_{tt} and b-tagging efficiency*
  - Individually for each systematic variation and $\sqrt{s}$ → 1 orthogonal set of uncertainties for each $\sqrt{s}$
  - Individual uncertainties are grouped for publication

Lepton scale and resolution	1.2
Lepton identification	1.7
Jet resolution	1.2
Jet identification	0.1
b-tagging	1.0

- Extrapolation to full phase space

CMS

- Multidifferential simultaneous fit of fiducial σ_{tt} at 7 and 8 TeV and systematic uncertainties
  - Fine split of uncertainty sources → 148 partially correlated parameters
  - Correlation matrix provided
  - Uncertainties cannot be grouped easily

BTAGH_BFragmentation	**1.00**												
BTAGH_DeltaR	-0.04	**1.00**											
BTAGH_GluonSplitting	-0.03	-0.03	**1.00**										
BTAGH_IFSR	0.00	0.00	0.00	**1.00**									
BTAGH_IP-bias	0.01	0.00	-0.07	0.00	**1.00**								
BTAGH_JetAway	-0.08	-0.13	-0.05	0.00	-0.02	**1.00**							
BTAGH_KT	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**						
BTAGH_LT-Bias	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**					
BTAGH_LT-Cb	-0.11	-0.06	0.02	0.00	0.01	-0.15	0.00	0.00	**1.00**				
BTAGH_LT-others	-0.07	-0.06	-0.18	0.00	-0.02	-0.16	0.00	0.00	0.02	**1.00**			
BTAGH_MuPt	-0.01	-0.03	-0.06	0.00	-0.03	-0.06	0.00	0.00	-0.03	-0.05	**1.00**		
BTAGH_PS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**	
BTAGH_PT-l2c	-0.03	-0.03	-0.03	0.00	0.00	-0.02	0.00	0.00	-0.01	-0.07	0.00	0.00	**1.00**
BTAGH_S8-ptrel	-0.05	-0.04	0.08	0.00	0.02	-0.13	0.00	0.00	-0.14	-0.05	-0.02	0.00	-0.01
BTAGH_TCT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JES: High p_T Extra	-0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.00	-0.02	0.01	0.00	0.00	0.00
JES: Single pion ECAL	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00
JES: Single pion HCAL	-0.02	-0.01	-0.02	0.00	0.01	0.00	0.00	0.00	-0.03	0.00	0.00	0.00	0.00
Top p_T	0.01	0.03	0.00	0.00	-0.01	0.06	0.00	0.00	0.04	0.03	0.01	0.00	0.01
B-hadron ν decay fraction	0.05	0.03	0.05	0.00	0.00	0.07	0.00	0.00	0.05	0.06	0.02	0.00	0.01
b-fragmentation tune	-0.06	-0.06	-0.04	0.00	0.01	-0.13	0.00	0.00	-0.08	-0.08	-0.03	0.00	-0.01
MG+PY → PH+PY	0.01	-0.01	0.01	0.00	0.01	-0.01	0.00	0.00	-0.02	0.01	0.00	0.00	0.00
ME/PS matching	0.03	0.00	0.08	0.00	0.01	-0.04	0.00	0.00	0.01	-0.04	-0.02	0.00	-0.01

- Extrapolation to full phase space

*N.B.: efficiency to reconstruct and b-tag a jet from a top quark decay

Challenges for the combination

- Combination correlation matrix will be large and include σ_{tt} at 7 and 8 TeV simultaneously
  - ✓Can be interpreted by combination tools e.g. BLUE NIM A270 (1988) 110, NIM A500 (2003) 391

- Fiducial range defined differently (different experiments)
  - ✓Cannot be combined

- CMS: extrapolation leads to additional uncertainties not constrained in the fit and therefore not accounted for in the CMS correlation matrix
  - ✓Can be treated as additional orthogonal set (as done in the analysis)
  - ✓Probably numerically not significant

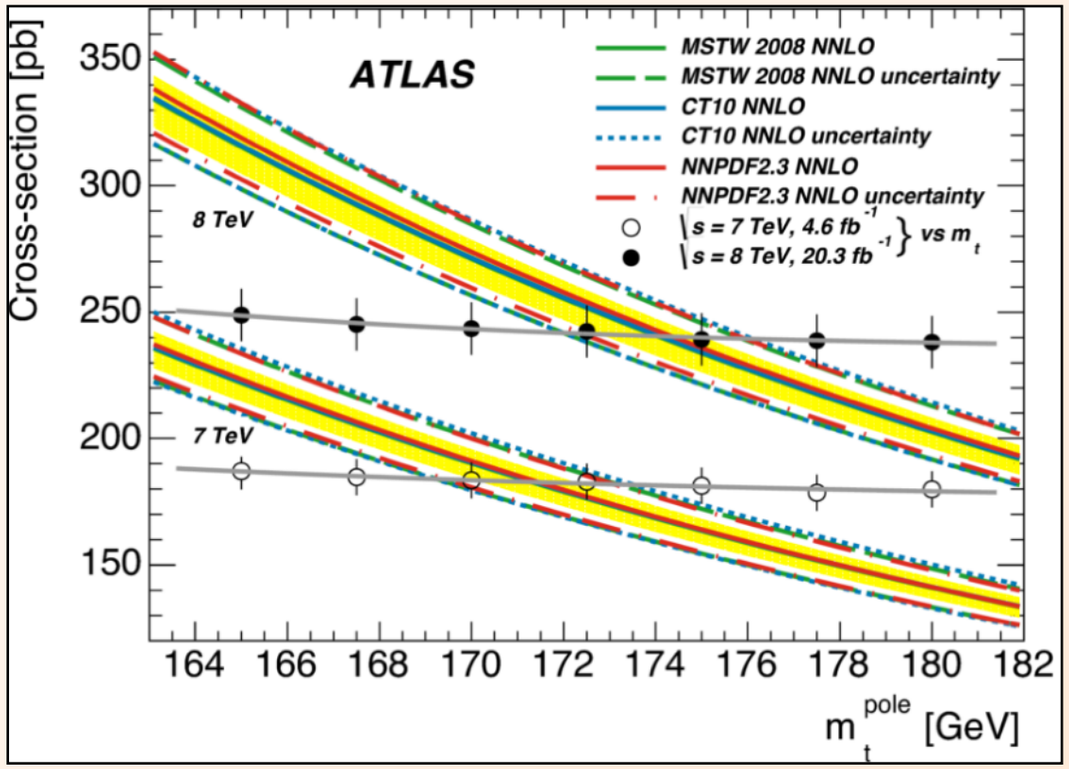
- Map the fine-split correlated uncertainty sources (CMS) to ATLAS uncertainties (in particular JES and b-tag uncertainty sources)
  - Correlations between groups are studied but not individual sources
  - Sources cannot be grouped easily due to correlations in-between them (CMS)
  - ? Possible way out: contribution of JES and b-tagging uncertainties small in both measurements → effect of assumptions on correlations: may be negligible

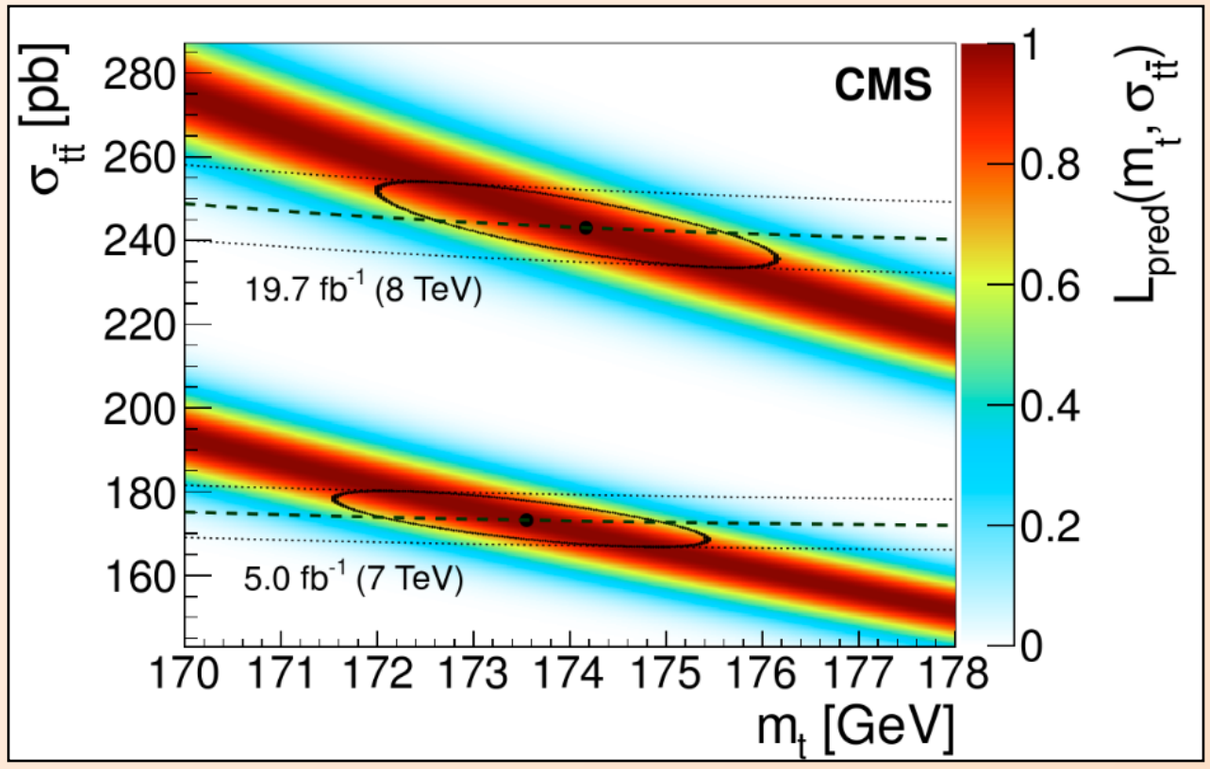
Top-quark pole mass

- Result of combination:
  - Combined σ_{tt} at 7 TeV
  - Combined σ_{tt} at 8 TeV
  - Correlation coefficient between both
  - Relative weight of each measurement

✓All input needed for an extraction of the top quark pole mass (m_t)

➡Aim for an extraction from combined σ_{tt}





➡Highly precise top-quark pole mass measurement at NNLO

Summary

Status of the measurements

- High precision for top-quark pair cross section measurements in Run 1
- Precision for Run 2 already increased significantly

➡Summarised in new summary plots

- Now comparing to predictions using different recent PDF sets

Combination plans

- CMS and ATLAS published ‘legacy’ measurements at 7 and 8 TeV
  - Equally and highly precise
  - Large contribution of orthogonal uncertainties
- Expect gain in precision from combination
- Pole-mass extraction from combined result

➡Aim for a publication