ATLAS and CMS inclusive top quark pair cross section measurements

C. Diez Pardos (CMS - DESY)

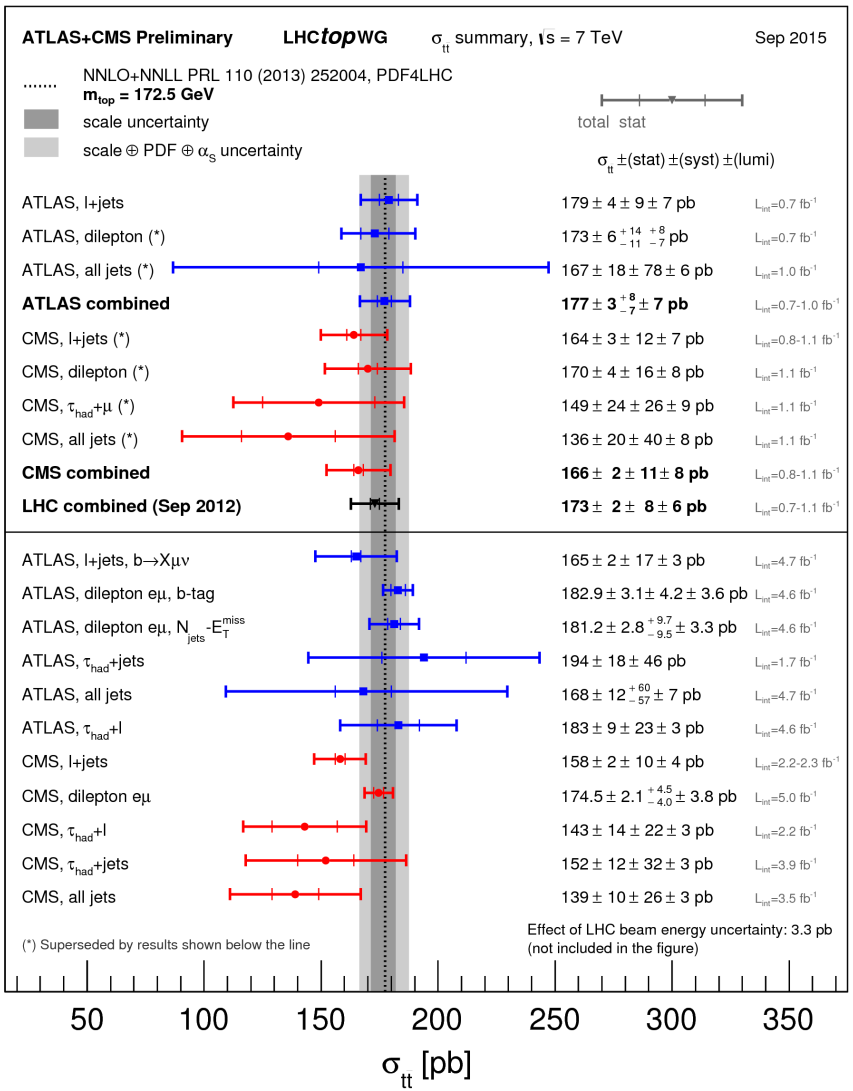
M. Aldaya (CMS - DESY), Elizaveta Shabalina (ATLAS - University of Göttingen)

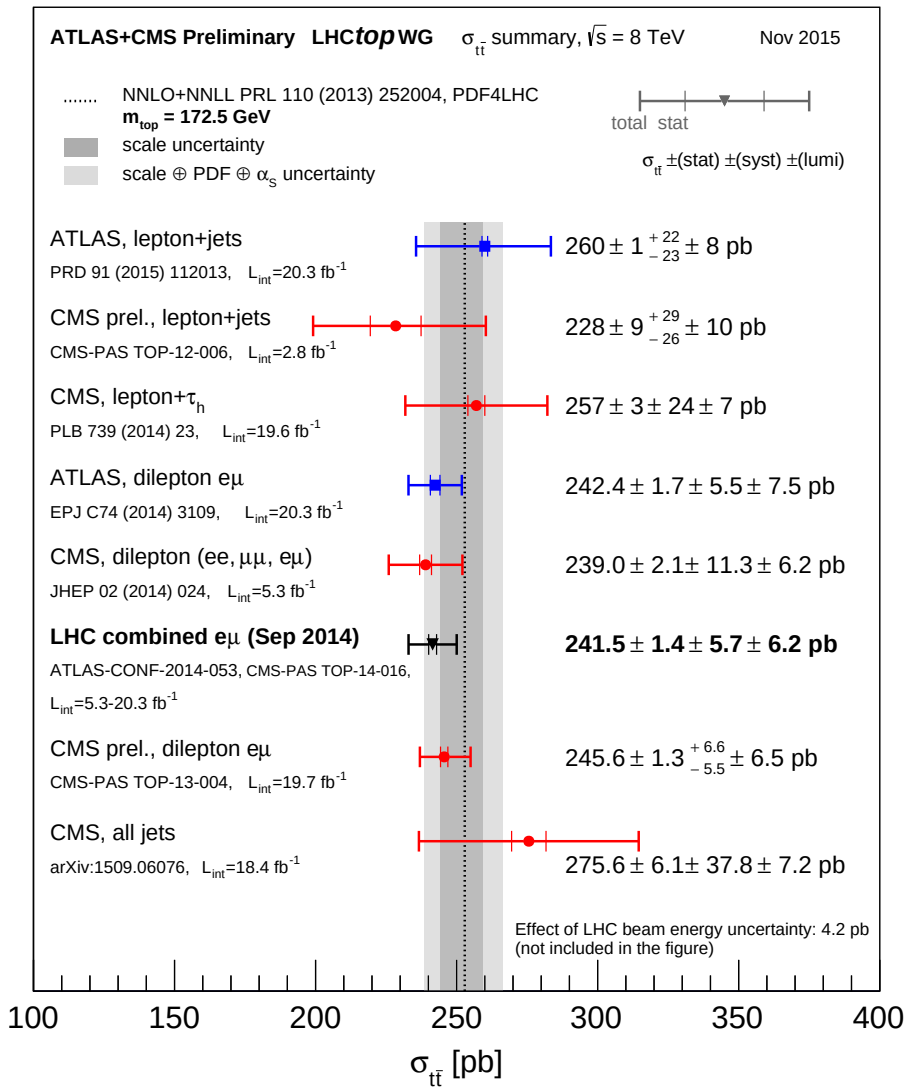
17.11.2015

LHCTopWG Open session

Overview of cross section measurements: 7 and 8 TeV

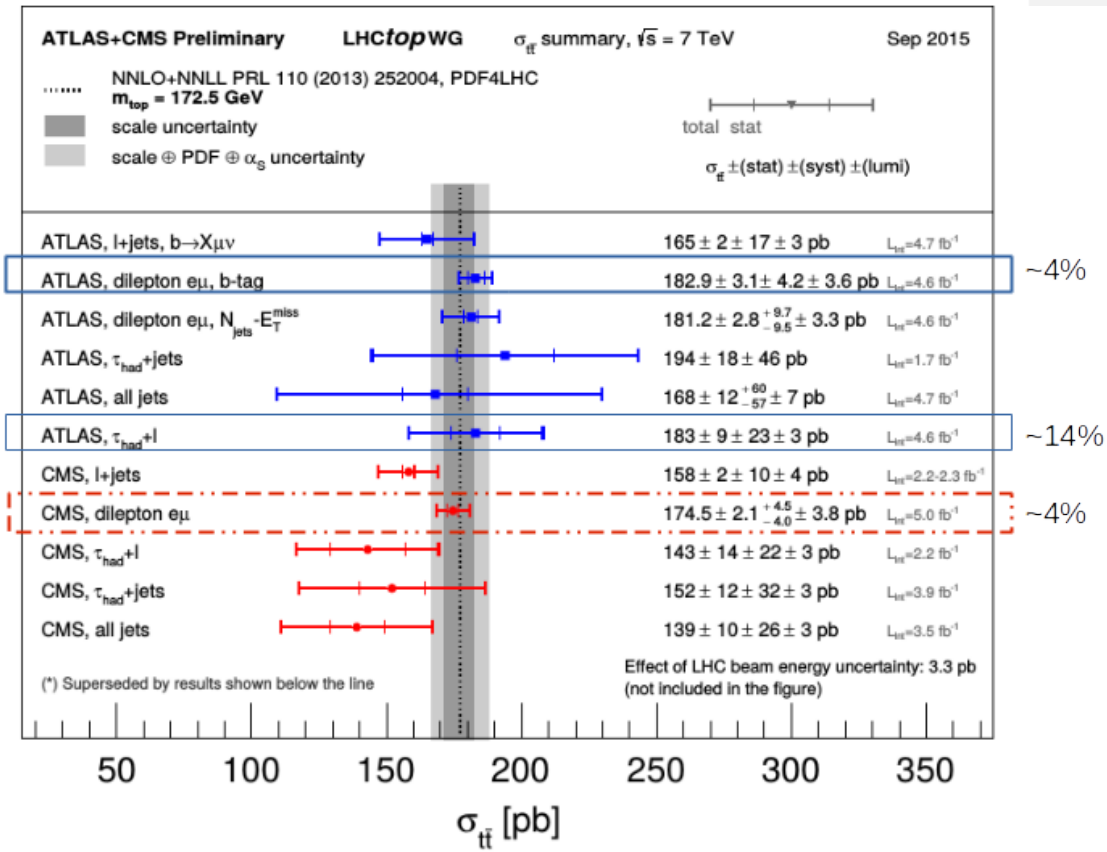
A fine crop of measurements to be selected for the LHC combination





Measurements at 7 TeV

- Combination at 7 TeV was performed in 2012 with up to 1/fb of data
- Dilepton ($e\mu$) combination viable
- Other measurements use a partial data set or are only preliminary results (except for τ_{had}+l [1])
  - Evaluate the impact of adding additional channels
  - No JES split, mass dependence available

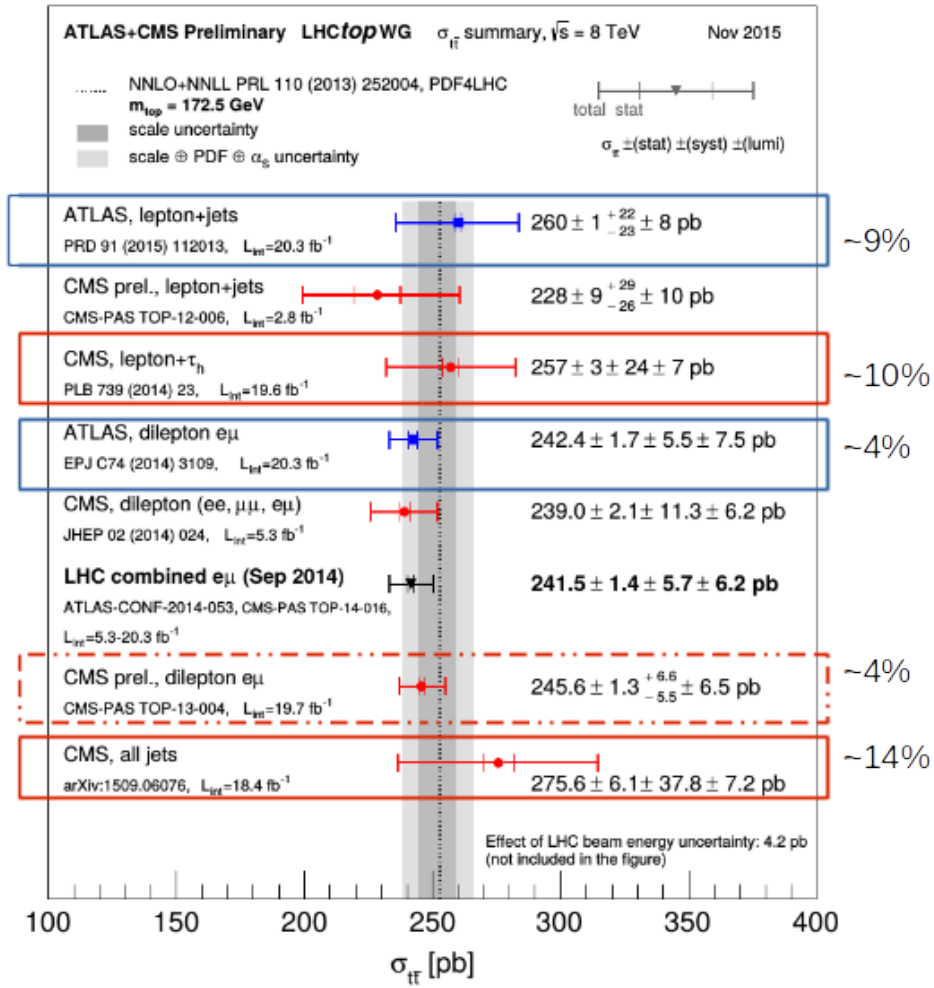


[1] Phys. Rev. D 92, 072005 (2015) Measurement of $t\bar{t}$ BR:

$\sigma = 178 \pm 3(\mathrm{stat}) \pm 16(\mathrm{syst}) \pm 3(\mathrm{lum})$ pb (9.2%) obtained from combined dilepton, l+jets and τ_{had}+l

Measurements at 8 TeV

- Latest LHC combination at 8 TeV in $e\mu$ channel
  - Use BLUE method: Best Linear Unbiased Estimate
  - Classify uncertainties: according to physics origin & correlation between experiments (detector, signal, bck. from data or simulation, lumi)
- Final ATLAS results in $e\mu$ and l+jets channels published
- CMS results in $e\mu$ is out as preliminary (working on publication), l+τ and all hadronic are published
- No JES breakdown in the public documents (but internally)

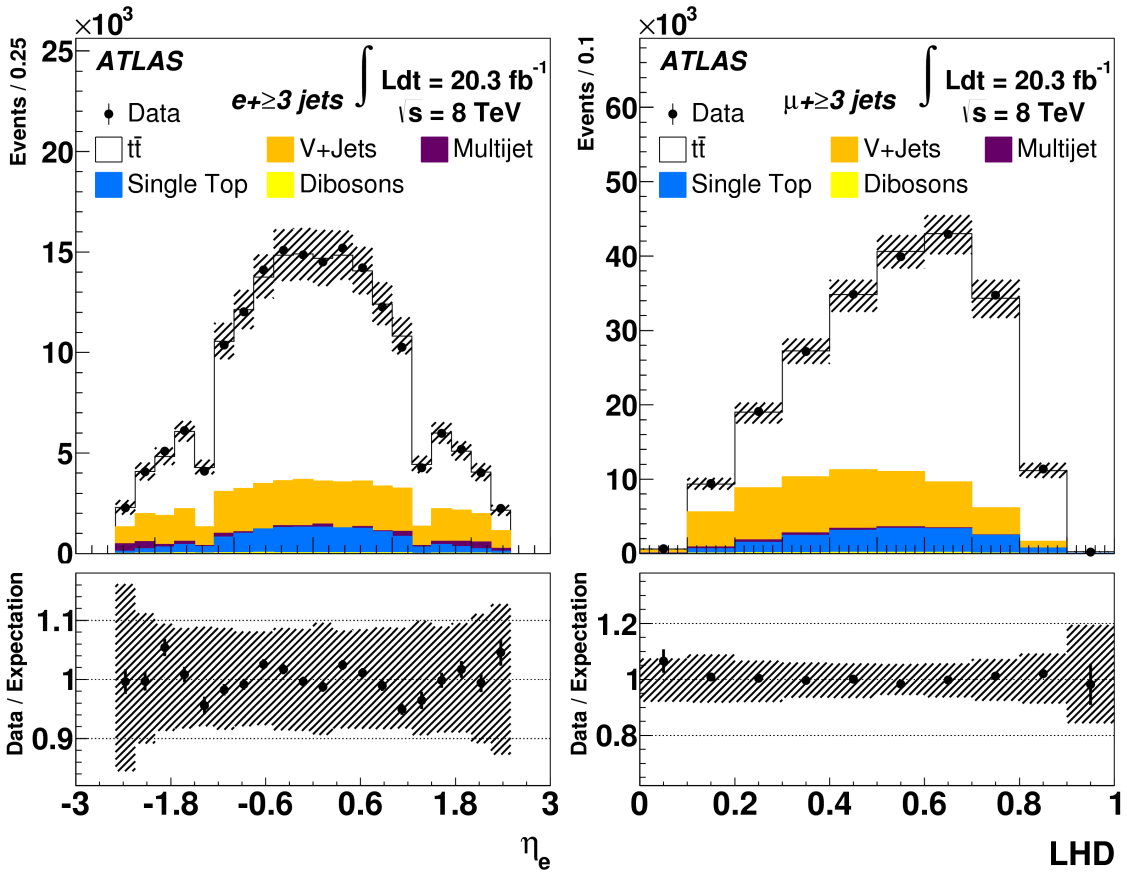


8 TeV: ATLAS l+jets [Phys. Rev. D 91, 112013 (2015)]

- 1 isolated high-p_T μ/e, $\geq$3 jets, $\geq$1 b-tagged jet

  MET, m_T(W) cuts
- Fit to likelihood function from kinematic variables
- Dominant uncertainties:

Uncertainty	
PDF	5.9%
MC generator	3.3%
Jet/E_T^{miss}	3.2%
Luminosity	2.8%
Parton Shower	2.6%
Total	**8.7%**



Mass dependence: $(\Delta\sigma/\sigma)/\Delta m_t = -1.1\%/\text{GeV}$

$$\sigma_{t\bar{t}} = 260 \pm 1(stat)^{+22}_{-23}(syst) \pm 8(lum.)\ \textbf{pb}$$

8 TeV: CMS τ_h+lepton [Phys. Lett. B 739 (2014) 23]

Selection:

- 1 isolated high-p_T μ/e, $\geq$3 jets, $\geq$1 b-tagged jet

  1 τ_h candidate

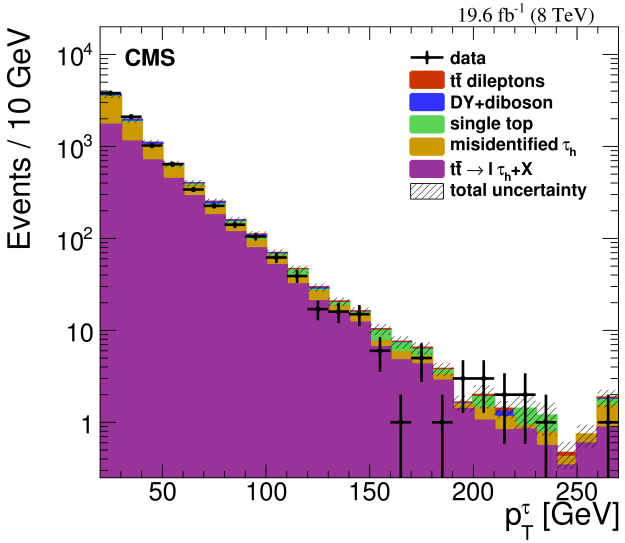
  MET cut

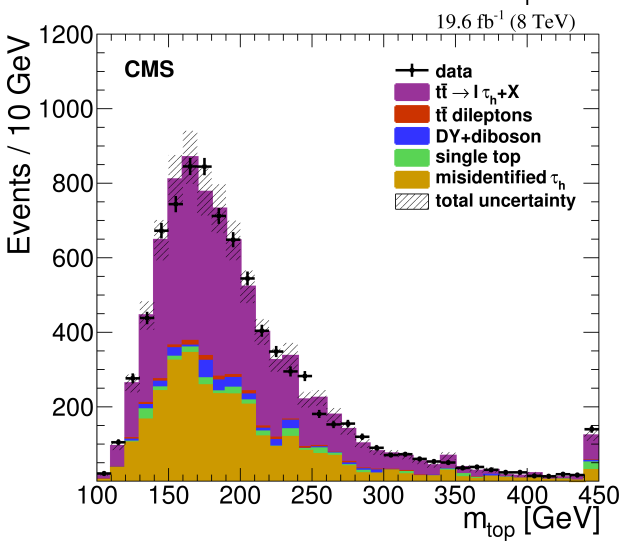
- Reconstruction of m_t for additional separation

Main uncertainties:

τ_h Identification	6%
τ_h Mis-Identifcation	4.3%
Factorization Scale	2.9%
Total systematic	9.5%
Total statistical	1%
Luminosity	2.6%

- Dependence on m_t described by a linear variation





$\sigma_{t\bar{t}} = 257 \pm 3(stat) \pm 24(syst) \pm 7(lum.)$ **pb**

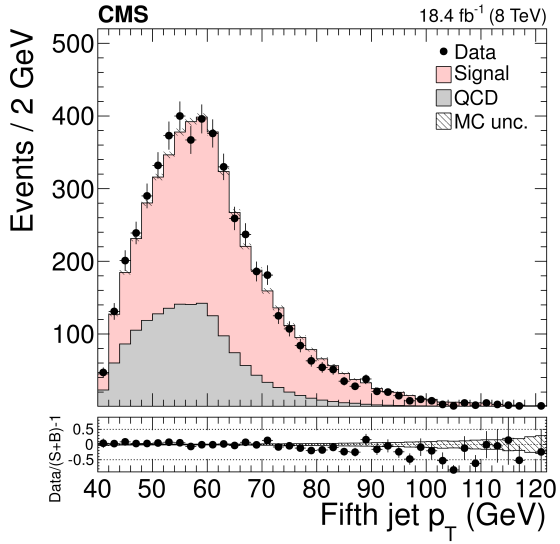
8 TeV: CMS full hadronic [arXiv:1509.06076]

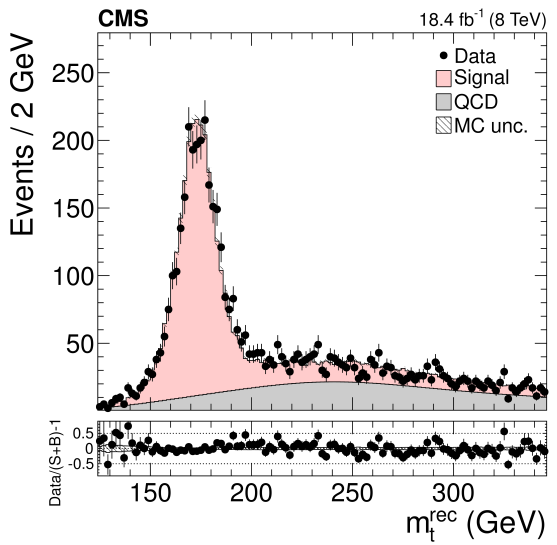
- Signature: $\geq$6 jets, $\geq$2 b-tagged jet
- Reconstruction of $t\bar{t}$ system
- Unbinned maximum likelihood fit to m_t extract signal and background normalizations
- Uncertainties:

Source	
Background modeling	±4.9%
JES	−7.0, +6.8%
JER	±3.5%
b tagging	±7.3%
Trigger efficiency	−2.2, +2.0%
Underlying event	±4.4%
Matching partons to showers	−4.2, +2.4%
Factorization and renormalization scales	−0.5, +3.8%
Color reconnection	±1.4%
Parton distribution function	±1.5%
Hadronization	±2.0%

$$\frac{\sigma_{t\bar{t}}(m_t)}{\sigma_{t\bar{t}}(m_t = 172.5)} = 1.0 - 2.4 \times 10^{-2}\,(m_t - 172.5) + 8.3 \times 10^{-4}\,(m_t - 172.5)^2\,.$$

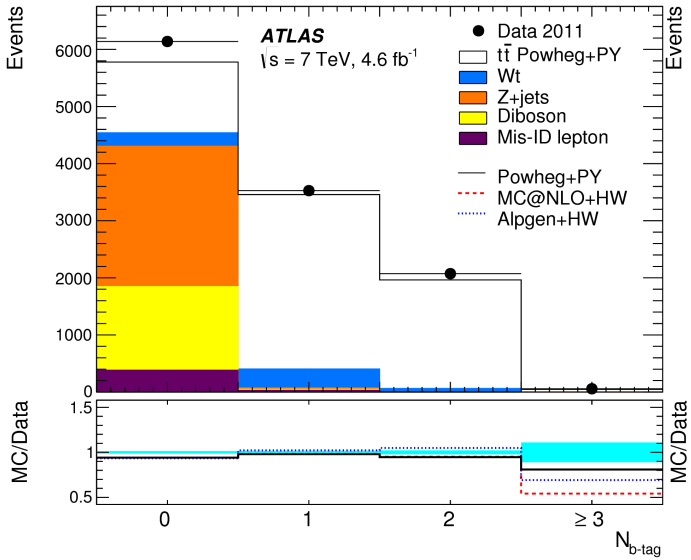
$\sigma_{t\bar{t}} = 275.6 \pm 6.1(stat) \pm 37.8(syst) \pm 7.2(lum.)$ **pb**

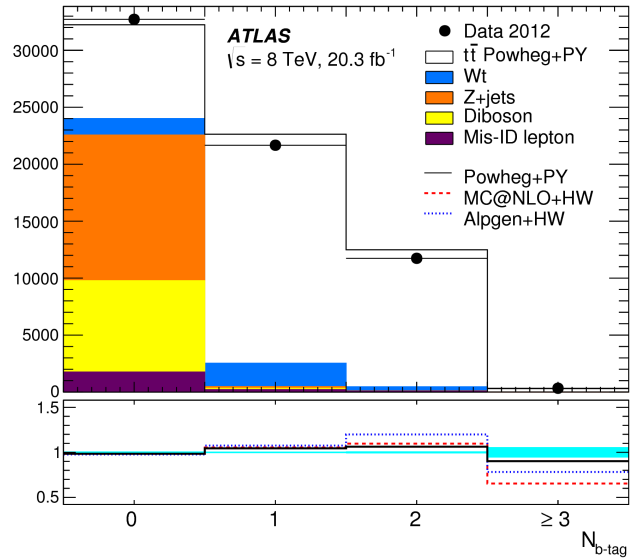




ATLAS: $e\mu$ 7 and 8 TeV [EPJC 74 (2014) 3109]

- Reference signal $t\bar{t}$: Powheg+Pythia
- Use single lepton triggers ($p_T > 24$GeV)
- One isolated opposite charge $e\mu$ pair ($p_T > 25$GeV)
- 1 or 2 b-tagged jets
- Main BGs estimated from data





- Simultaneous determination of σ_{tt} and ε_b in events with 1 (N_1) and 2 (N_2) b-tags

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

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

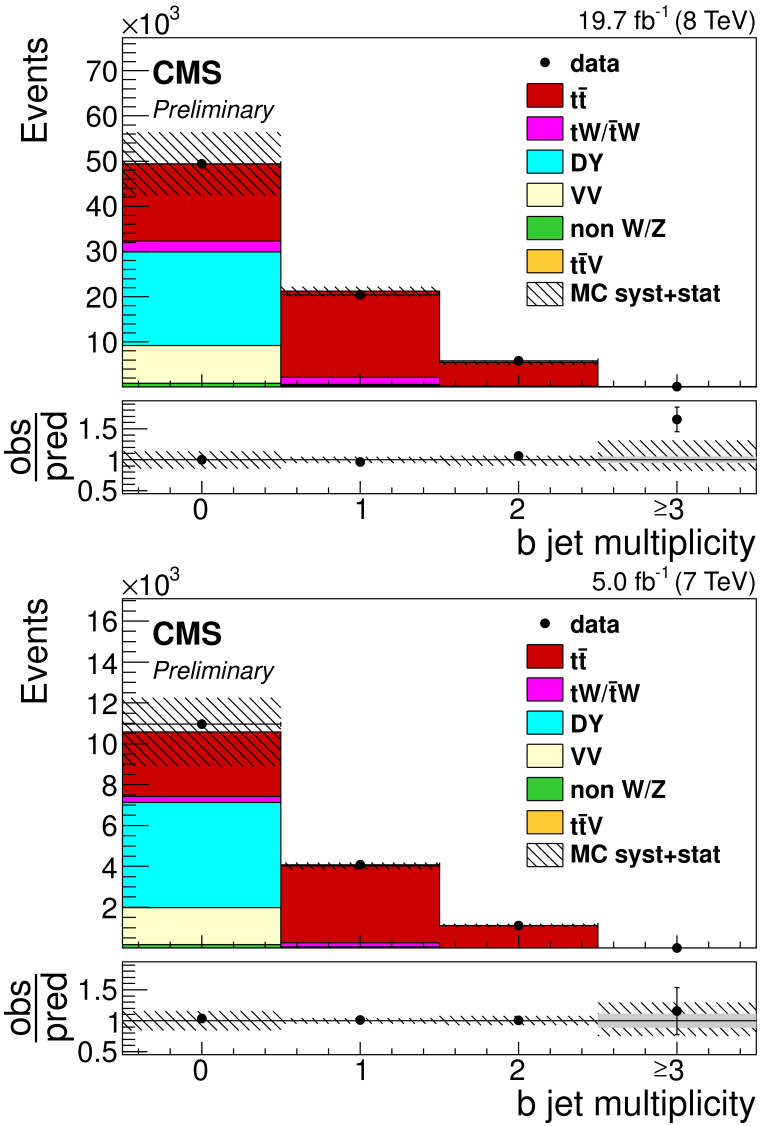
- ε_b: product of b-tagging efficiency & jet kinematic acceptance for tt events
- $\varepsilon_{\mu e}$: leptonic acceptance
- C_b: tagging correlation

$\sigma_{t\bar{t}} = 182.9 \pm 3.1(stat) \pm 4.2(syst) \pm 3.6(lum.)$ **pb** (7TeV)

$\sigma_{t\bar{t}} = 242.4 \pm 1.7(stat) \pm 5.5(syst) \pm 7.5(lum.)$ **pb** (8TeV)

CMS: $e\mu$ 7 and 8 TeV [PAS-TOP-13-004]

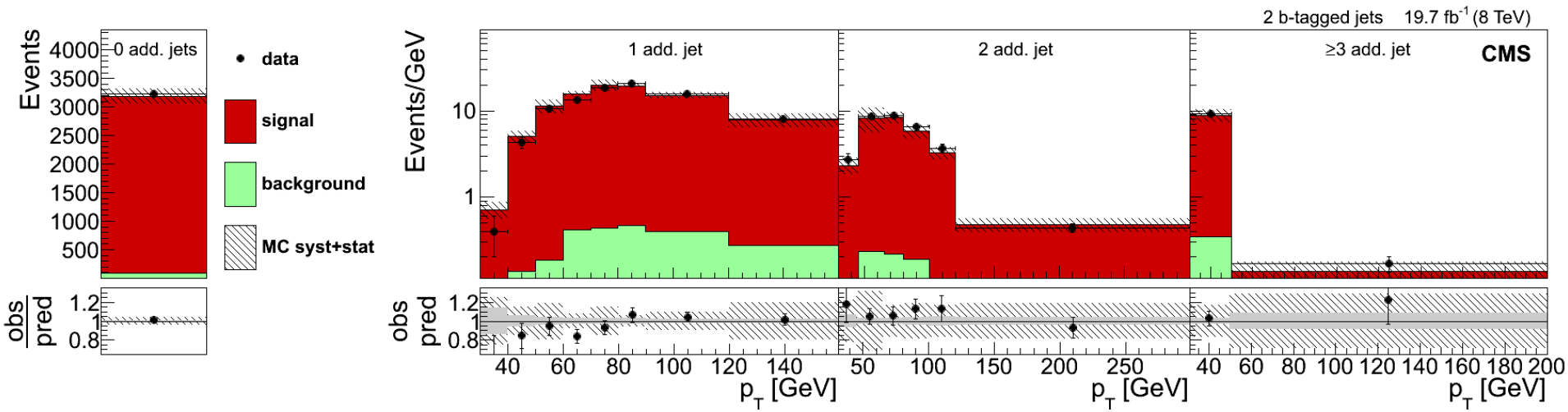
- Reference signal $t\bar{t}$: Madgraph+Pythia
- Dilepton triggers (Mu8*Mu17*, Ele8*Ele17*)
- One isolated opposite charge $e\mu$ pair ($p_T > 20$GeV)
- Jets
- b-tagged jets identified with low mistag rate (0.1%)
- No minimun requirement on jets, b-jets!



CMS: $e\mu$ 7 and 8 TeV

- Simultaneous 7 & 8 TeV binned likelihood fit with systematics as nuisance parameters:
  - N b-tagged jet and additional non-tagged Njets categories
  - Fit to the softest non-tagged jet p_T distribution in each category
- Large constraints on JES, extra radiation, b-tagging, etc.
- Main uncertainties: luminosity, trigger and lepton Id. eff, DY
- Uncertainties correlated between 7 and 8 TeV data (details sl.14)

Figure: 8TeV post-fit distribution, 2 b-tagged jets category



- $\sigma = 173.6 \pm 2.1(\text{stat}) \pm^{4.5}_{4.0} (\text{syst}) \pm 3.8(\text{lum})$ **pb** at $\sqrt{s} = 7$ TeV
- $\sigma = 244.9 \pm 1.4(\text{stat}) \pm^{6.3}_{5.5} (\text{syst}) \pm 6.4(\text{lum})$ **pb** at $\sqrt{s} = 8$ TeV

Uncertainties: experimental sources

CMS-PAS-TOP-14-016/ ATLAS-CONF-2014-054	ATLAS
Cross section [pb]	242.4
Uncertainty [pb]	
Statistical	1.7
Detector model	
Trigger	0.4
Lepton scale and resolution	1.2
Lepton identification	1.7
Jet resolution	1.2
Jet identification	0.1
b-tagging	1.0
Pileup (Included in JES/Lept Id.)	–
Non-JES subtotal	2.6
UncorrJES	0.6
InsituJES	0.6
IntercalibJES	0.3
FlavourJES	0.9
bJES	0.1
Background from data	
Z+jets	<0.1
Lepton misidentification	0.8
Class subtotal	0.8
Background from simulation	
Dibosons	0.3
Single top quark	2.0

CMS: PAS-TOP-13-004

Source	Uncertainty [%]	
	7 TeV	8 TeV
Trigger	1.2	1.2
Lepton ID/isolation	1.4	1.5
Lepton energy scale	0.1	0.1
Jet energy scale	0.7	0.9
Jet energy resolution	0.1	0.1
Single top	0.9	0.6
DY	1.2	1.2
$t\bar{t}$ other	0.1	0.1
$t\bar{t} + V$	0.0	0.1
Diboson	0.2	0.6
W+jets	0.0	0.0
QCD	0.0	0.0
B-tag	0.5	0.5
Mistag	0.2	0.1
Pileup	0.3	0.3

(JES, B-tag: divided in individual components)

Uncertainties: modelling sources

CMS-PAS-TOP-14-016/
ATLAS-CONF-2014-054

	ATLAS
Cross section [pb]	242.4
Uncertainty [pb]	
Signal model	
Scale	0.7
Radiation	–
Generator and parton shower	3.0
PDF	2.7

CMS: PAS-TOP-13-004

Source Vis. PS	Uncertainty [%]	
	7 TeV	8 TeV
Q^2 scale	0.3	0.3
ME/PS matching	0.2	0.1
MG+PY → PH+PY	0.2	0.4
Hadronization (JES)	0.6	0.8
Top p_T	0.3	0.3
Color reconnection	0.1	0.0
Underlying event	0.0	0.1
PDF	0.2	0.7

Extrapolation to full PS

Source	Uncertainty [%]	
	7 TeV	8 TeV
Total (vis)	$\pm^{3.5}_{3.4}$	$\pm^{3.7}_{3.4}$
Q^2 scale (extrapol.)	$\pm^{0.4}_{0.0}$	$\pm^{0.2}_{0.1}$
ME/PS matching (extrapol.)	$\mp^{0.1}_{0.1}$	$\pm^{0.3}_{0.3}$
Top p_T (extrapol.)	$\pm^{0.4}_{0.2}$	$\pm^{0.8}_{0.4}$
PDF (extrapol.)	$\mp^{0.2}_{0.1}$	$\mp^{0.1}_{0.2}$
Total	$\pm^{3.6}_{3.4}$	$\pm^{3.8}_{3.5}$

- ATLAS: radiation included in *lepton identification*
- CMS: considers also CR, UE, hadronization treatment: consistent with mass measurements

ATLAS/CMS: Mapping signal model systematics

**Updates wrt treatment in previous result

	ATLAS	CMS
Generaror and parton shower	**$t\bar{t}$ modelling:** • Powheg-PY vs. MC@NLO-HW ▯ Varies both generator & frag/had model	**tt modelling:** • Powheg-PY vs. Madgraph-PY** • Top pt** • CR/UE tunes* ▯ Had: considered to be partially covered by the JES uncertainty and the b-JES uncertainties (same split as in top quark mass measurements)**
Radiation	**Radiation:** included in lepton ID uncertainty • Compare Alpgen+PY vs. AcerMC+PY with different tunes, constrained to bracket data Largest effect on lepton isolation efficiencies (determined from data)	**ME-PS matching:** • Difference between MadGraph+PY samples with different parameter
Scale	**QCD scale:** ($Q^2 = m_{top}^2+p_{T,top}^2$) • Difference between 2 Powheg-PY samples with varied (separately) μ_R and μ_F • Variation only in ME • Evaluated at generator level	**QCD scale:** ($Q^2 = m_{top}^2+\Sigma p_T^2$, sum over add partons) • Difference between 2 MadGraph-PY with varied (simultaneously) μ_R and μ_F • Variation in ME and PS
PDF	▪ PDF: Envelope of CT10, MSTW2008, NNPDF2.3	▪ PDF: CT10 envelope

→ Table modified from *Maria's talk, LHCTopWG Jan. 2015*

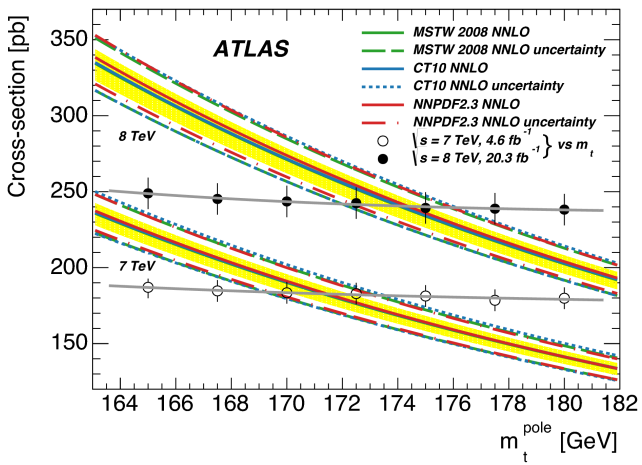
CMS: 7 and 8 TeV correlations

Uncertainty source	ρ
Trigger	0.8
Electron ID	0.9
Electron energy scale	0.9
Muon ID	0.9
Muon energy scale	0.9
JES: Flavor	1
JES: Pileup	0
JES: Absolute extrapolation	1
JES: Other	0
Jet energy resolution	0.9
Each background	0.9
B-Tag (JES)	0.2
B-Tag (stat)	0
B-Tag (syst)	1
Mistag	0.8
Pile-up	0.5
Q^2 scale	1
ME/PS matching	1
MG+PY $\rightarrow$ PH+PY	1
b-fragmentation tune	1
Semileptonic branching fraction B hadron	1
Top quark p_T modelling	1
Color reconnection	1
Underlying event	1
PDF	1
Luminosity	0

- Table: assumed (pre-fit) correlations for the simultaneous 7 and 8 TeV fit
  - depend on method used to extract them, same simulation, stat. component
- Full correlation matrix covering 7 and 8 TeV uncertainty sources will be provided in the paper
  $\rightarrow$ direct input for combination tools
- Need to assign the correlations between individual sources and the corresponding groups (eg. JES groups) -
  - eg. JES (27 sources), b-tagging, DY split in different b-tagged jet categories.

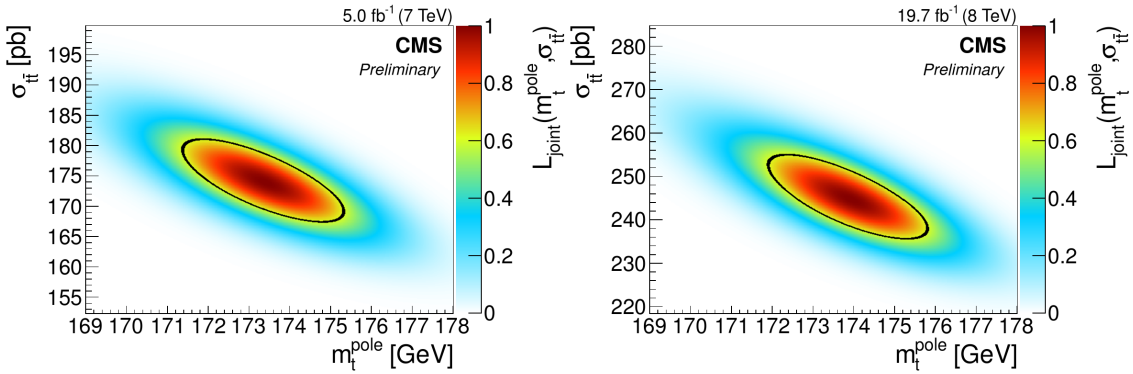
ATLAS & CMS: top quark pole mass extraction

- Mass dependence of predicted σ allows determining m_t from measured $\sigma(t\bar{t})$
  - m_t^{pole} extracted by comparing the most precise predicted and measured σ
  - ATLAS/CMS Final result: combination of 7 and 8 TeV



PDF	$m_t^{\rm pole}$(GeV) from $\sigma_{t\bar{t}}$ $\sqrt{s} = 7$ TeV	$\sqrt{s} = 8$ TeV
CT10 NNLO	171.4 ± 2.6	174.1 ± 2.6
MSTW 68 % NNLO	171.2 ± 2.4	174.0 ± 2.5
NNPDF2.3 5f FFN	$171.3^{+2.2}_{-2.3}$	174.2 ± 2.4

Combined: $m_t^{pole} = 172.9^{+2.5}_{-2.6}$ GeV (Uncert. from all three PDF sets combined)



	$m_t(7\,\text{TeV})$	$m_t(8\,\text{TeV})$
NNPDF3.0	$173.4 \pm^{2.0}_{2.0}$ GeV	$173.9 \pm^{1.9}_{2.0}$ GeV
MMHT2014	$173.7 \pm^{2.0}_{2.1}$ GeV	$174.2 \pm^{1.9}_{2.2}$ GeV
CT14	$173.9 \pm^{2.3}_{2.4}$ GeV	$174.3 \pm^{2.2}_{2.4}$ GeV

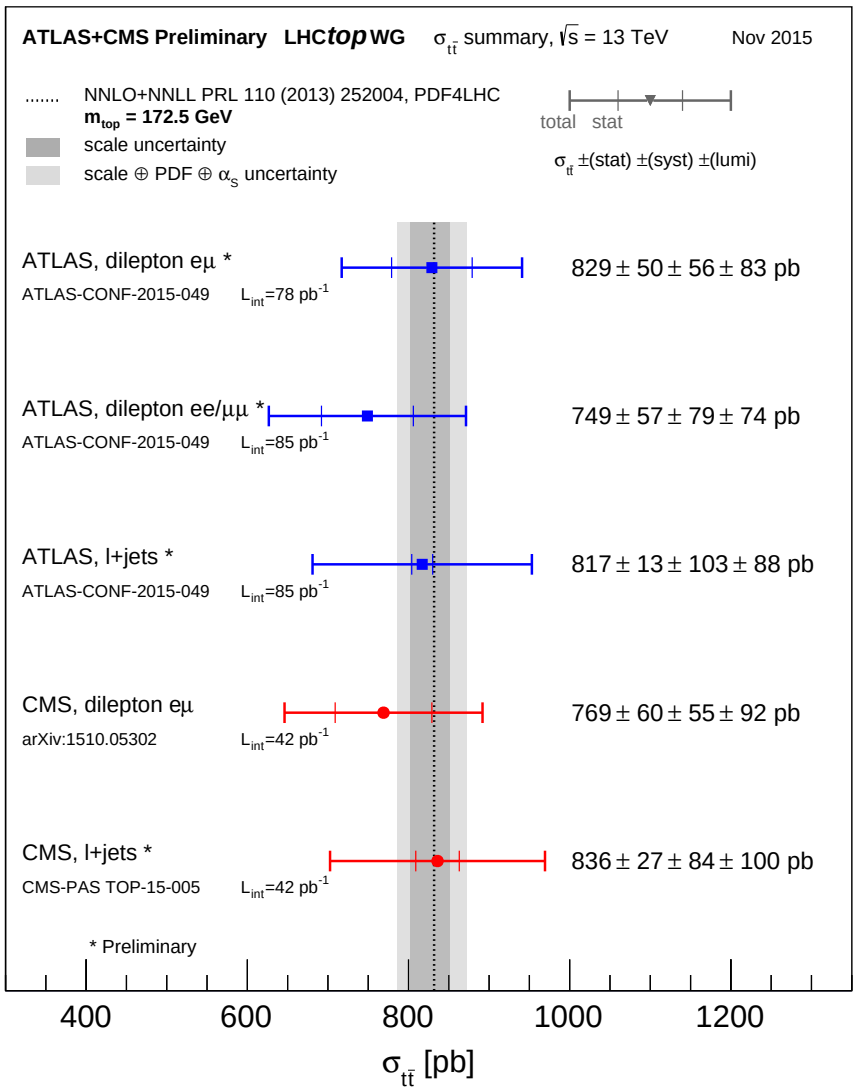
Combined:

	m_t
NNPDF3.0	$173.6 \pm^{1.7}_{1.8}$ GeV
MMHT2014	$173.9 \pm^{1.8}_{1.9}$ GeV
CT14	$174.1 \pm^{2.1}_{2.2}$ GeV

→ More details: Efe's talk

Overview of cross section measurements: 13 TeV

- Measurements available in dilepton and l+jets channel
- Precision around 14-16%
- Dominated by lumi
- Large statistical uncertainty
- Plan: combination only after the next round of (more precise) measurements



Outlook

- $e\mu$ measurements at 7 and 8 TeV lead in precision ($\sim$4%)
  - Expect to dominate final result
  - Main effort put in mapping uncertainties and assigning correlations
- Other channels in agreement with overall picture ($\sim$9-14%)
  - Not much gain expected in a combination
  - To be assessed if uncertainties are complementary to $e\mu$
- Could provide also the top quark pole mass extraction from the combined result
- 13 TeV results: wait until the next round of results (much higher precision)

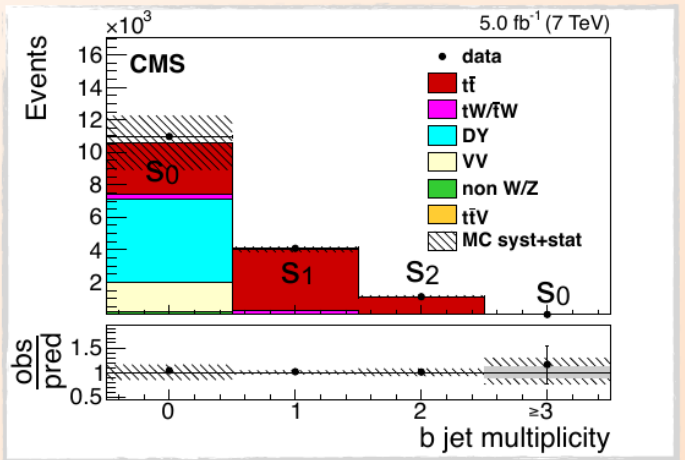
BACK UP

Parameterization of Signal Contribution

$$s_1 = \mathcal{L} \cdot \epsilon_{e\mu} \cdot \sigma_{t\bar{t}}^{\text{vis}} \cdot 2\epsilon_b(1 - C_b\epsilon_b)$$
$$s_2 = \mathcal{L} \cdot \epsilon_{e\mu} \cdot \sigma_{t\bar{t}}^{\text{vis}} \cdot 2\epsilon_b^2 C_b$$

neither in s_1 nor in s_2

$$s_0 = \mathcal{L} \cdot \epsilon_{e\mu} \cdot \sigma_{t\bar{t}}^{\text{vis}} \cdot (1 - 2\epsilon_b^2 C_b - 2\epsilon_b(1 - \epsilon_b C_b))$$



Implement this information in the fit as follows:

- Express signal contribution with s_i for each b-tagged jet category i.
- Derive all parameters from simulation (ε_b, C_b, $\varepsilon_{e\mu}$)
- Parameterize them as function of all systematic uncertainties (λ)

➡ With these Eqs: Introduced explicitly non-linear terms in the likelihood

- Accurate modelling of expected signal rates $O(\lambda^4)$
- Avoids mismodelling effects from linear approximations