Top-quark production at LHC

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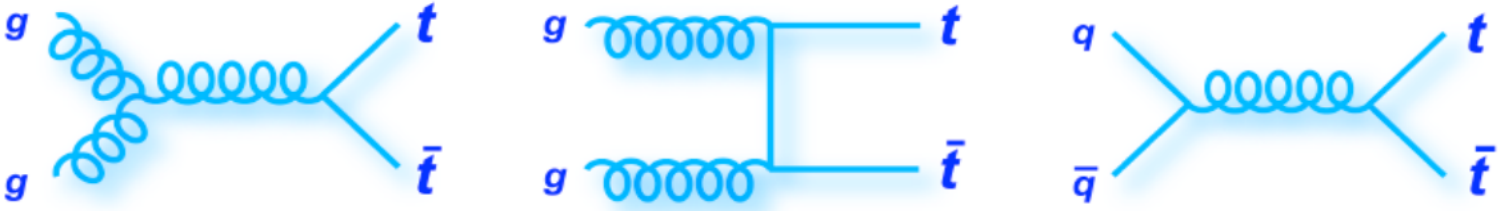
27th Rencontres de Blois on "Particle Physics and Cosmology"

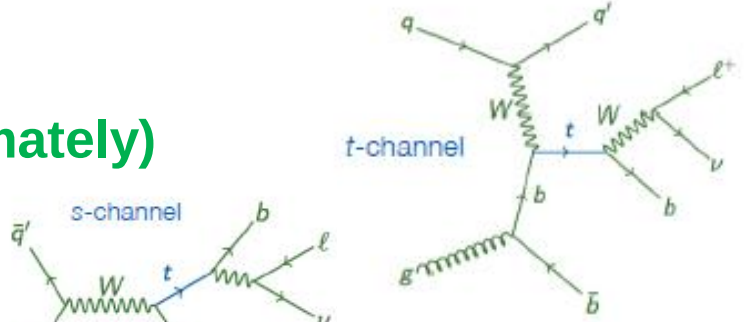
Blois 2/6/2015

Top quark(s) production

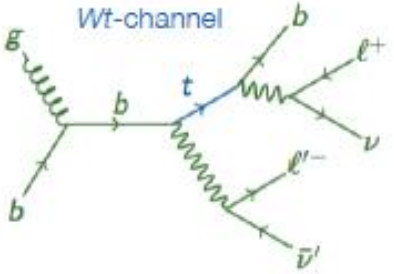
- **Top pair** production at the LHC through gg (**>84%**) and qq

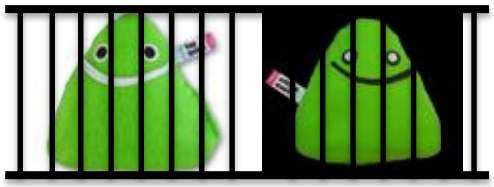


- **Single-top** production (at LO)
  - **t-, s-channel** and **Wt production,**
- **LHC Run 1**: **per experiment (approximately)**
  - **6M** top-quark pair events (1/second)
  - **2M** t-channel single-top events
  - **150k** s-channel single-top events
  - **3k** tt+Higgs
  - **20** tttt

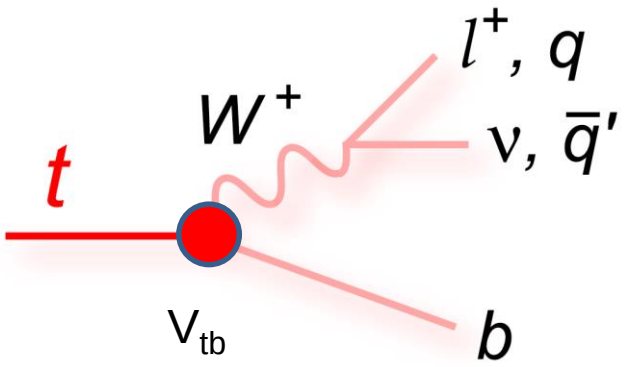


- Sensitive to **new physics** & **test** of perturbative **QCD**
- Can constrain **modeling** (PDF, ISR/FSR)
- Important **background** to many Higgs and BSM searches

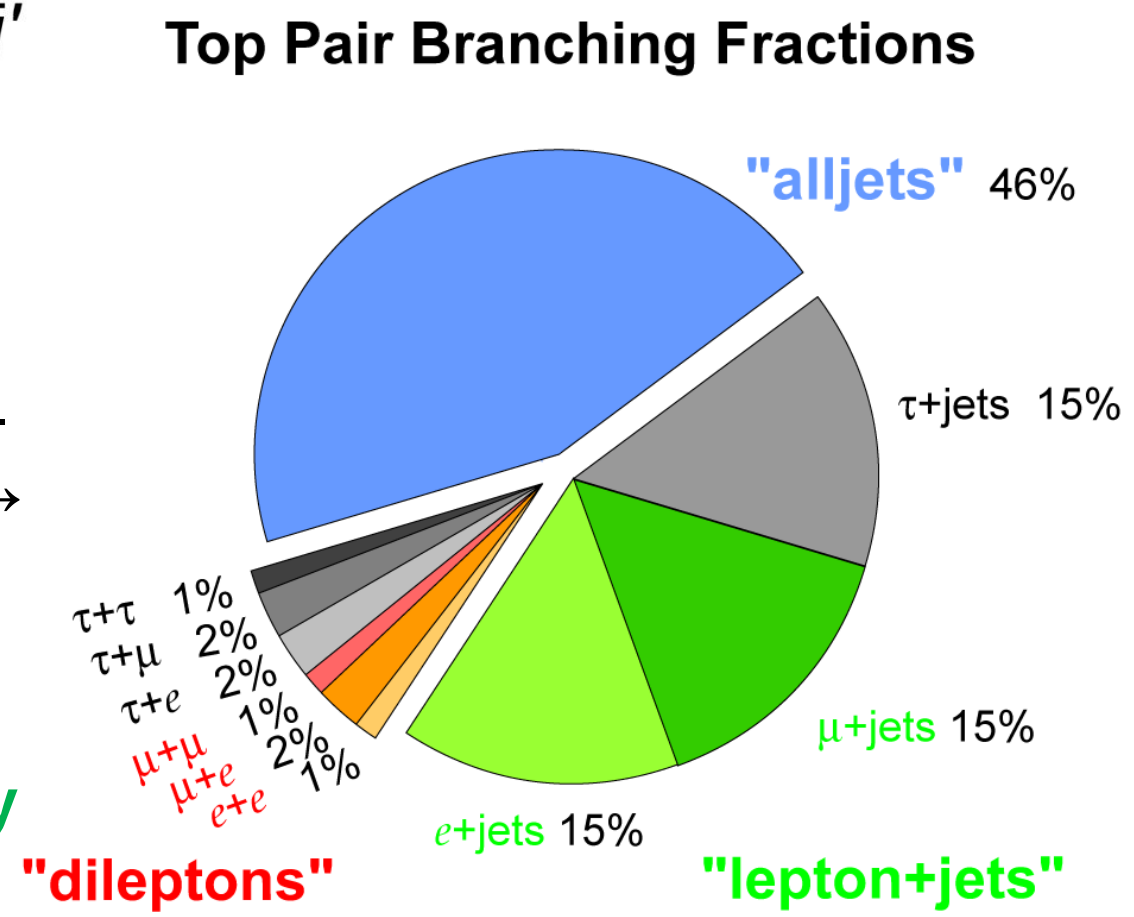




Top quark decay



t→Wb, W→jets or lepton + *v*

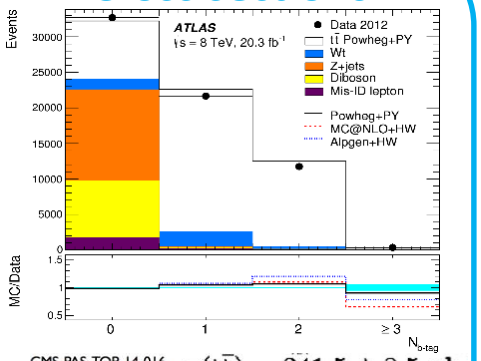


- Decays ~100% to W-boson and b-quark → $|V_{tb}|$ ~ unity
- Final state topology depends on **W decay**

Learning about top quark

- **ATLAS** TOP Public Page:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
- **CMS** TOP Public Page:
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP
- Every topic deserves a dedicated long presentation:

Cross sections



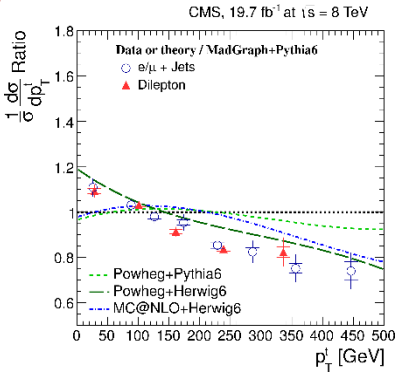
CMS-PAS-TOP-14-016 / ATLAS-CONF-2014-054 $\sigma(t\bar{t}) = 241.5 \pm 8.5$ pb

CMS-PAS-TOP-12-002 / ATLAS-CONF-2013-098 $\sigma(t - ch) = 85 \pm 12$ pb

CMS-PAS-TOP-14-009 / ATLAS-CONF-2014-038 $\sigma(tW) = 25.0 \pm 4.7$ pb

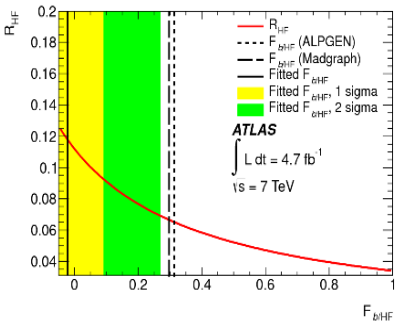
CMS-PAS-TOP-13-009 / arXiv:1410.0647 $\sigma(s - ch) < 11.5$ pb

Differential



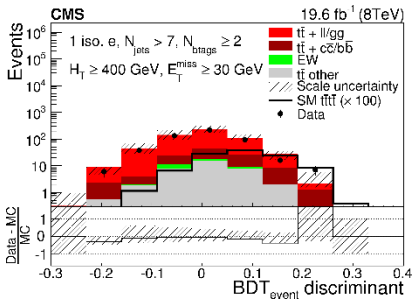
Phys. Rev. D 90, 072004
CMS PAS TOP-14-004
CMS PAS TOP-12-042
arXiv:1505.04480

tt + cc/bb



CMS PAS TOP-12-024
PLB 746 (2015) 132
Phys.Rev. D89 (2014) 072012
arXiv:1411.5621

tttt



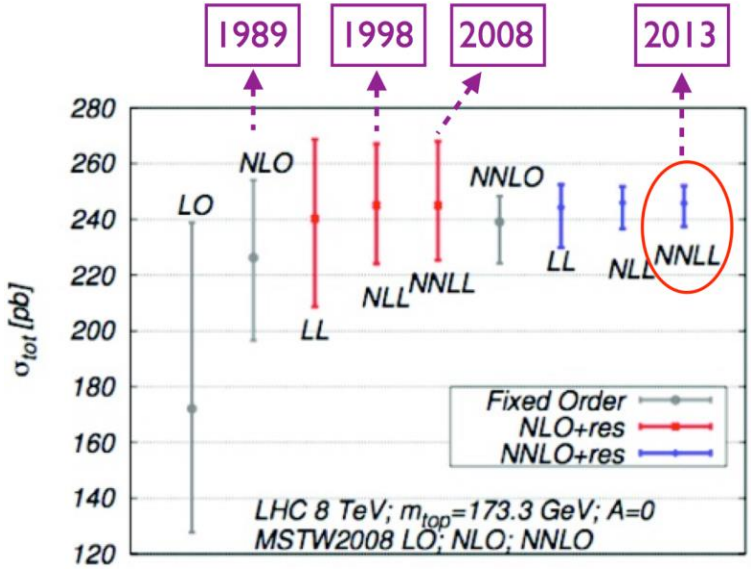
JHEP 11 (2014) 154
ATLAS-CONF-2012-130
arXiv:1505.04306

tt+V (V=γ,W,Z) covered in next talk by Kelly Beernaert

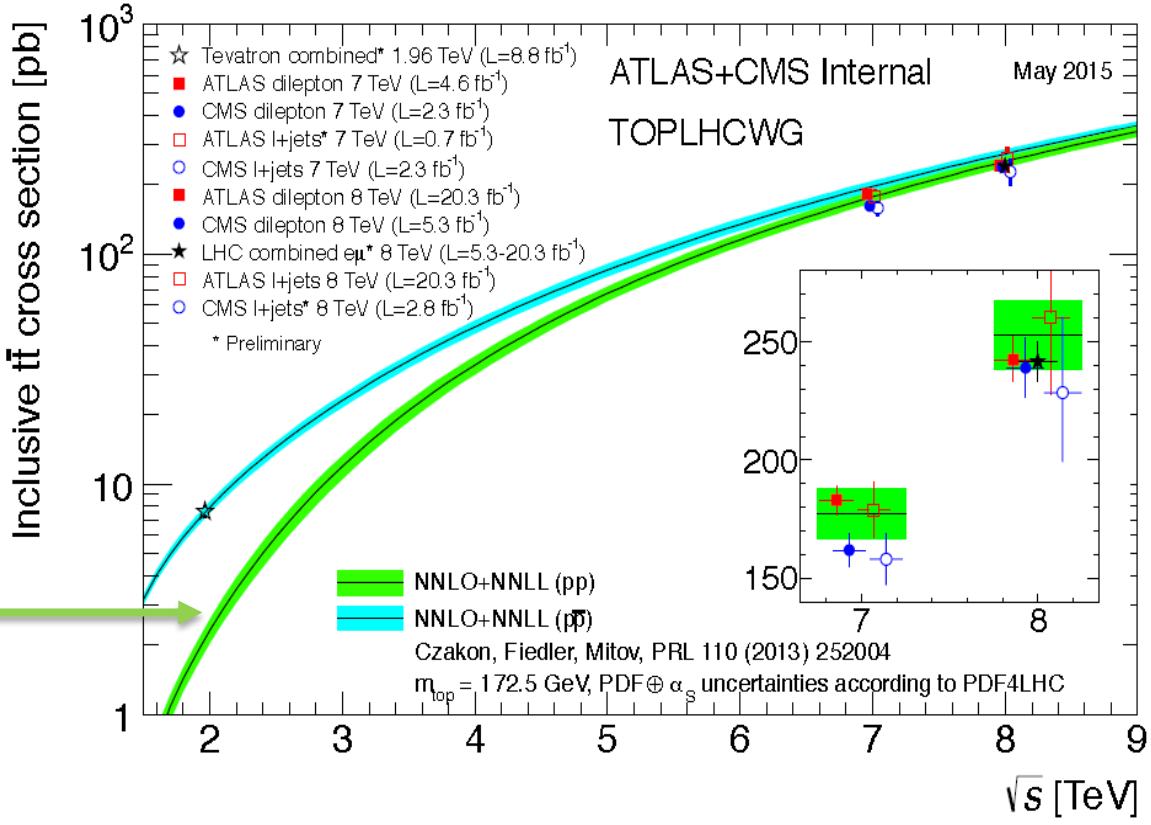
Inclusive measurements

Inclusive top-pair production: Summary

- **Excellent progress both on the theory and experiment sides!**



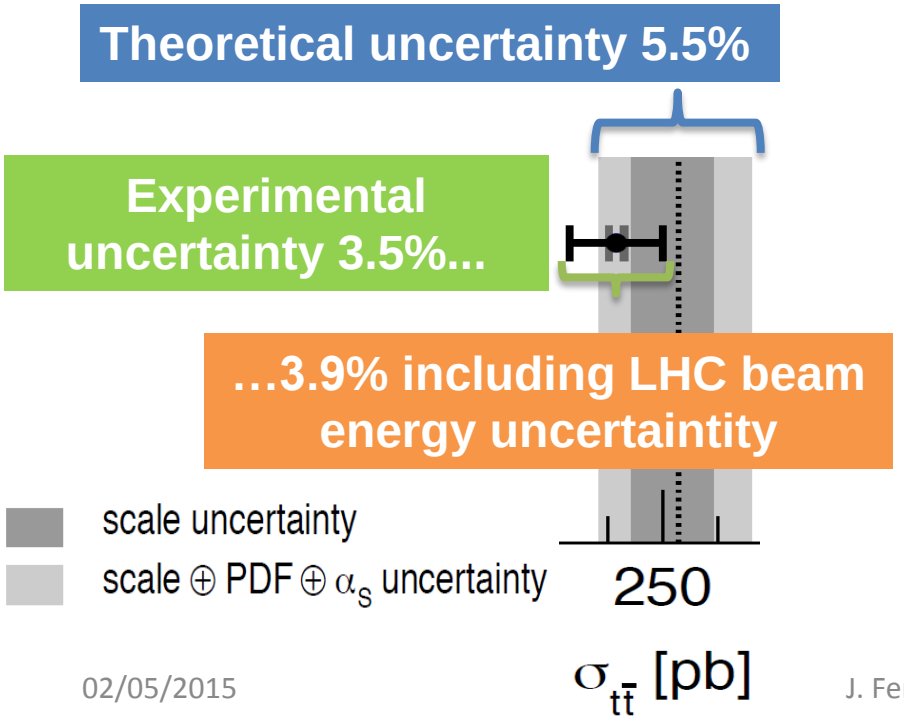
LHC WG :
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/TopLHCWG

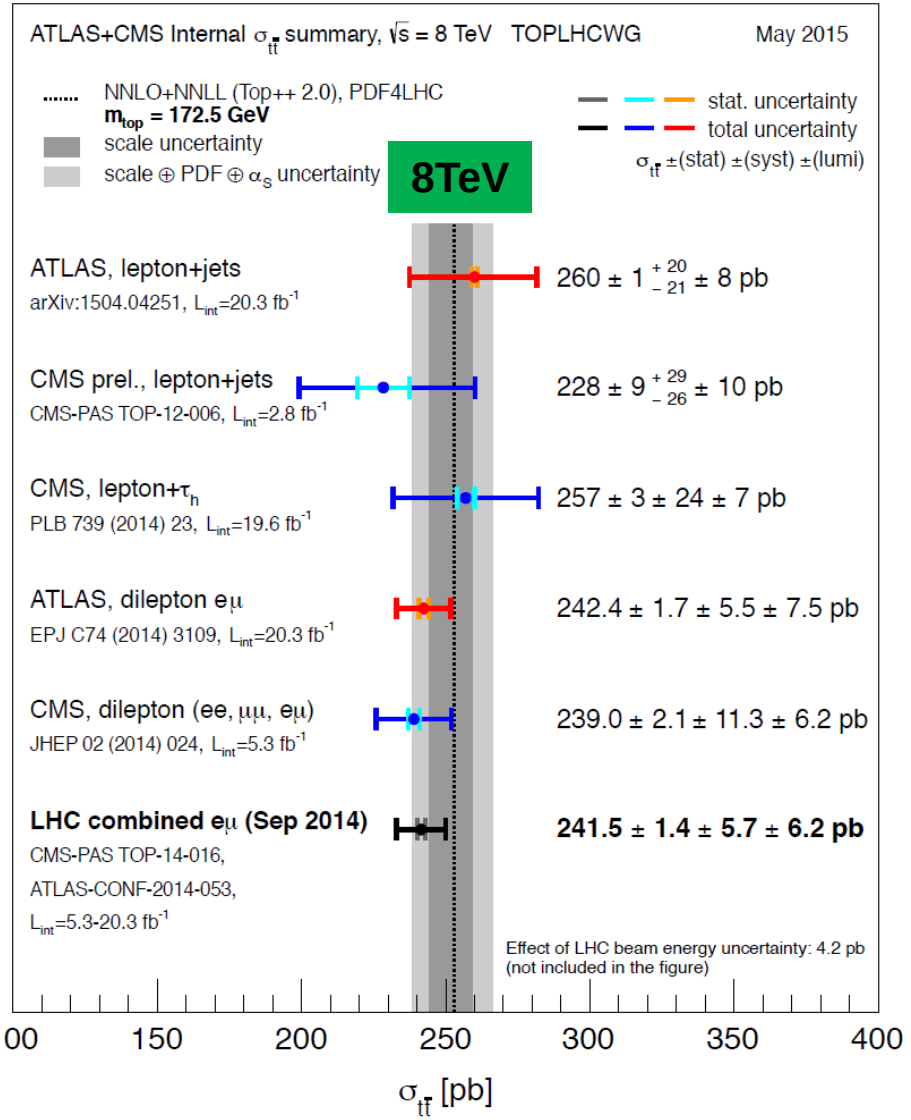


Theory band represents uncertainties due to **renormalisation** and **factorisation** scale, **parton density functions** and the **strong coupling**

Top pair inclusive cross section

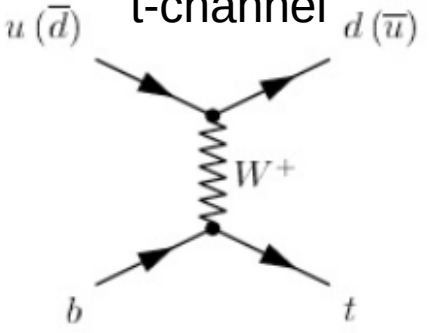
- Very precise QCD prediction to NNLO with NNLL corrections available since 2013
- All measurements are systematics limited
- Best results from dilepton analyses
- All measurements agree with predictions
- Experimental uncertainties challenge theoretical ones!



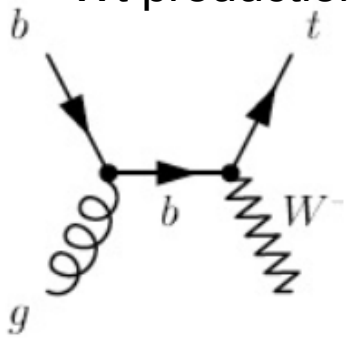


Single top inclusive production

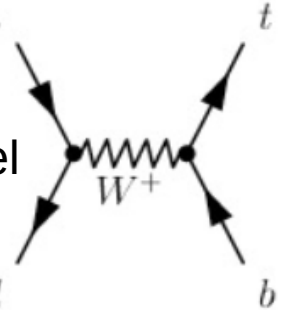
t-channel

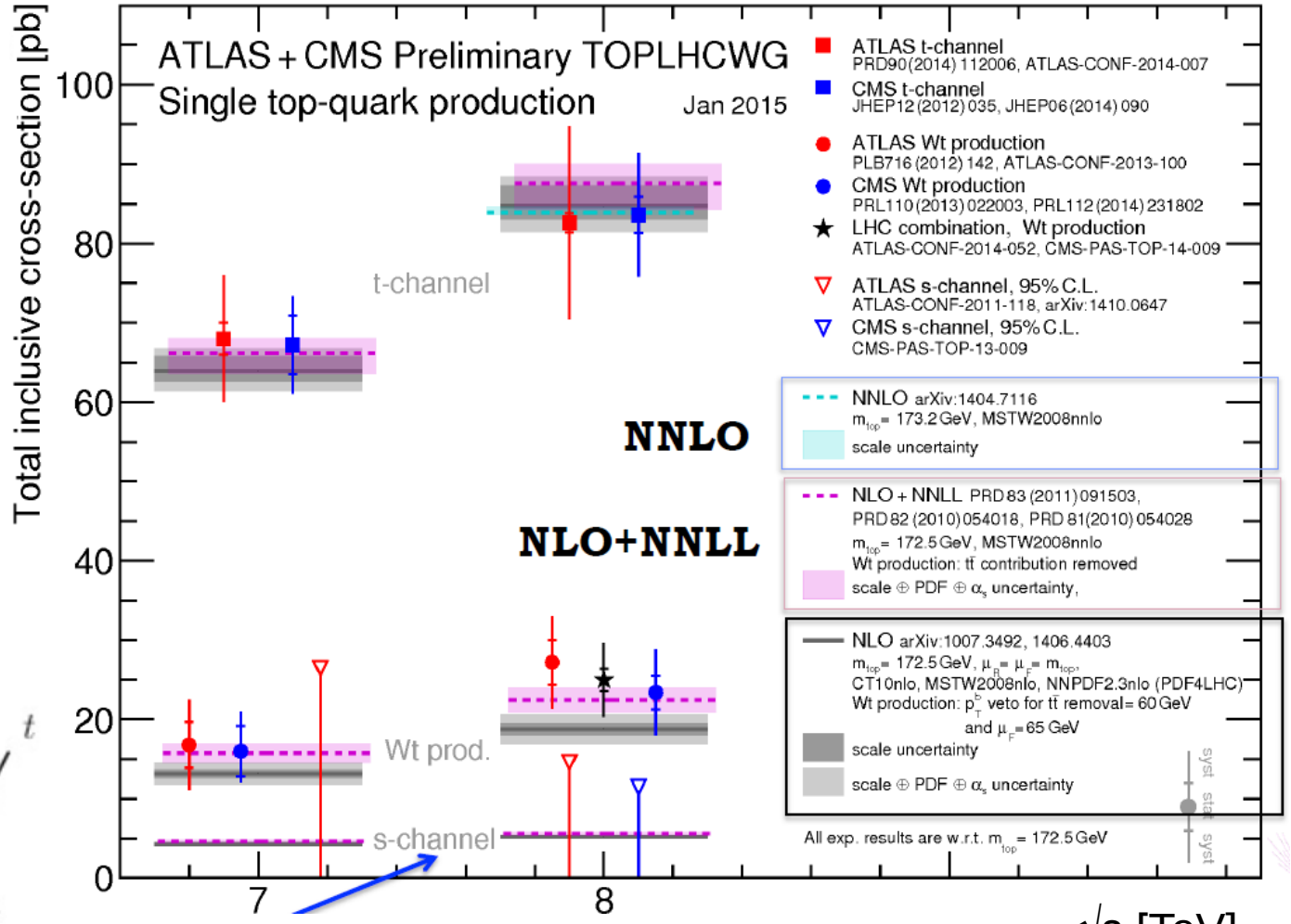


Wt production



s-channel





Upper limits

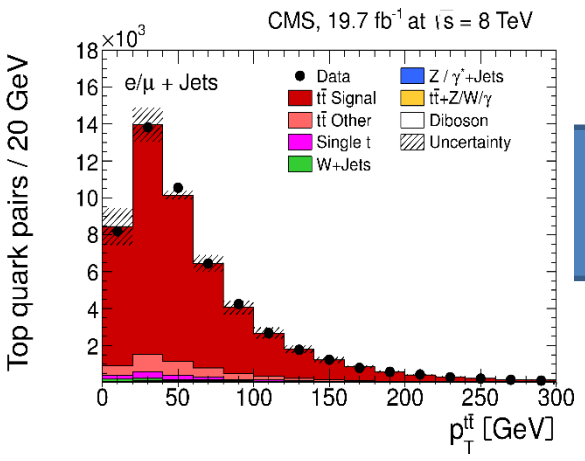
Different processes sensitive to new physics

Differential measurements

Top pair differential measurement

- Differential cross sections **as a function of top and top decay product kinematics**
  - Measurements performed in both fiducial (visible) and full phase space
  - Probe perturbative QCD, test and tune MC models with measurements
- **Top quark full kinematic reconstruction necessary and background subtraction**
- Unfolding techniques used (correcting bin to bin migration):
  - Account for acceptance and detector effects (resolution, efficiency, etc.)
  - Correct observed distributions to particle or parton-level
  - Compare with generators and/or calculations to unfolded data distribution

Kin. Reconstruction



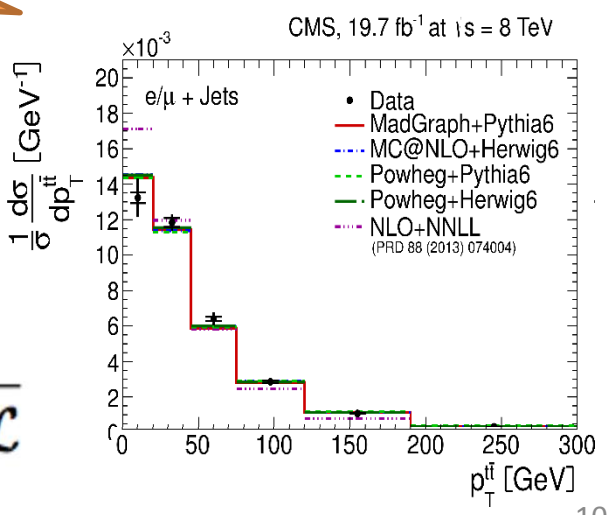
Example for l+jets @8TeV arXiv:1505.04480

new

- Background subtraction
- Unfolding

$$\frac{1}{\sigma}\frac{d\sigma_i}{dX} = \frac{1}{\sigma}\frac{x_i}{\Delta_i^X \mathcal{L}}$$

Diff. cross section



Top pair differential measurement

Fiducial (a.k.a. visible) **particle-level** differential cross-section:

- Experimentally directly accessible region
- Correct for detector response only (resolutions and efficiency)
- Minimally model dependent

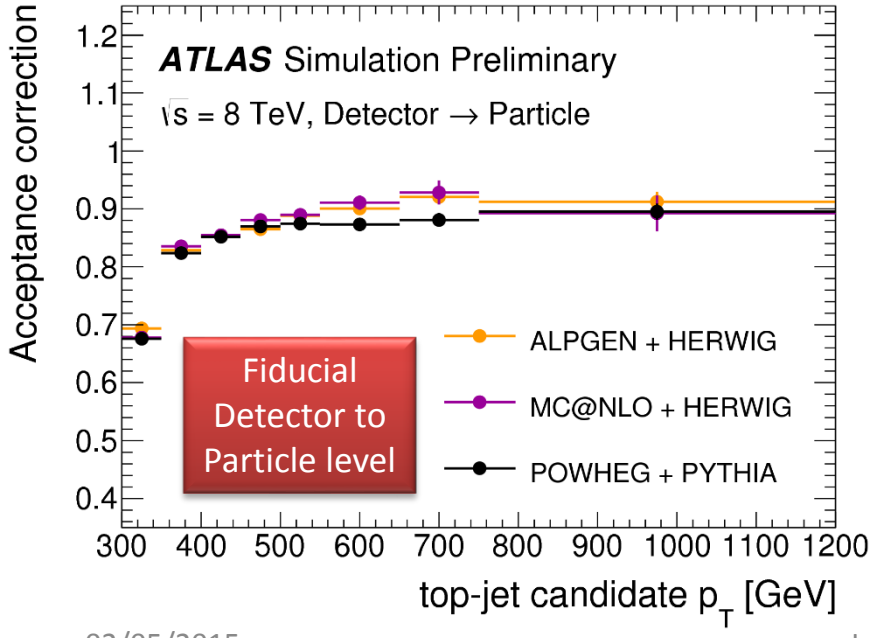
Full phase-space extrapolation:

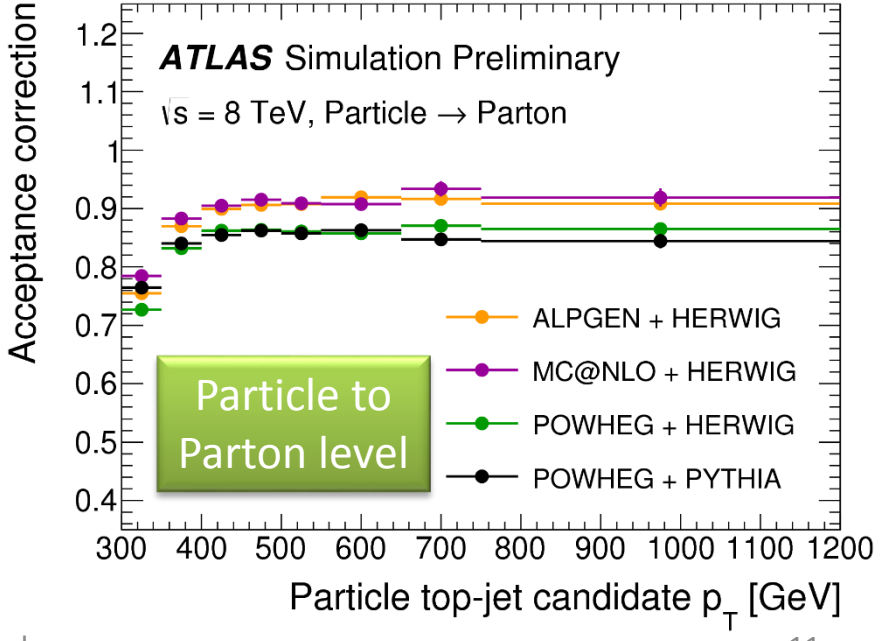
- Model dependent

Full phase-space parton-level:

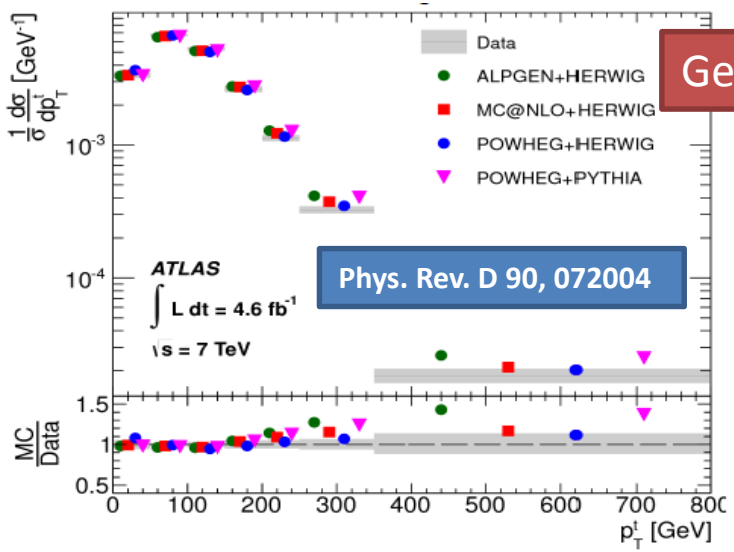
- Remove hadronization effects
- Model dependent

ATLAS-CONF-2014-057



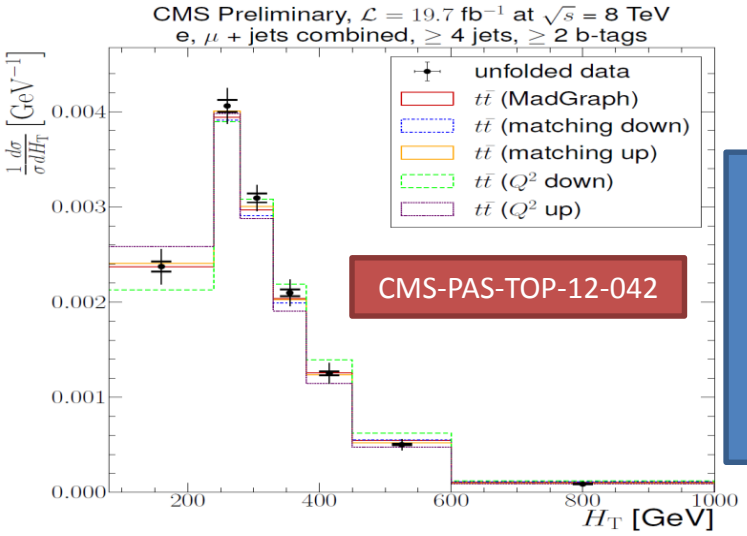


Top pair differential measurement tests



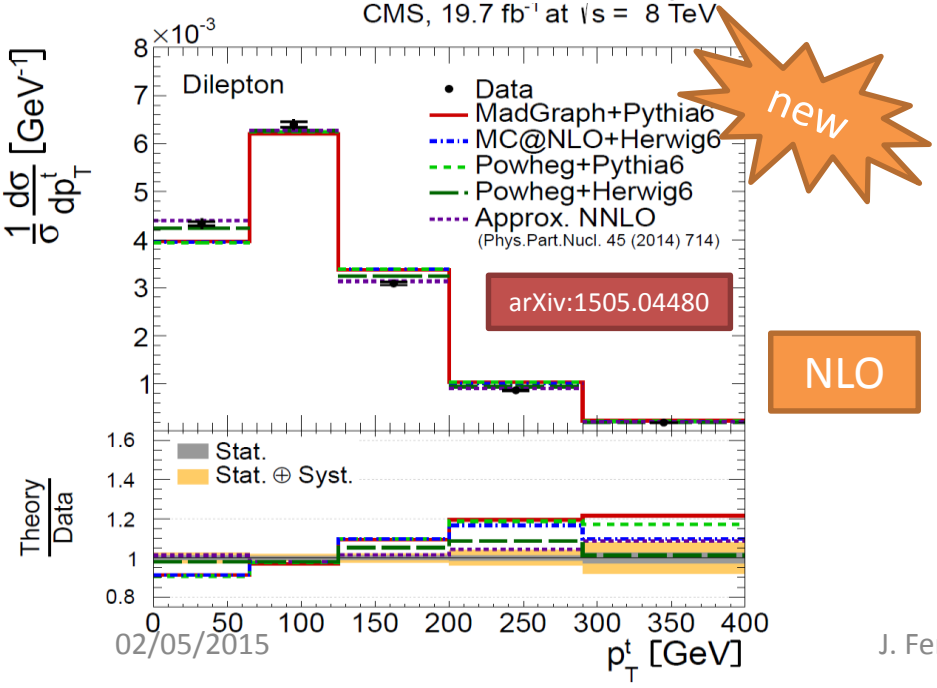
Generators

Phys. Rev. D 90, 072004



CMS-PAS-TOP-12-042

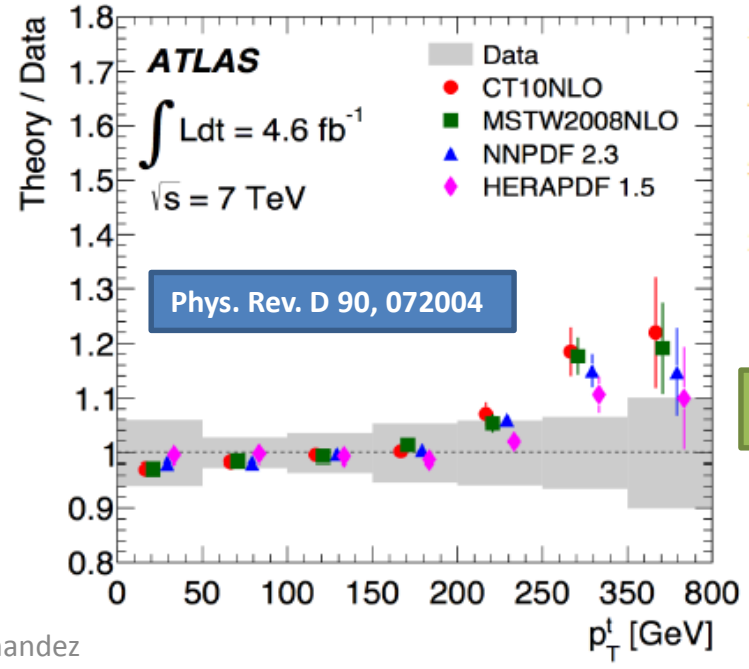
Global event variables and syst. shifts



new

arXiv:1505.04480

NLO

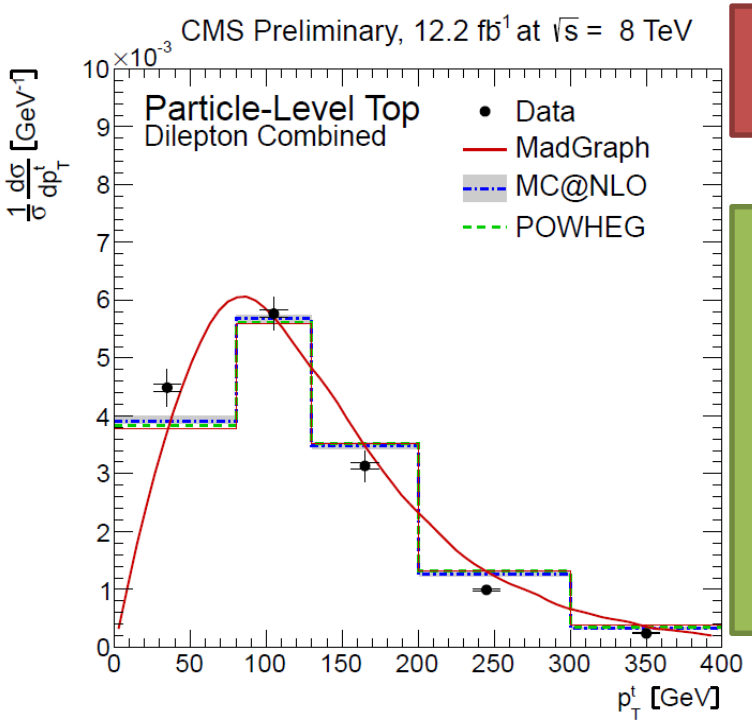


Phys. Rev. D 90, 072004

PDFs

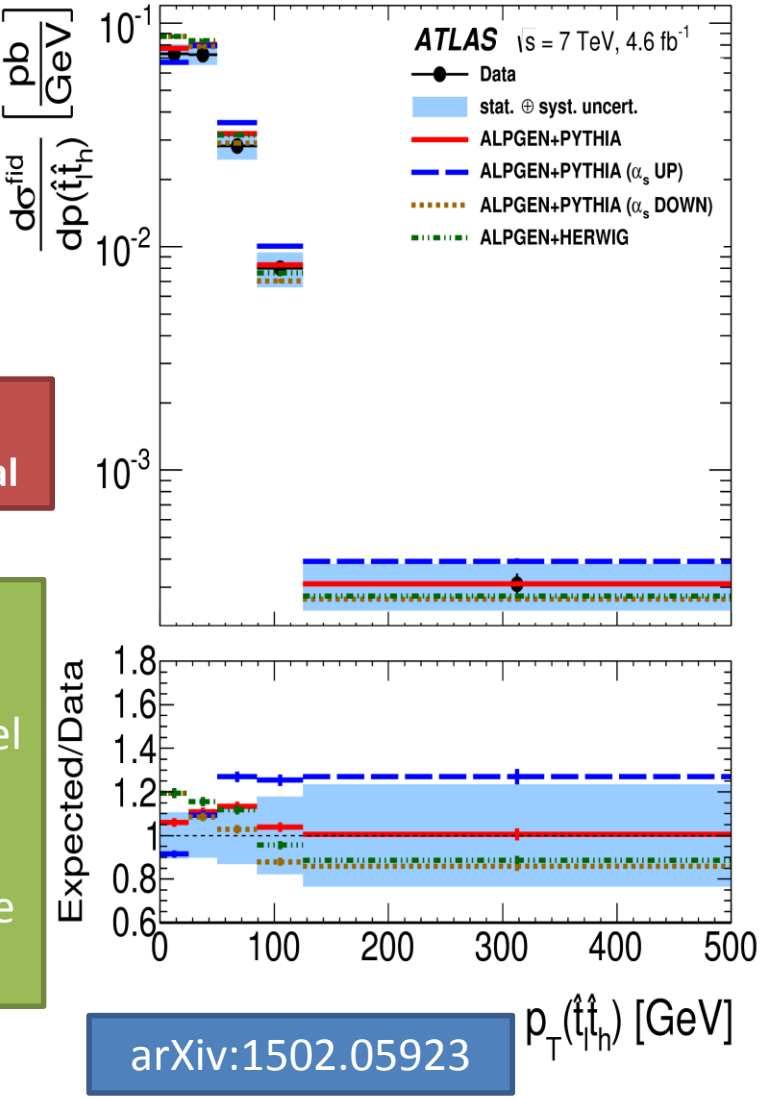
Top pair differential: particle level

- top and tt at particle level built from **objects directly related to particle-level observables** (leptons, jets, ET_{miss})
- Strongly correlated with top quark at parton level, **reduced model dependence**
- Data/MC comparisons sensitive to PDF sets and models
- **Main systematics**: b-tagging, jet energy, ISR/FSR P. Shower



CMS-TOP-028
Additional material

Extending measurement from particle-level to construct top proxy (pseudo-top) from particle level objects



arXiv:1502.05923

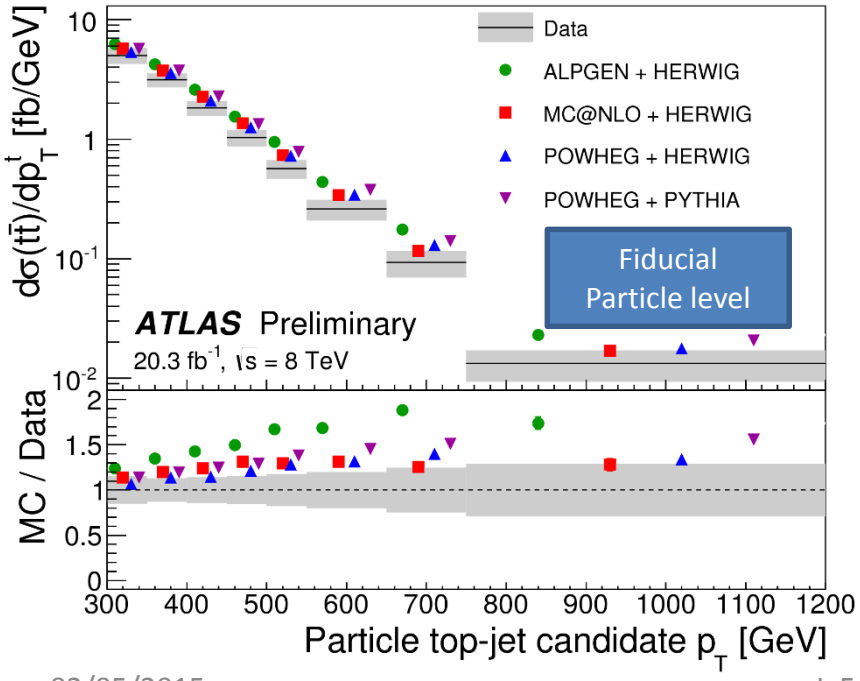
Top pair differential: boosted

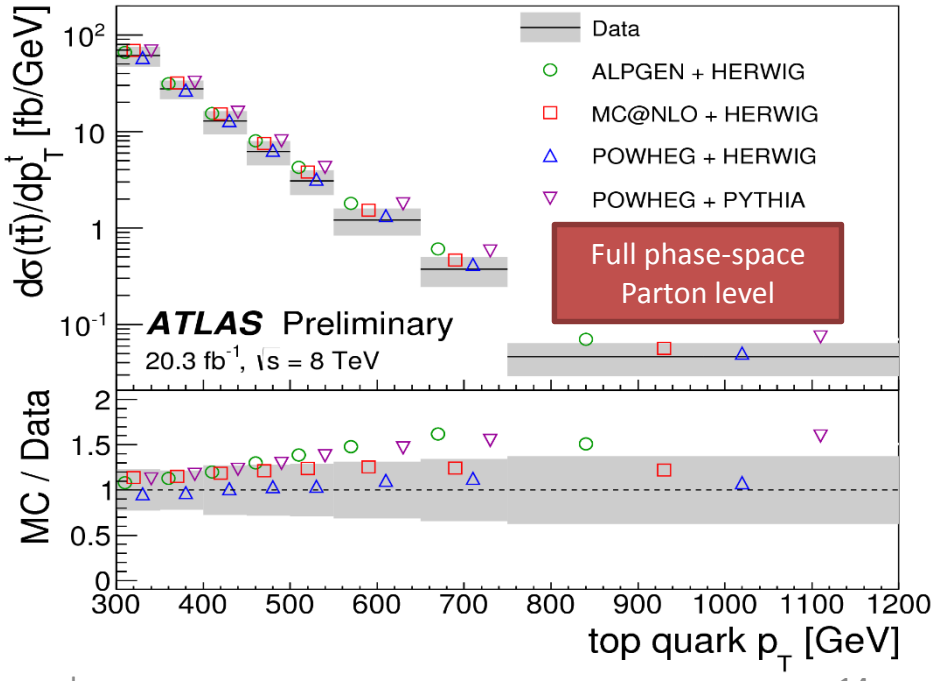
First boosted (lepton+jets) top pair differential cross-section w.r.t. hadronic top:

- top ID with jet substructure techniques
- Jet reconstruction algorithms up to TeV range
- anti-kt jet with R=1.0, $p_T^t > 300$GeV

ATLAS-CONF-2014-057

- Main systematics: **large-R jets energy scale (15-30%)**
- NLO and LO MC normalized to NNLO+NNLL QCD predictions **overestimate data** (at higher pT). Better description by **Powheg+Herwig** at parton level
- Modeling uncertainty **much larger at parton level**!



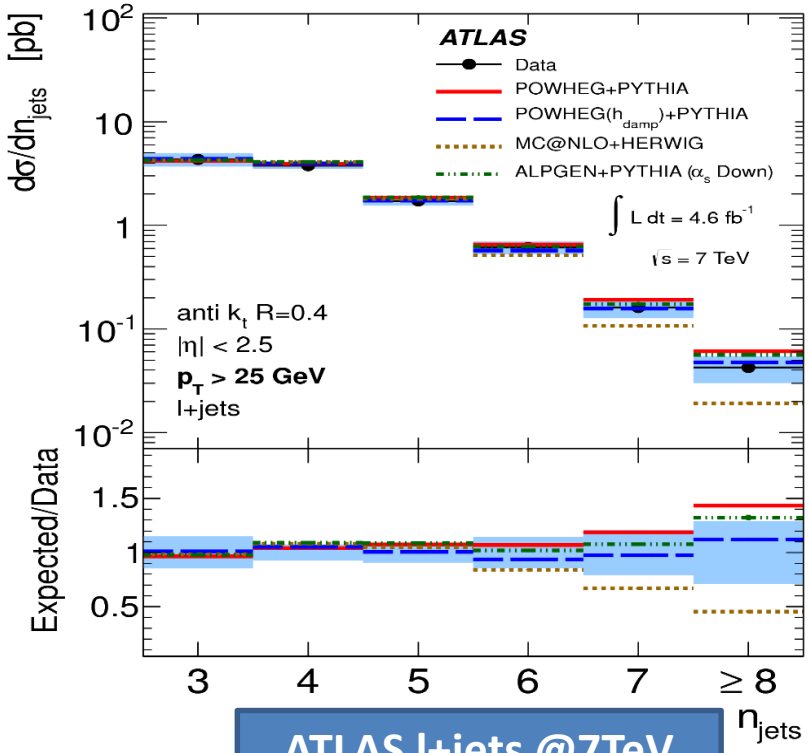


tt+jets: fiducial differential vs njets

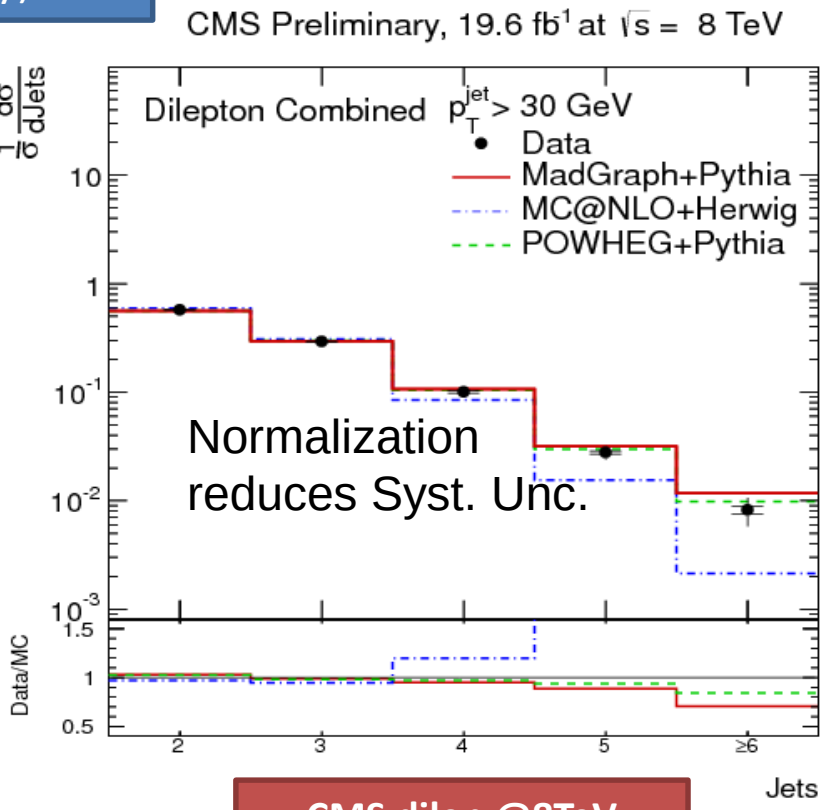
Total systematics on jet multiplicity: 10 to 30% (background modeling and jet energy scale)
- Data discriminate models and validate choice of scale
- POWHEG+PYTHIA with tuning of hard radiation

best overall description (accuracy and consistency)

MadGraph+Pythia6 showing generally good agreement with the data



ATLAS l+jets @7TeV
JHEP01(2015)020



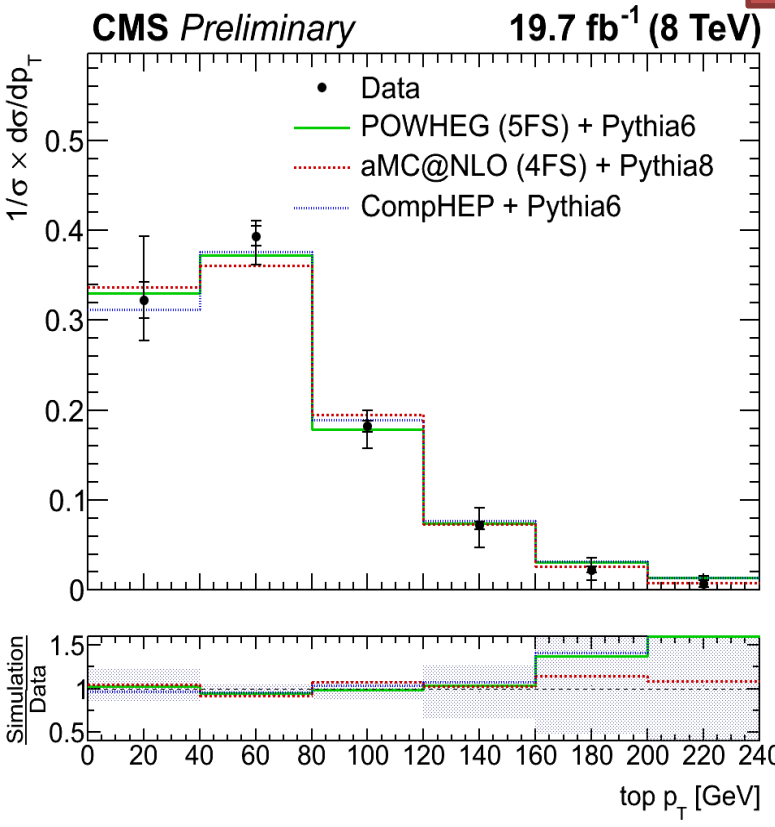
CMS dilep @8TeV
CMS-PAS-TOP-12-041

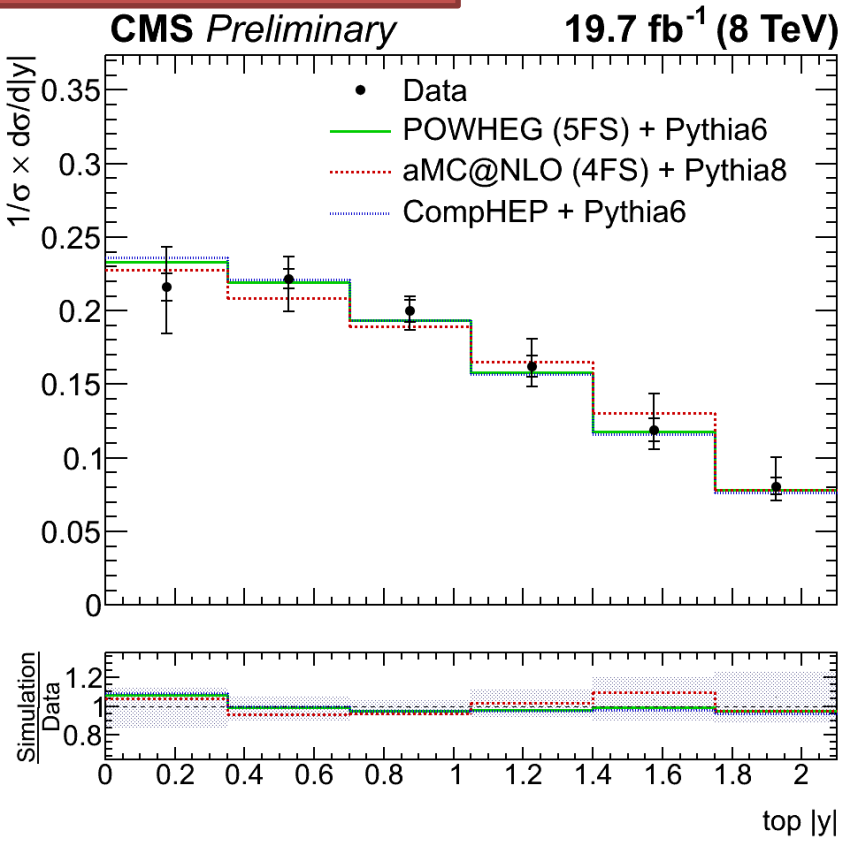
Single top t-channel: differential

Differential cross sections as functions of top p_T and $|y|$. Leptonic decay channels.

- Comparison with MC after showering/had. using different modeling for b-quarks
- All three simulations describe describe the unfolded data within statistical and systematic uncertainties

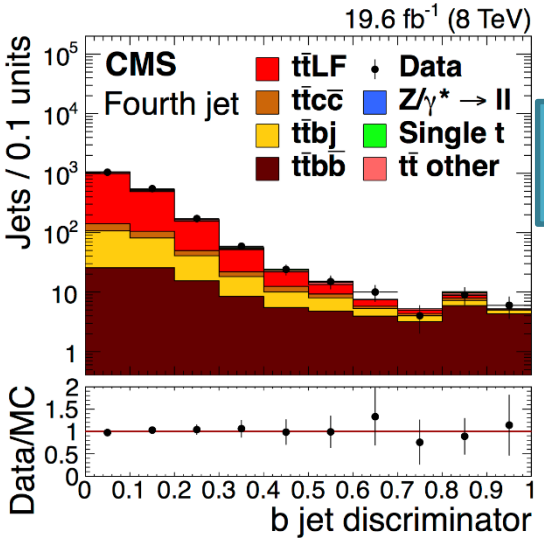
CMS-PAS-TOP-14-004



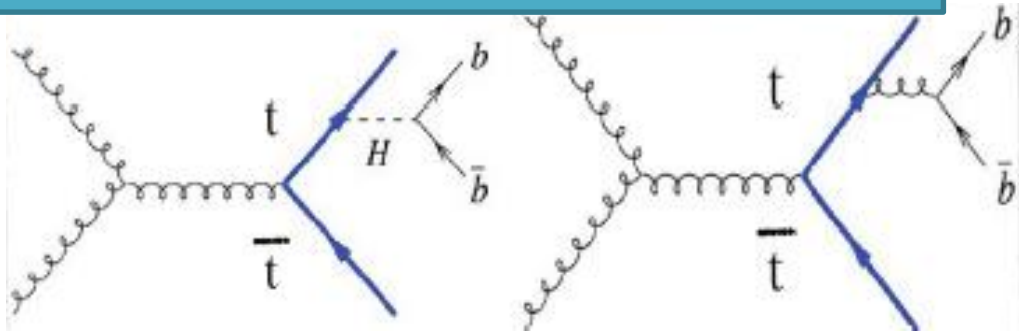


tt + cc/bb

tt+cc/bb



Main background in the search for ttH and as a figure of merit for testing the validity of NLO QCD calculations



Dilepton ATLAS@7TeV 2D fit: (jet pT, vertex mass)

Phys.Rev. D89 (2014) 072012

ALPGEN+HERWIG = 3.4%

POWHEG+HERWIG = 5.2%

$$R_{HF} = \frac{\sigma(t\bar{t}+b+X \; or \; t\bar{t}+c+X)}{\sigma(t\bar{t}+j)} = \frac{\sigma(t\bar{t}+HF)}{\sigma(t\bar{t}+j)} = [6.2 \pm 1.1\,(stat) \pm 1.8\,(syst)]\%$$

Dilepton CMS@8TeV Fit to b-tag discriminator on signal+background categories.

PLB 746 (2015) 132

$$\frac{\sigma(t\bar{t}b\bar{b})}{\sigma(t\bar{t}jj)} = 0.022 \pm 0.004\,(stat) \pm 0.005\,(syst) at\ Jet\ p_T > 40GeV$$

$$\frac{\sigma(t\bar{t}b\bar{b})}{\sigma(t\bar{t}jj)}(NLO\ QCD) = 0.011 \pm 0.003$$

MADGRAPH+PYTHIA=0.013 ± 0.002

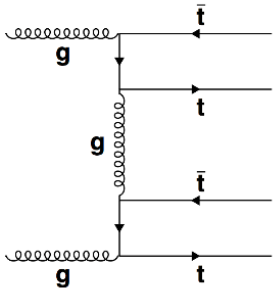
POWHEG+PYTHIA =0.014 ± 0.002

NLO predictions and MCs systematically lower than observed ratios

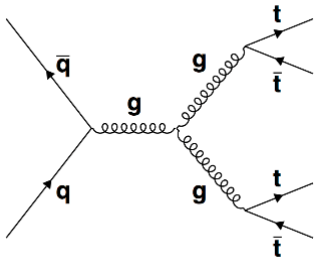
Dominant systematic: mistag efficiency

tttt

tttt



- σ(tttt) SM ≈ 1 fb @ 8 TeV (MG)
- Many BSM models predict enhancement of this cross section (SUSY squark/gluino decays)
- Will be of interest for Run 2:
  - cross section ~9-15 times larger



No significant excess observed over SM expectations

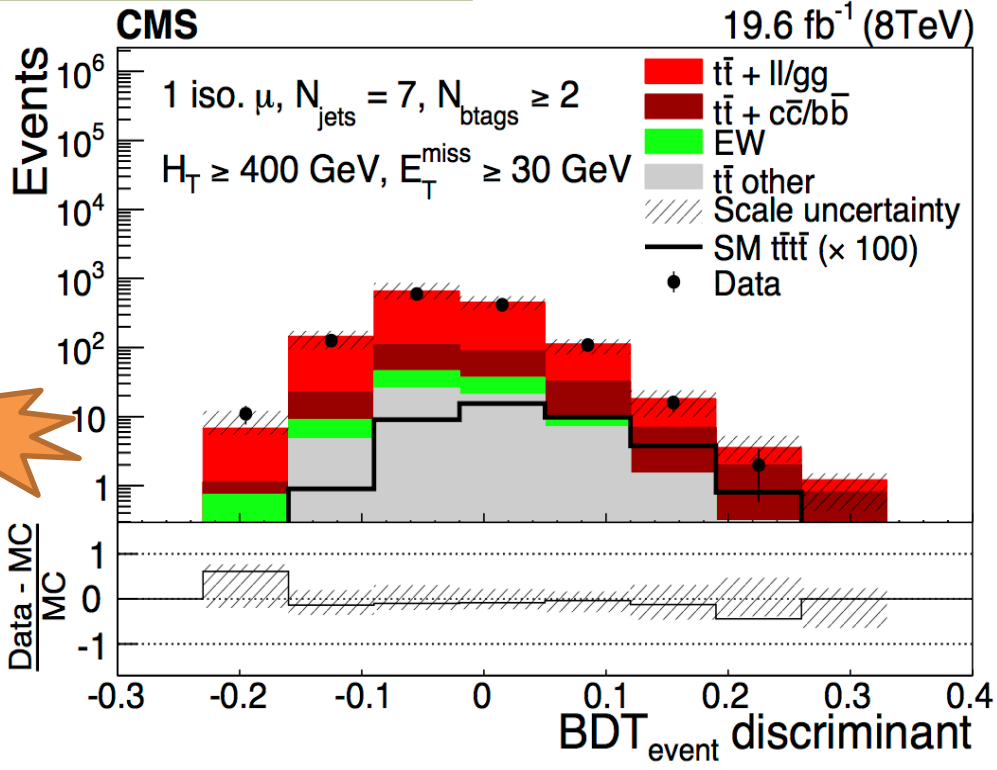
CMS 8TeV result (dilepton)
Cross section limit:
- Observed: 32 fb (25 x SM)
- Expected: 32 ± 17 fb

JHEP 11 (2014) 154

new

ATLAS 8TeV result (lepton+jets): the observed (expected) 95% CL upper limit on the production cross section is 34 (47) times the SM prediction, or 23 fb (32 fb)

arXiv:1505.04306



Conclusions/Summary

- **Rich and mature top physics program @ Run 1**
  - Single top measured (upper limit in s-channel)
  - Inclusive and differential cross sections
  - Study of four-top & tt+HF production
- **Precise and extended** cross section :
  - **Theoretical calculations challenged by precision of experimental data (in a hadronic collider)**
- Top community eager to look at LHC Run2 data

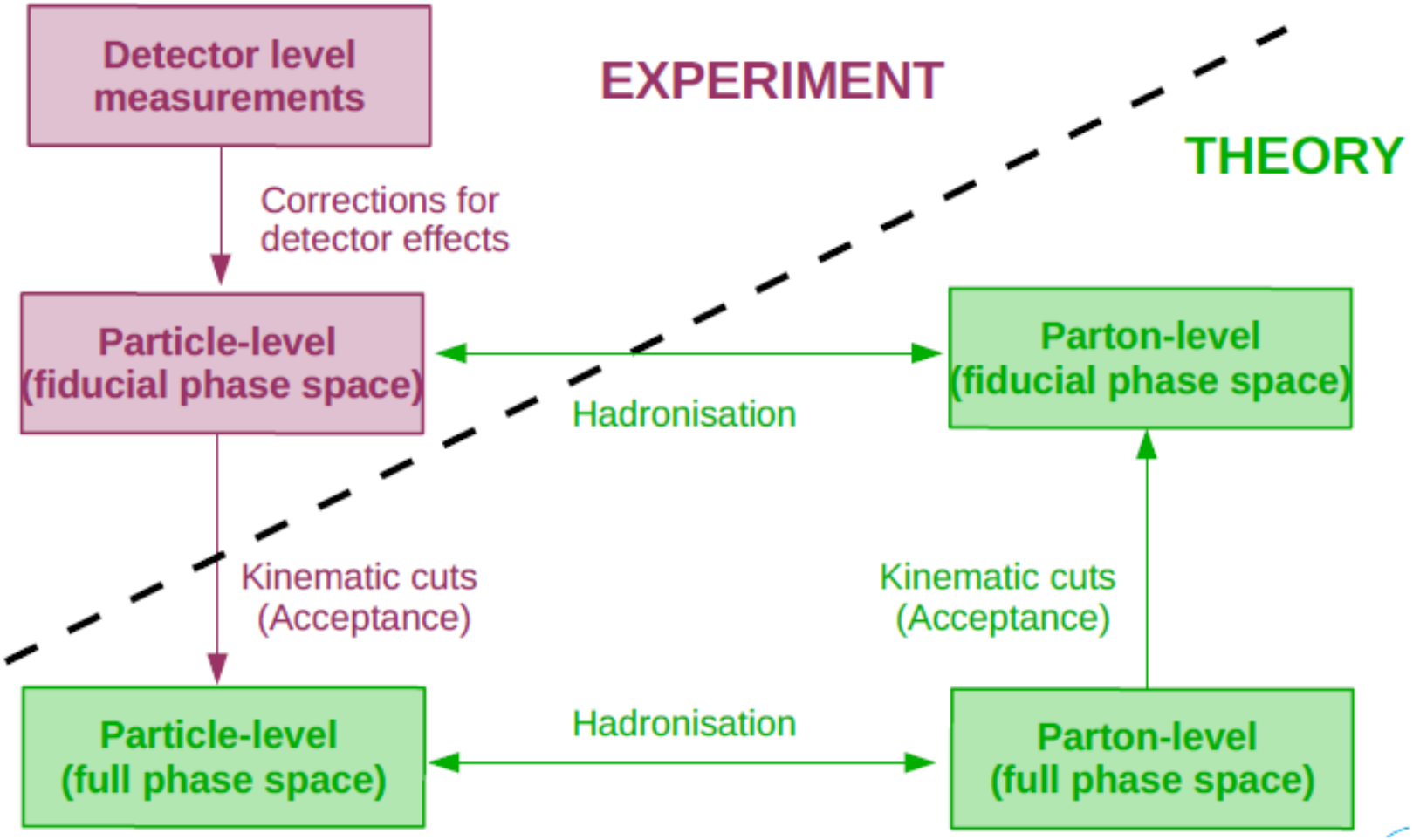
More top quarks: cross section increases by a factor ~3 !

Backup

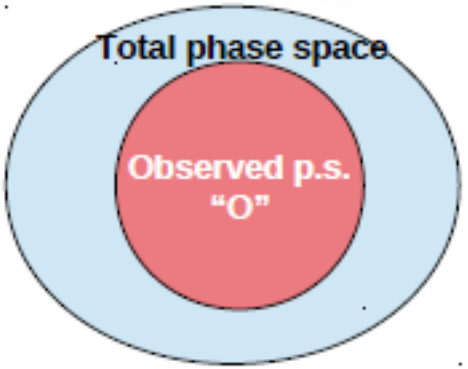
Overview of top pair differential measurements

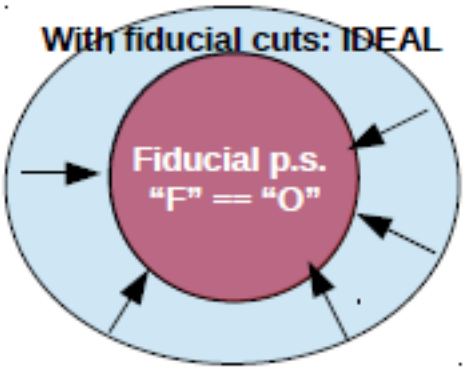
	Full phase space	Fiducial (visible) phase space
Objects	Parton-level	Particle-level
Top,tt	ATLAS(L+J) 7TeV Phys. Rev. D 90, 072004 (2014) CMS (L+J,L+L) 7TeV EPJ C73 (2013) 2339 CMS (L+J,L+L) 8TeV arXiv:1505.04480	ATLAS (L+J) 7TeV arxiv:1502.05923 CMS (L+J,L+L) 8TeV arXiv:1505.04480
Boosted top	ATLAS(L+J) 8TeV ATLAS-CONF-2014-057	ATLAS(L+J) 8TeV ATLAS-CONF-2014-057
Final state (leptons, jets)		CMS (L+J,L+L) 7TeV EPJ C73 (2013) 2339 CMS (L+J,L+L) 8TeV arXiv:1505.04480
Global event variables	CMS (L+J) 7TeV CMS-PAS-TOP-12-019 CMS (L+J) 8TeV CMS-PAS-TOP-12-042	
tt + jets	CMS (L+L) 8TeV CMS-PAS-TOP-12-041	ATLAS (L+L) 7TeV Eur. Phys. J. C72 (2012) 2043 ATLAS (L+J) 7TeV JHEP01(2015)020 ATLAS (L+J) 7TeV ATL-PHYS-PUB-2015-002 CMS (L+J,L+L) 7TeV Eur. Phys. J. C74 (2014) 3014 CMS (L+L) 8TeV CMS-PAS-TOP-12-041

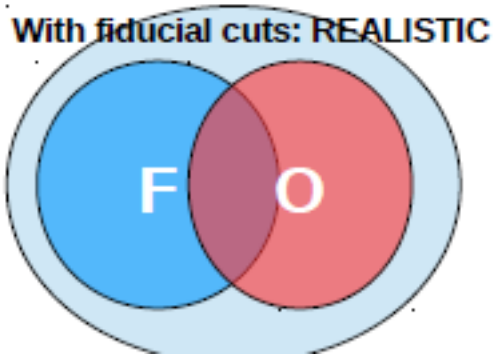
Fiducial vs Full
Particle vs Parton

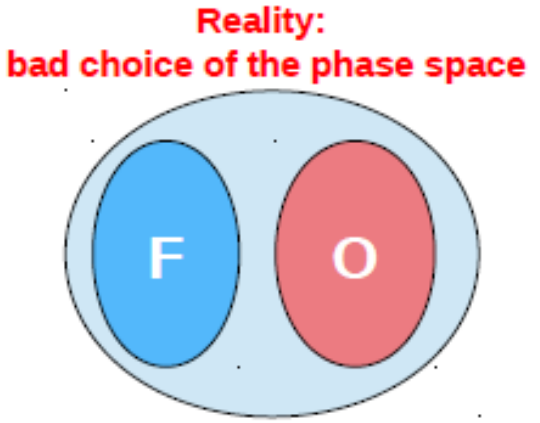


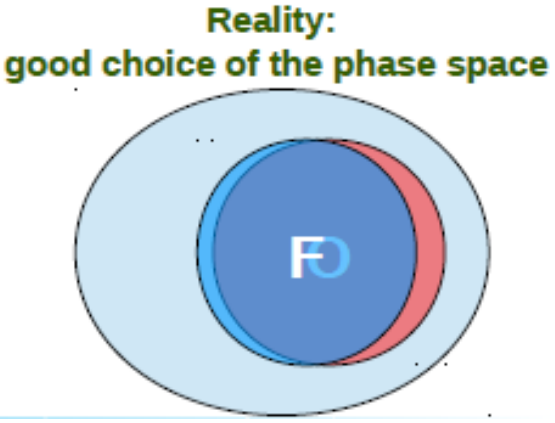
Phase space: total, fiducial, observed











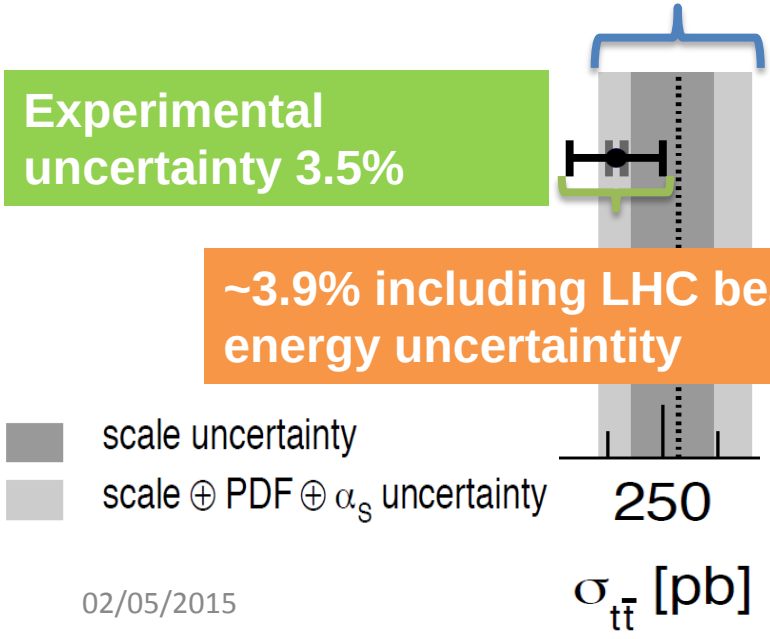
Top pair inclusive mtop=173.34

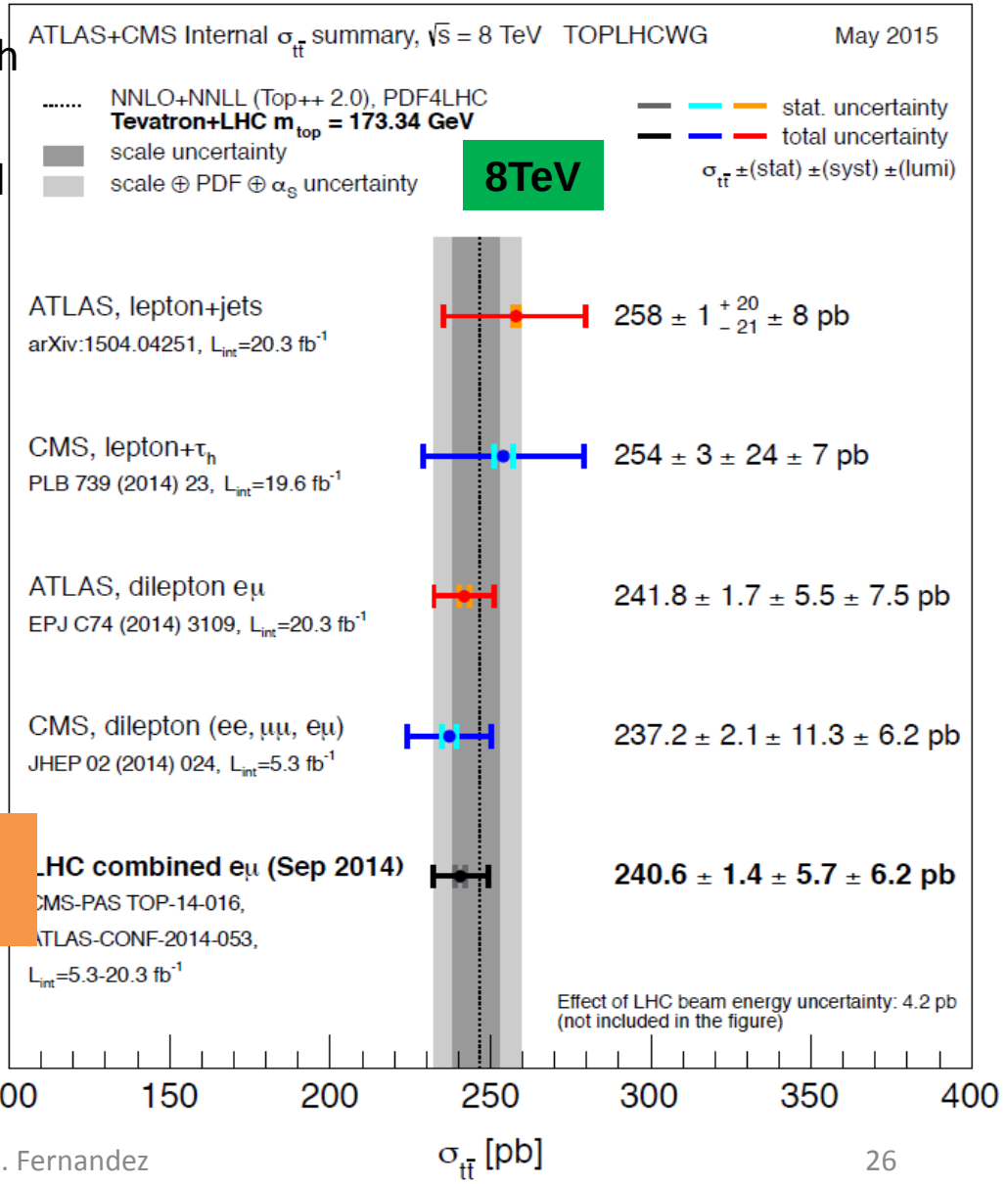
- Very precise QCD prediction to NNLO with NNLL corrections available since 2013
- All measurements are systematics limited
- Best results from dilepton analyses
- All measurements agree with predictions
- Experimental uncertainties challenge theoretical ones!

Theoretical uncertainty 5.5%

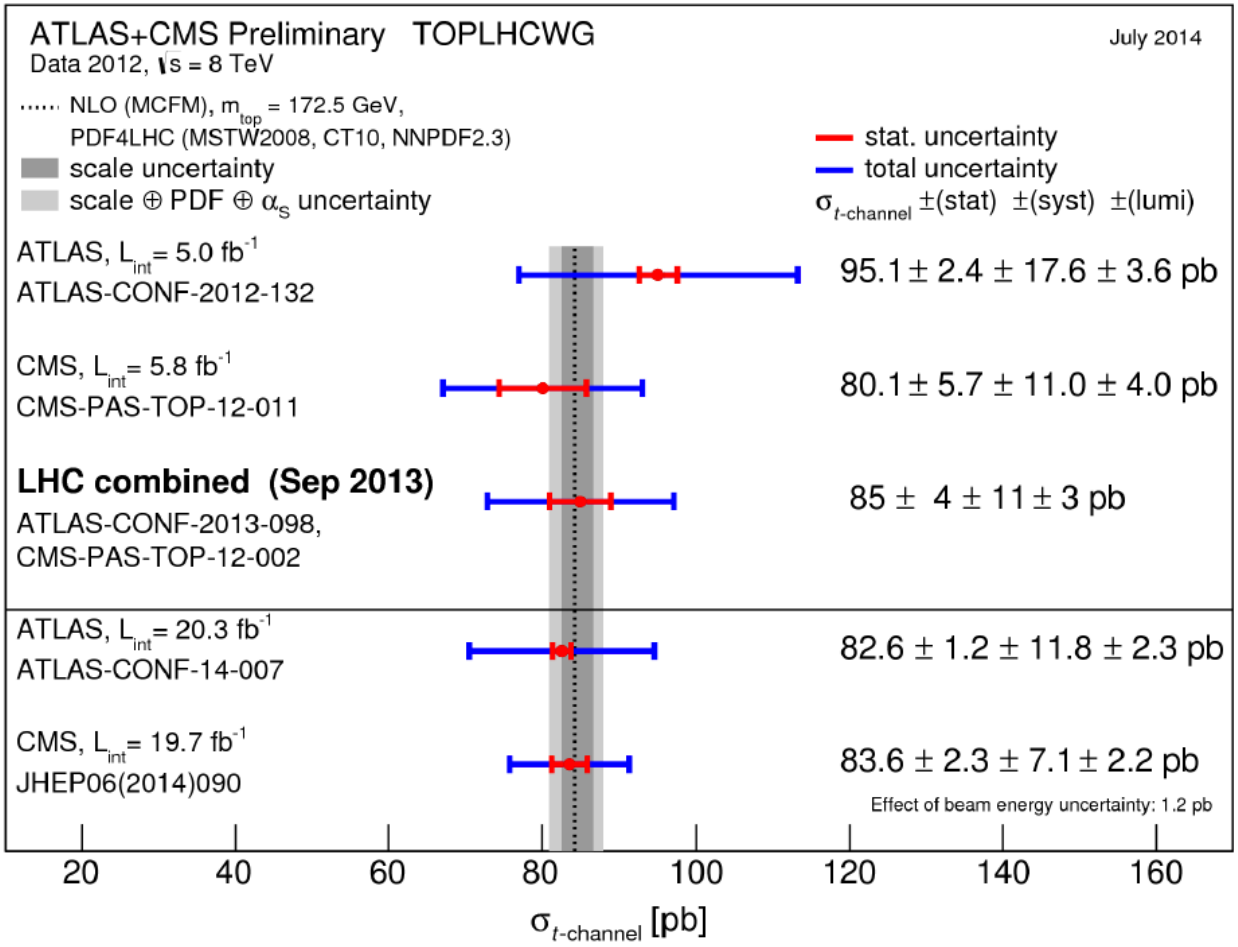
Experimental uncertainty 3.5%

~3.9% including LHC beam energy uncertaintity

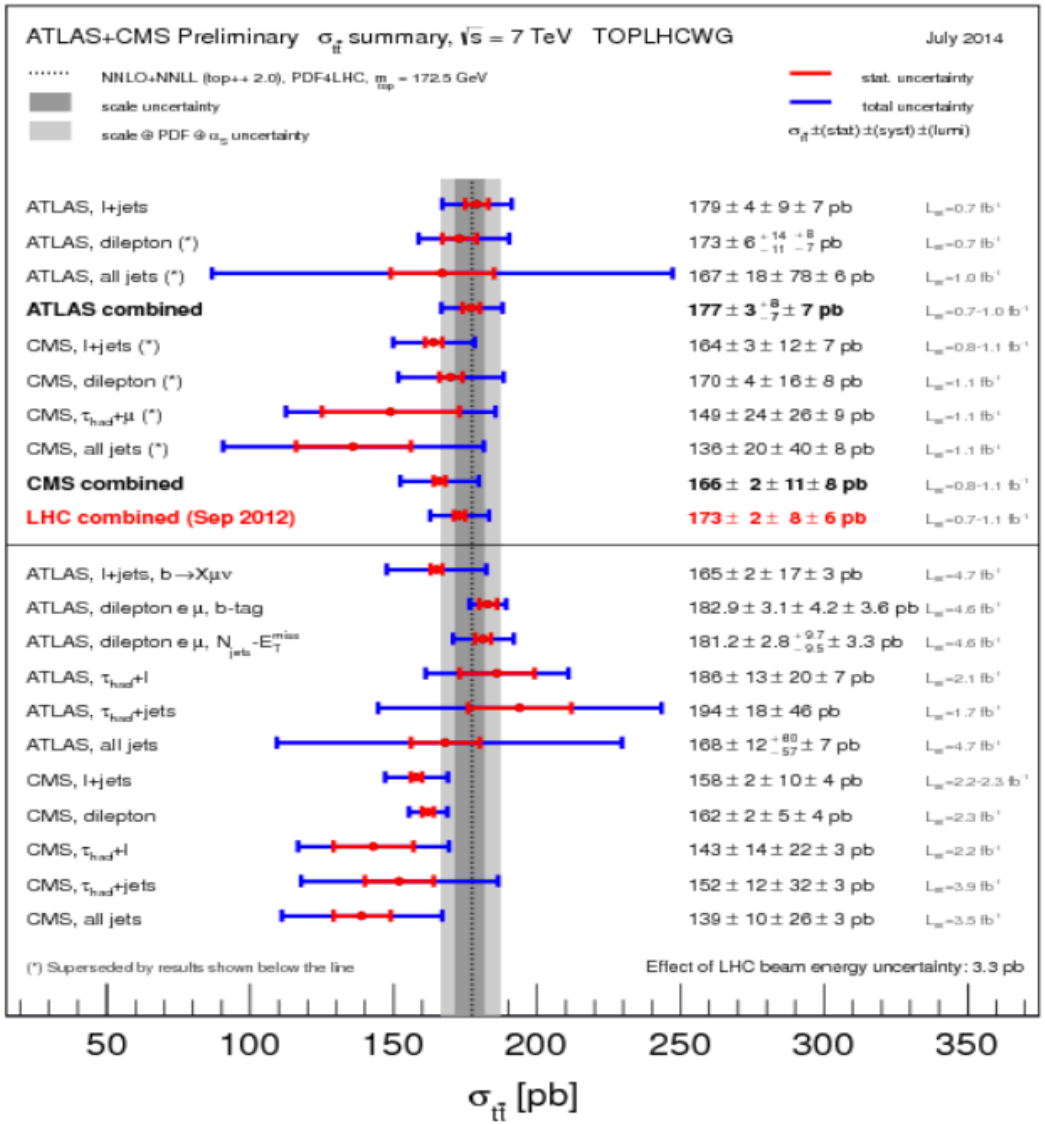




Summary Single top: t-channel @8TeV



Inclusive Cross Sections 7TeV



LHC 7TeV Combination