PDF CONSTRAINTS FROM TOP-QUARK PAIR DIFFERENTIAL MEASUREMENTS

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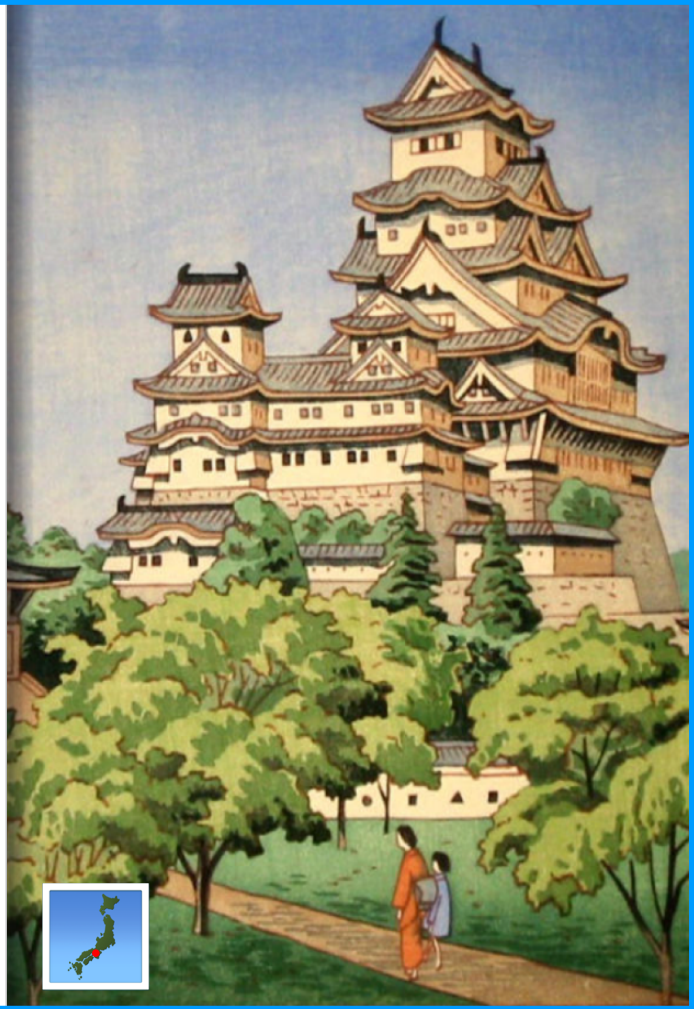


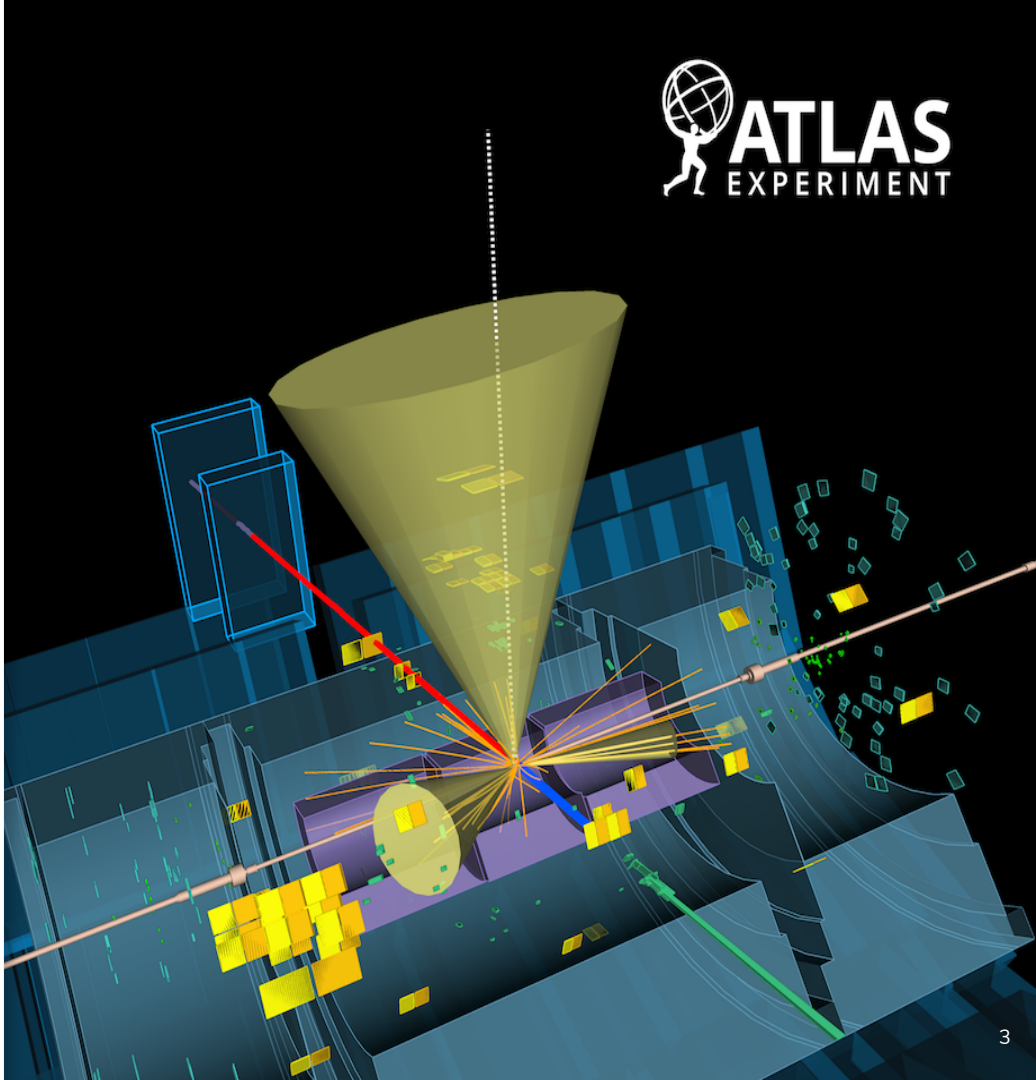
1.

TOP QUARK

Discovered in:	**Mass:**	**Generation:**
1995	173.21 GeV	Third
Discovered at:	**Charge:**	**Spin:**
Fermilab	2/3	1/2

TOP EVENT

Run-2 ATLAS event



Why top?

Heaviest fundamental particle in the Standard Model

Large coupling to SM Higgs + m_{top} is a fundamental parameter in SM

Short Lifetime(~10^{-25} s)

Decays before hadronization – Unique among the quarks!

Access to Polarization + Spin Correlations

TOP QUARK

Processes including top are backgrounds for new physics

Good Understanding → Improvements in Searches

Hints of new physics?

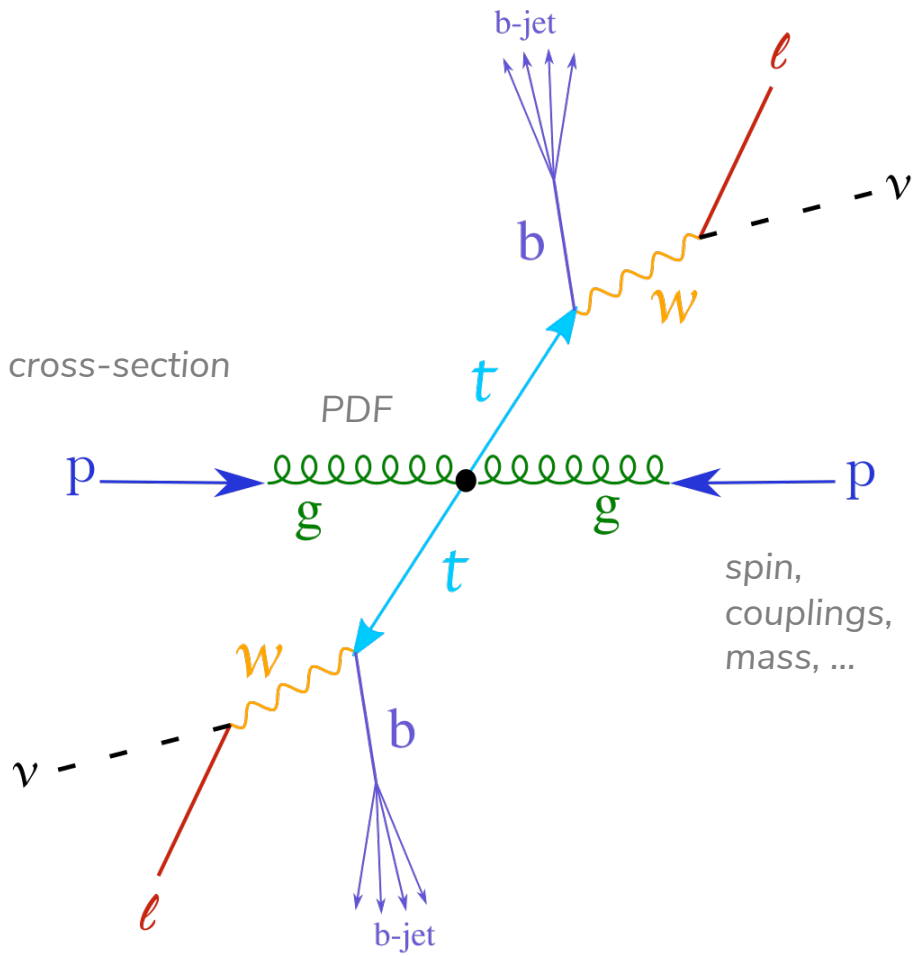
Exotic Particles Could Decay Preferentially to Top Quarks

What can we measure?

Cross-section

Properties

PDFs



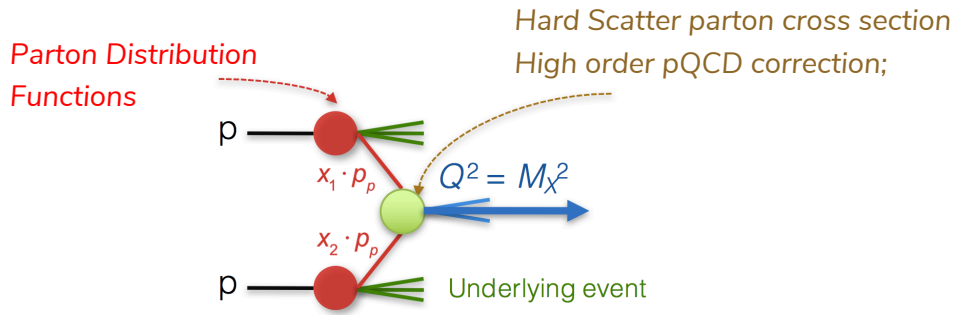
Cross-section and PDF

"Measured" Cross Section

Parton Distribution Functions

"Theoretical" Cross Section

$$\sigma = \sum_{i,j} \int dx_1 dx_2 f_i(x_1, \mu_F) f_j(x_2, \mu_F) \hat{\sigma}_{ij}(s; \mu_F, \mu_R)$$



$f_i(x_\lambda, \mu_F)$ probability density to observe a parton *i* with longitudinal momentum fraction x_λ in incoming hadron λ, when probed at a scale μ_F

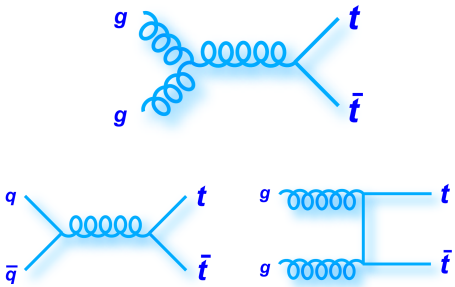
μ_F factorization scale – determines proton structure

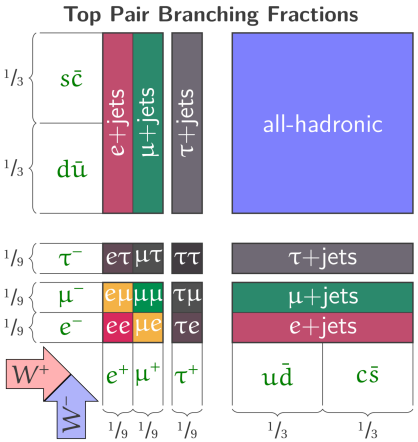
μ_R renormalization scale – size of strong coupling constant

$$\mu_F \sim Q = \sqrt{q^2}$$

Top Pairs

Production and decay



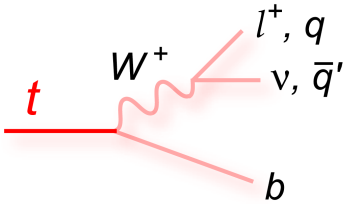


Top Pair Production

gg fusion is the dominant at LHC

Top Pair Decay

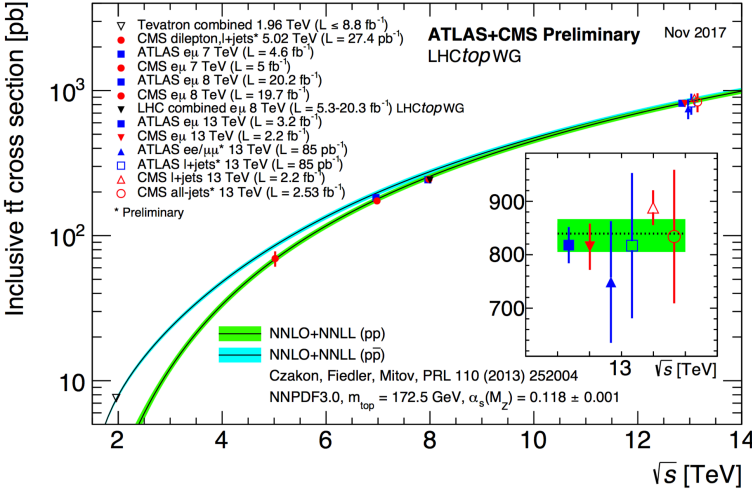
All hadronic dominant but dilepton is the cleanest signature.

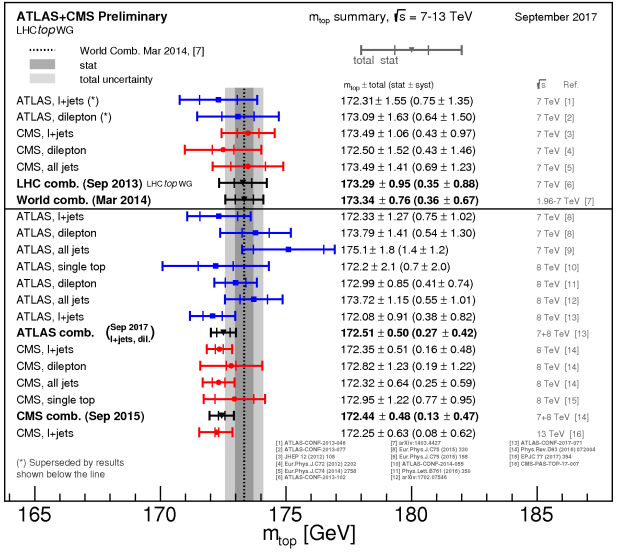


Top Decay

Branching ratio to Wb ~ 1

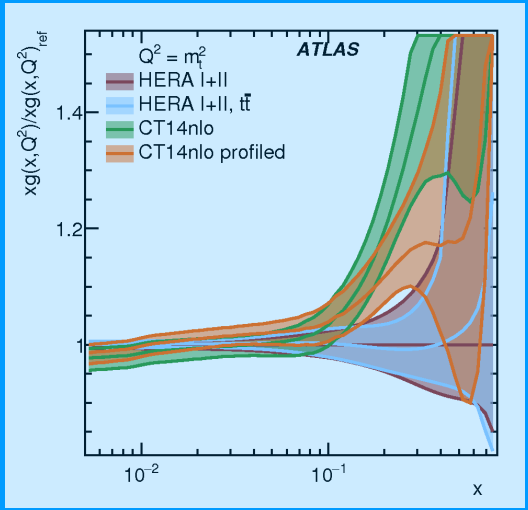
Top Measurements at LHC





2.

TOP PAIRS SENSITIVITY TO PDFs



*"Measurement of lepton differential distributions and the top quark mass in ttbar production in pp collisions at √ s = 8 TeV with the **ATLAS** detector"*

Eur. Phys. J. C 77 (2017) 804

Differential and Particle

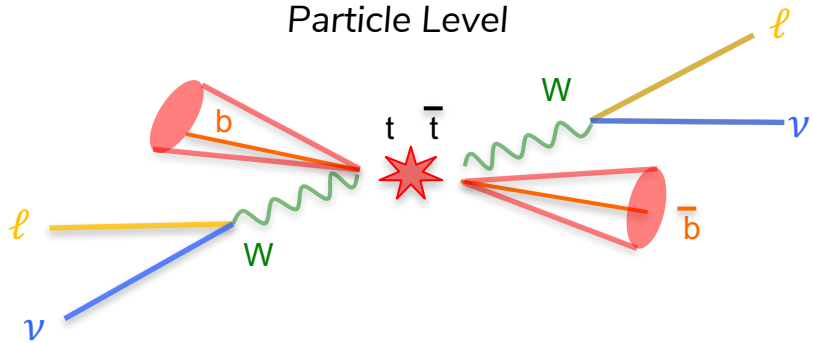
DIFFERENTIAL:

- Statistics available in LHC is really large, we can measure cross section with more detail.
- Compute cross section as a function of kinematic variables : $p_T(t)$, $y(t)$, ...
- **Benefits :**
  - evaluate MC generators / parton showers / PDF

PARTICLE-LEVEL:

- Fiducial region defined to closely follow the event selection using "stable" particles (> $0.3 \cdot 10^{-10}$ s)
- Minimize the extrapolation and the theoretical uncertainty

Particle Level



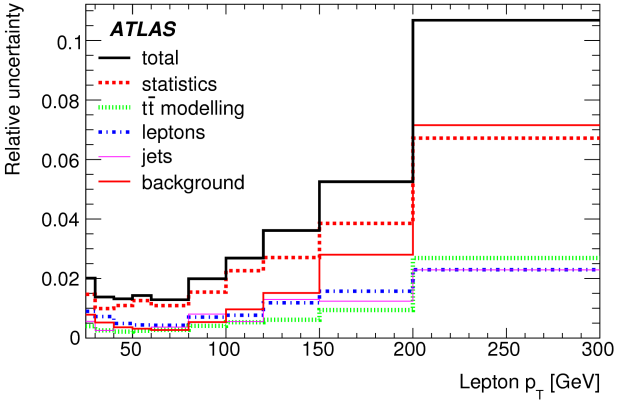
Analysis

Top pairs differential cross sections for final states eμbb$\nu\nu$ with 20.2 fb^{-1}, at $\sqrt{s}$ = 8 TeV

- Clean experimental signature, **little sensitivity to JES and QCD modelling**.
- Selection of **eμ + 1 or 2 b-tagged jets :**

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

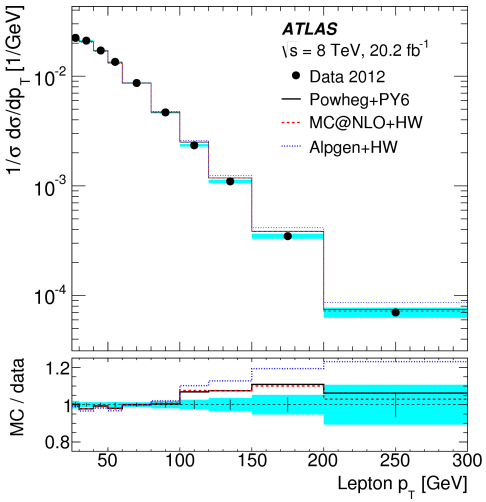
- Solve equations and measure ε and $\sigma_{t\bar{t}}^i$ simultaneously → yields a **particle-level fiducial** measurement for $p_T(\ell) > 25$ GeV and $|\eta(\ell)| < 2.5$, with no requirements on jets. No unfolding required.
- Total uncertainties for the normalized cross sections at the level of 1-2% at low p_T, and 10-20% at high p_T

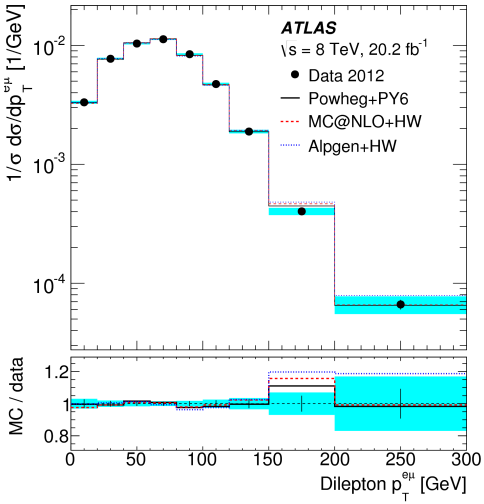


Results

Differential Cross-sections

- Measure **normalized** (and absolute) differential cross sections for **8 variables** : $p_T(l)$, $\eta(l)$, $p_T(e\mu)$, $p_T(e)+p_T(\mu)$, $E(e)+E(\mu)$ $m(e\mu)$, $y(e\mu)$ and $\Delta\phi(e\mu)$
  - Reduces dependence in jets → minimizes uncertainties in hadronic variables
  - No need for full kinematic reconstruction of the ttbar system
  - Some of the variables are sensitive to PDFs





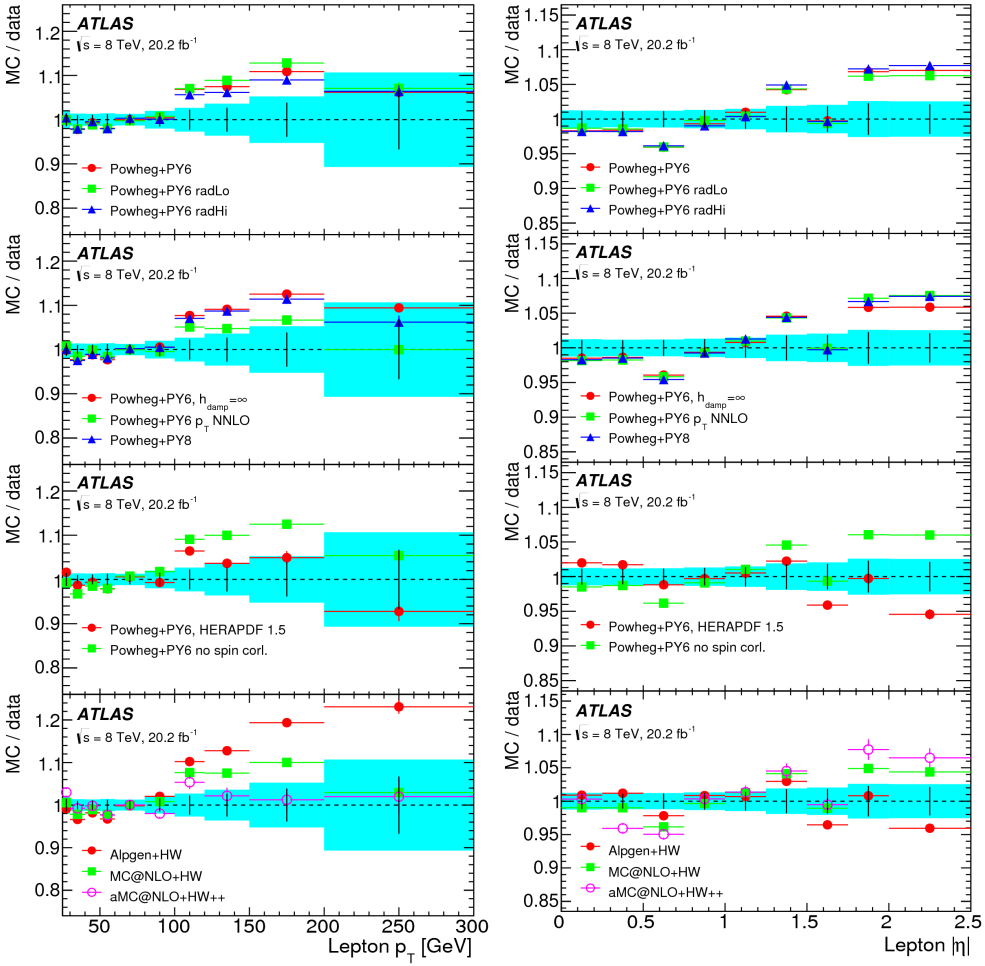
Results

⟹ Lepton p_T :

Data softer than all the predictions (NLO and LO), except for Powheg+HERAPDF and aMC@NLO+Herwig++

⟹ Lepton η :

Data results lie between NLO (CT10) and Alpgen+Herwig. Powheg+Pythia with HERAPDF gives better description than CT10 – ***sensitive to PDFs***

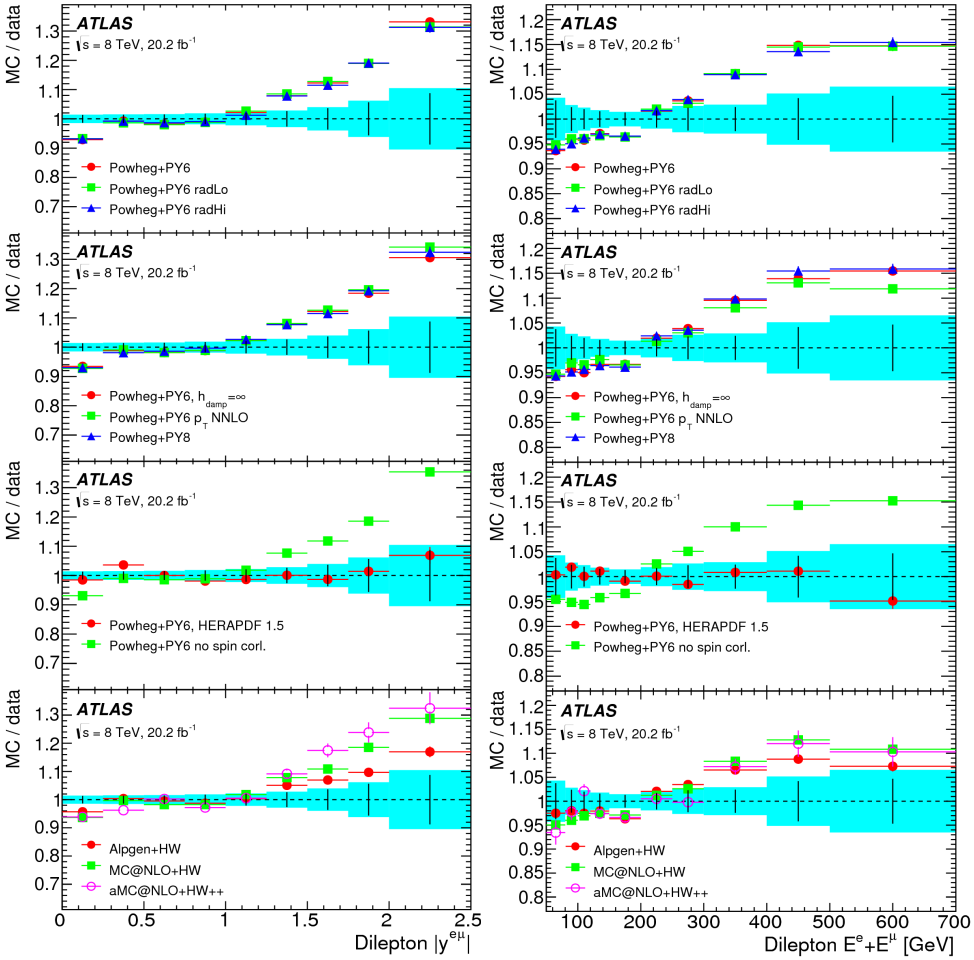


Results

⟹ y(eμ), E(e)+E(μ)

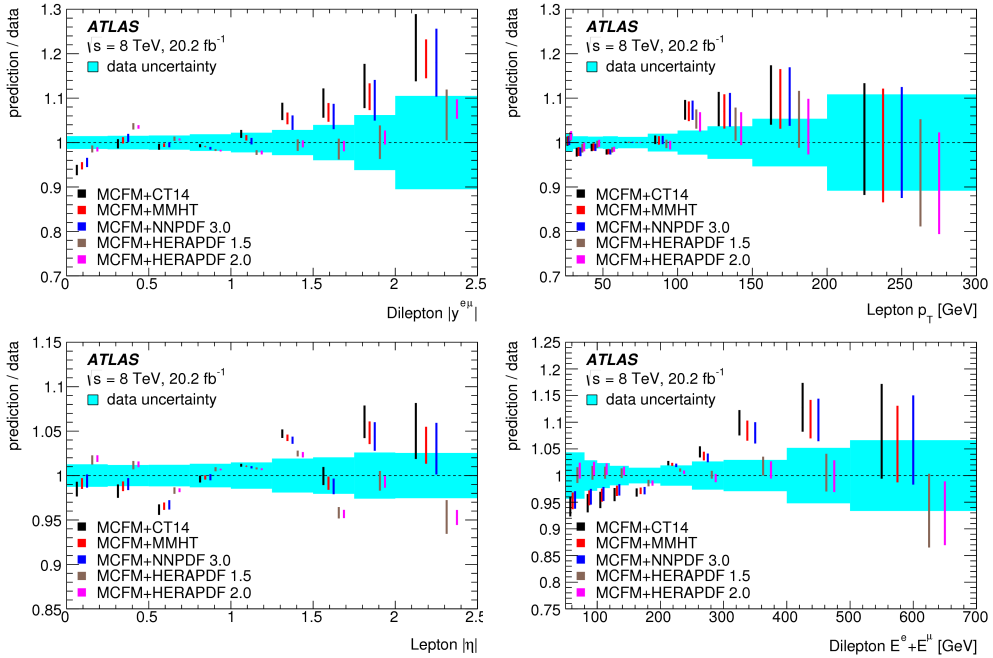
Data softer than predictions from all generators, Powheg+HERAPDF better agreement

- Similarly to single lepton p_T



PDF Sets Comparison

Comparison to fixed-order predictions with MCFM combined with APPLGRID.

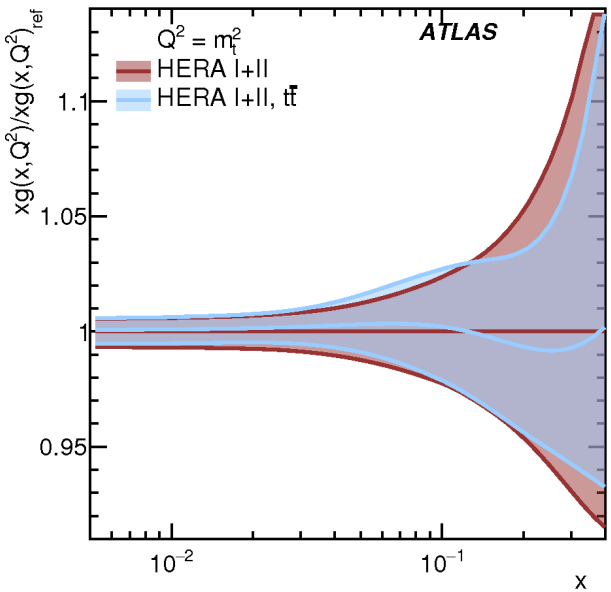


- Comparison of MCFM predictions with various PDF sets.
- The results for HERAPDF1.5 and HERAPDF2.0 are close to data, CT14, MMHT and NNPDF3.0 PDF sets describe data slightly less well, particularly for: $p_T(l)$, $\eta(l)$, $y(e\mu)$ and $E(e)+E(\mu)$.

PDF Fit

Constrains on the gluon PDF using MCFM. Package XFitter used for fitting.

- Explored the sensitivity to the gluon PDF through a QCD analysis including DIS data (HERA I+II) with and without dilepton η(l), y(eμ) and E(e)+E(μ) normalized distributions.
- Gluon PDF uncertainties reduced from 4% to 2.5% at high Bjorken-x ~ 0.1



QCD scales fixed to $\mu_F = \mu_R = m_t/2$

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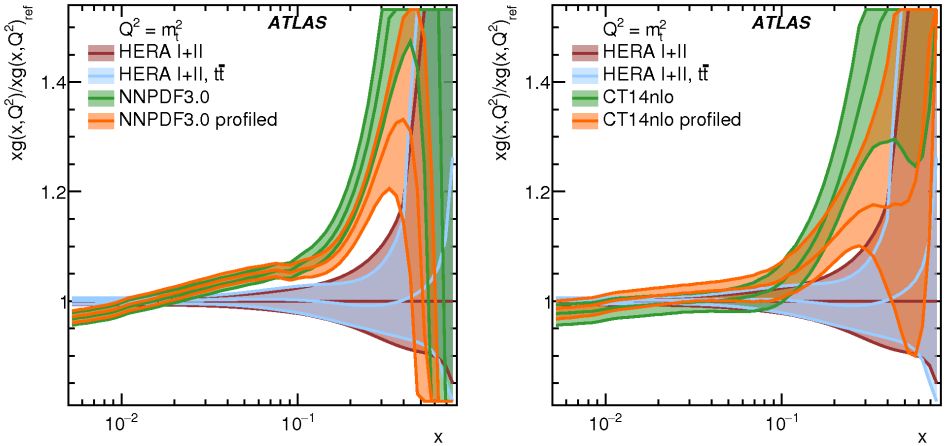
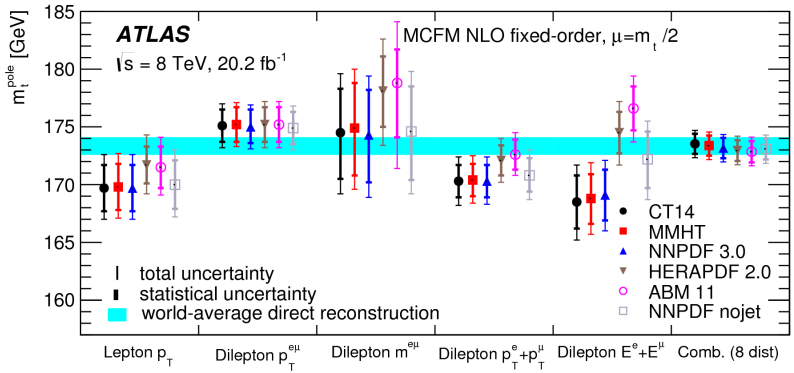
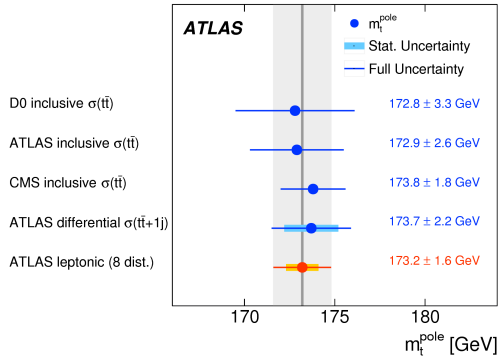


- Comparison to NNPDF3.0 and CT14 PDF sets

Top mass extraction



- Template fit to fixed order NLO QCD predictions with MCFM:
  - Using all distributions taking into account correlations
- χ^2 minimization including PDF and QCD scale uncertainties
- NNPDF 3.0 used for central value.
- Theory uncertainty dominated by the different QCD scale variation (1.1GeV)



$$m_{top}^{pole} = 173.2 \pm 0.9(\text{stat}) \pm 0.8(\text{exp}) \pm 1.2(\text{theo})\text{GeV}$$

Summary & Conclusions

- *Lepton and dilepton differential cross sections distributions were measured in the $e\mu bb\nu\nu$ final state with $L = 20.2\ fb^{-1}$, at $\sqrt{s} = 8$ TeV with ATLAS.*
- *Absolute and normalized cross-sections were obtained and corrected to fiducial volume. Results compared to predictions to NLO and LO event generators, generally a good description was observed.*
- *Distributions involving rapidity are better described by HERAPDF PDF sets.*
- *Data are sensitive to the gluon PDF around $x \sim 0.1$ and have potential to reduce PDF uncertainties.*
- *Some distributions are sensitive to the top quark mass. Most precise result was obtained from a fit of fixed order predictions to all (8) distributions simultaneously. The result is in agreement with other pole mass determinations.*

Backup

Event Selection

- Electrons E_T>25 GeV, |η|<2.47 and excluding transition region
  - 98% efficient cuts on ETCone20 and pTCone30, looser than top WG default 90%
- Muons p_T>25 GeV, |η|<2.5, require mini-isolation in variable-size cone <0.05
- Jets p_T>25 GeV, |η|<2.5, standard JVF prescriptions
- b-tag using MV1 at 70% efficiency working point
- Jets removed with ΔR<0.2 of electron, leptons removed if ΔR to nearest jet <0.4
- Full 2012 data, event level cosmic-veto, e-μ overlap removal, jet cleaning

MC Samples

Table 1 Summary of simulated event samples used for $t\bar{t}$ signal and background modelling, giving the matrix-element event generator, PDF set, parton shower and associated tune parameter set. More details, including generator version numbers and references, are given in the text

Process	Matrix-element	PDF	Parton shower	Tune	Comments
$t\bar{t}$	POWHEG	CT10	PYTHIA6	P2011C	$h_{\text{damp}} = m_t$
	POWHEG	CT10	HERWIG+JIMMY	AUET2	$h_{\text{damp}} = \infty$
	MC@NLO	CT10	HERWIG+JIMMY	AUET2	
	ALPGEN	CTEQ6L1	HERWIG+JIMMY	AUET2	incl. $t\bar{t}\,b\bar{b}$, $t\bar{t}\,c\bar{c}$
	POWHEG	CT10	PYTHIA6	P2012 radHi	$h_{\text{damp}} = 2m_t$, $\frac{1}{2}\mu_{F,R}$
	POWHEG	CT10	PYTHIA6	P2012 radLo	$h_{\text{damp}} = m_t$, $2\mu_{F,R}$
Wt	POWHEG	CT10	PYTHIA6	P2011C	diagram removal
Z, W+jets	ALPGEN	CTEQ6L1	PYTHIA6	P2011C	incl. $Zb\bar{b}$
WW, WZ, ZZ	ALPGEN	CTEQ6L1	HERWIG	AUET2	
$t\bar{t}+W$, Z	MADGRAPH	CTEQ6L1	PYTHIA6	P2011C	
$W\gamma$+jets	SHERPA	CT10	SHERPA	default	
t-channel top	ACERMC	CTEQ6L1	PYTHIA6	AUET2B	

Table 7 Summary of particle-level simulation samples used in the comparison to the corrected data distributions in Sect. 6.2, giving the matrix-element event generator, PDF set, parton shower and associated tune parameter set. The four groups shown correspond to the four panels for each measured distribution shown in Figs. 9, 10, 11 and 12

	Matrix-element	PDF	Parton shower	Tune	Comments
1	POWHEG	CT10	PYTHIA6	P2011C	$h_{\text{damp}} = m_t$
	POWHEG	CT10	PYTHIA6	P2012 radHi	$h_{\text{damp}} = 2m_t$, $\frac{1}{2}\mu_{F,R}$
	POWHEG	CT10	PYTHIA6	P2012 radLo	$h_{\text{damp}} = m_t$, $2\mu_{F,R}$
2	POWHEG	CT10	PYTHIA6	P2011C	$h_{\text{damp}} = \infty$
	POWHEG	CT10	PYTHIA6	P2011C	$h_{\text{damp}} = m_t$, NNLO top p_{T}
	POWHEG	CT10	PYTHIA8	A14	$h_{\text{damp}} = m_t$
3	POWHEG	HERAPDF 1.5	PYTHIA6	P2011C	$h_{\text{damp}} = m_t$
	POWHEG	CT10	PYTHIA6	P2011C	$h_{\text{damp}} = \infty$, no spin corl.
4	ALPGEN	CTEQ6L1	HERWIG+JIMMY	AUET2	incl. $t\bar{t}\,b\bar{b}$, $t\bar{t}\,c\bar{c}$
	MC@NLO	CT10	HERWIG+JIMMY	AUET2	
	MG5_AMC@NLO	CT10	HERWIG++	UE-EE-5	