X Workshop ATLAS Italia

Milano, 10-12 February 2015

Top pair and single top quark production cross section

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Outline

Status of the art and perspective for

- Top quark pair production
- Single top quark production

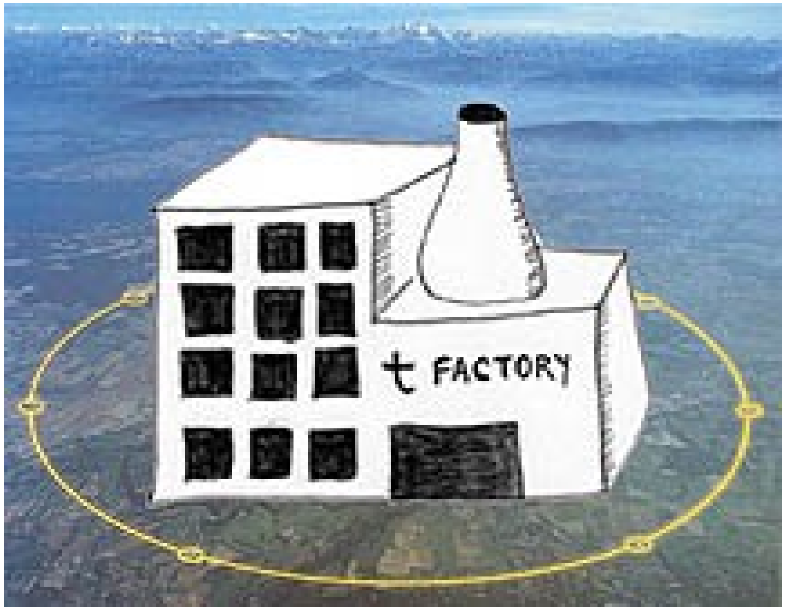
Why top physics at LHC ?

Tevatron: σ_{tt}~7 pb (~10^4 events)

LHC is a Top factory

LHC@8TeV: σ_{tt}~240 pb (~$5\text{x}10^6$ events)

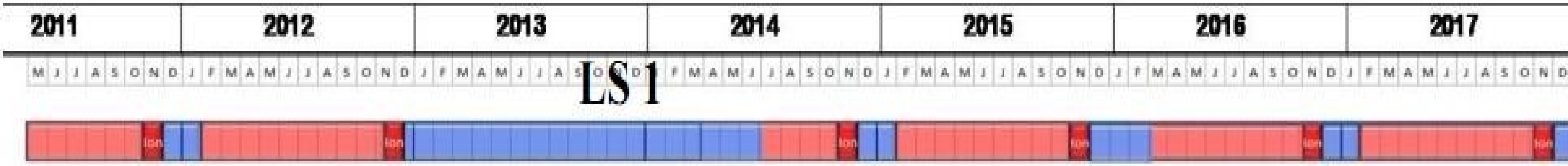
LHC@14TeV: σ_{tt}^{th} ~ 953.6 pb
(~ $95\text{x}10^6$ expected events)



Top physics at LHC moved to precision measurements

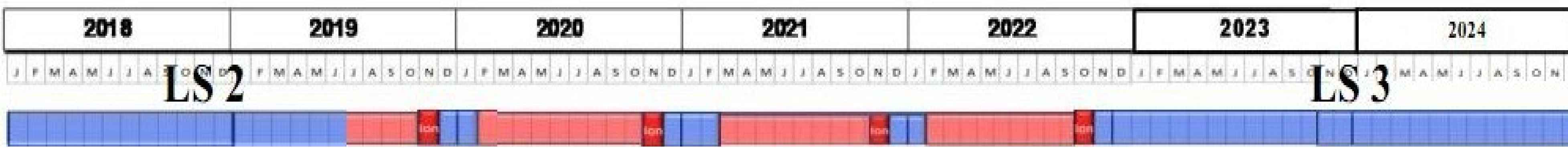
- Precision tests of QCD with available NNLO predictions
- Precision measurements can be included within DGLAP fits
- Modeling of SM tt background for BSM physics searches

Run 2 and beyond



Run 1 : L = 0.7×10^{34} $cm^{-2}s^{-1}$
pile-up ~ 30
$\sqrt{s}$ = 7/8 TeV
bunch spacing 50 ns
$\int Ldt$ = 25 fb^{-1}

Run 2 : L = 1.5×10^{34} $cm^{-2}s^{-1}$
pile-up ~ 40
$\sqrt{s}$ = 13/14 TeV
bunch spacing 25 ns
$\int Ldt$ ~ 100 fb^{-1} (~40-45 fb^{-1} /exp per year)



Run 3 : L = 2.0×10^{34} $cm^{-2}s^{-1}$
pile-up ~ 60
$\sqrt{s}$ = 14 TeV
bunch spacing 25 ns
$\int Ldt$ ~ 300 fb^{-1}

HL-LHC

L = 5.0×10^{34} $cm^{-2}s^{-1}$
pile-up ~ 140
$\sqrt{s}$ = 14 TeV
luminosity levelling
$\int Ldt$ ~ 3000 fb^{-1}

Increased E_{CM} :
Larger xsec increase for
$gg \rightarrow X$ dominated processes
Higher Pile-Up:
higher rates for trigger
Worse jet resolution &
b-tagging performance

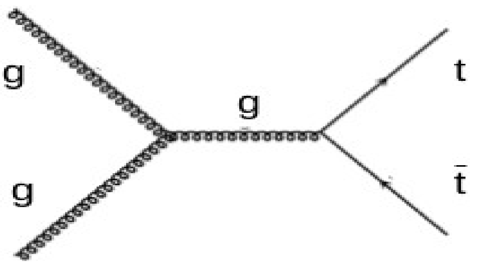
Top studies at Run2

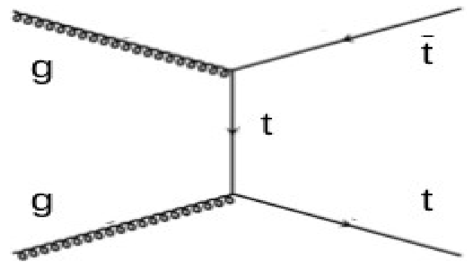
- ➔ All searches (FCNC decays, tt resonances, top partners, …)
- ➔ Top properties (Top quark mass,charge asimmetry,Yukawa coupling,...)
- ➔ Differential cross section measurements (resolved and boosted topology)
- ➔ $t\bar{t}V$, $t\bar{t}H$

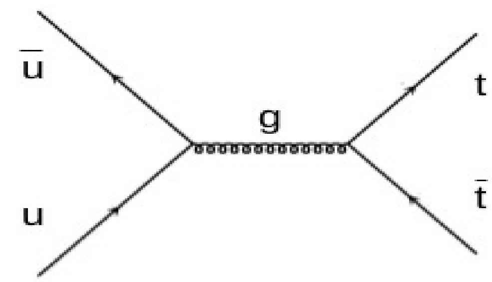
Top pair production at LHC

gluon fusion

$q\bar{q}$ annihilation







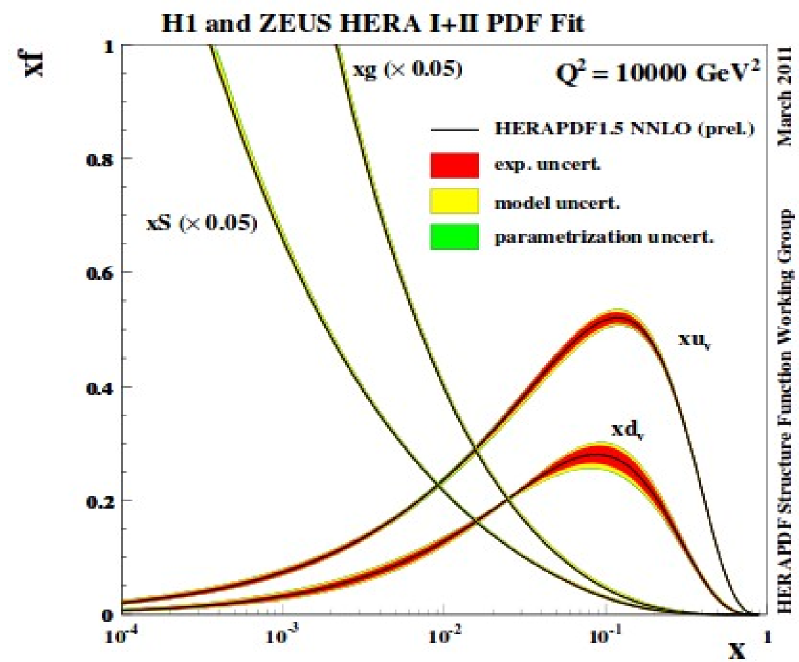
	Tevatron 2 TeV	LHC 8 TeV	LHC 14 TeV
gg	10%	85%	90%
qq	90%	15%	10%

arXiv:1303.6254

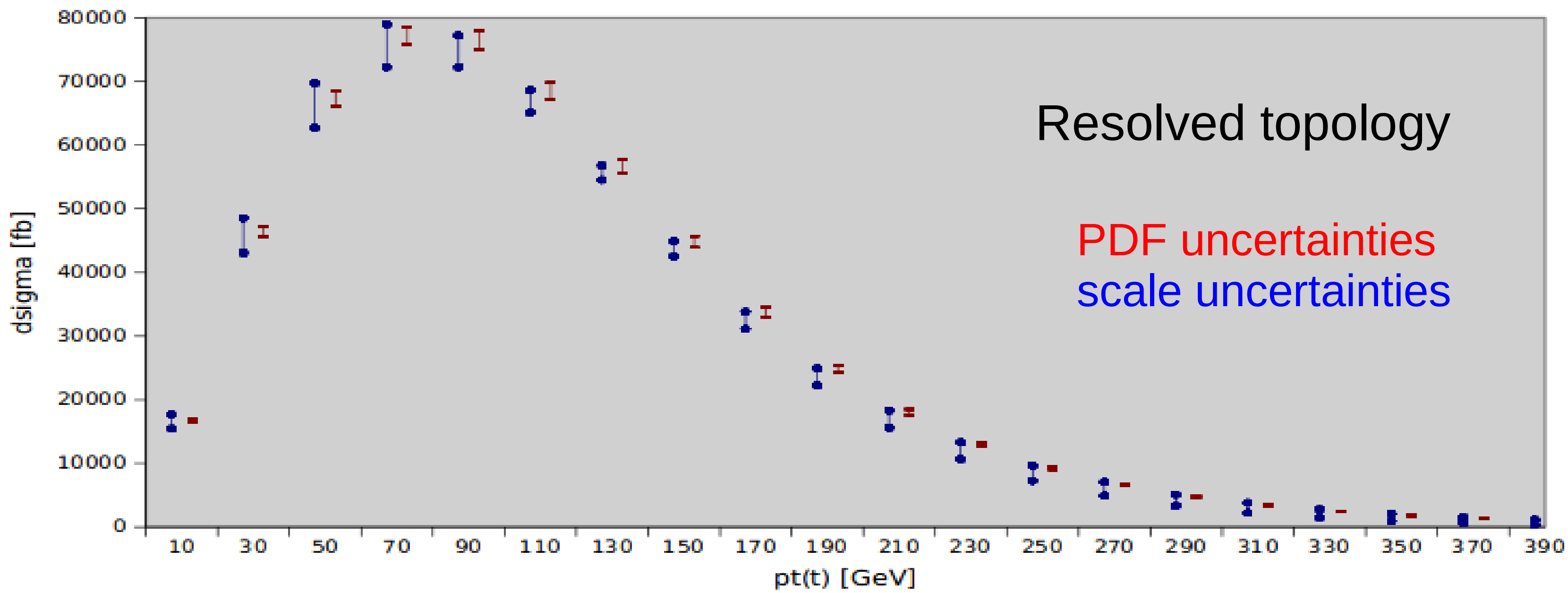
NNLO+NNLL Accuracy

$$\sigma_{t\bar{t},\ 8\mathrm{TeV}} = 245.8\ ^{+6.2}_{-8.4}(\mathrm{scales})\ ^{+6.2}_{-6.4}(\mathrm{pdfs})$$

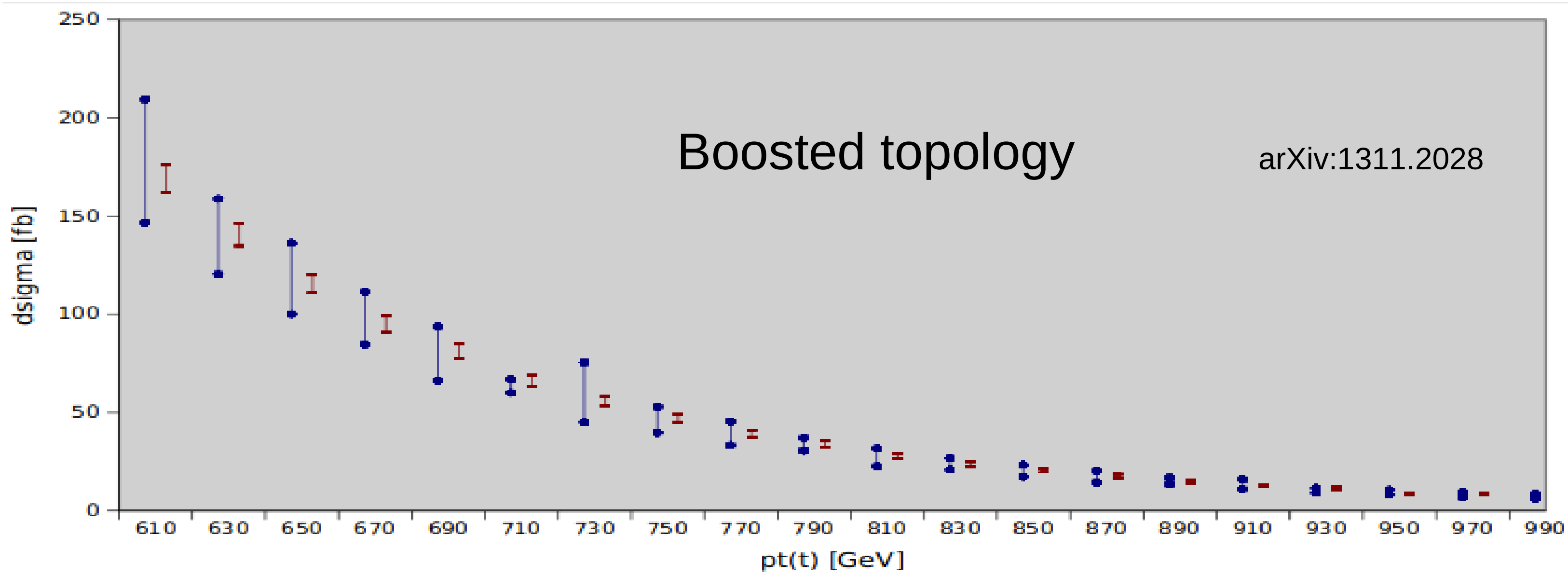
$$\frac{\delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} \sim 4\ \%$$



NLO $t\bar{t}$ differential cross section



NLO QCD
Calculations
@ 14 TeV

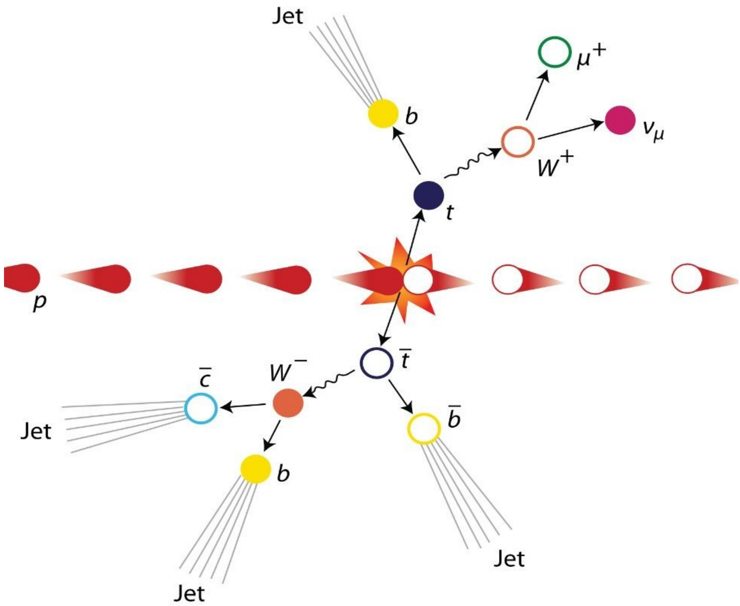


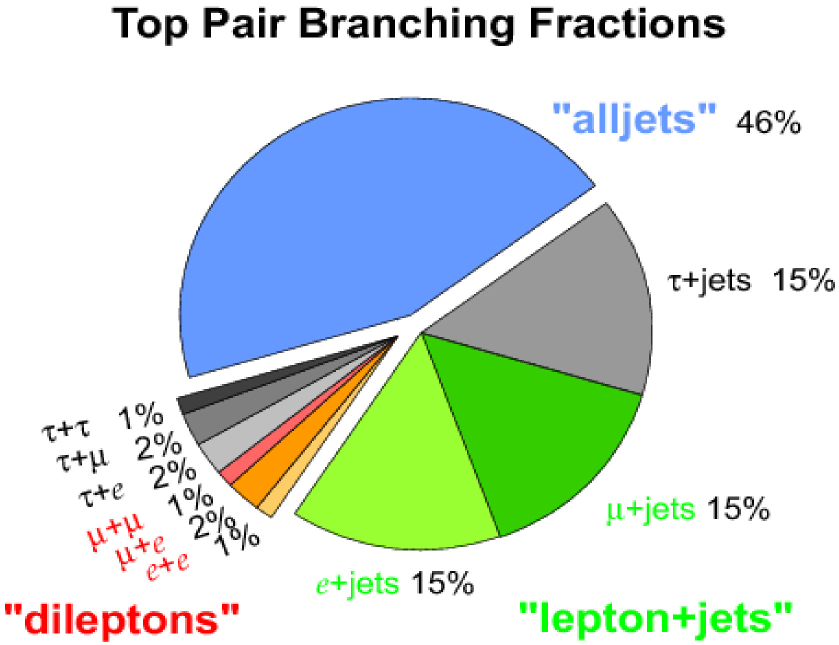
✔ Scale uncertainty dominating the predictions
✔ NNLO differential predictions needed

Top quark signatures

Leptonic Top

Hadronic Top



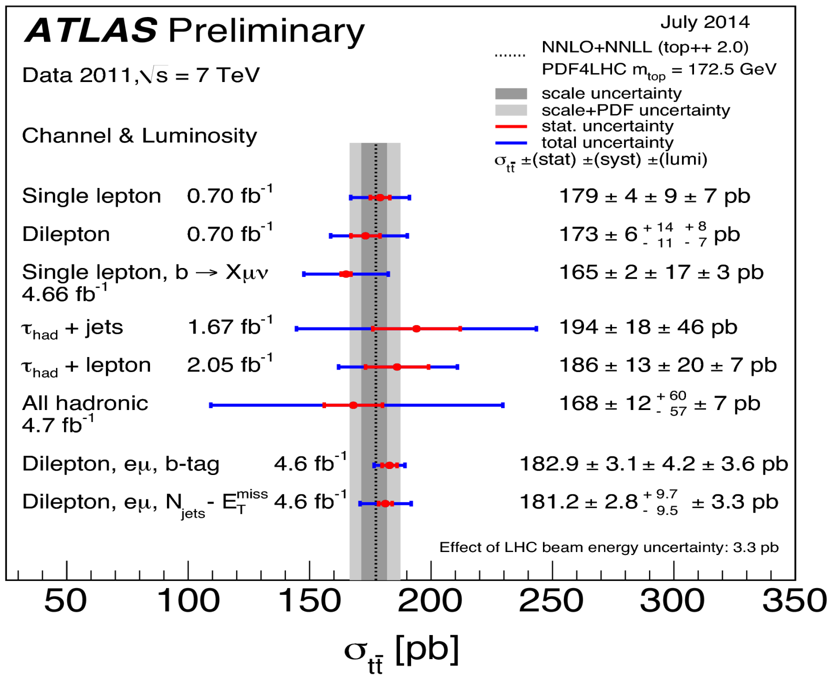


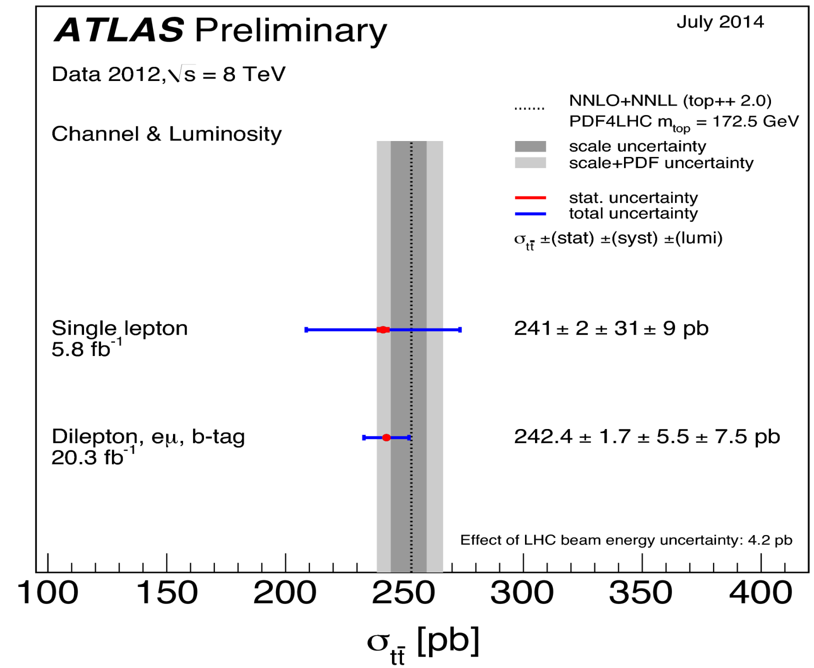
Final state signatures :
dilepton (low prob. & low bkg)
l+jets (compromise between prob. & bkg)
fully hadronic (large prob. & large bkg)

Main background sources

- Full hadronic: QCD
- Single lepton: W+jets, fake leptons, single top
- Dilepton: Z,γ*+jets, fake leptons

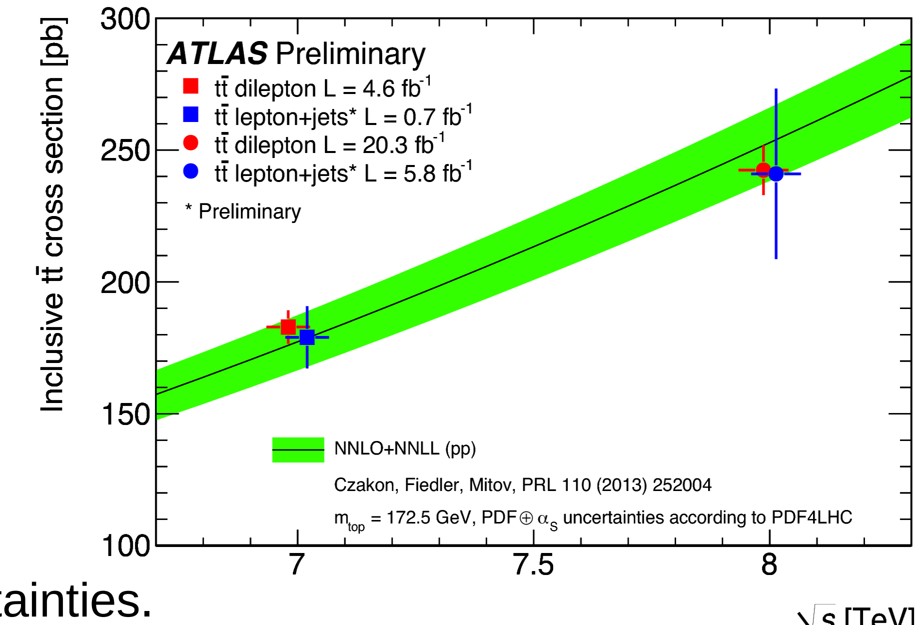
Total $t\bar{t}$ cross section





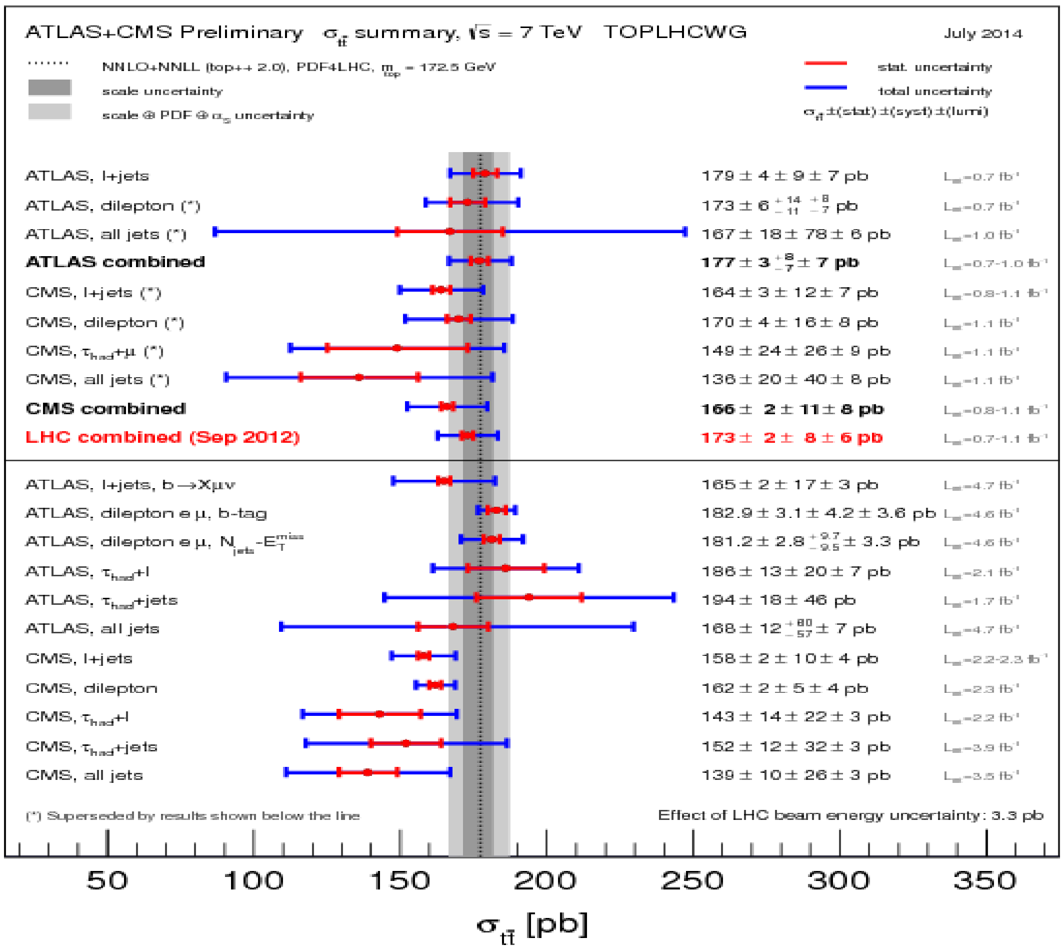
Latest NNLO+NNLL theoretical predictions
(Czakon, Fiedler, Mitov 2013) arXiv:1303.6254

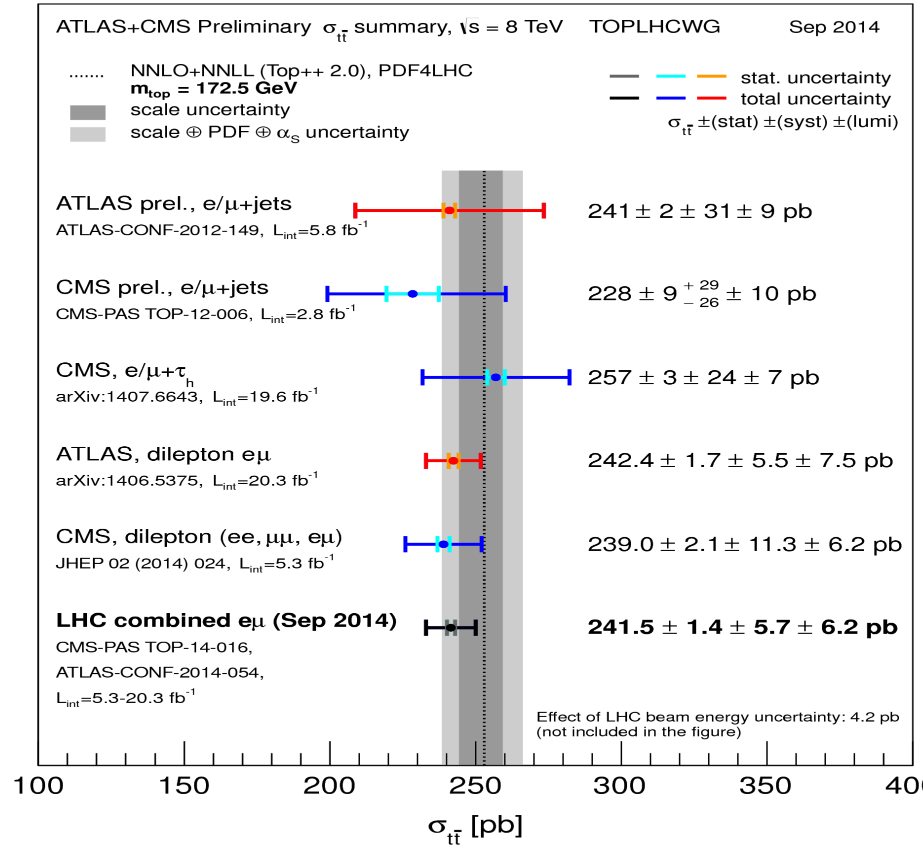
Collider	$\sigma_{\rm tot}$ [pb]	scales [pb]	pdf [pb]
Tevatron	7.164	+0.110(1.5%) −0.200(2.8%)	+0.169(2.4%) −0.122(1.7%)
LHC 7 TeV	172.0	+4.4(2.6%) −5.8(3.4%)	+4.7(2.7%) −4.8(2.8%)
LHC 8 TeV	245.8	+6.2(2.5%) −8.4(3.4%)	+6.2(2.5%) −6.4(2.6%)
LHC 14 TeV	953.6	+22.7(2.4%) −33.9(3.6%)	+16.2(1.7%) −17.8(1.9%)



Good agreement.
Comparable theoretical and experimental uncertainties.

Total $t\bar{t}$ cross section - Comparison with CMS





7TeV:

ATLAS Combined - Tot. Unc. 6%

CMS Combined - Tot. Unc. 8.2%

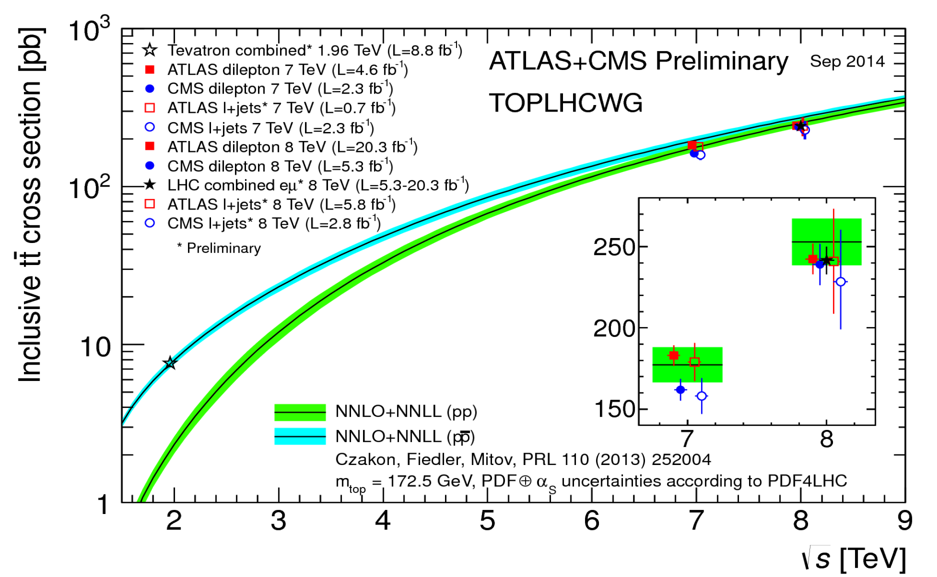
LHC Combined - Tot. Unc. 5.9%

8TeV :

ATLAS (eμ channel) - Tot. Unc. 3.9%

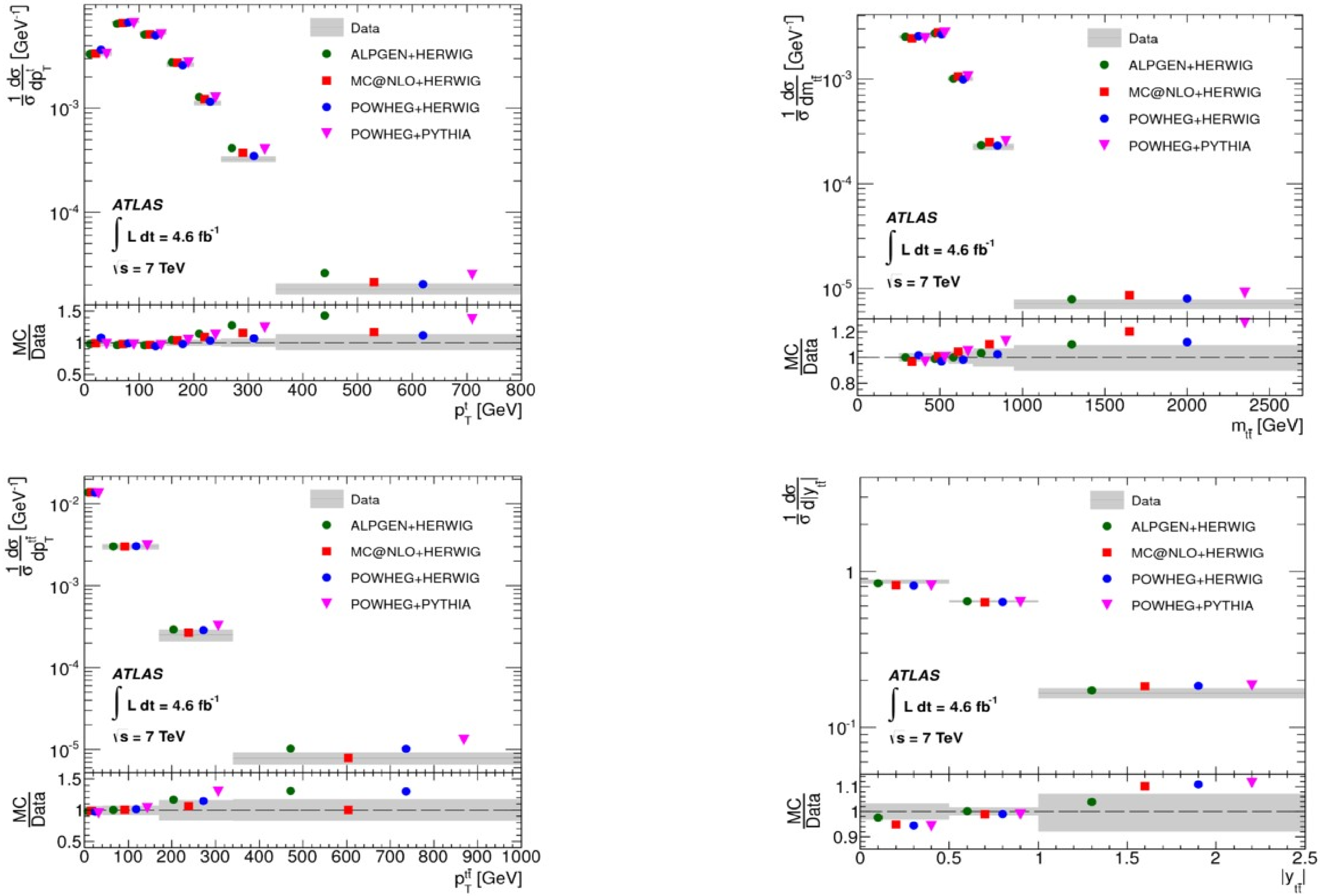
CMS (ee,eμ,μμ channels) - Tot. Unc. 5.4%

LHC Combined (eμ) - Tot. Unc. 3.5%



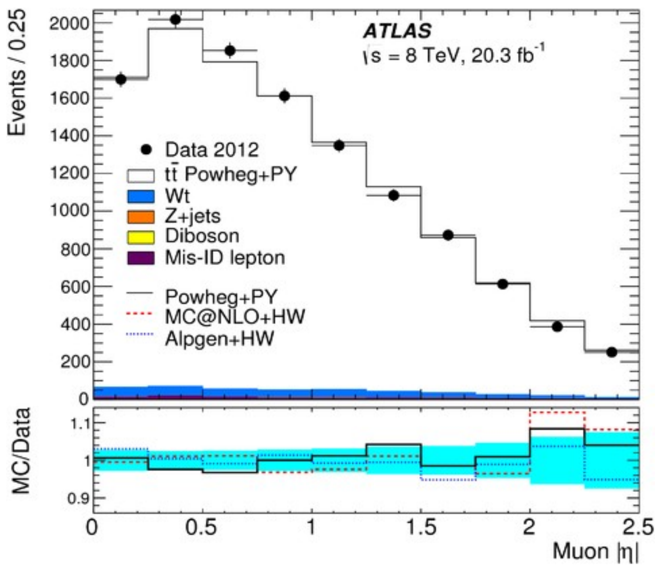
Normalized differential cross sections

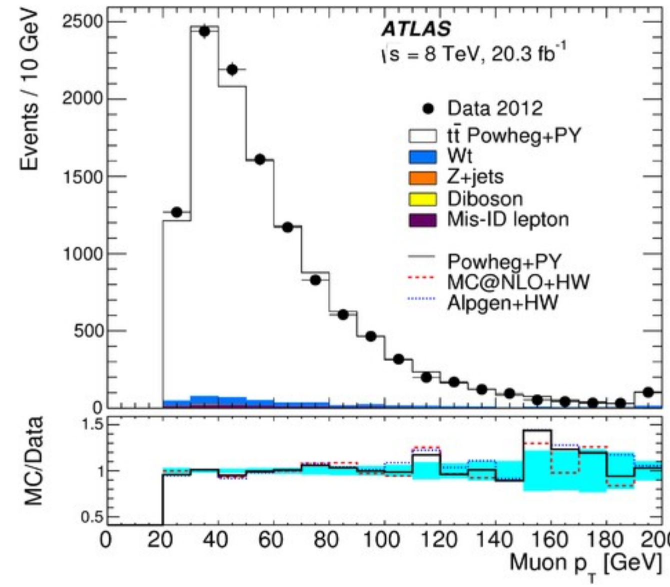
Lepton+jets @ 7TeV *2011 data* ∫Ldt = 4.6 fb^{-1}

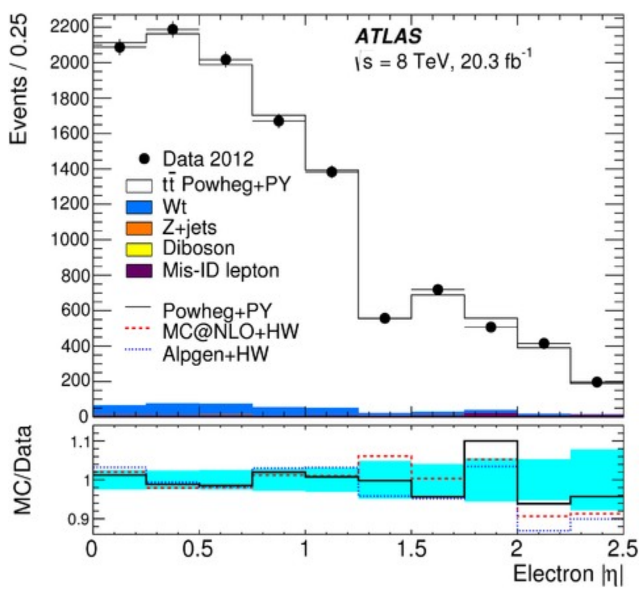


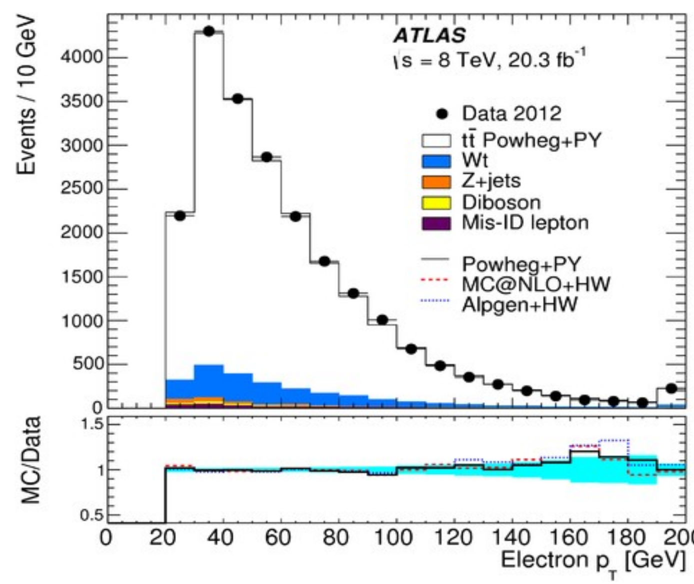
POWHEG+HERWIG provides the best description of the distribution over the full range

Dilepton (eμ with b-tag) differential distributions









Good agreement between theory and data

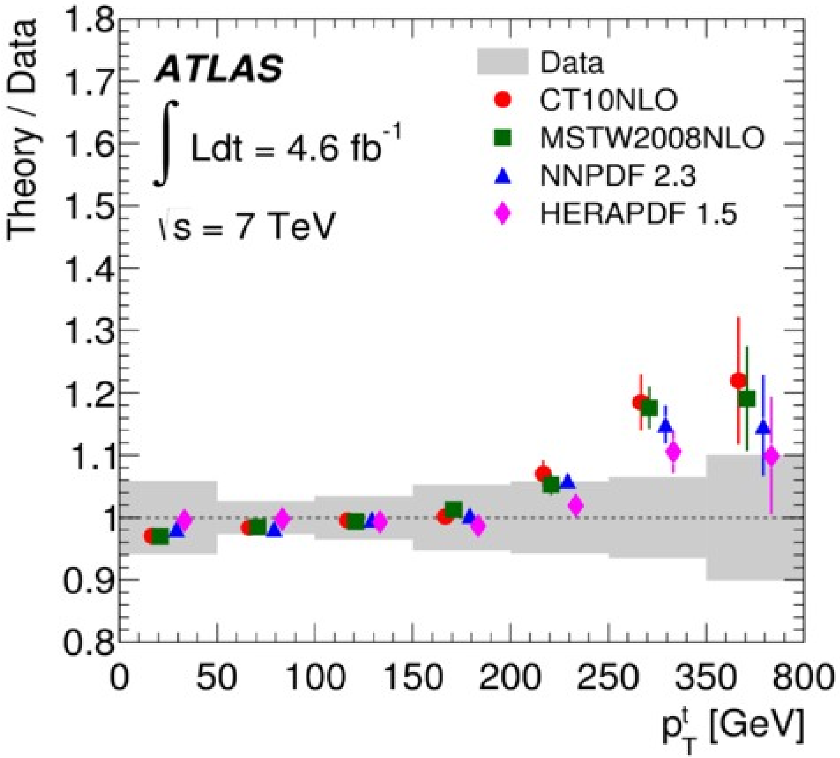
PDFs

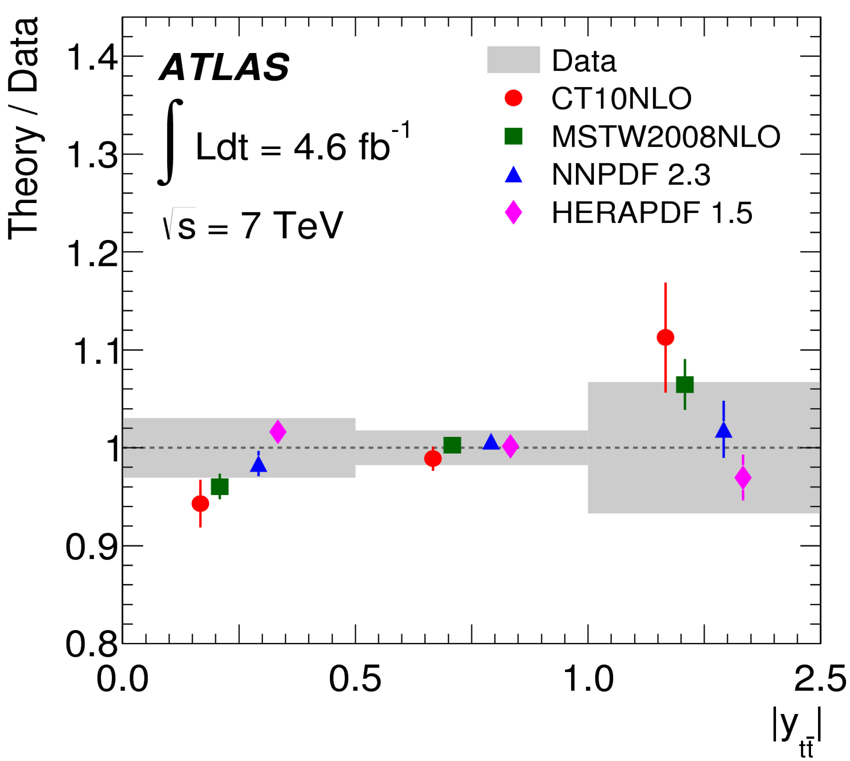
Recent and forthcoming $t\bar{t}$ cross section measurements have the potential to improve the determination of the PDFs

➔ Differential measurements

➔ At least NLO predictions (MCFM)

➔ Forthcoming NNLO predictions





Theory/data in better agreement using HERAPDF 1.5

What can we do with early Run2 data?

- Focus on di-lepton e-μ (with b-tagging)
  - Already used for precise measurements at 7 and 8 TeV
  - Large cross section (σ≈830 pb at 13 TeV) means we can do a lot already with ≤ 1 fb-1
  - Initial sample with 50 ns bunch spacing and low trigger thresholds will be very useful

- Early cross section measurements
  - l+jets final state:
    - more complex and harder systematics but important to study even for potential BSM effects
  - Di-lepton with same lepton flavour (ee/μμ)
    - Here we may start to look at differential distributions

- Ratios of measured cross sections either between different processes or between same processes at different energies (8 and 13 TeV)

$t\bar{t}$ cross section: general considerations for Run2

From the *ATLAS Nov 2014 Physics Workshop "Ready for Run-2"*

- The luminosity uncertainty will be the dominant systematics
- Lepton efficiencies should be about 2-3%
- JES uncertainties could become significant
- Single lepton triggers with low p_T thresholds are strongly preferred
- The number of the recommended systematic variations by the CP groups is considered too large

Run2 – Trigger issues

- For run-2

  Single lepton triggers e24_tight_EM20VHI and mu20_iloose_MU15 should be able to use, with offline p_T>25 GeV (maybe slightly higher for e)

- Beyond 1 fb^{-1} will have to increase offline p_T cuts or move to dilepton triggers

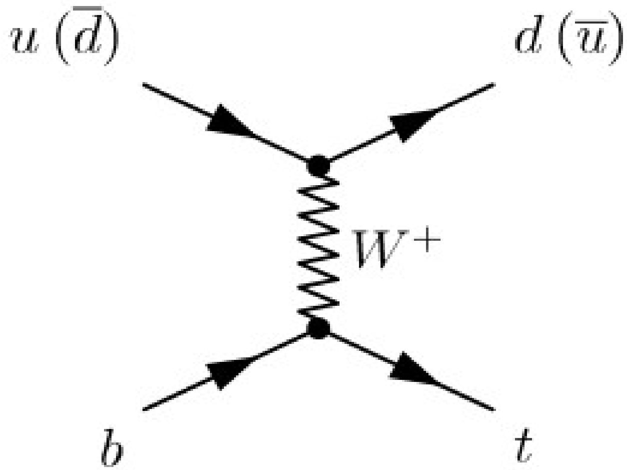
- If moving to p_T > 30 GeV removes 20% of acceptance

  Possible increase in extrapolation uncertainty for inclusive cross section

Single top production at LHC

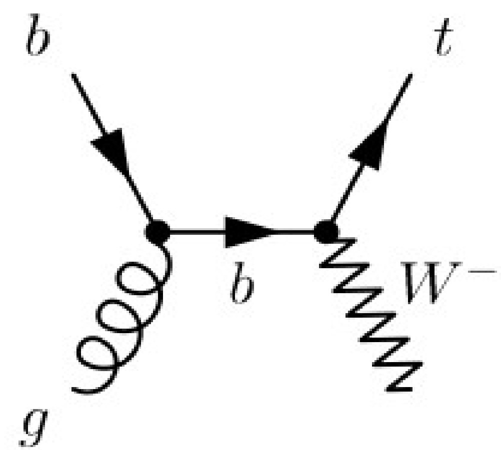
Electroweak single top production at LHC is lower than the *strong* top pair production

t-channel



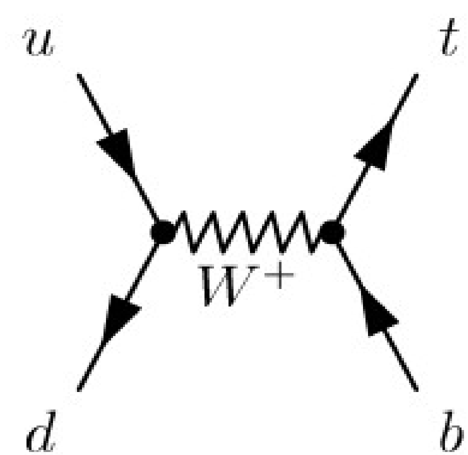
NLO+NNLL
σ_{8TeV}= 87.8±3.4 pb

Wt-channel



NLO+NNLL
σ_{8TeV}= 22.4±1.5 pb

s-channel



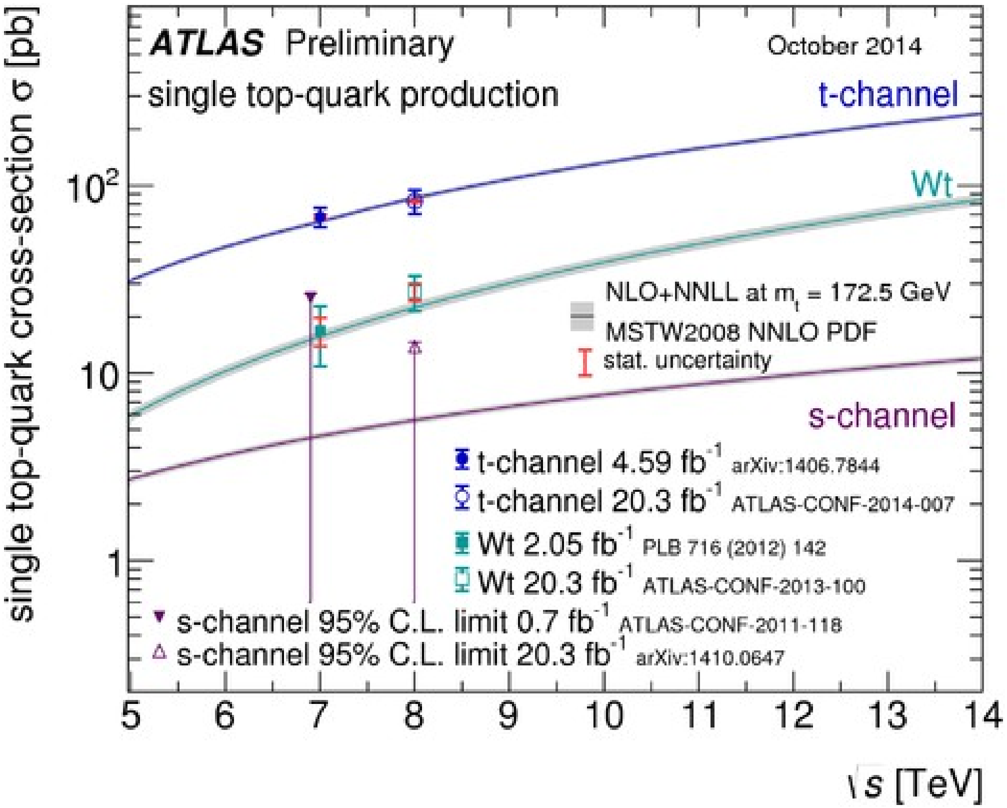
NLO+NNLL
σ_{8TeV}= 5.6±0.2 pb

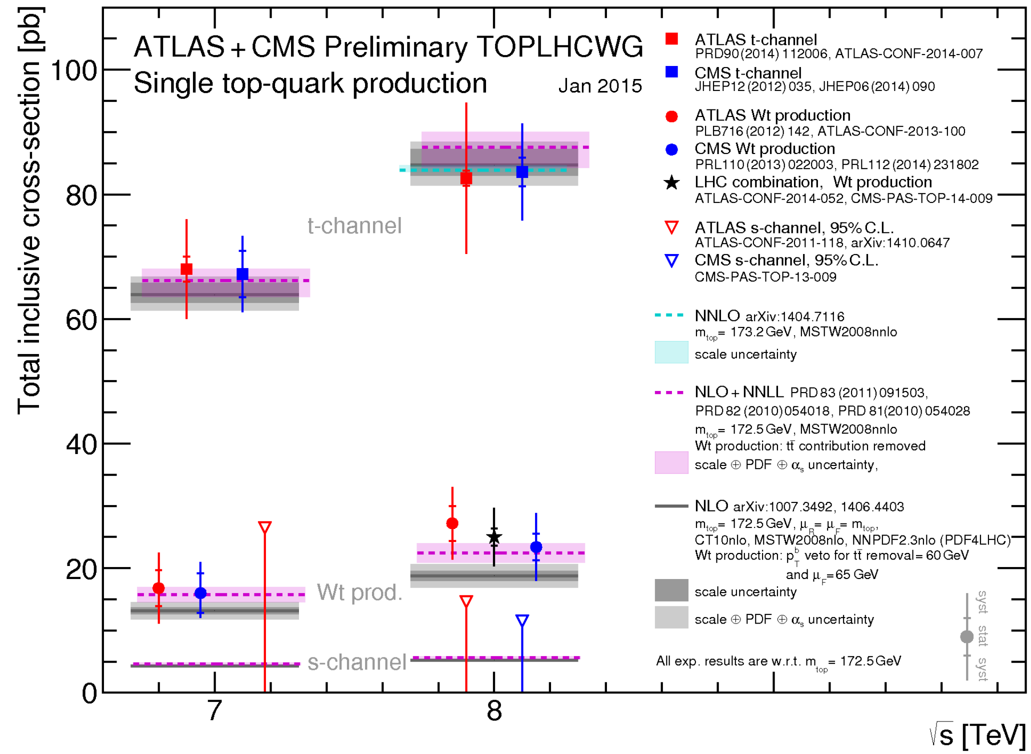
$\delta\sigma_t/\sigma_t$ ~ from 2 up to 7 %

Why Single Top studies ?

- Relevant test of the SM
- Sensitive to the *Wtb vertex* in different ways
- Non-standard couplings → *new physics*
- Verify the unitarity of the CKM matrix
- Constraints on the *b-quark* PDF
- Background in several new physics scenarios

Total single top cross section





Latest ATLAS results at 8TeV :

$\sigma_{\text{t-channel}}$ = 82.6 ± 1.2 (stat) ± 11.4 (syst) ± 3.1 (PDF) ± 2.3 (lumi) pb

$\sigma_{\text{Wt-channel}}$ =27.2 ± 5.8 pb → 4.2 σ evidence with 4.0 σ expected for SM

At 7TeV:

Observed (expected) upper limit at 95% CL on $\sigma_{\text{s-channel}}$ < 26.5 (20.5) pb

General considerations on single top xsec measurements for Run2

- If the systematic uncertainties due to JES, MET and b-tagging will be less than a factor of 2 worse than those of Run-1, the measurements are expected to be feasible

- A calibration of forward jets is required (up to η of 4.5, but could also afford to cut at around 3.5), which is currently the dominant uncertainty in the t-channel

- A b-tagger optimised for c-jet rejection is needed

- Low p_T single lepton triggers are needed

Conclusions

- Results at 7 and 8 TeV already show how rich is the Top Physics programme at the LHC

- Several measurements in top physics will profit from the increased top production cross-section at 14 TeV and a larger integrated luminosity

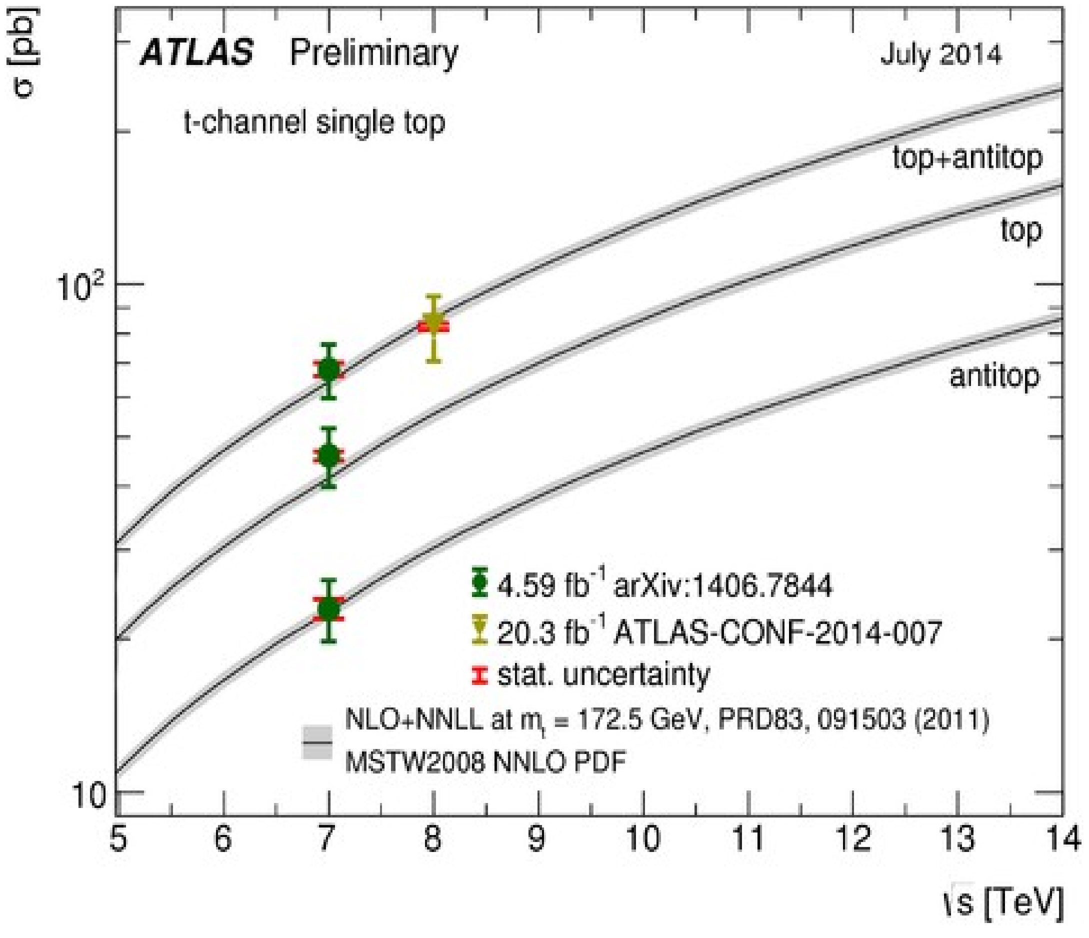
- Better determination of PDF's with future NNLO differential predictions

- Continue to search for BSM Physics

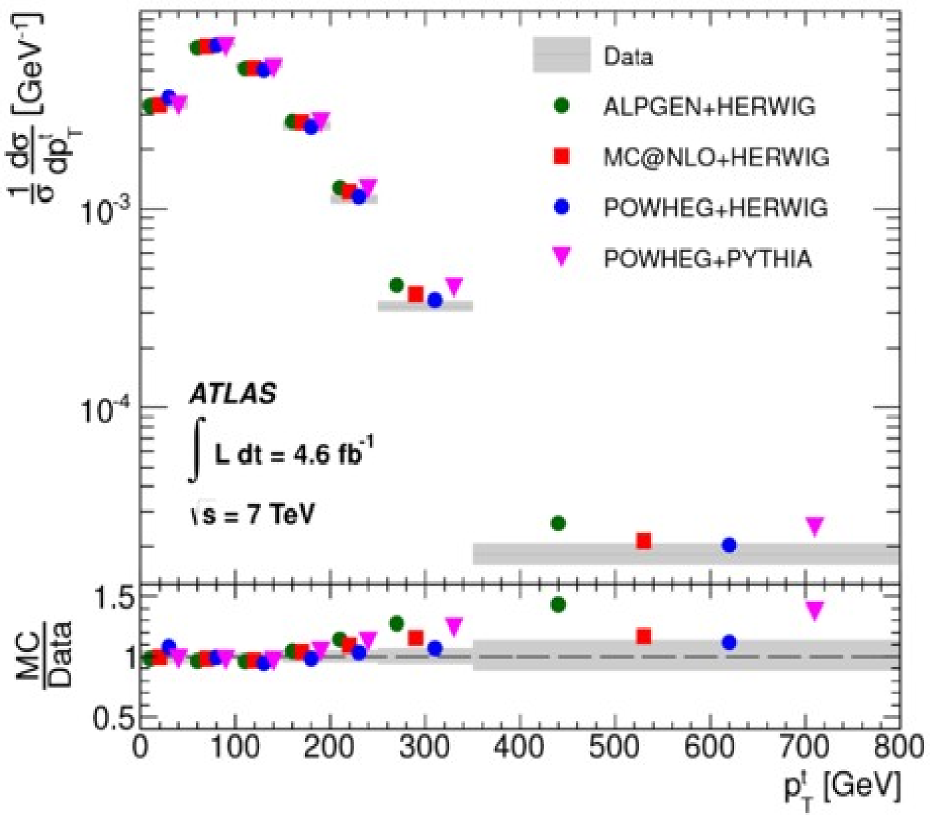
Backup slides

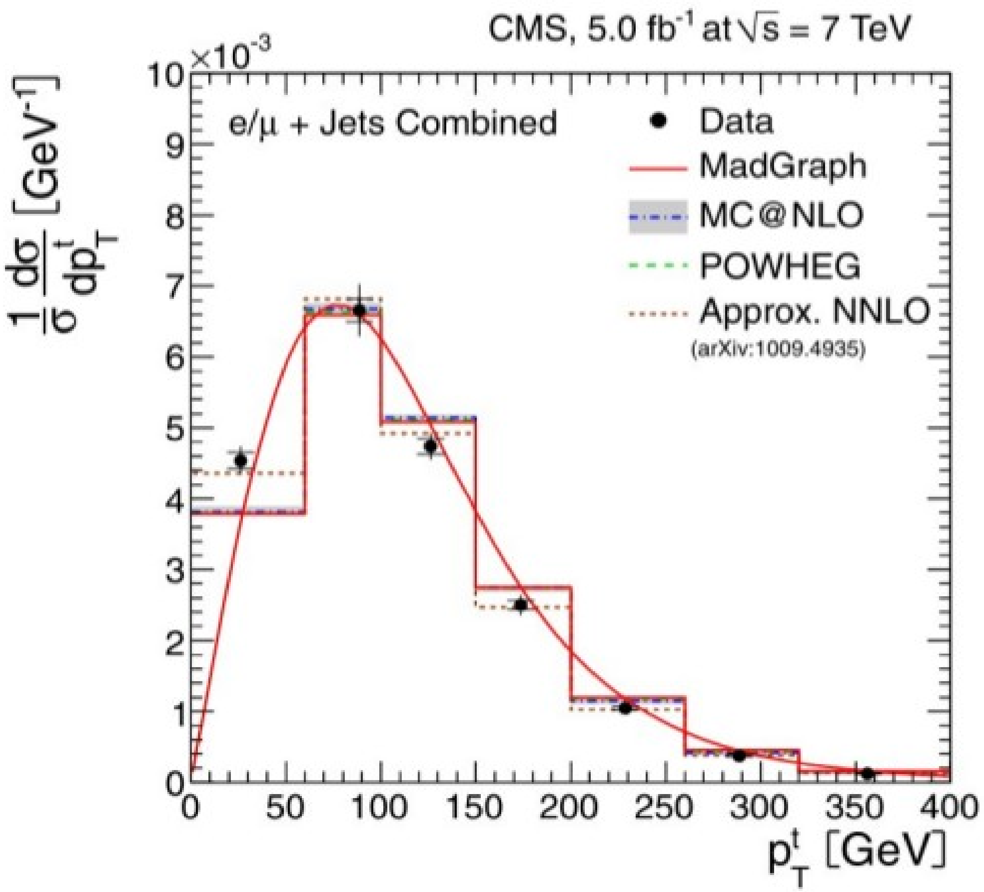
t-channel single top: THE GOLDEN channel

- Inclusive, differential and fiducial xs measurements
- Ratio $R_t = \sigma(tq)/\sigma(\bar{t}q)$
- Top and W polarization
- Anomalous couplings
- BSM searches



Normalized diff. cross section – Comparison with CMS





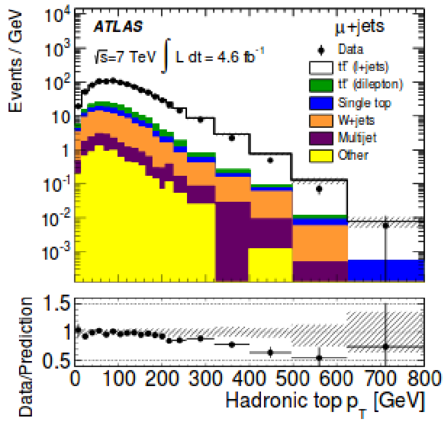
ATLAS and CMS results are generally consistent with SM predictions

MC tend to overestimate the measured cross section at large transverse momentum for ATLAS

POWHEG+HERWIG provides the best description of the distribution over the full range

$t\bar{t}$ differential cross section

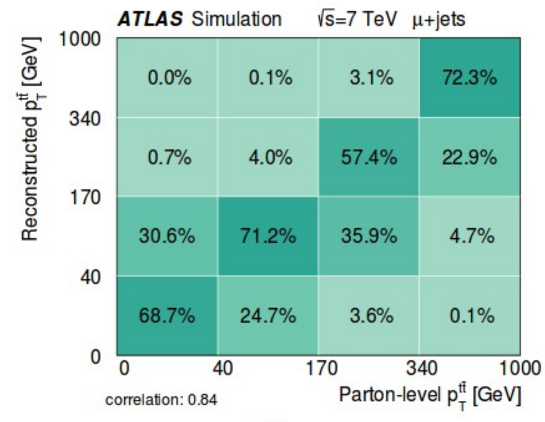
Event selection + $t\bar{t}$ kinematic reconstruction



Bin-wise cross section measurement

- Subtract background
- Unfolding: correct for detector effects and acceptance

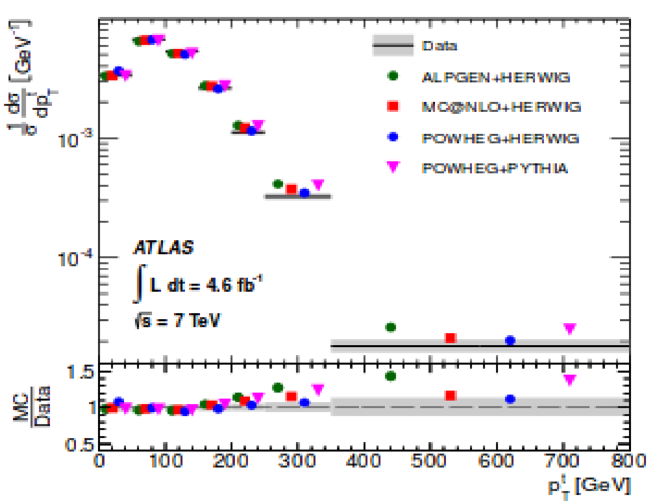
$$\frac{1}{\sigma}\frac{d\sigma^i}{dX} = \frac{1}{\sigma}\frac{N^i_{\mathrm{Data}} - N^i_{\mathrm{BG}}}{\Delta^i_X \epsilon^i L}$$



Migration matrix

Differential $t\bar{t}$ cross sections

- Normalised to in-situ measured σ
- 'Visible' or extrapolated to full phase space
- Compare to theory predictions



Why differential measurements ?

➔ test/tune $t\bar{t}$ production models in different phase space regions

➔ look for discrepancies wrt SM predictions

➔ measurements to include in PDF fits, providing info about PDFs themselves

➔ background for BSM searches