Top-Quark Pair Production at LHC

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Universität Hamburg
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HELMHOLTZ GEMEINSCHAFT

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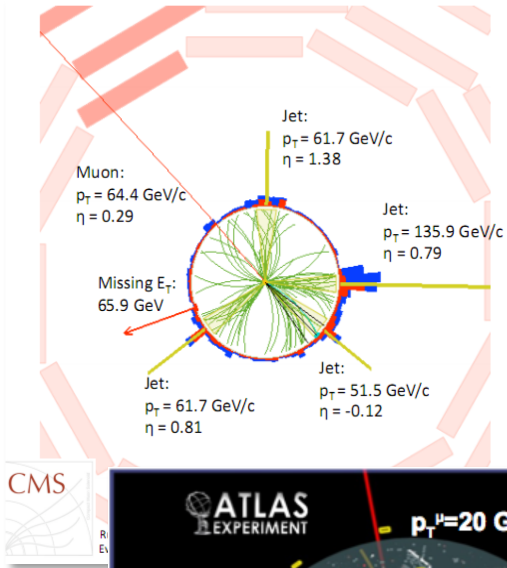
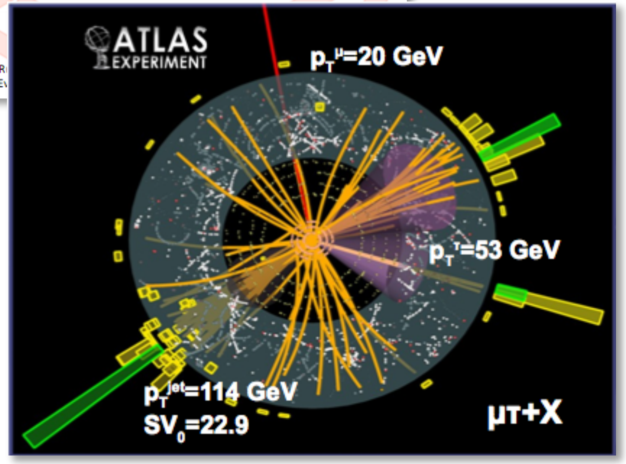
Outline

- Introduction
- Top-quark pair cross sections
- Differential top-quark pair cross sections
- Measurements of $t\bar{t}$+ (b-)jets, W, Z, γ

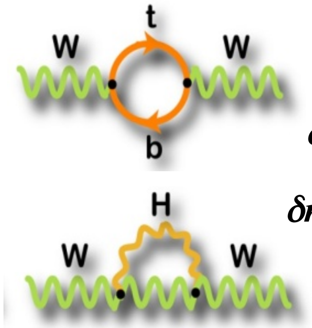




All top quark physics results are available here:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Top quark production

- **Top quarks: key to QCD, electroweak (EWK) and new physics**
  - Large mass ➔ large coupling to Higgs (y ~ 1)
  - Sensitive to Higgs mass through EWK loop corrections
  - Decays before hadronising: "bare" quark
  - New physics may preferentially couple/decay to top
  - Major source of background for many searches



$\delta m_W \propto m_t^2$

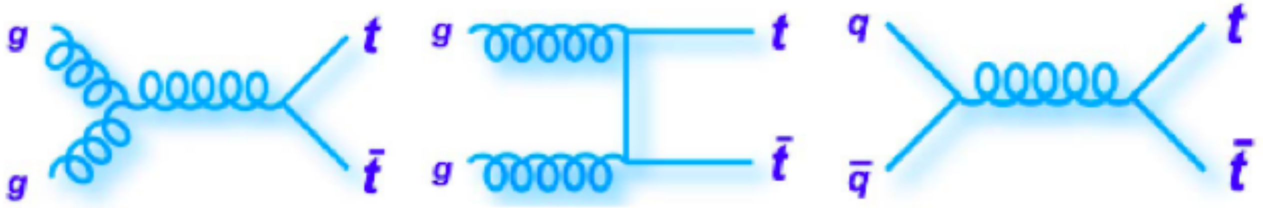
$\delta m_W \propto ln(m_H)$

➔ Tool for precise tests of Standard Model (SM), sensitive probe to New Physics

- **LHC is a 'top factory': several million $t\bar{t}$ events produced at 7 & 8 TeV !!**
  - Great opportunity to study the details of $t\bar{t}$ production mechanisms
    - In particular, through top-quark kinematic distributions
  - Production of $t\bar{t}$ in association with QCD jets or additional particles could reveal new physics ; background to $t\bar{t}H$ and beyond SM searches
  - Theory predictions & models need to be tuned & tested with measurements

Top-pair production and decay

- $t\bar{t}$ production dominated by gluon fusion at LHC (~90%)



	LHC (7TeV)	Tevatron
gg	~80%	~15%
$q\bar{q}$	~20%	~85%

Full NNLO calculation now available ($gg \rightarrow t\bar{t}$) !

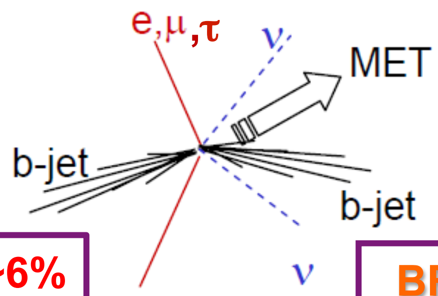
NNLO+NNLL very precise:
2.2% (Tevatron)
~ 3% (LHC)

Collider	σ_{tot} [pb]	scales [pb]	pdf [pb]
Tevatron	7.164	$+0.110(1.5\%)$ $-0.200(2.8\%)$	$+0.169(2.4\%)$ $-0.122(1.7\%)$
LHC 7 TeV	172.0	$+4.4(2.6\%)$ $-5.8(3.4\%)$	$+4.7(2.7\%)$ $-4.8(2.8\%)$
LHC 8 TeV	245.8	$+6.2(2.5\%)$ $-8.4(3.4\%)$	$+6.2(2.5\%)$ $-6.4(2.6\%)$

[Czakon, Fiedler, Mitov, arXiv:1303.6254]

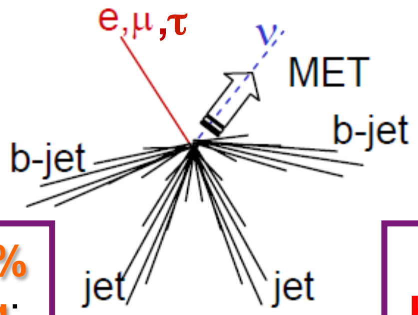
- In SM, $t \rightarrow W^{+}b$ (~100%) ➔ W decay modes define top final states

BR(μ,e)~6%
Low bg:
Z+jets



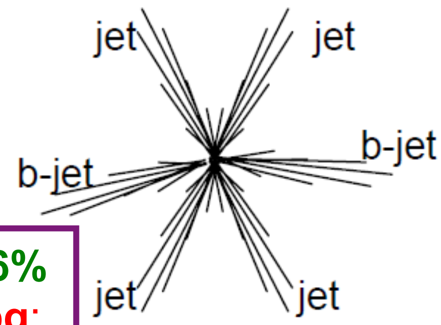
dileptons

BR(μ,e)~34%
Moderate bg:
W+jets



lepton + jets

BR~46%
Huge bg:
QCD



all hadronic

$\sigma(t\bar{t})$ measurements at Tevatron

First Tevatron combination !

- CDF (up to L = 8.8 fb^{-1}): **(6.5%)**

$\sigma_{tt} = 7.71 \pm 0.31\ (\text{stat}) \pm 0.40\ (\text{syst})\ \text{pb}$

- D0 (L = 5.4 fb^{-1}): **(8%)**

$\sigma_{tt} = 7.56\,^{+0.63}_{-0.56}\ (\text{stat+syst+lumi})\ \text{pb}$

- **Tevatron combined:** **(5.5%)**

$\sigma_{tt} = 7.65 \pm 0.20\ (\text{stat}) \pm 0.36\ (\text{syst})\ \text{pb}$

Theory: NNLO+NNLL **[arXiv:1204.5201]**
(approx. NNLO+NNLL for gg)

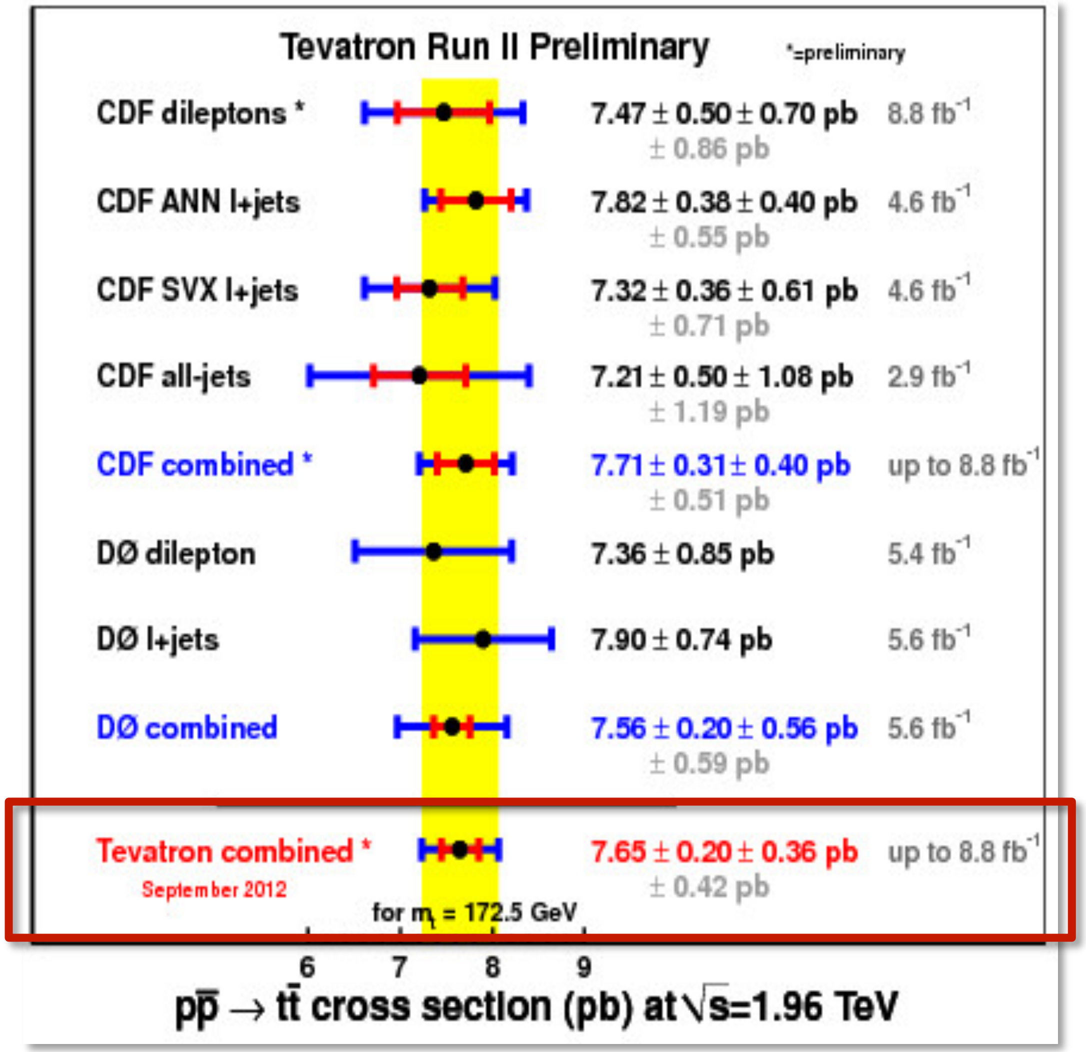
$\sigma_{tt} = 7.24\,^{+0.24}_{-0.27}\ \text{pb}$ (4%)

Full NNLO+NNLL:

$\sigma_{tt} = 7.164\,^{+0.110}_{-0.200}\ (\text{scales})\,^{+0.169}_{-0.122}\ (\text{pdf})\ \text{pb}$ **(2.2%)**

Main systematics:
signal modelling, jet reconstruction

PLB 604 (2011) 403
D0 Note 6363 **CDF Note 10926**

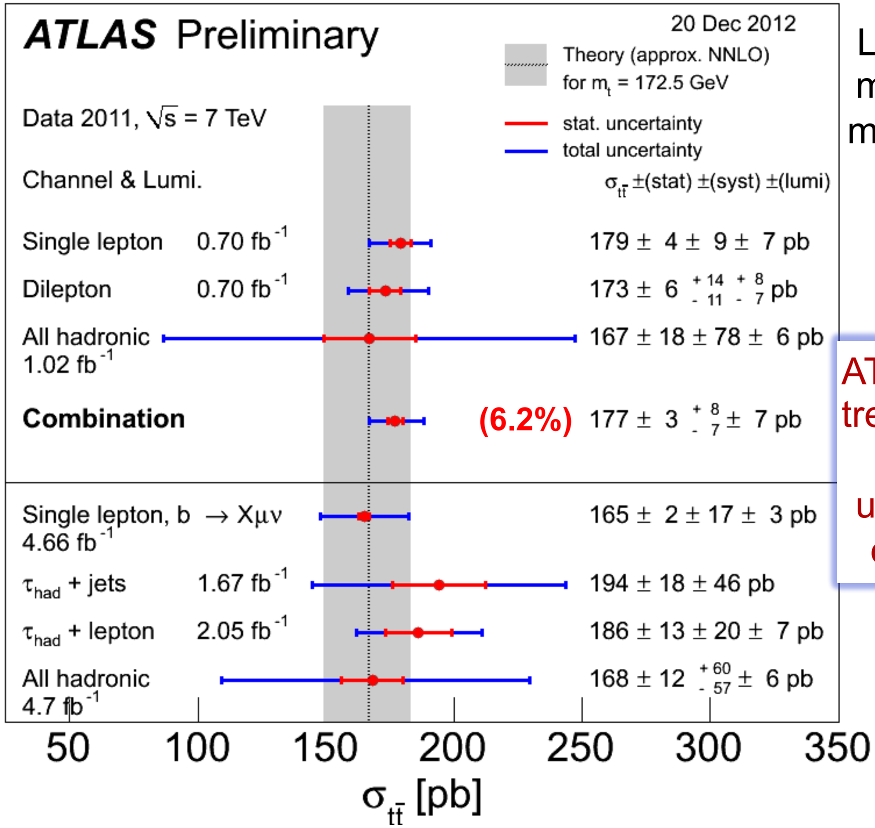


Good agreement between channels
and with SM predictions

Summary of σ(tt̄) results at LHC (7 TeV)

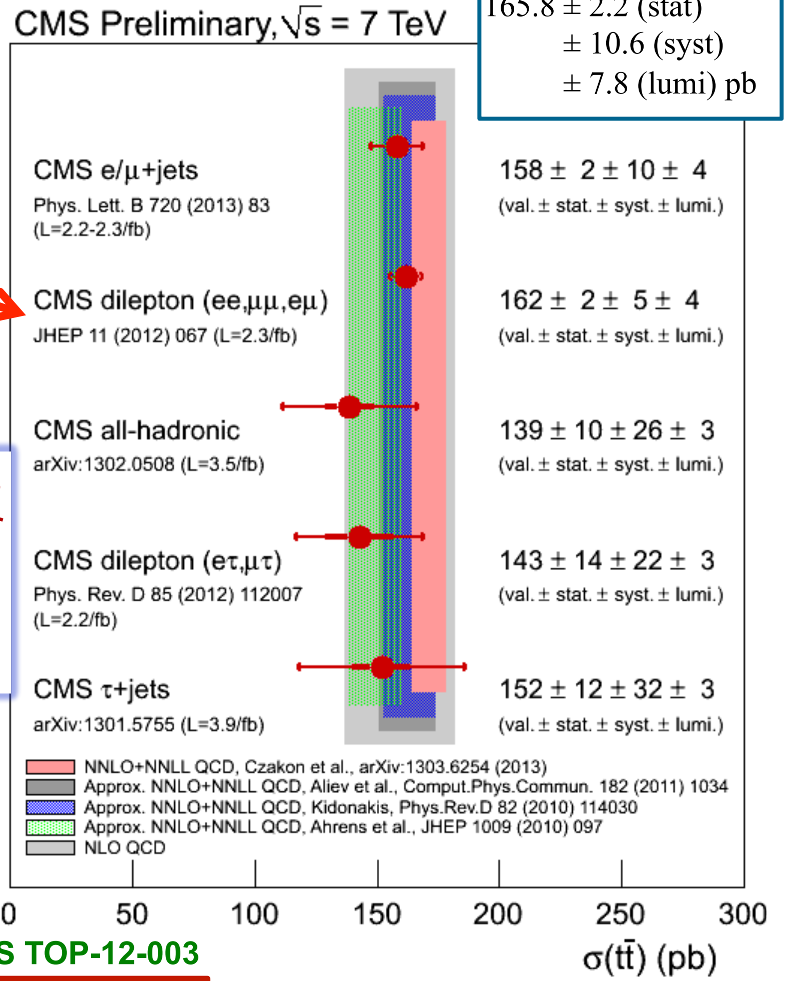
- All final states investigated (except ττ)
- Measurements from likelihood fits (traditionally from counting)
- Data-driven estimates for main backgrounds
  - QCD, W+jets, Z+jets, …

CMS combined
(up to 1.1 fb^{-1}): **(8%)**
165.8 ± 2.2 (stat)
± 10.6 (syst)
± 7.8 (lumi) pb



LHC's single most precise measurement **(4%)**

ATLAS & CMS treat generator modelling uncertainties differently !



First LHC combination !
(up to L = 1.1 fb^{-1})

ATLAS-CONF-2012-134, CMS-PAS TOP-12-003

$$\sigma_{tt} = 173.3 \pm 2.3\ (\text{stat}) \pm 9.9\ (\text{syst})\ \text{pb}$$ **(5.8%)**

σ(tt̄) results @ LHC (8 TeV)

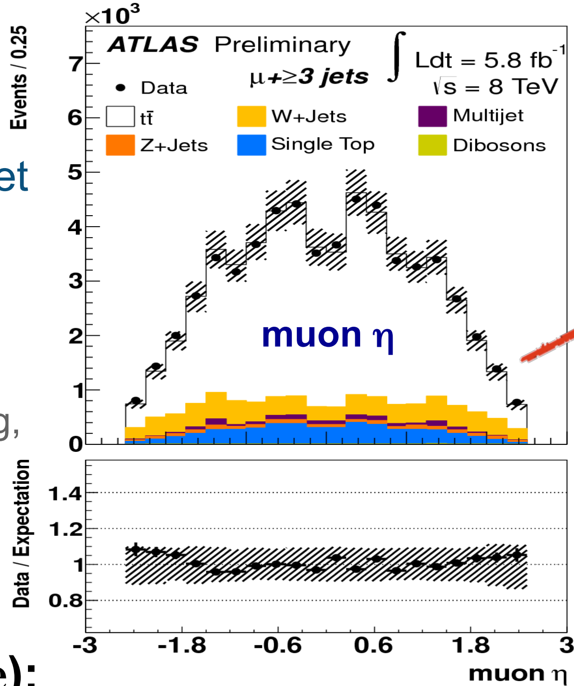
l+jets:

1 isolated high-p_T μ/e,
≥ 3 jets, ≥ 1 b-tagged jet

- Fit to likelihood discriminant (lepton η , aplanarity)

Main syst: signal modelling, jet/E_T^{miss} reco

ATLAS-CONF-2012-149



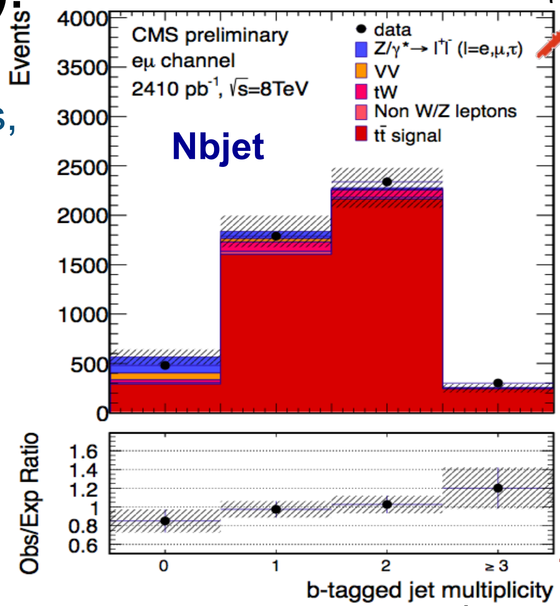
Dileptons (ee, μμ, μe):

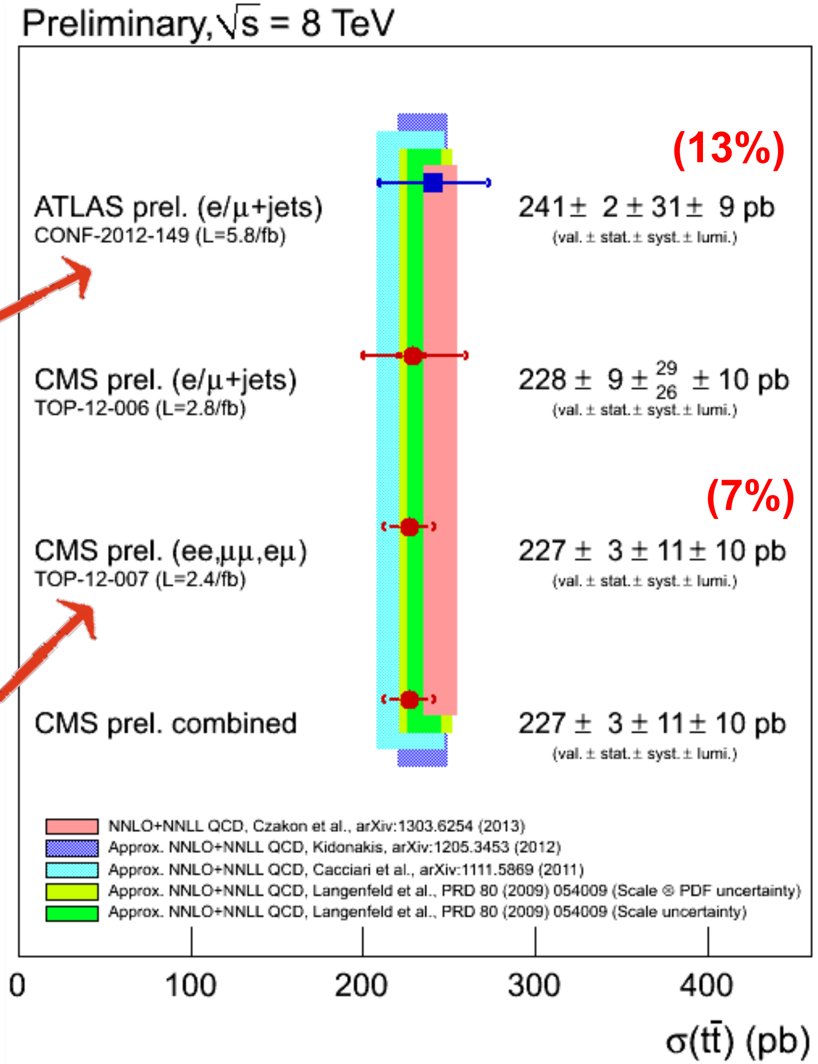
2 OS isolated,
high-p_T leptons, ≥ 2 jets,
≥ 1 b-tagged jet

- E_T^{miss} for ee, μμ; veto Z-mass region
- Cut-&-count

Main syst: lepton ID, jet energy scale

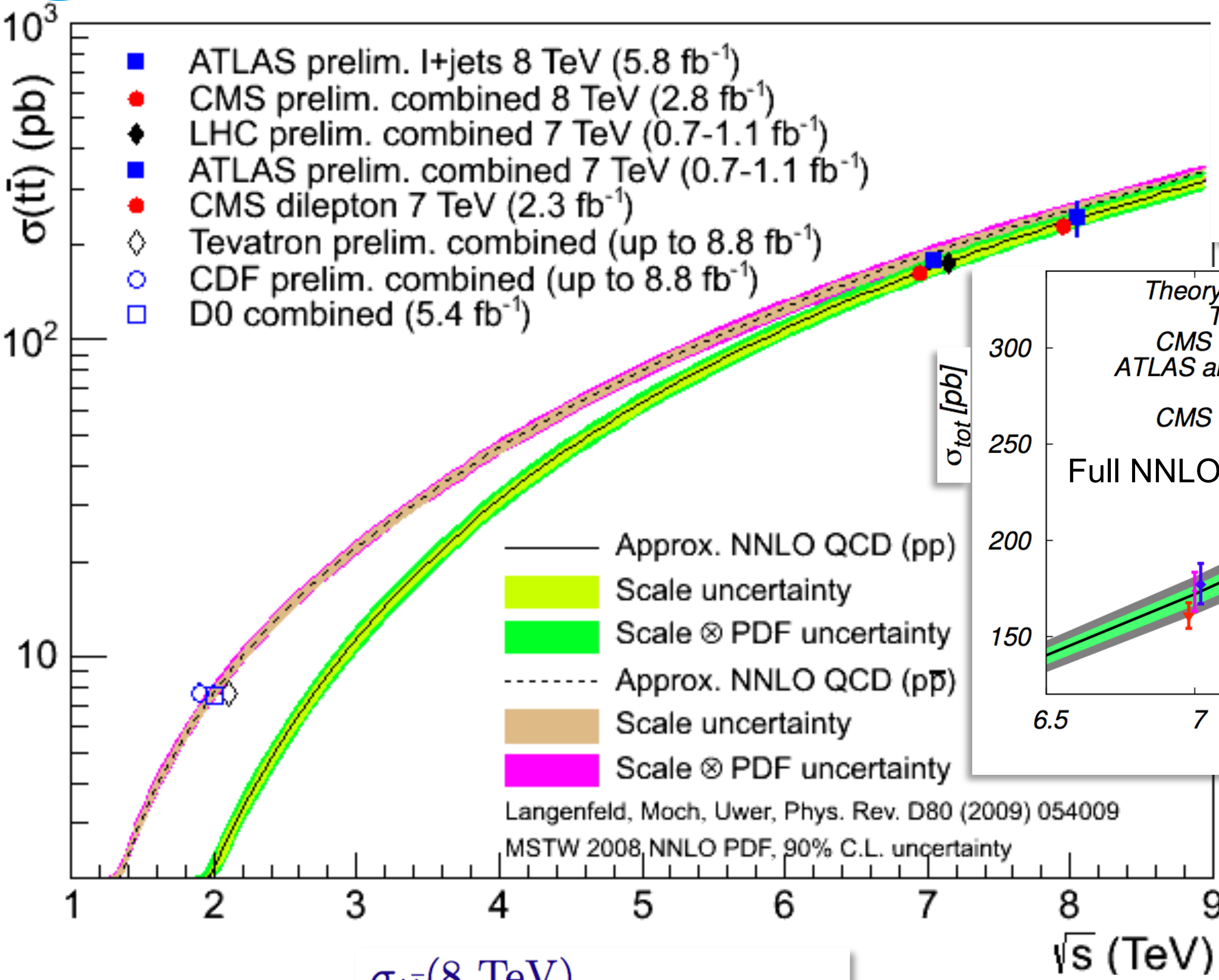
CMS-PAS TOP-12-007



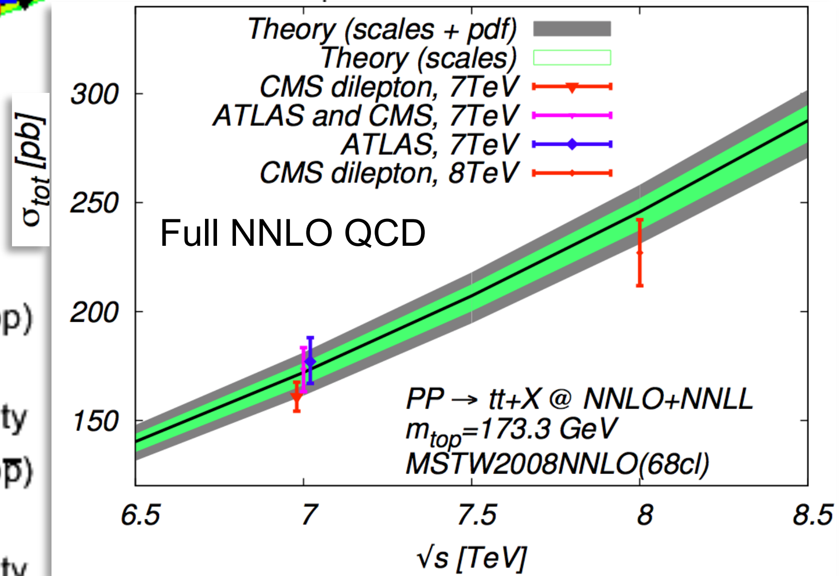


Good agreement between channels and with SM predictions

Summary of σ(tt̄) results vs. √s



- Measurements dominated by syst. uncertainties
- ATLAS & CMS use different prescriptions for the common theor. aspects



[arXiv:1303.6254]

ATLAS-CONF-2012-024
ATLAS-CONF-2012-149
ATLAS-CONF-2012-134
CMS-PAS TOP-12-003
CMS-PAS TOP-12-007
JHEP 11 (2012) 067

Ratio 8 TeV / 7 TeV: $$\frac{\sigma_{t\bar{t}}(8\ \text{TeV})}{\sigma_{t\bar{t}}(7\ \text{TeV})} = 1.41 \pm 0.11$$

(exp. uncerts. uncorr. th. uncerts. fully corr. , in agreement with arXiv:1303.7215)

First determination of α_s from $\sigma(t\bar{t})$

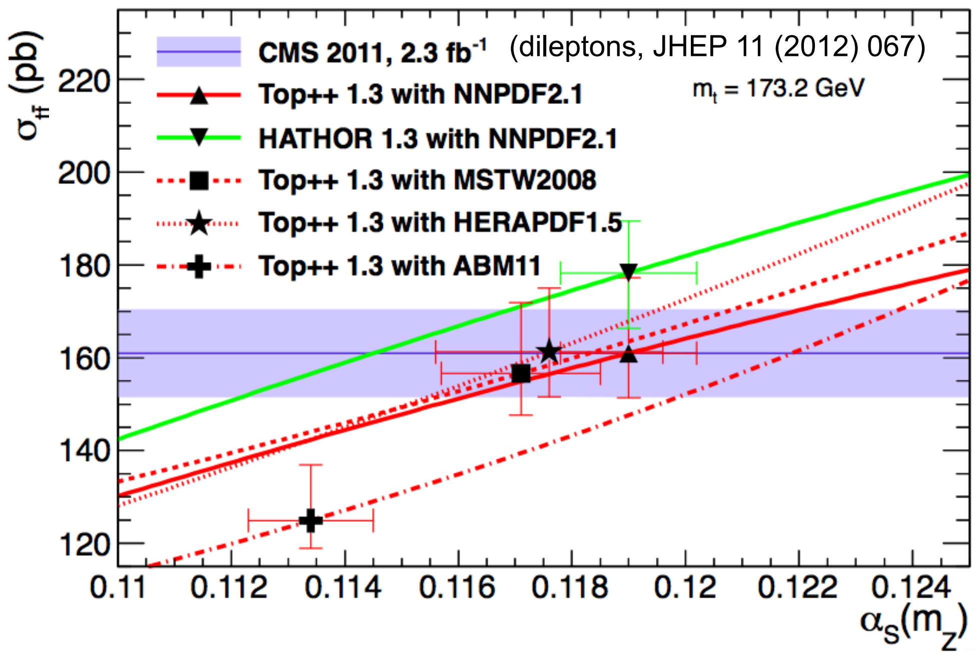
CMS-PAS TOP-11-022

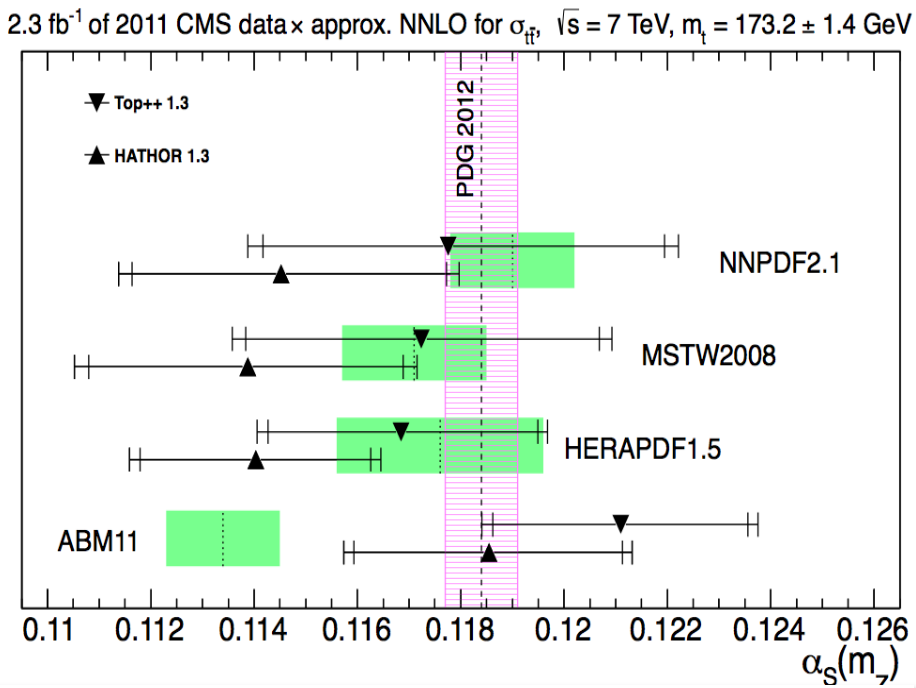
High precision of $\sigma(t\bar{t})$ measurement can be used to determine $\alpha_S(m_Z)$

α_S determined at hadron colliders has large theory uncertainty due to missing NNLO contributions → Use approx. NNLO calculations to determine $\alpha_S(m_Z)$ from measured $\sigma(t\bar{t})$

$\sigma(t\bar{t})$ dependence on α_S determined (at fixed m_{top}) for approx. NNLO calculations and for different PDFs (results with full NNLO in editorial review)

Most probable α_S results from joint likelihood: theory ⊗ experiment





Compatible with PDG value within uncertainties

Differential $t\bar{t}$ cross sections

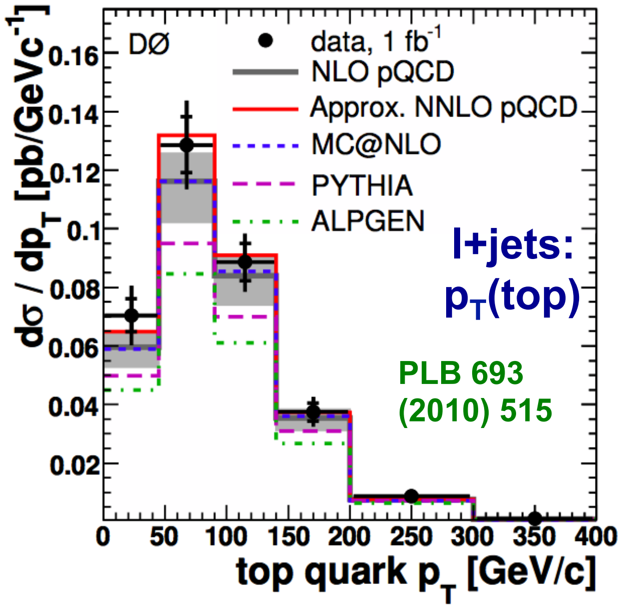
- Measure top quark kinematic distributions

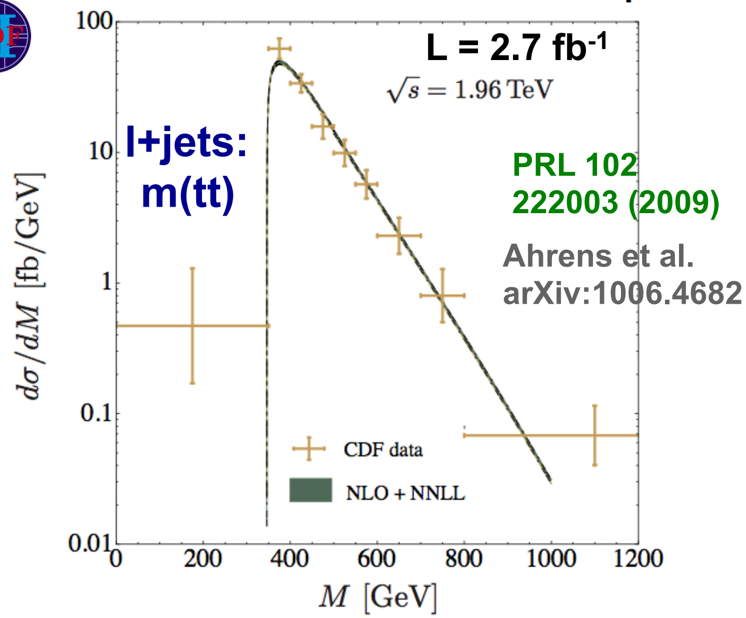
  top, top pairs, (b)-jets, leptons, lepton pairs, E_T^{miss}, …
  - Scrutinise theory predictions & models
  - Enhance sensitivity to new physics
  - Extract/use for PDF fits (future)

$$\frac{1}{\sigma_{t\bar{t}}}\frac{d\sigma_{t\bar{t}}}{dX}$$

- Main analysis ingredients:
  - cross section measurement
  - kinematic reconstruction of $t\bar{t}$ system
  - correct for detector effects & acceptance (unfolding)
- Visible or extrapolated to full phase space
- Corrected to parton or particle level
- Normalized to inclusive $\sigma(t\bar{t})$ in corresponding phase space
  - Only shape uncertainties contribute

Better agreement with NLO & approx. NNLO predictions

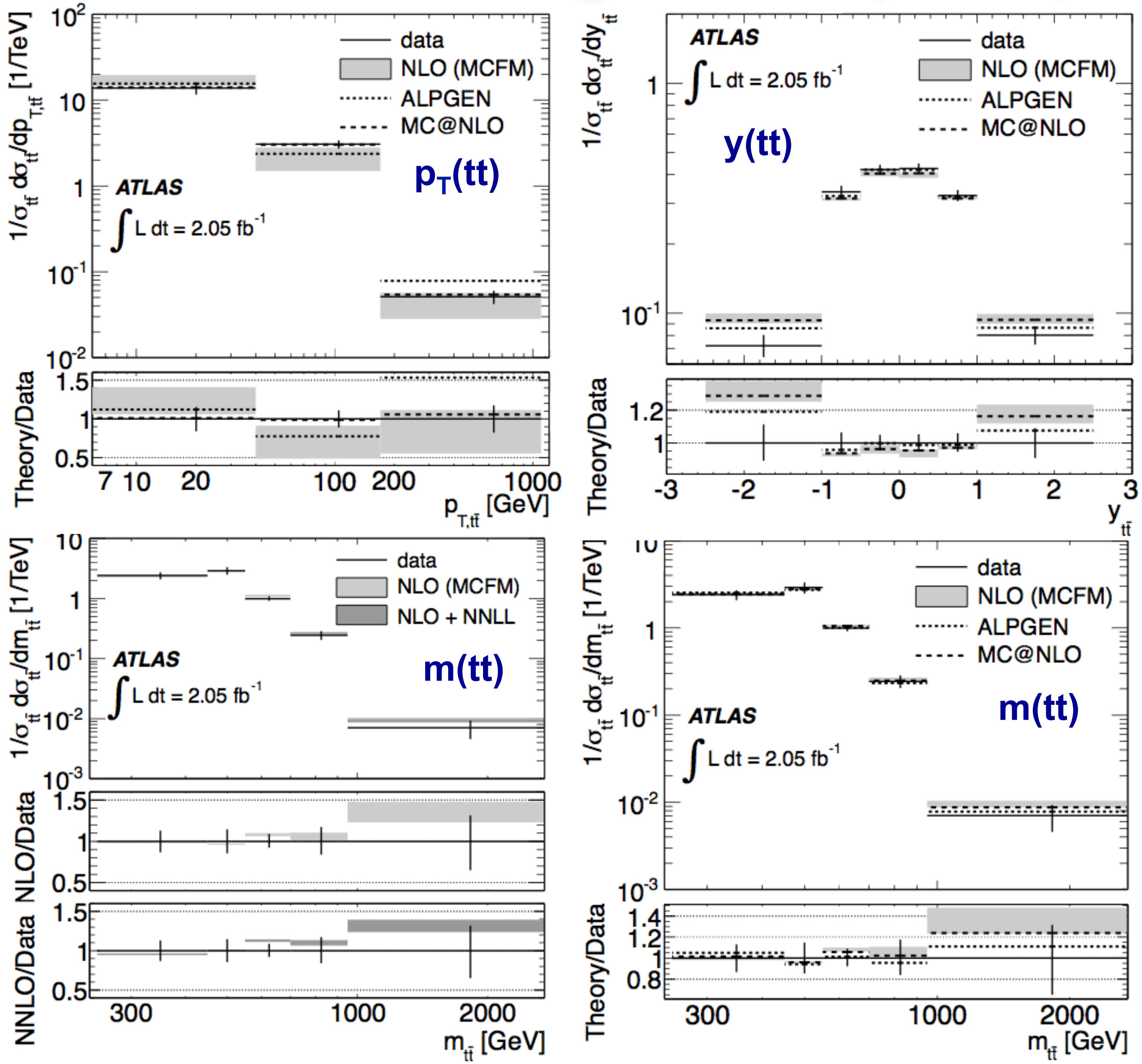




Differential tt̄ cross sections @ ATLAS (7 TeV)

- l+jets
  (≥4 jets, ≥1 b-tag)
- Un-regularised unfolding
- Comparison to different predictions:
  - MCFM
  - MC@NLO+Herwig
  - ALPGEN+Herwig
  - NLO+NNLL → m(tt̄)

  [Ahrens et al. arXiv:1003.5827]



In general, good agreement between data and predictions

Main syst: jet/E_T^{miss} reco

- Full covariance matrix provided

EPJC (2013) 73:2261

Differential $t\bar{t}$ cross sections @ CMS (7 TeV)

- l+jets
  (≥ 4 jets, ≥ 2 b-tags)
  dileptons
  (≥ 2 jets, ≥ 1 b-tags)

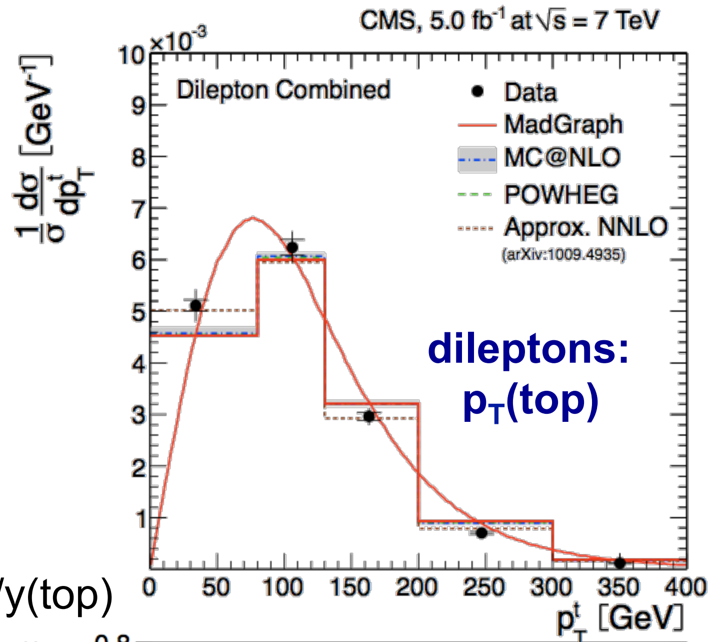
- Comparison to:
  - MadGraph+Pythia
  - MC@NLO+Herwig
  - POWHEG+Pythia
  - NLO+NNLL → $m(t\bar{t})$
  - approx. NNLO → p_T/y(top)

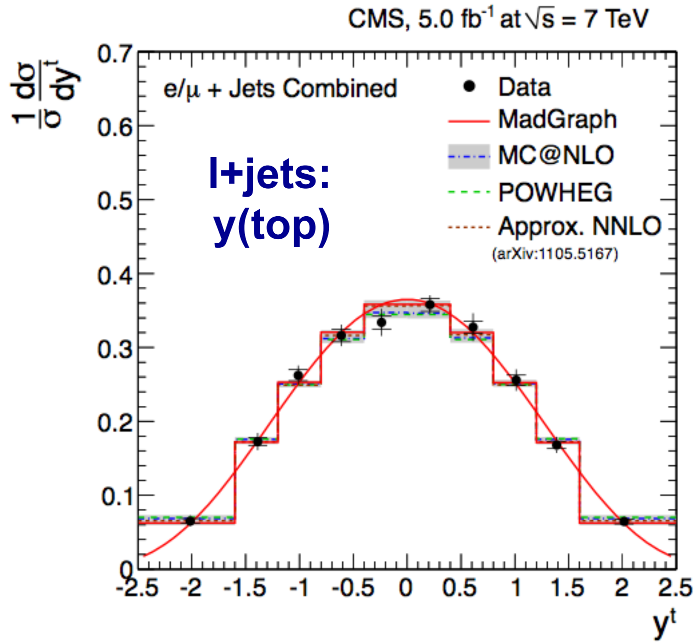
Softer p_T(top) in data, better described by approx. NNLO

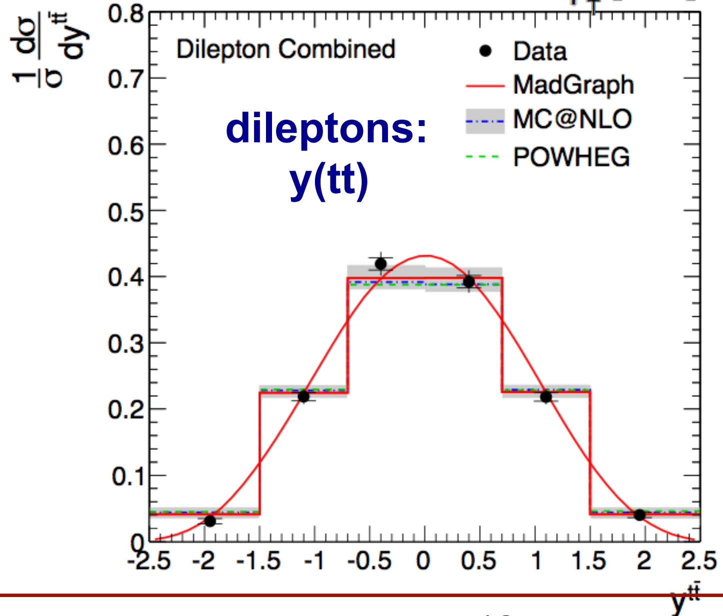
In general, good agreement btw data and predictions

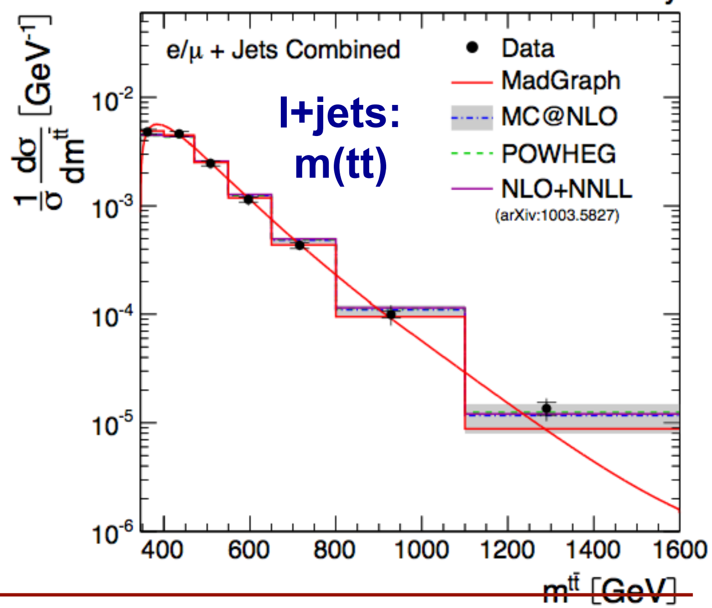
Typical syst: signal & bg modelling, b-tagging, lepton selection

arXiv:1211.2220 (→ EPJC)





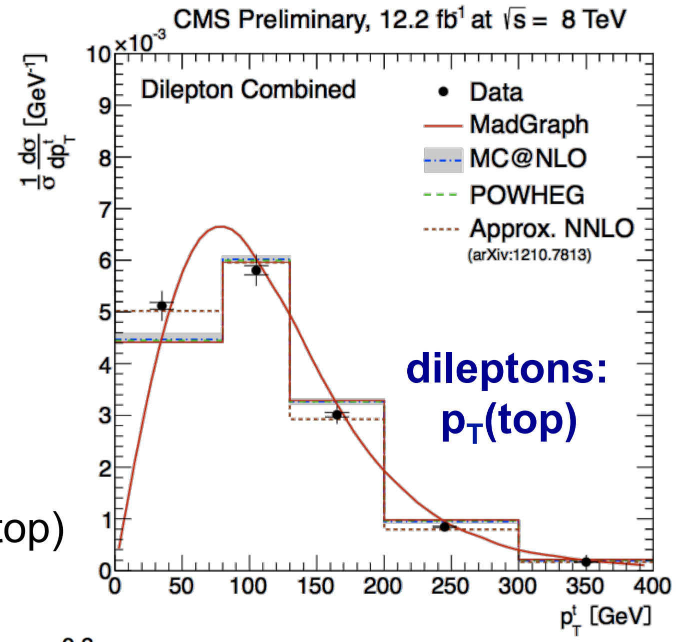


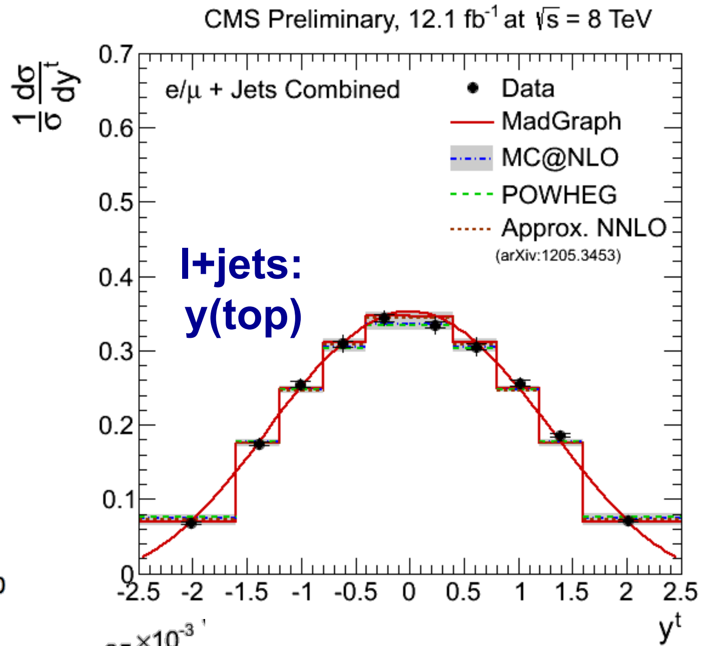


Differential $t\bar{t}$ cross sections @ CMS (8 TeV)

- l+jets
  (≥ 4 jets, ≥ 2 b-tags)
  dileptons
  (≥ 2 jets, ≥ 1 b-tags)

- Comparison to:
  - MadGraph+Pythia
  - MC@NLO+Herwig
  - POWHEG+Pythia
  - approx. NNLO → p_T/y(top)



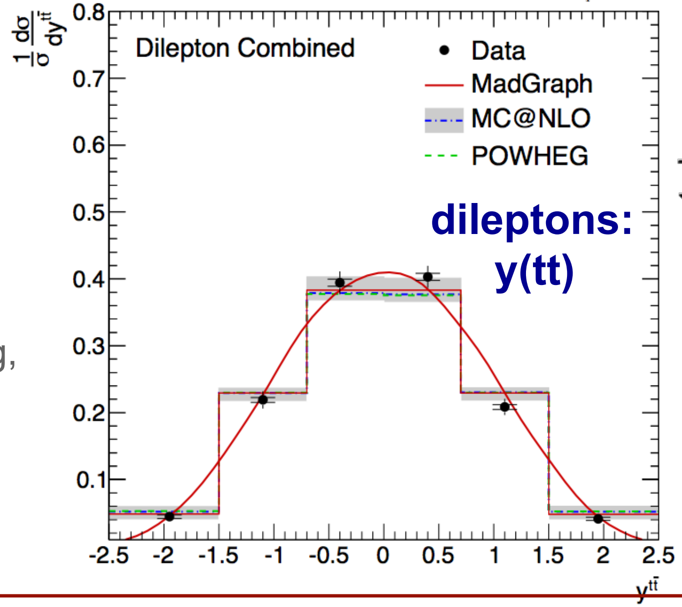


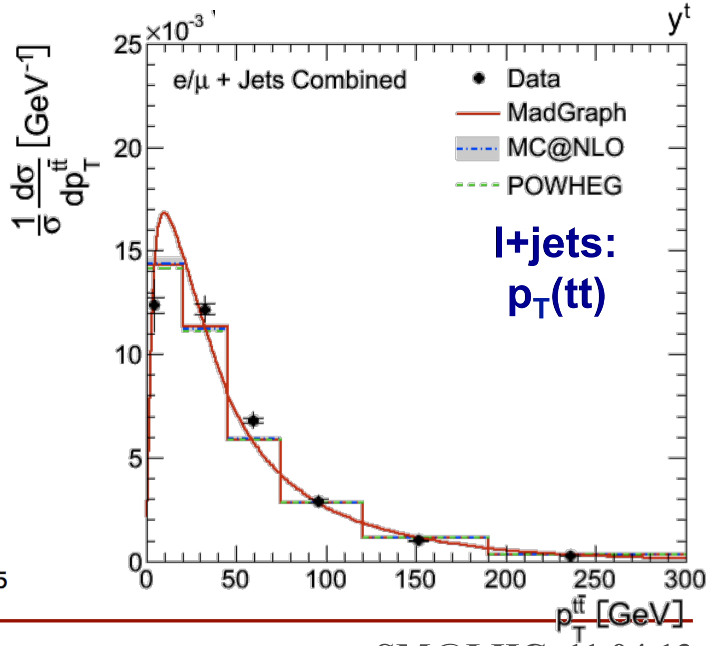
Softer p_T(top) in data, better described by approx. NNLO

In general, good agreement btw data and predictions

Typical syst: signal modelling, kinematic reco (dileptons), bg modelling (l+jets)

CMS-PAS TOP-12-027
CMS-PAS TOP-12-028

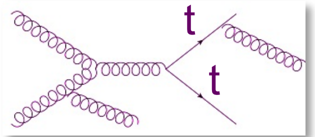




Jet multiplicity in $t\bar{t}$(+jets) events

LHC: high fraction of $t\bar{t}$ events with extra hard jets from initial (final) state radiation

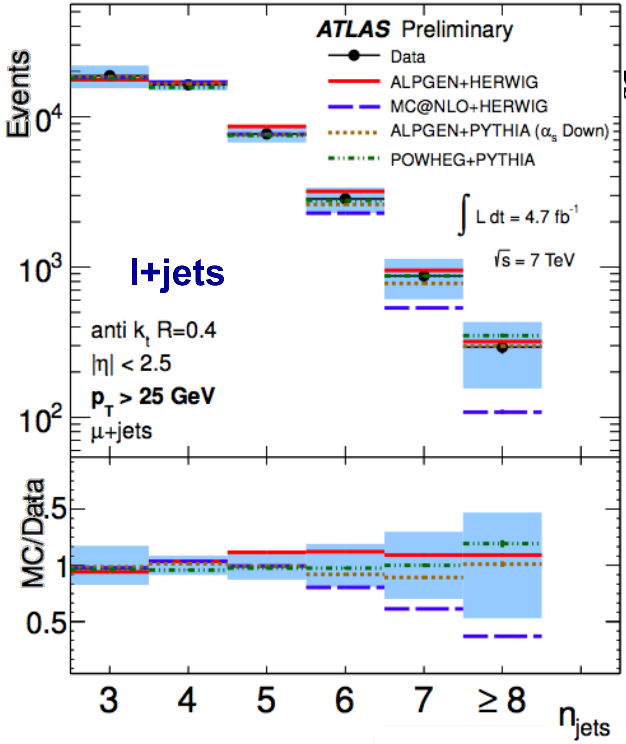
- Tune & test radiation modelling in MC with measurements
- Important for top, Higgs and many BSM studies



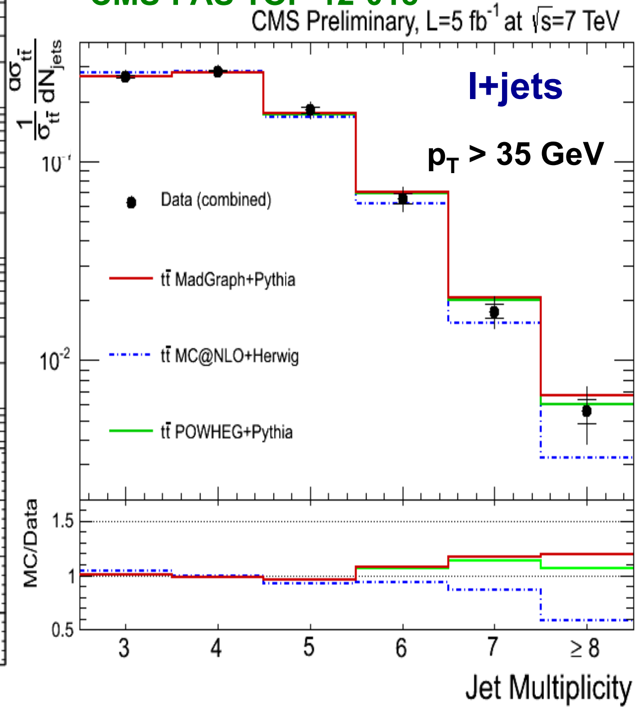
Compare **N_{jets}** (ATLAS) and **$1/\sigma_{tt}\ d\sigma_{tt}/dN_{jets}$** (CMS) to ME+PS and NLO generators

- Corrected to particle level, presented in the visible phase space

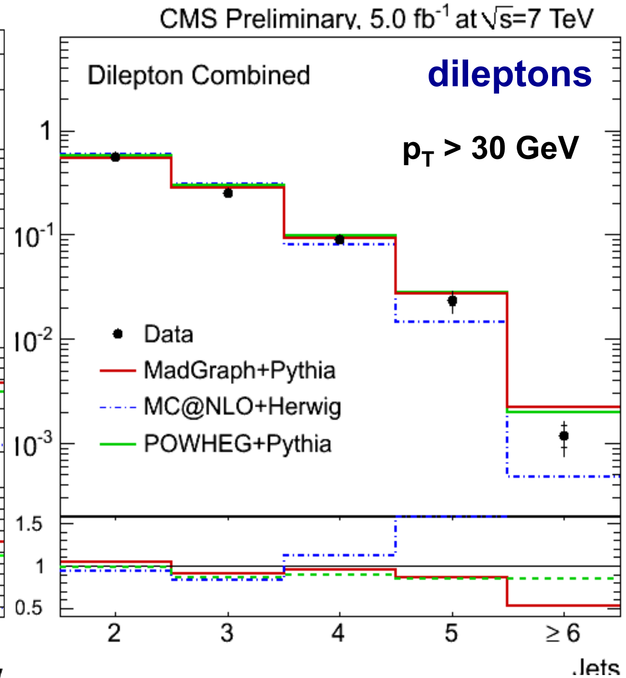
ATLAS-CONF-2012-155



CMS-PAS TOP-12-018



CMS-PAS TOP-12-023



General good agreement between data and predictions

MC@NLO+Herwig underestimates large jet multiplicities

$t\bar{t}$ with veto on extra jets: "gap fraction"

EPJC (2012) 72:2043

CMS-PAS TOP-12-023

- Dilepton channels
(≥ 2 jets, ≥ 1, 2 b-tags)

- Fraction of events with **no** extra jet above a given p_T (Q_0)
→ sensitive to leading-p_T add. jet

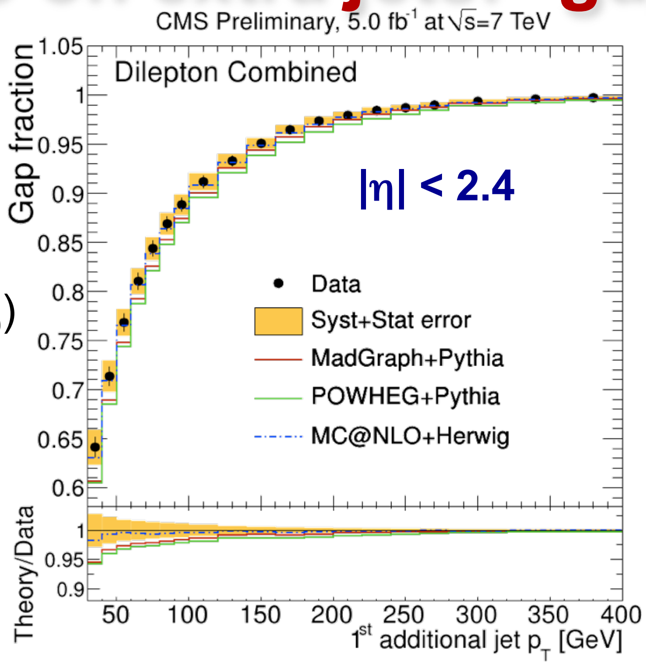
- Corrected for detector effects, compared to ME+PS and NLO generators

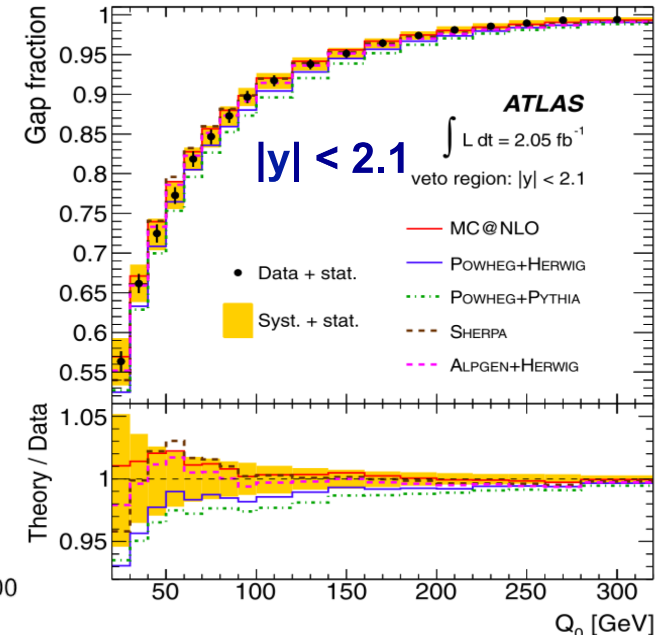
In general, good agreement btw data and predictions

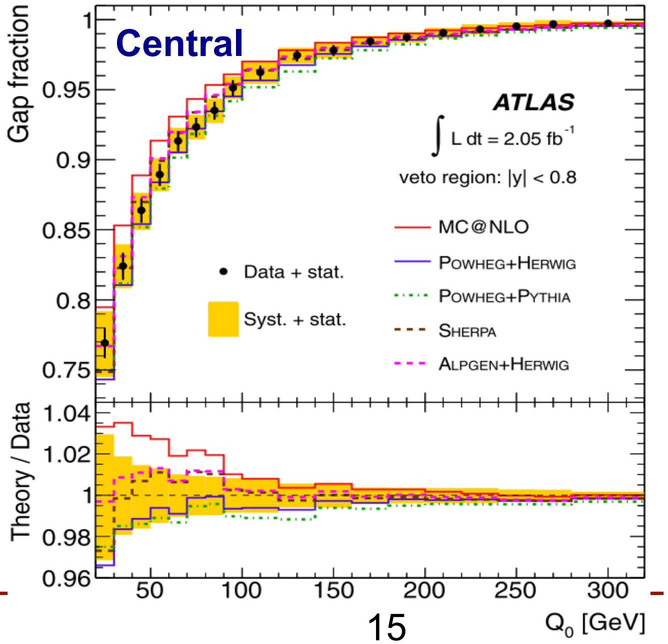
- Central region: MC@NLO overshoots data (too few jets)

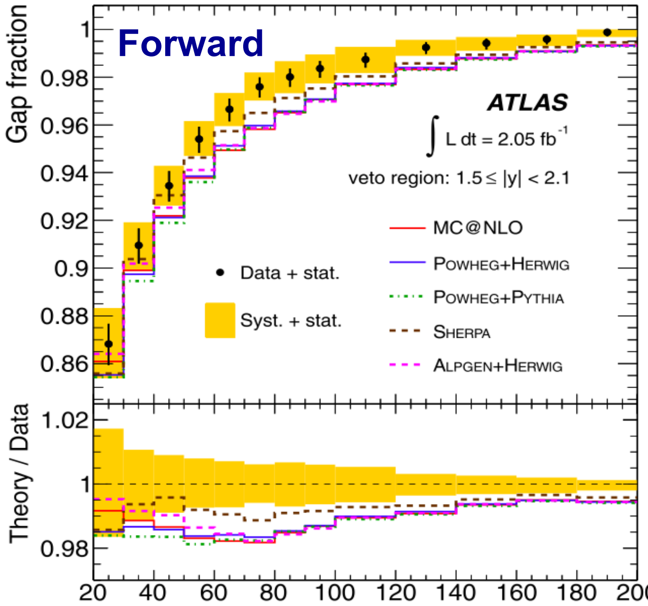
- Forward region: all generators produce too much radiation

Constrain QCD radiation uncertainty









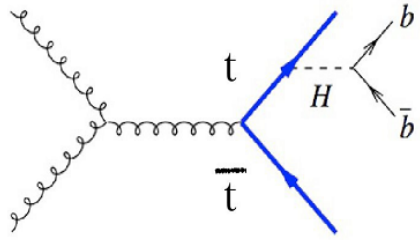
Associated $t\bar{t}$ + $b\bar{b}$ production

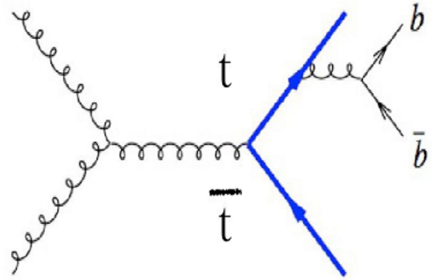
CMS-PAS TOP-12-024

Test pQCD calculations ; irreducible, non-resonant bg for $t\bar{t}H(b\bar{b})$

- Predictions have large uncerts (scales)
- Measure ratio $\sigma(t\bar{t}b\bar{b})/\sigma(t\bar{t}jj)$

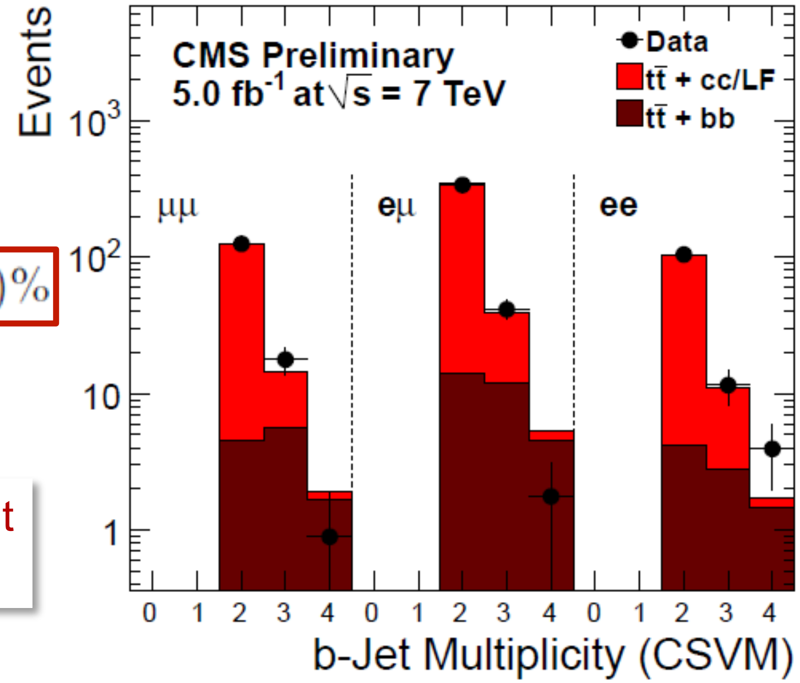
  → large cancellation of uncertainties





- Dilepton events with ≥ 4 jets, ≥ 2 b-tags
- Signal extraction by fit to the b-jet multiplicity
- σ ratio at particle level in visible phase space:

$$\sigma(t\bar{t}b\bar{b})/\sigma(t\bar{t}jj) = 3.6 \pm 1.1(\text{stat.}) \pm 0.9(\text{syst.})\%$$



- In agreement with predictions:

MadGraph: 1.2%

Powheg: 1.3%

First measurement of σ(ttbb)/σ(ttjj) !

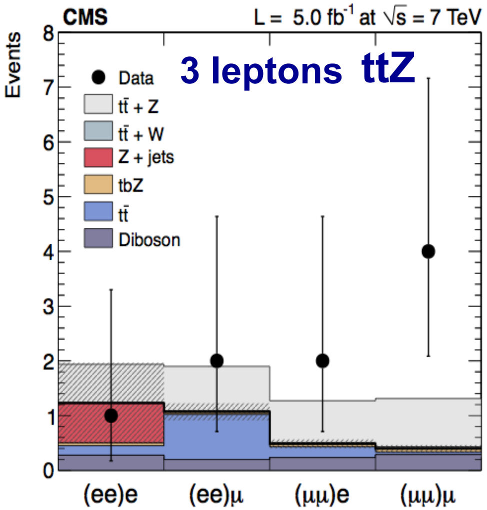
Statistically limited

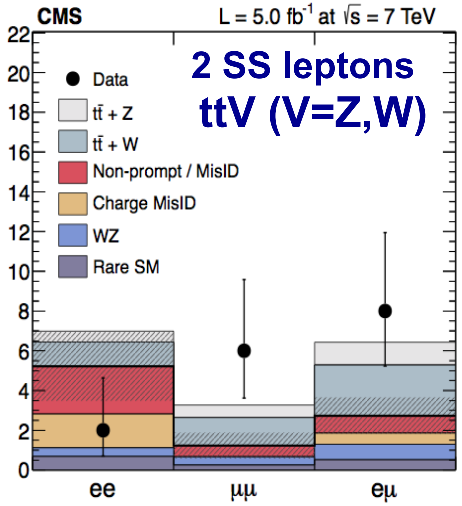
Main syst: mistag efficiency

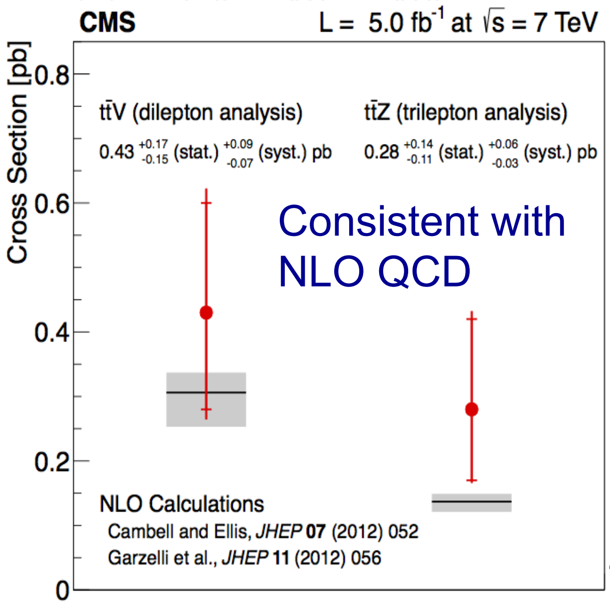
Associated $t\bar{t}$ + W/Z/γ production

Measure top couplings to bosons ; important bgs for BSM searches

$t\bar{t}$+W/Z arXiv:1303.3239 (→ PRL) ATLAS-CONF-2012-126







3.3σ for ttZ
3σ for ttV

ATLAS:
upper limit on
σ(ttZ) < 0.71 pb
@ 95% CL
(0.74 pb exp.)

Consistent with
SM σ = 0.14 pb

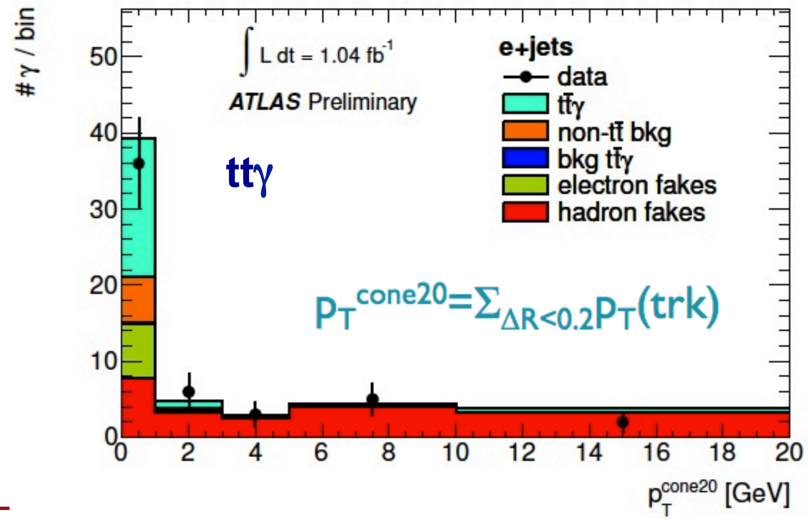
$t\bar{t}$+γ ATLAS-CONF-2011-153

- l+jets evts with ≥ 4 jets, 1 btag, 1 photon
- Likelihood fit to photon isolation

$$\sigma_{t\bar{t}\gamma} \cdot \mathrm{BR} = 2.0 \pm 0.5\,(\mathrm{stat.}) \pm \pm 0.7\,(\mathrm{syst.}) \pm 0.08\,(\mathrm{lumi.})\ \mathrm{pb}$$

(extrapolated to $p_T(\gamma)$ > 8 GeV in l+jets & dileptons)

- 2.7σ (exp. 3.0 ± 0.9)
- Consistent with SM (2.1 ± 0.4 pb)



Summary & outlook

- The LHC has become a real "top factory"
  - Increasing precision on inclusive $t\bar{t}$ cross section, competing with theory
  - First round of top-pair differential cross section measurements
  - Measurements of $t\bar{t}$+X, where X = (b-)jets, W, Z, γ, …

- So far, good agreement with SM

- Larger samples of 8 TeV data (~20 fb^{-1}) will allow for even more precise measurements
  - Trade off statistics for systematics
  - Validate MC models & parameter variations
  - Compare with (N)NLO predictions

- Prospects for new type of measurements?
  - Cross section ratios 8/7 TeV and double ratios $t\bar{t}$/Z
  - Measurements in visible phase space, particle level

  → definition of top quark at particle level

Mangano, Rojo, arXiv:1206.3557,
Czakon et al., arXiv:1303.7215

Additional information

Top quark mass from $\sigma(t\bar{t})$

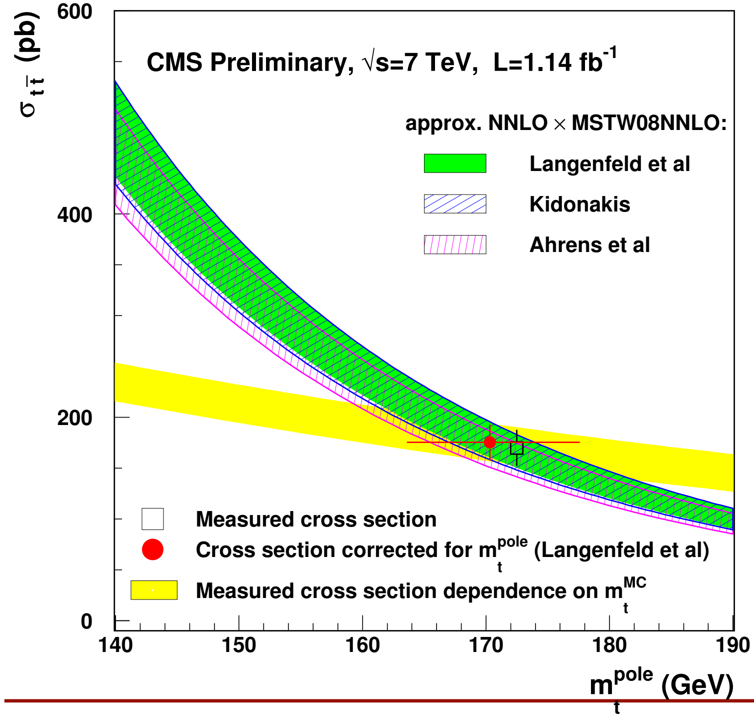
CMS-PAS TOP-11-008
ATLAS-CONF-2011-054

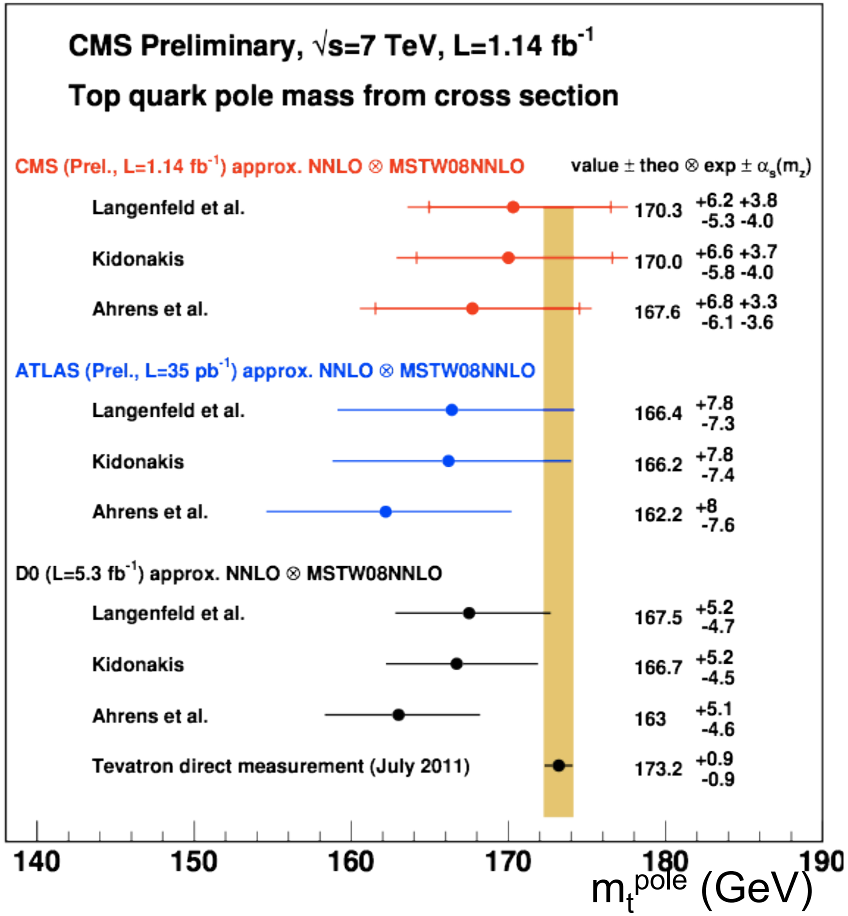
Mass dependence of predicted cross section allows determining m_t from measured σ_{tt}

→ provides top mass in unambiguous definition

- Extract **pole** and **$\overline{\text{MS}}$ mass** from measured cross section in dileptons

- Most probable mass results from joint likelihood: theory $\otimes$ experiment





Good agreement between different calculations
Results consistent also with other experiments

Precision limitations:
- Syst. uncert. of the measurement
- PDF uncert. + α_S uncert. in the PDF

First σ(tt̄) combination at LHC (7 TeV)

- **ATLAS & CMS combination** (up to L = 1.1 fb^{-1})
  - Use individual ATLAS, CMS combinations as input

ATLAS-CONF-2012-134, CMS-PAS TOP-12-003

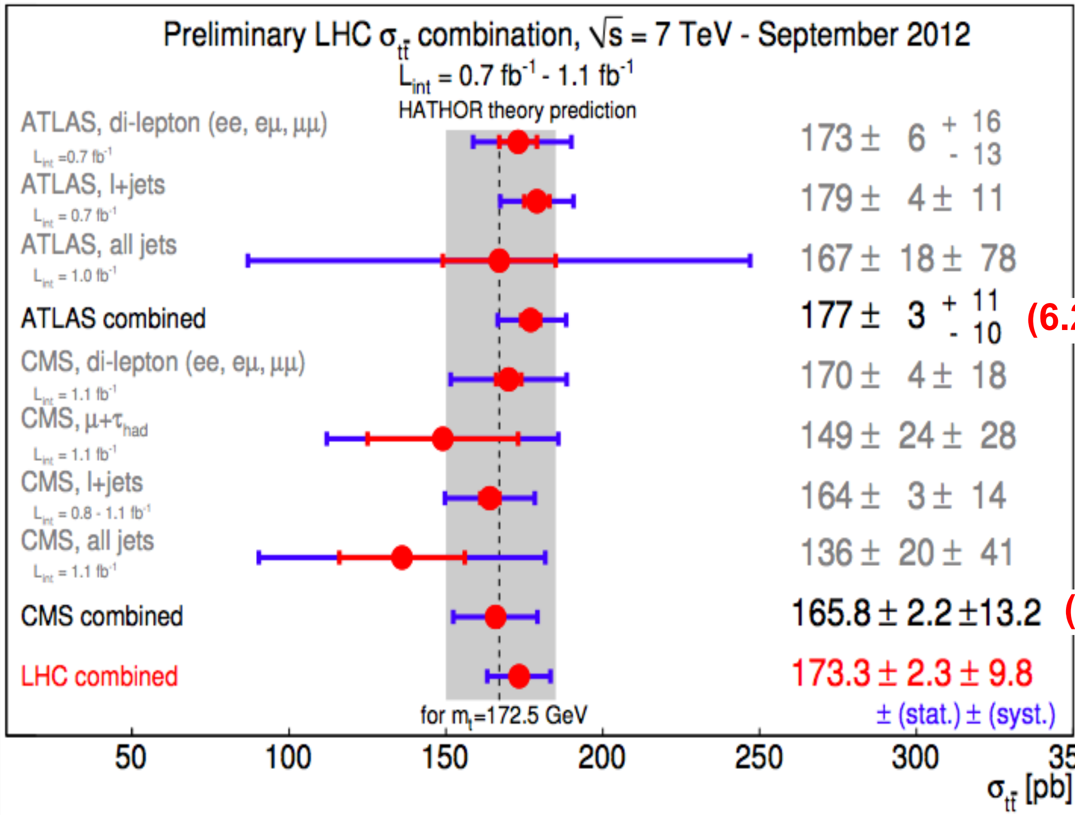
$\sigma_{tt} = 173.3 \pm 2.3\ (\text{stat}) \pm 9.9\ (\text{syst})\ \text{pb}$

(5.8%)

Full NNLO+NNLL:

$$\sigma_{tt} = 172.0\ ^{+4.4}_{-5.8}\ (\text{scales})\ ^{+4.7}_{-4.8}\ (\text{pdf})\ \text{pb}$$

(~3%)



(6.2%)

(8%)

- First step in discussion towards harmonising systematics treatment
  - So far, differences in treatment of e.g. signal model uncertainties

Main systematics:
luminosity, detector & signal modelling

Improvements expected with new measurements: more statistics, better luminosity syst.

NB: not using latest measurements based on full dataset

Good agreement between experiments and with SM predictions

First σ($t\bar{t}$) combination at LHC (7 TeV)

	ATLAS	CMS	Correlation	LHC combination
Cross-section	177.0	165.8		173.3
Uncertainty				
Statistical	3.2	2.2	0	2.3
Jet Enegy Scale	2.7	3.5	0	2.1
Detector model	5.3	8.8	0	4.6
Signal model				
Monte Carlo	4.2	1.1	1	3.1
Parton shower	1.3	2.2	1	1.6
Radiation	0.8	4.1	1	1.9
PDF	1.9	4.1	1	2.6
Background from data	1.5	3.4	0	1.6
Background from MC	1.6	1.6	1	1.6
Method	2.4	n/e	0	1.6
W leptonic branching ratio	1.0	1.0	1	1.0
Luminosity				
Bunch current	5.3	5.1	1	5.3
Luminosity measurement	4.3	5.9	0	3.4
Total systematic	10.8	14.2		9.8
Total	11.3	14.4		10.1

- Signal modelling uncertainties
- ATLAS:
  - generator: MC@NLO vs Powheg (vs Alpgen for recent results)
  - shower model: Powheg+Pythia vs Powheg+Herwig
  - ISR/FSR: ACER+Pythia with more/less radiation
  - PDF
- CMS:
  - Q^2 variation in Madgraph
  - ME-PS matching
  - MC tune (for some analyses)
  - PDF

More info: σ(tt) in l+jets @ ATLAS (8 TeV)

- Aplanarity: smallest eigenvalue of M_{ij}

$$M_{ij} = \frac{\sum_{k=1}^{N'_{\mathrm{objects}}} p_{ik} p_{jk}}{\sum_{k=1}^{N'_{\mathrm{objects}}} p_k^2},$$

- Systematic uncertainties (%):

Source	$e+ \geq 3$ jets	$\mu+ \geq 3\,jets$	combined
Jet/MET reconstruction, calibration	6.7, -6.3	5.4, -4.6	5.9, -5.2
Lepton trigger, identification and reconstruction	2.4, -2.7	4.7, -4.2	2.7, -2.8
Background normalization and composition	1.9, -2.2	1.6, -1.5	1.8, -1.9
b-tagging efficiency	1.7, -1.3	1.9, -1.1	1.8, -1.2
MC modelling of the signal	±12	±11	±11
Total	±14	±13	±13

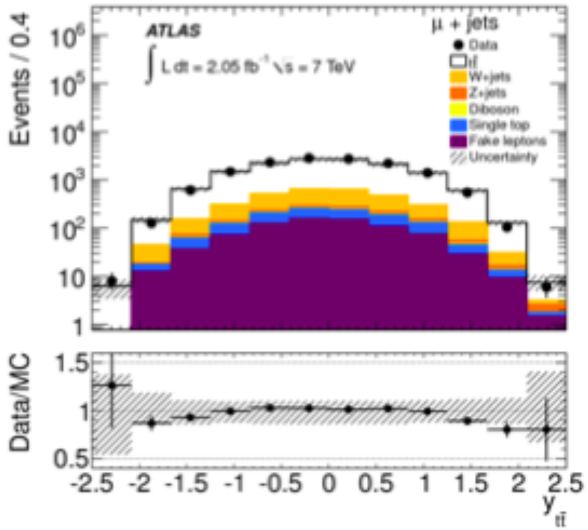
Luminosity: 3.6 %

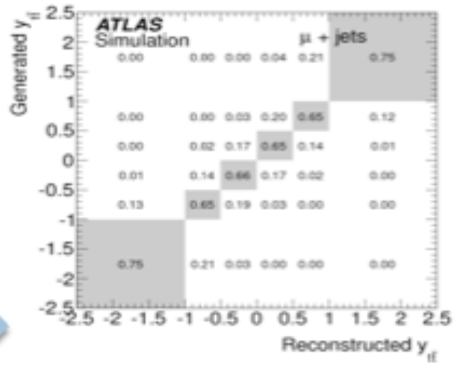
More info: diff cross sections @ ATLAS

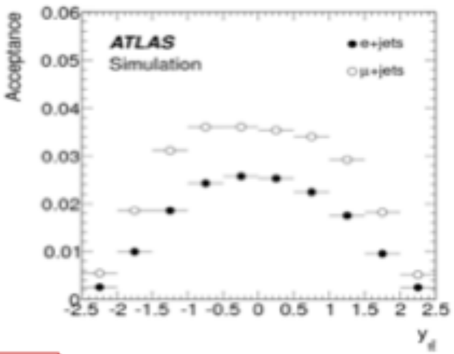
- l+jets channel: 1 isolated $\mu(e)$ $p_T > 20$ (25) GeV ; ≥ 4 jets ($p_T > 25$ GeV, $|\eta| > 2.5$), ≥ 1 b-tag ; $E_T^{miss} > 20$ (30) GeV, $m_T(W) > 60$ (25) GeV – E_T^{miss}

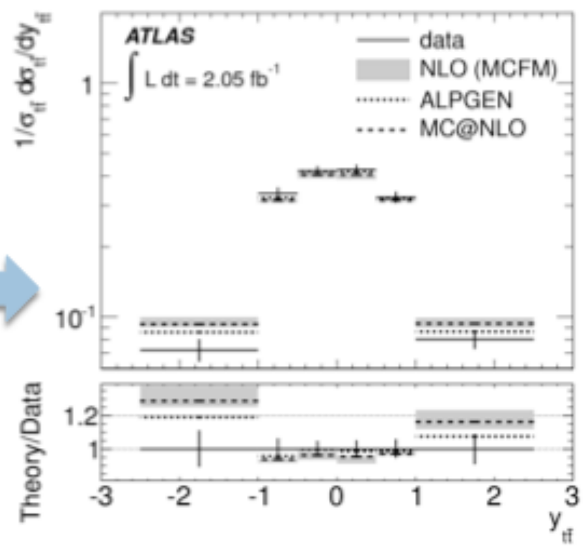
- tt kinematic reco using a likelihood fit of the measured objects to a theoretical LO representation of the tt decay

- Unfolding by matrix inversion





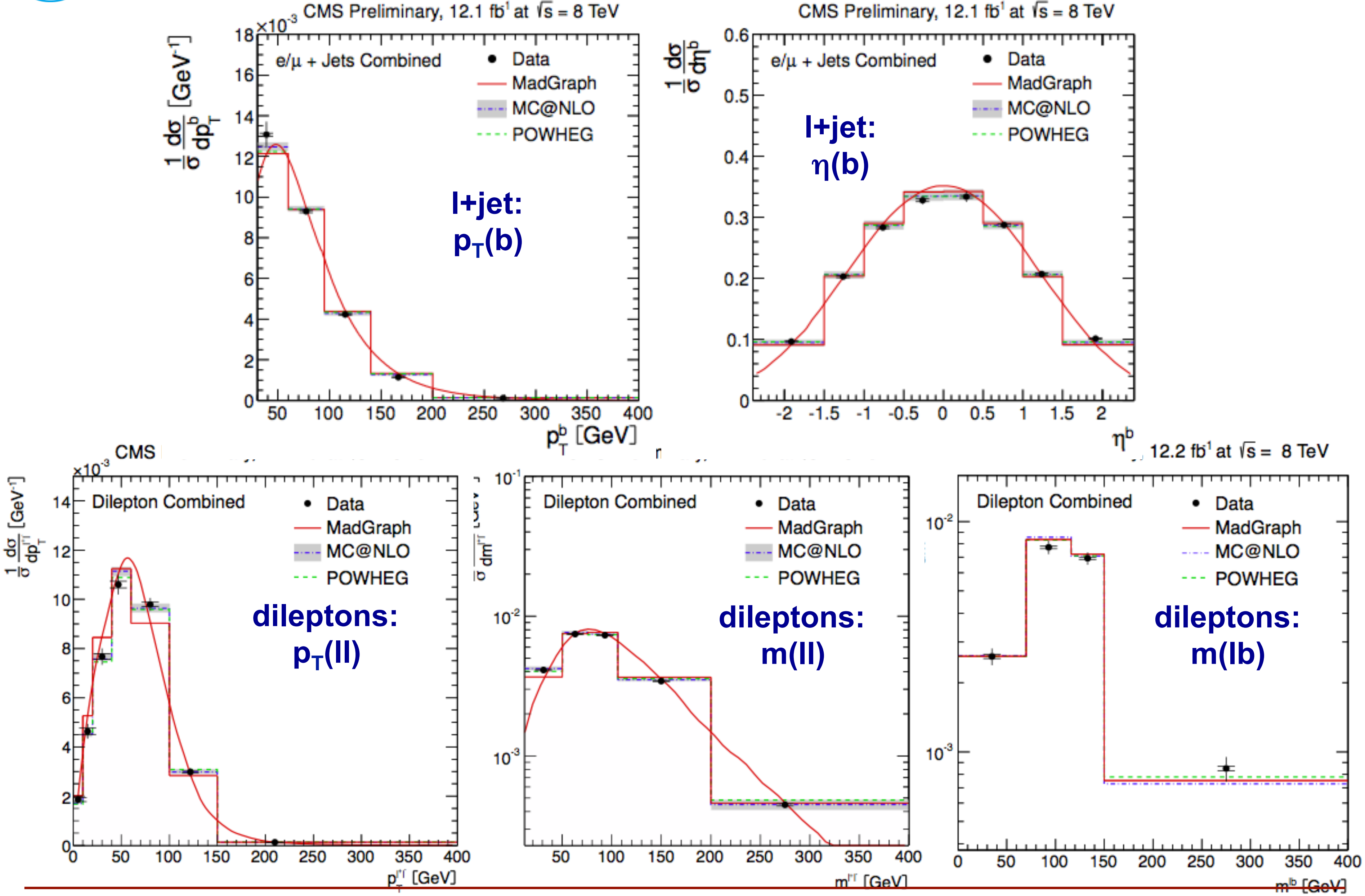




$$\sigma_j = \frac{\sum_i \left(M^{-1}\right)_{ji}\left(N_i - B_i\right)}{A_j L}$$

Here M_{ij} is the bin migration matrix, N_i is the number of observed events in bin i, B_i is the number of background events , A_j is the acceptance and L is luminosity.

More info: 1/σ dσ/dX @ CMS (8 TeV)



More info: $1/\sigma\ d\sigma/dX$ @ CMS – Phase Space

reconstructed quantities:
top quarks, $t\bar{t}$ system

→ extrapolated parton level PS

correct for

detector effects
hadronization effects
extrapolate to full PS

→ as close to theory as possible

directly measurable quantities:
lepton(s), b-jets

→ visible particle level PS

correct for

detector effects
no hadronization correction
visible PS, no extrapolation:

$p_T^{jets} > 30$ GeV, $\eta^{jets} < 2.4$,

$p_T^{lep} > 20$ (30) GeV, $\eta^{lep} < 2.4$ (2.1)

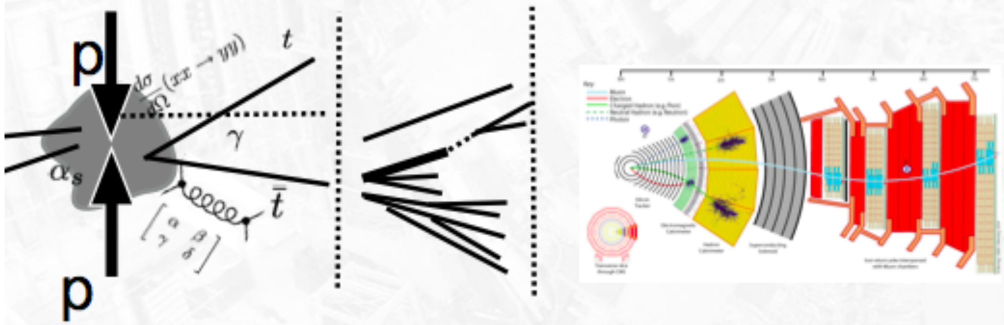
for dilepton (lepton+Jets) PS

→ object definition on generator level:

- particles after radiation & hadronization
- jets: same jet algorithm
- b-Jets: identified by B-hadron
- leptons: from W, $\Delta R(lep,genJet)>0.4$

→ as model independent as possible

parton **particle** **reconstructed**



More info: 1/σ dσ/dX @ CMS – syst (7 TeV)

- Determined individually for each bin of the measurement
- Normalized cross sections: only shape uncertainties contribute, correlated uncertainties cancel

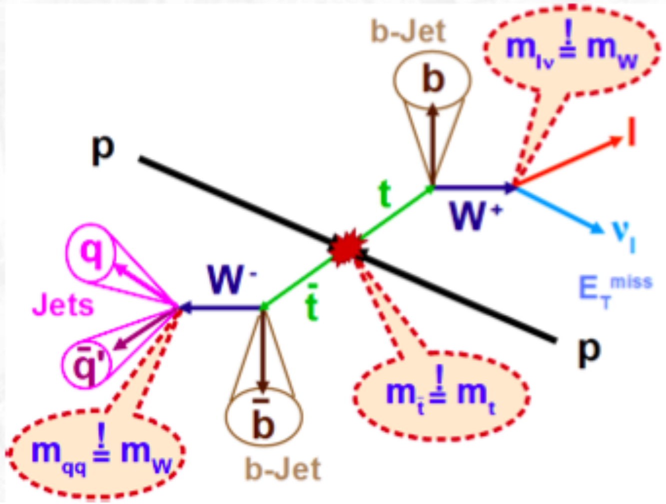
Typical values per bin at 7 TeV

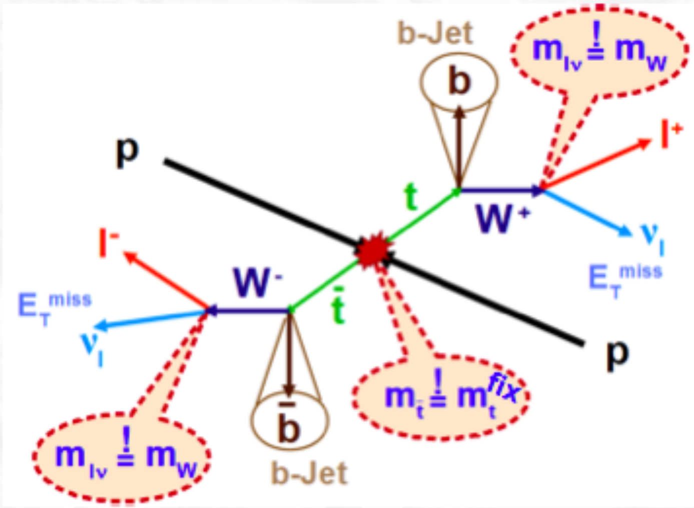
	Source	Method	Systematic uncertainty (%) ℓ+jets	Systematic uncertainty (%) dileptons
Experimental	Background	vary with 30%-50%	3.5	0.5
	Trigger eff.	p_T-η dependent	0.5	1.5
	Lepton sel.	p_T-η dependent	0.5	2.0
	Jet energy scale	p_T-η dependent	1.0	0.5
	Jet energy resolution	p_T-η dependent	0.5	0.5
	Pileup	vary $\sigma_{\text{inel.}}(\text{pp}) \pm 8\%$	0.5	0.5
	b tagging	p_T-η dependent	1.0	0.5
	Kinematic reco	p_T-η dependent	–	0.5
Model	Q^2	vary factor 0.25–4	2.0	1.0
	ME/PS threshold	vary factor 0.5–2	2.0	1.0
	Hadronisation	PYTHIA vs. HERWIG	2.0	2.0
	Top-quark mass	172.5 ± 0.9	0.5	0.5
	PDF choice	PDF4LHC	1.5	1.0

More info: $1/\sigma\ d\sigma/dX$ @ CMS – Kin reco

Lepton + jets: Kinematic fit

- vary measured 4-momenta for lepton, jets and neutrino
- to fullfil constrains:
  - $m_W \equiv$ 80.4 GeV
  - $m_t \equiv m_{\bar{t}}$
- neutrino: E_t^{miss}, p_z unmeasured as initial value
- consider 5 leading jets
- use b-tag information for b-jet association
- choose permutation with lowest variation wrt. object resolution (minimum χ^2)





Dilepton: Kinematic reco (~MWT)

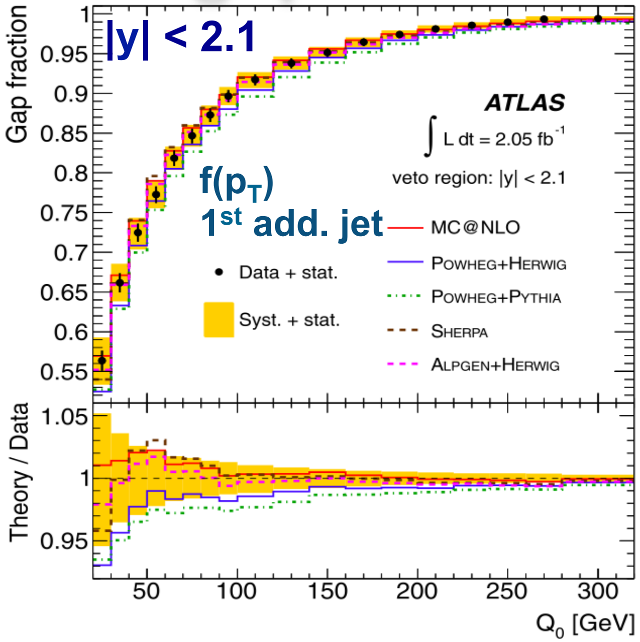
- underconstrained (2 neutrinos)
- constraints:
  - $m_W \equiv$ 80.4 GeV
  - $m_t \equiv m_{\bar{t}}$ = fixed
  - $p_{\nu 1}(x,y) + p_{\nu 2}(x,y) = E_t^{miss}(x,y)$
- vary m_t (1 GeV steps): 100 – 300 GeV
- prefer solutions with b-tagged jets
- choose solution with best reconstructed neutrino energy wrt. MC spectrum

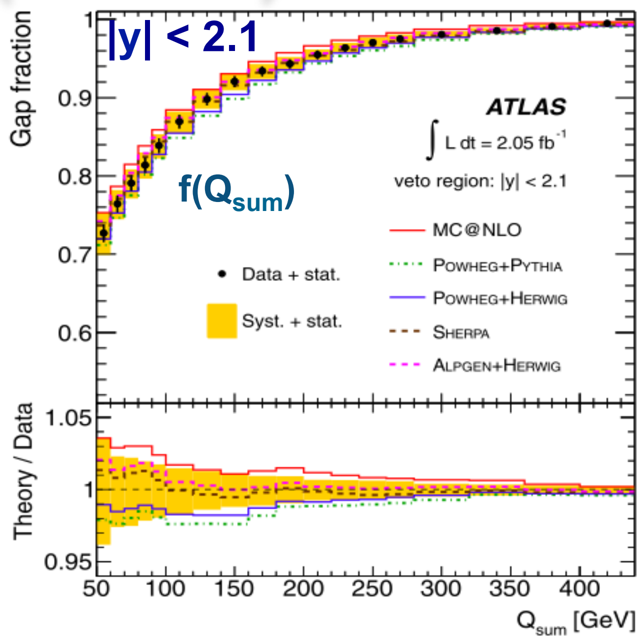
More info: gap fraction (ATLAS)

- Also as a function of Q_{sum}:

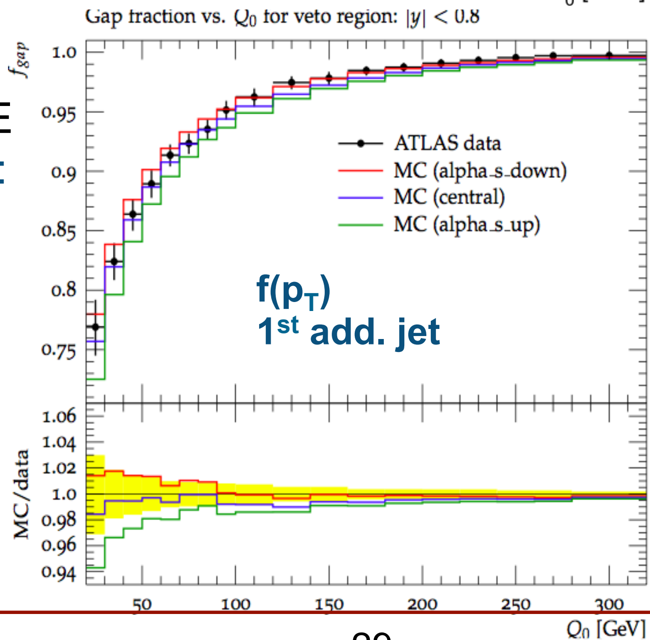
  $F(Q_{sum})$: fraction of evts in which the scalar p_T sum of all additional jets is below a certain threshold

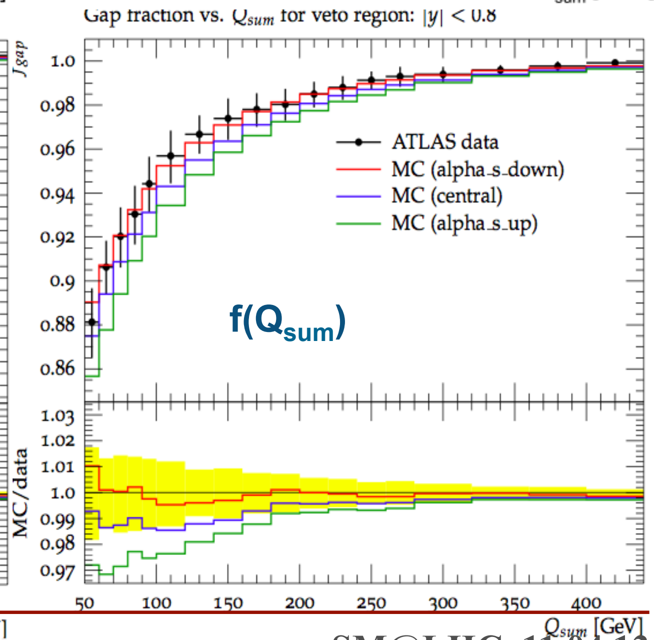
- Gap fraction vs. different generators:
  - General good agreement between data and predictions for the full η range





- Gap fraction vs. Alpgen +Pythia varied α_S value in ME (→ ISR/FSR variation): x 2, x 0.5:
  - α_S_up variation seems to be disfavoured by data





More info: gap fraction (CMS)

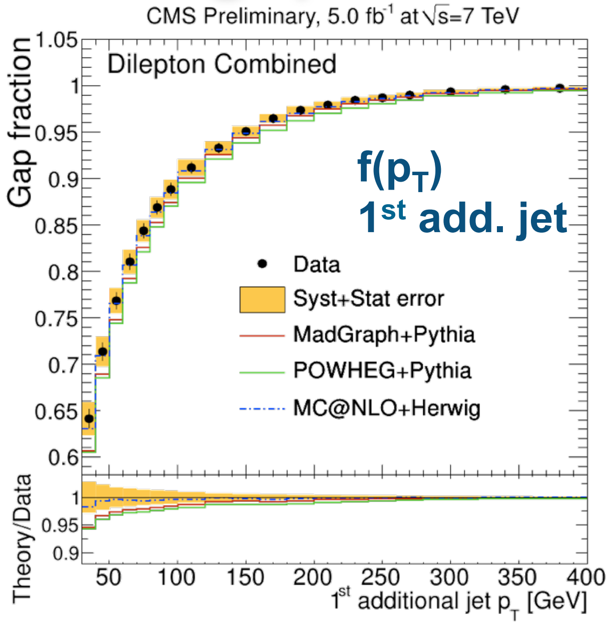
- Also as a function of H_T:

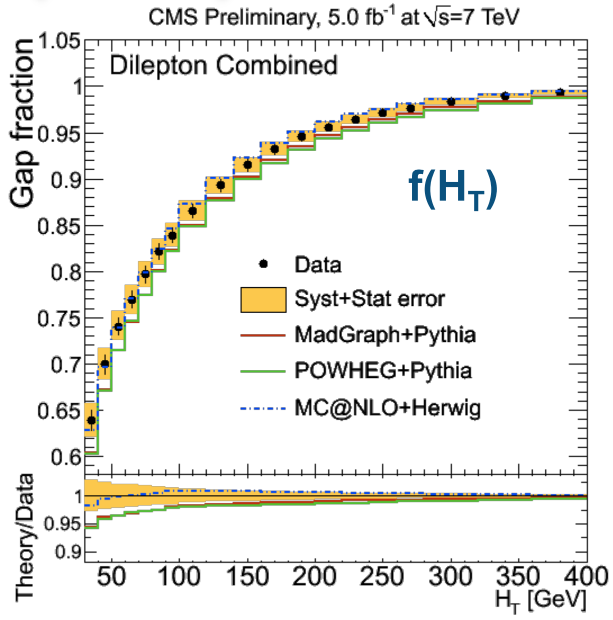
  $f(H_T)$: fraction of evts in which the scalar p_T sum of all additional jets is below a certain threshold

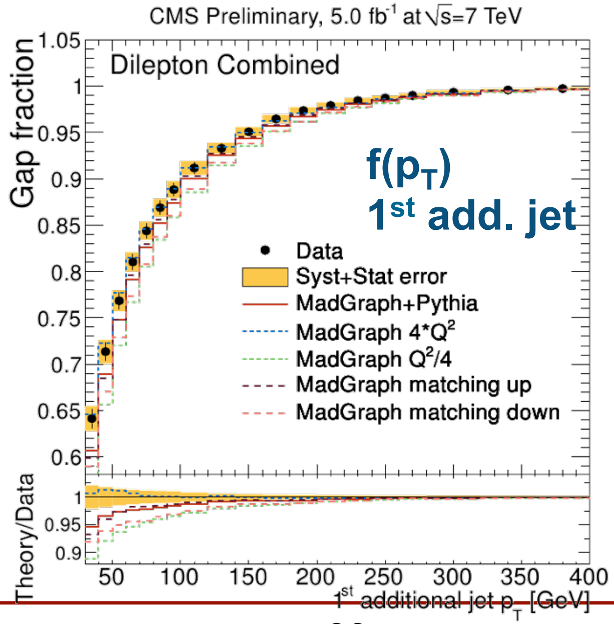
- Gap fraction vs. different generators:
  - General good agreement between data and predictions for the full η range

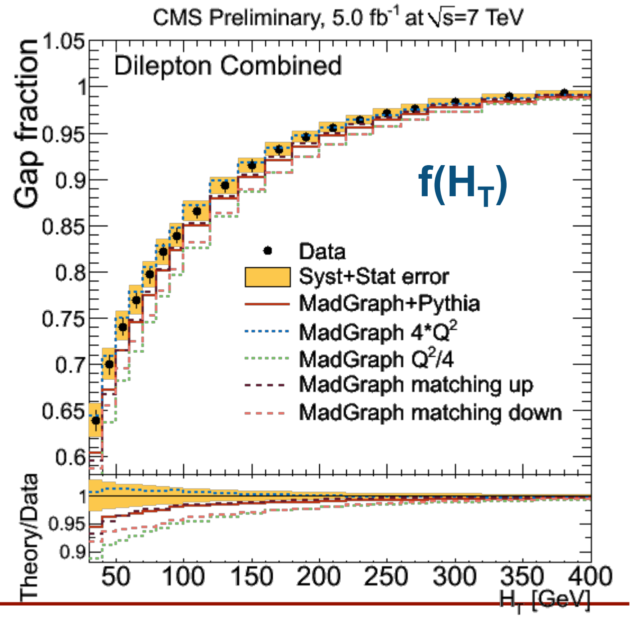
- Gap fraction vs. MadGraph varied scales:
  - Higher Q^2 seems to describe data better
  - Experimental precision smaller than spread due to parameter variation

    → variations could be significantly reduced









More info: $t\bar{t}$ + W/Z

arXiv:1303.3239 → PRL
ATLAS-CONF-2012-126

- **CMS**:

- Trilepton evts. from ttZ

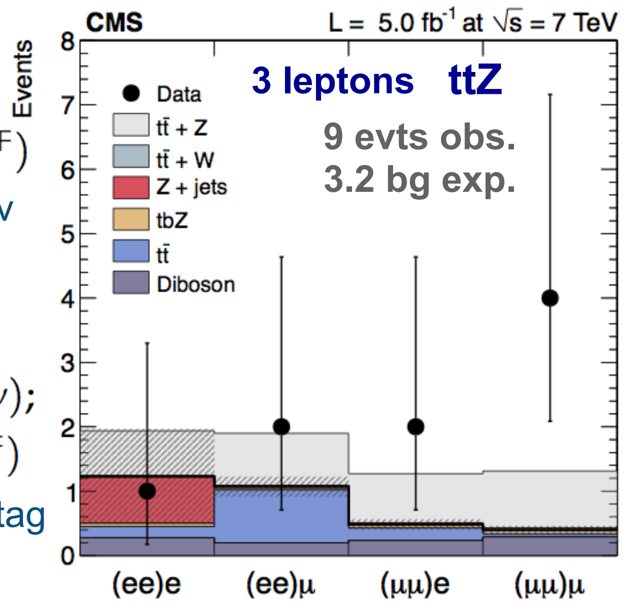
$$t\bar{t}Z \to (t \to b\ell^{\pm}\nu)(t \to bjj)(Z \to \ell^{\pm}\ell^{\mp})$$

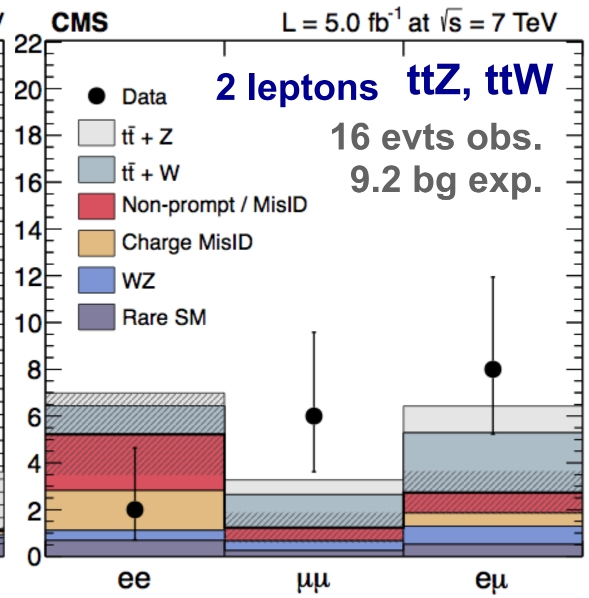
3 μ/e (p_T > 20, 20, 10), 2 OS same-flav
≥ 3 jets, ≥ 2 b-tags ; H_T > 120 GeV

- SS dileptons from ttV (V=W,Z)

$$t\bar{t}W \to (t \to b\ell^{\pm}\nu)(t \to bjj)(W \to \ell^{\pm}\nu);$$
$$t\bar{t}Z \to (t \to b\ell^{\pm}\nu)(t \to bjj)(Z \to \ell^{\pm}\ell^{\mp})$$

2 μ/e (p_T > 55, 30) SS, ≥ 3 jets, ≥ 1 b-tag
H_T > 100 GeV





- **ATLAS**: Trilepton evts from ttZ

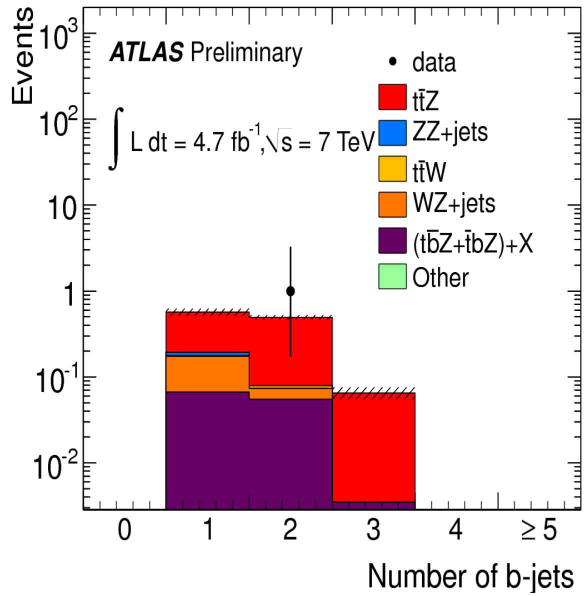
Harder selection than CMS

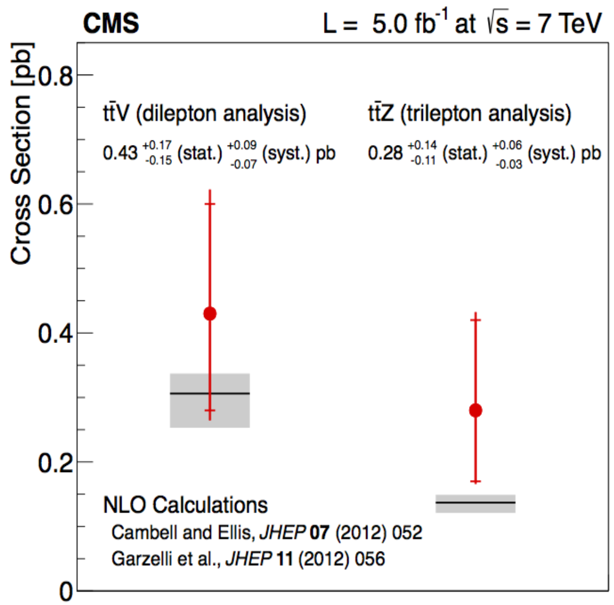
3 μ/(e) p_T > 20 (25), 2 OS same-flav
≥ 4 jets, ≥ 1 b-tag ; E_T^{miss} > 30 GeV

Upper limit on
σ(ttZ) < 0.71 pb @ 95% CL

0.74 pb expected

Consistent with SM σ = 0.14 pb





Towards a definition of top quark at particle level

- A distinctive property of the top quark is that it decays before hadronisation
- Nevertheless, the measurements of the top quark cross-section in a visible phase space is defined by parton-level quantities
- Extrapolation to the these quantities is thus inherently model and scheme dependent
- Common effort between ATLAS, CMS and theory to come up with a unified experimental top quark definition at particle level

- Select events at particle level consistent with the top quark lepton + jets final state:
  - 1 lepton, ≥4 jets ($p_T > 25$ GeV $|\eta| < 2.5$), 2 of which must be matched to b-hadrons.
- Then build pseudo-top quark vectors from simple algorithm:
  - Hadronic W boson from two jets closest in ΔR.
  - Leptonic W boson from lepton and sum of neutrinos.
  - Build hadronic top from hadronic W boson and b-jet combination which best matches the top mass.
  - Leptonic top then built from leptonic W boson plus remaining b-jet.
- Major difference to 'traditional' top reconstruction - no attempt to correct back to parton level.
- Definition very close to objects measured in detector - good candidate for unfolded measurements at hadron level.

First proposal by ATLAS for top quark in the l+jets final state

(open TOPLHC working group meeting Nov12, slide from M. Owen)