Top pair production cross-section and measurements of tt+X with the ATLAS detector

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On behalf of the ATLAS Collaboration

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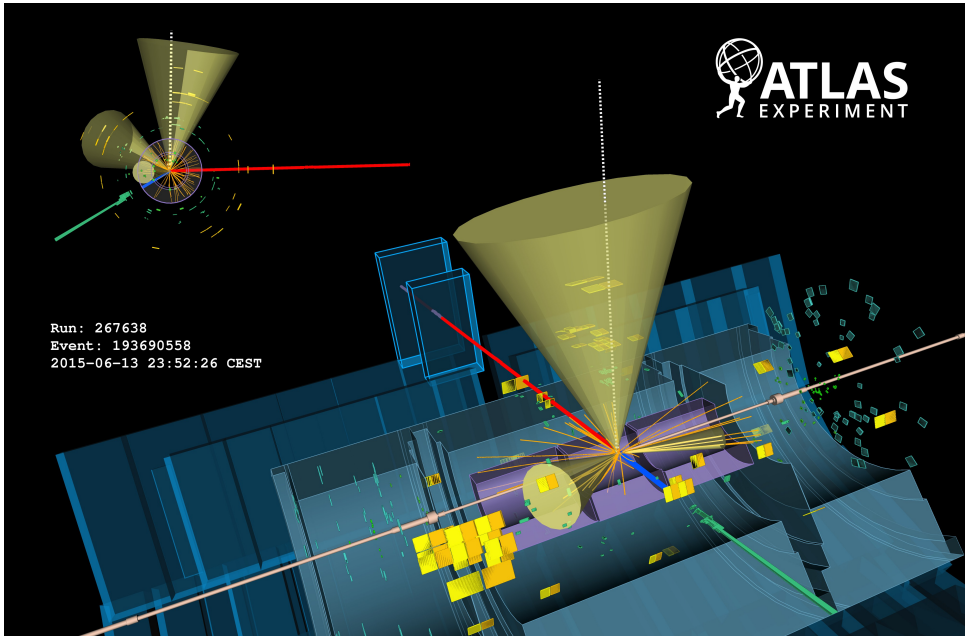


Outline

- Introduction
- Top-pair production cross-section
  - Inclusive and differential cross sections
  - Top quark kinematics and boosted top in TeV regime
- Measurements of $t\bar{t}$+X:
  - $t\bar{t}$+ jets
  - $t\bar{t}$+W, $t\bar{t}$+Z
  - $t\bar{t}$+γ
- Conclusion

- More Details:

- ATLAS: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

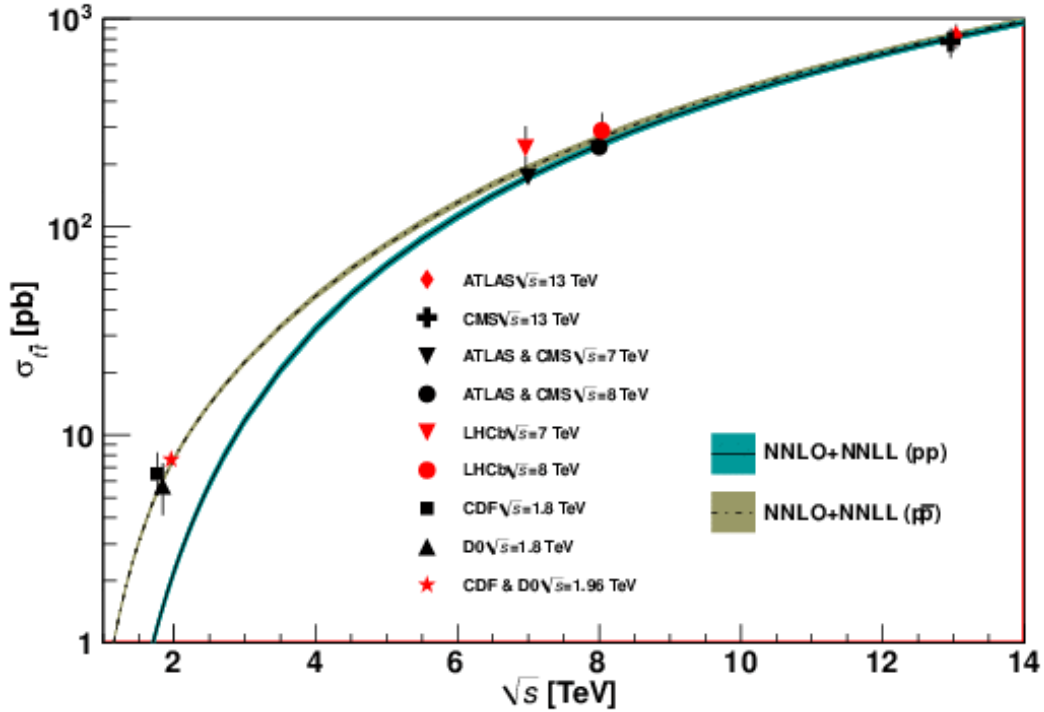
Introduction

- Top-quark was discovered at the Tevatron by CDF & D0 in 1995, the heaviest quark discovered so far: M_{top}=173±0.6 GeV (LHC+Tevatron).

- It's the only bare quark ever observed due to a short lifetime of 5×10^{-25} s.

- Top with large Yukawa coupling (y_t~1) may play special role in EWSB.

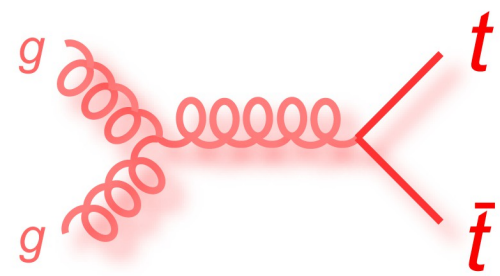
- Top-quark pair production is well understood, consistent with NNLO.



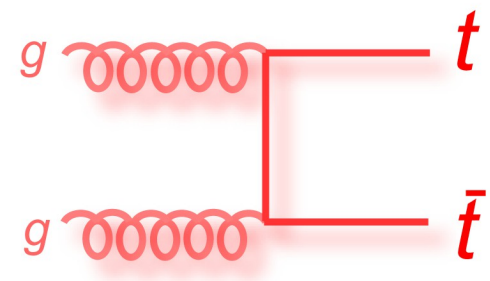
T.M. Liss et al, "The Top Quark", PDG 2016

Top-quark Pair Production at LHC

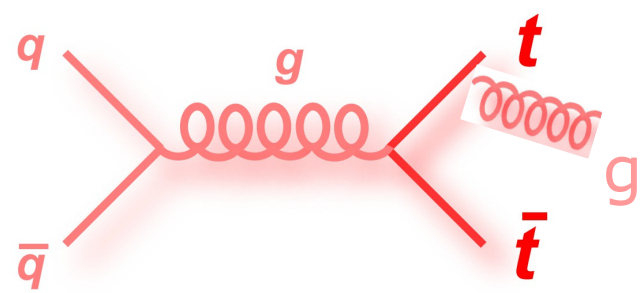
- Top-quark pair is predominately produced in gluon fusion (~90%) and $q\bar{q}$ annihilation (~10%) at LO at LHC.



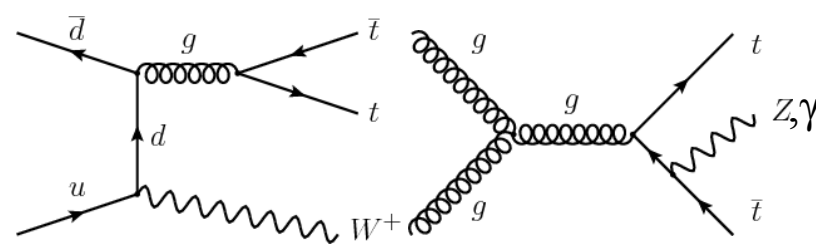
- The production cross section:
  - Sensitive to gluon PDFs, α_s, M_{top}.
  - Provide precision test of QCD in the TeV regime.



- Study of $t\bar{t}$ + X production provides:
  - Stringent test of higher-order QCD.
  - Probe for new physics beyond the SM.

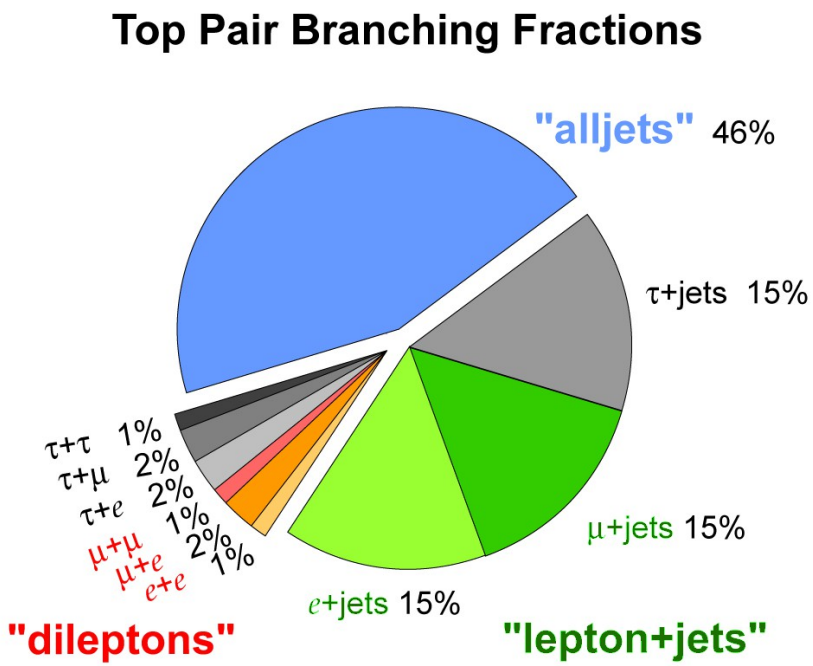


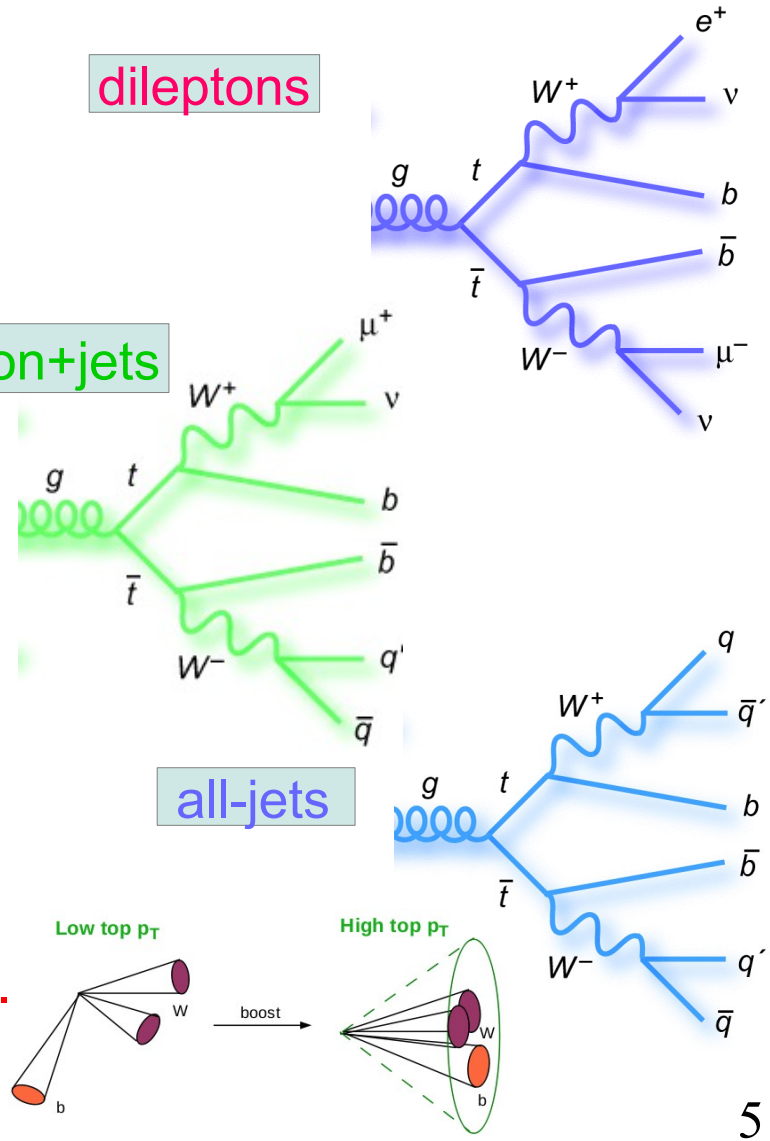
- Main background:
  - W+jets, Z+jets, single-top, diboson, multi-jets.



Top-quark Decay in SM

- Top-quark decays into Wb with B(t→Wb)=100%, final states determined by W decays.





- For high pT, top boosted in large-R jet (R=1):
  - Jet substructure technique by requiring 3 sub-jets(R_{sub}=0.2, f_{sub}=0.05) with a large mass.

Top pair-production at √s=13 TeV

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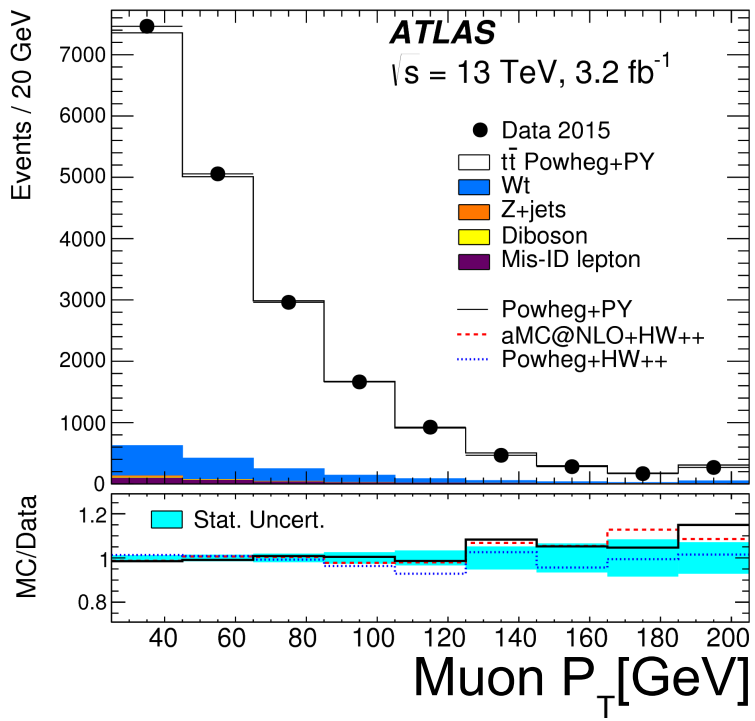
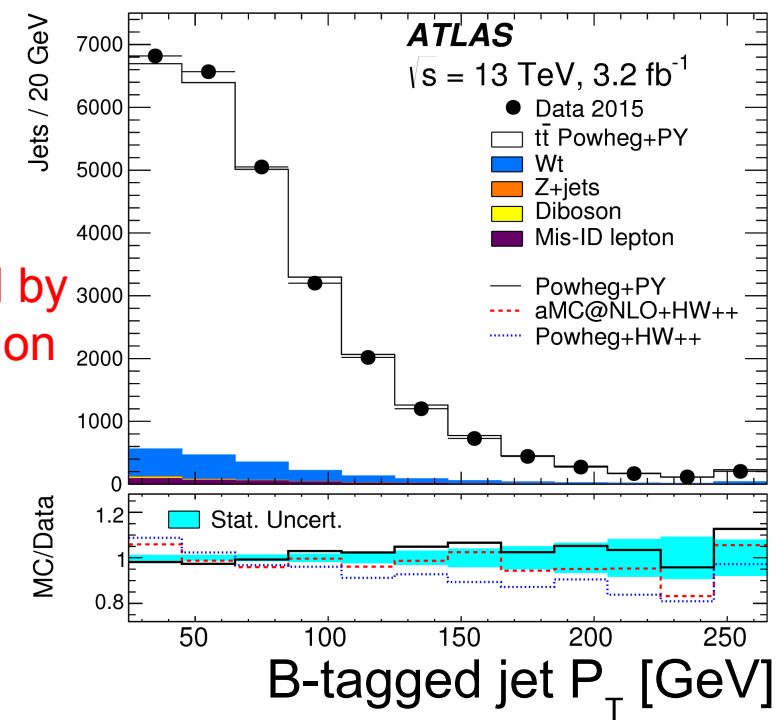
- Select eμ + >= 2jets+1b,2b using 3.2fb^{-1}.
- Likelihood fit $\sigma_{t\bar{t}}$, ε_{btag} simultaneously
- $\sigma_{t\bar{t}}$=818±8±27(syst)±19(lum)±12(beam)pb
- Total ~ 4.4% uncertainty.
- NNLO: 832^{+20}_{-29}(Scale)±35(PDF+α_s) pb

Event counts	N_1 (1b)	N_2 (2b)
Data	11958	7069
Single top	1140 ± 100	221 ± 68
Dibosons	34 ± 11	1 ± 0
$Z(\to \tau\tau \to e\mu)$+jets	37 ± 18	2 ± 1
Misidentified leptons	164 ± 65	116 ± 55
Total background	1370 ± 120	340 ± 88



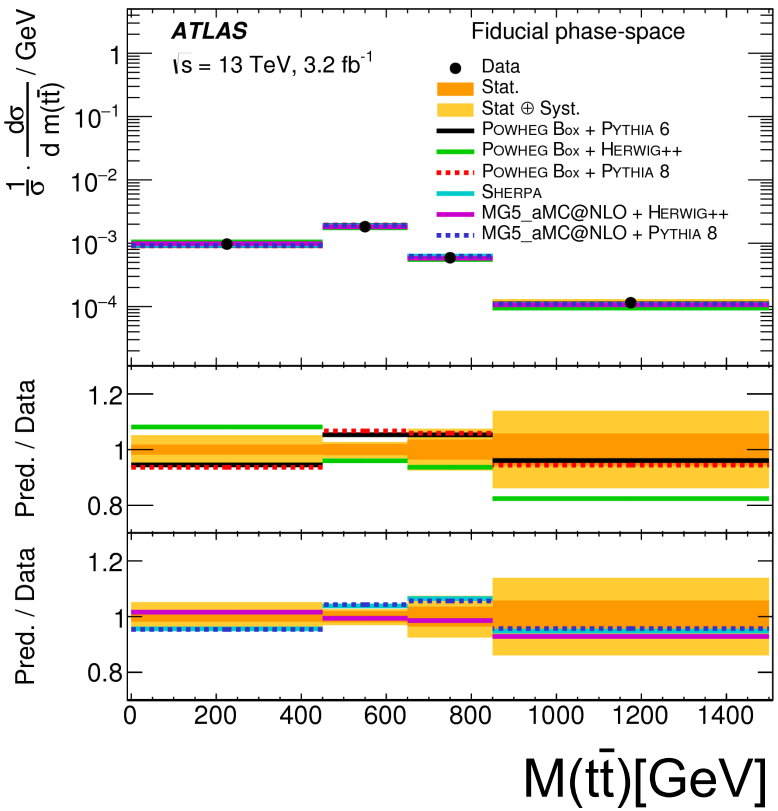
➔Syst is limited by top hadronisation uncertainty.

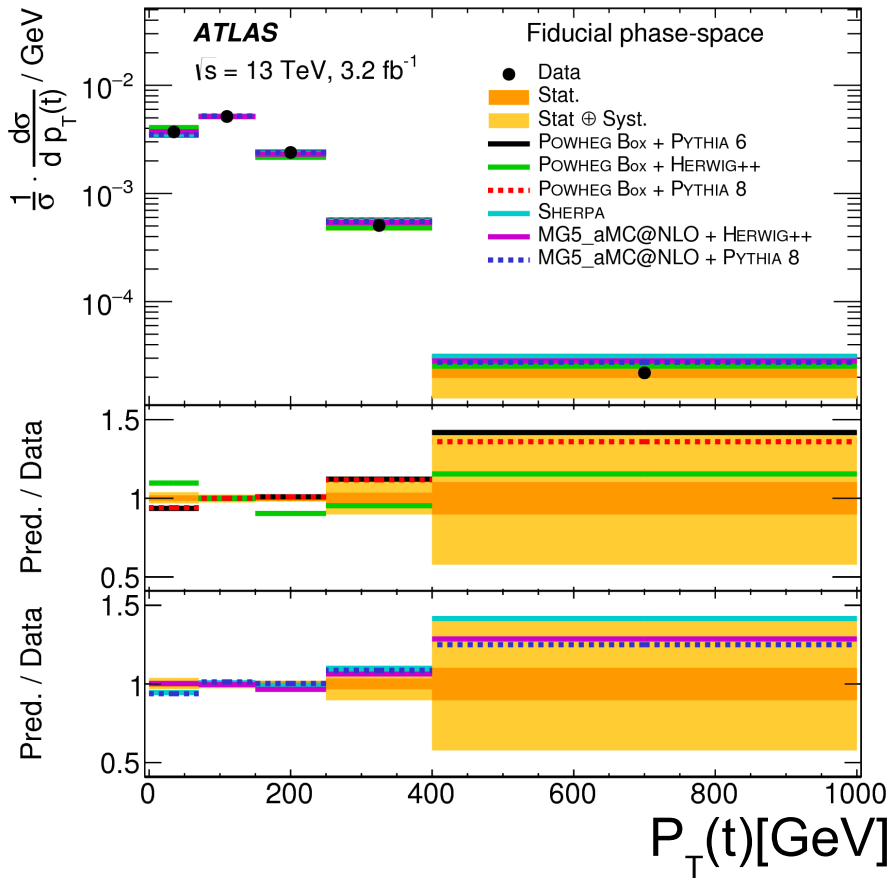


Differential $\sigma_{t\bar{t}}$ in eμ Channel.

ArXiv:1612.05220 ,accepted by EPJC

- Differential $\sigma_{t\bar{t}}$ as function of $m_{t\bar{t}}$, $P_{T,t\bar{t}}$, $y_{t\bar{t}}$, $P_{T,t}$, y_t , sensitive to top processes.
  - eμ + >=2jets with >=1 b-jet
  - Top reconstruction using neutrino weighting technique.



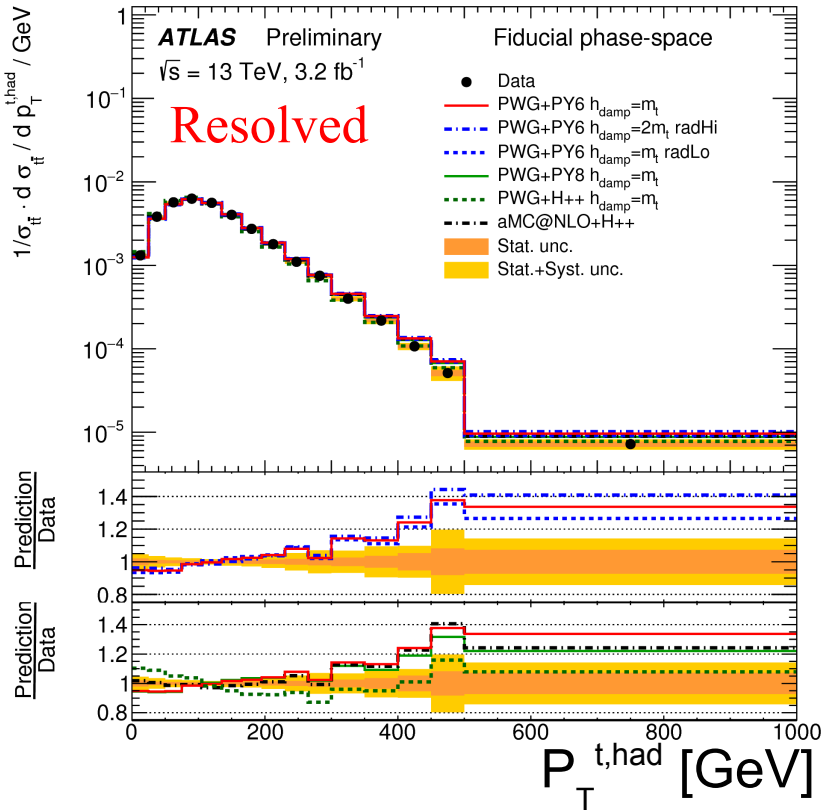


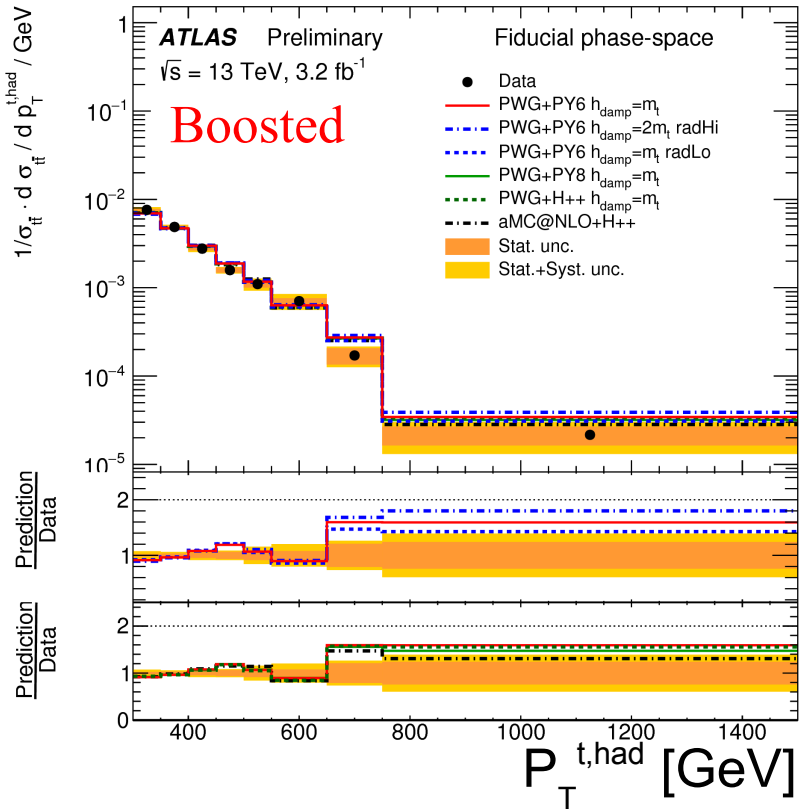
- Unfolded to particle level: fid. normalised differential $\sigma_{t\bar{t}}$ consistent with all ME+PS except Powheg-Box + Herwig++, deviates from data in $P_{T,t}$ and $m_{t\bar{t}}$(p-value=1-2%).

Differential $\sigma_{t\bar{t}}$ in lepton+jets channel

ATLAS-CONF-2016-040

- Events are divided into two regions:
  - Resolved for low P_T top-pair in $t\bar{t} \rightarrow$ lepton+>=4jets with 2bjets.
  - Boosted for high P_T >350 GeV top contained in large-R jet that selected using sub-structure technique.
- Unfolded to particle level in fid.: No MC describes data in $P_t^{t,had}$<350 GeV well.

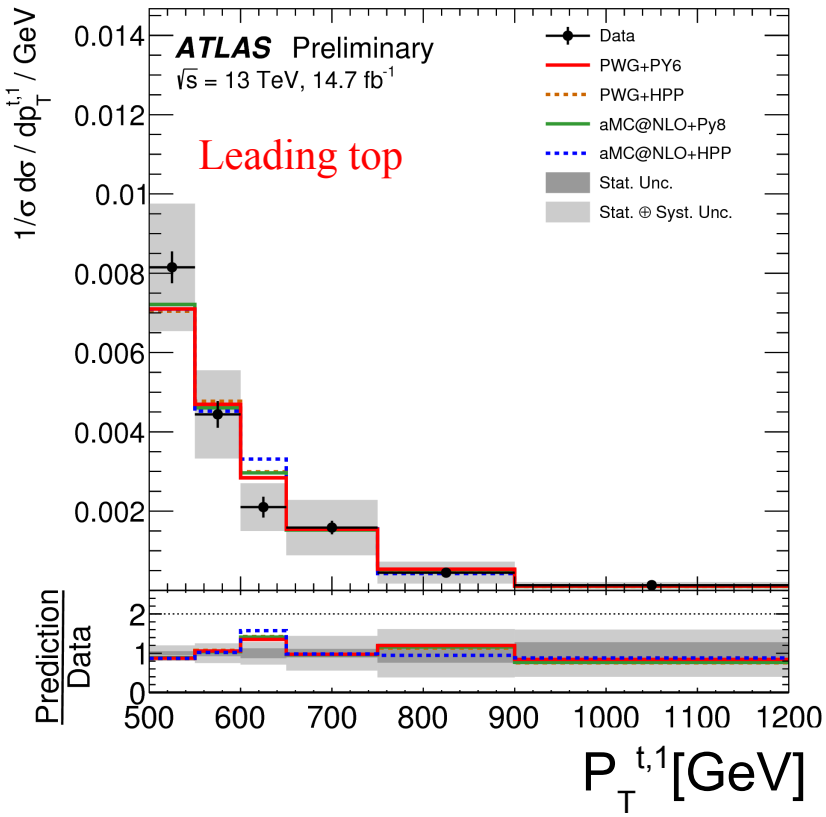


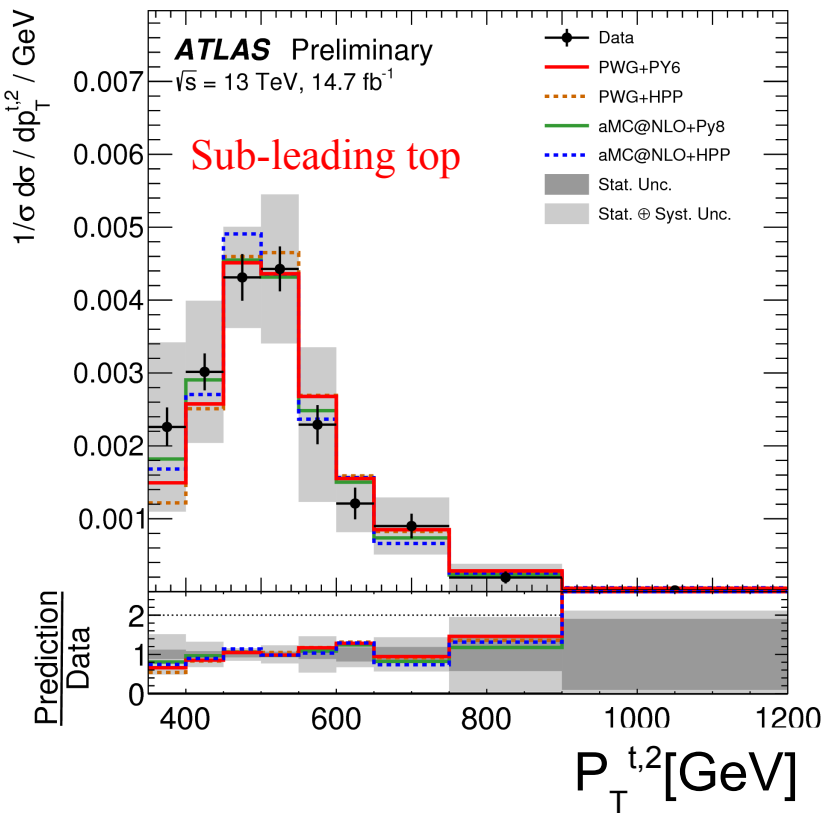


Differential $\sigma_{t\bar{t}}$ in all-hadronic channel

ATLAS-CONF-2016-100

- Selecting: two large-R jets: P_T>500,350 GeV and top candidates are separated from the multi-jet QCD using substructure technique.
- Unfolded to particle level: $\sigma_{t\bar{t}}^{fid} = 373 \pm 13^{+111}_{-92}$ fb, limited by jet energy scale.
  - normalised differential cross-section are consistent with MC predictions.

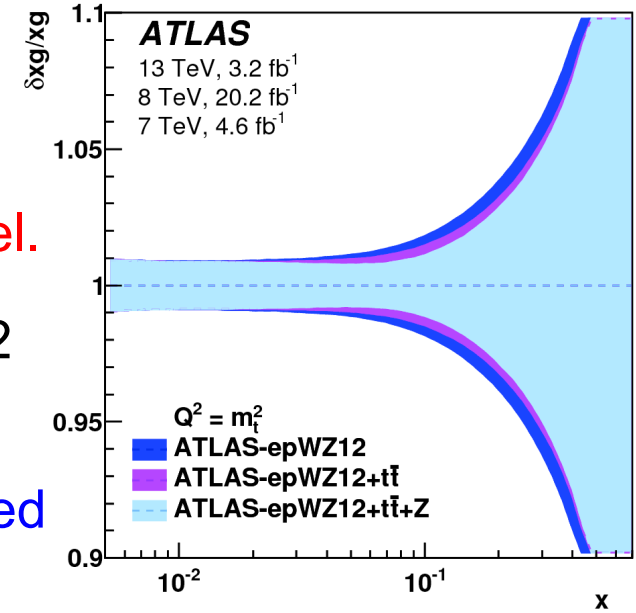


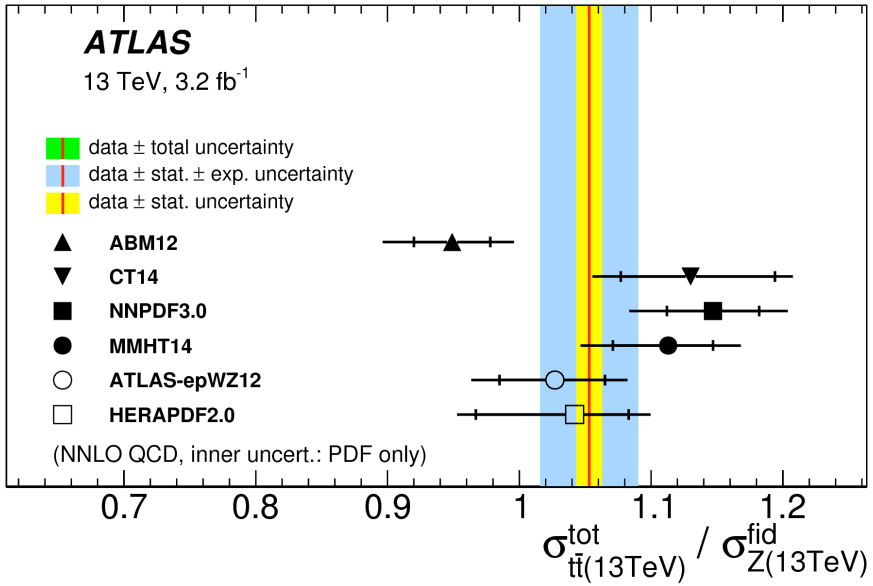


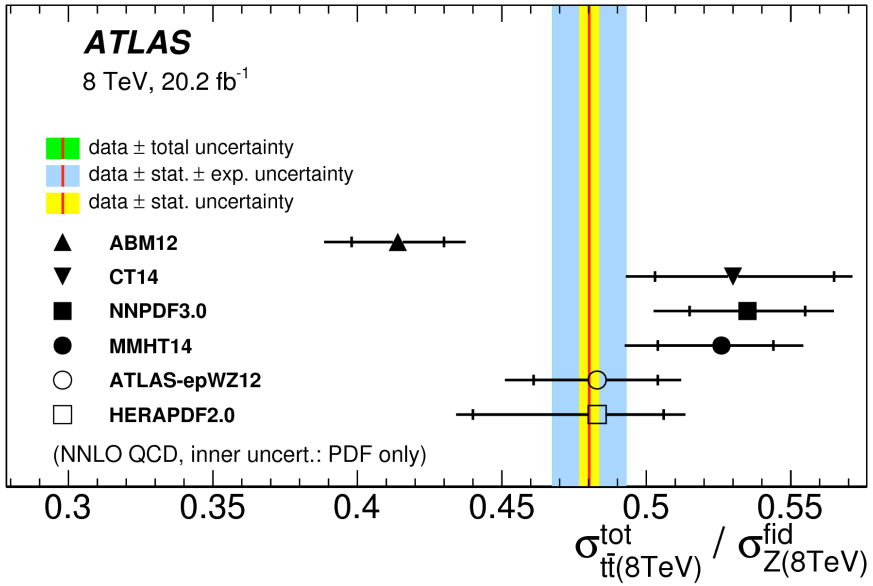
Ratio of $\sigma_{t\bar{t}}/\sigma_Z$

JHEP, 02(2017) 117.

- $\sigma_{t\bar{t}}$,σ_Z is driven by gluon(quark) in PDF.
- Ratio of cross sections is more sensitive to PDF where luminosity and some systematic would cancel.
- Ratios, double rations measured at Run1 and Run2 that compared to NNLO with different PDF sets.
  - Data are more precise than PDFs and can be used to constrain gluon content at large x region.



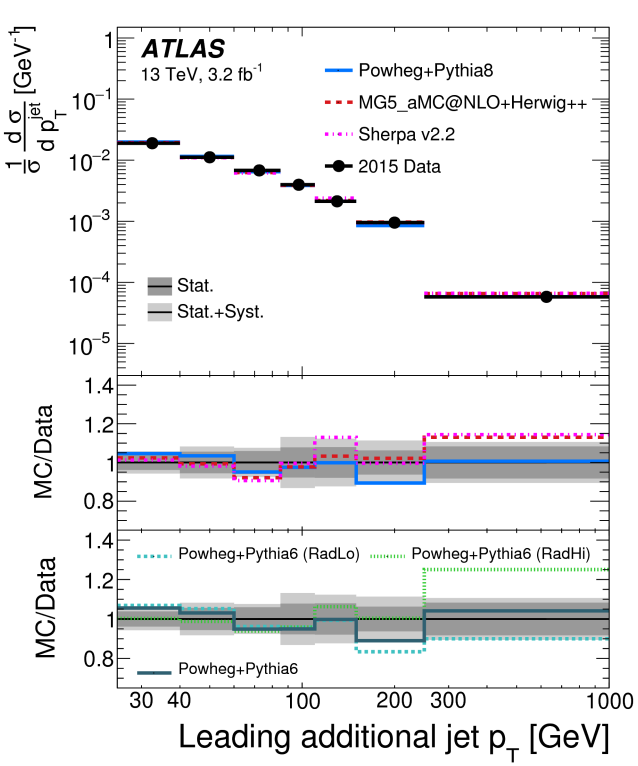


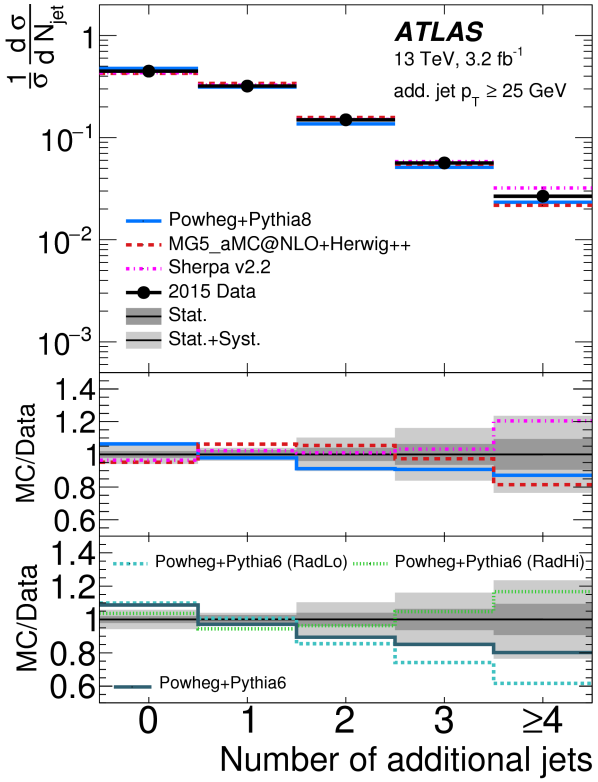


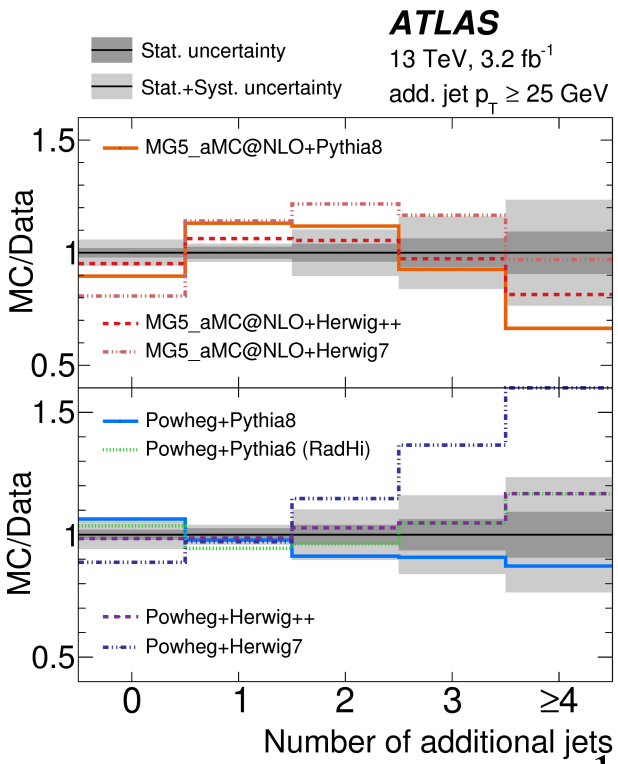
Study of $t\bar{t}$ + jets activity in eμ channel

arXiv:1610.09978, accepted by EPJC

- Important to tune PS modelling → Powheg+Pythia6(Rad-hi/Rad-lo)
- Selecting: $t\bar{t} \rightarrow e\mu$+2 bjets. → MG5_aMC@NLO+Herwg++; SHERPA v2.2.
- Count for additional jets. → Powheg+Herwig7 describes data poorly.
- Unfolded to particle-level in fid.: normalised differential $\sigma_{t\bar{t}}$ compared to MCs.







Measurement of $\sigma_{t\bar{t}W}$ and $\sigma_{t\bar{t}Z}$ at $\sqrt{S}$=13 TeV

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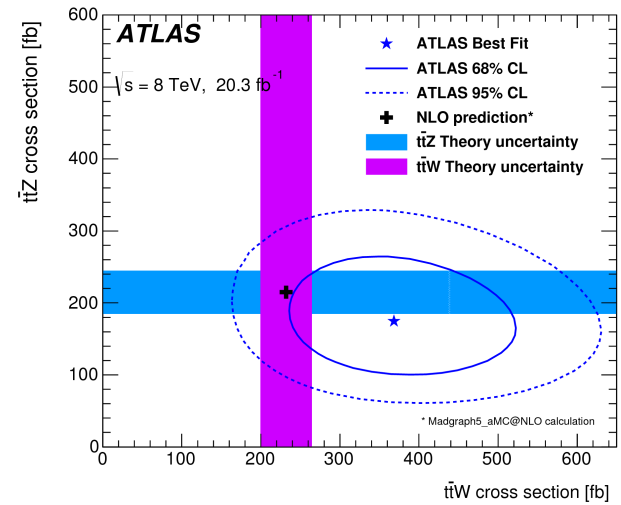
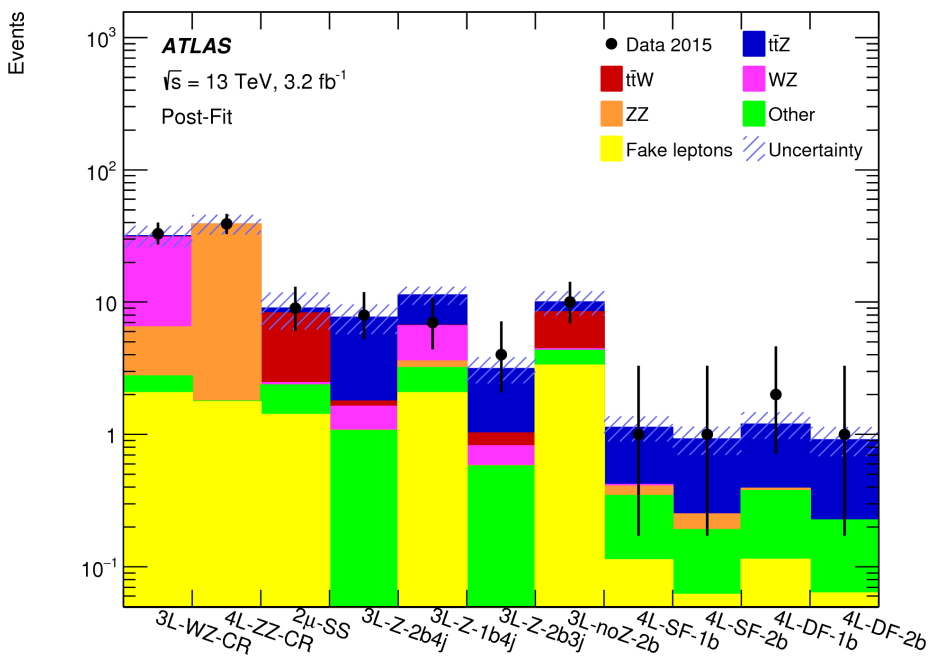
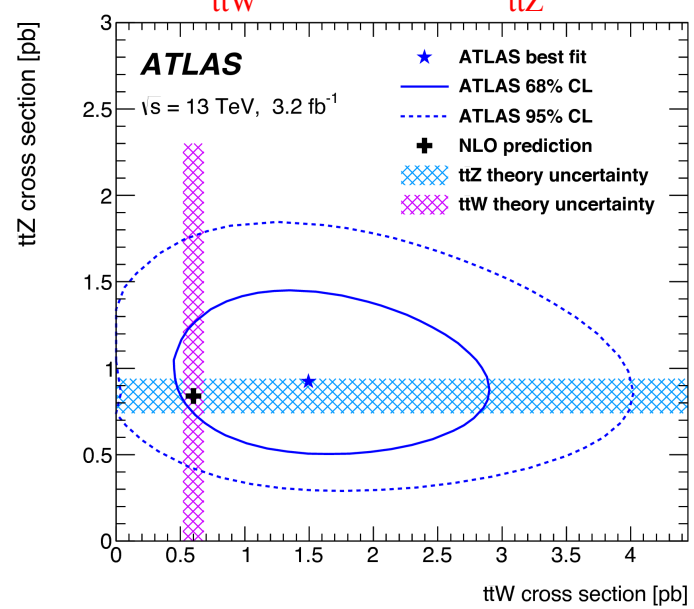
- Run2 $\sigma_{t\bar{t}Z}(\sigma_{t\bar{t}W})$=0.84±0.1(0.60±0.06)pb (NLO QCD, 1610.07922) increased significantly, sensitive to BSM.
- Select: $t\bar{t}V \rightarrow$ 2SS, 3, and 4 leptons in final states.
- Likelihood fit in signal and control regions(WZ,ZZ).
- Important background to $t\bar{t}H$ in Multi-lep channel.





Run2 data: $\sigma_{t\bar{t}W}$=1.5±0.8; $\sigma_{t\bar{t}Z}$=0.9±0.3 (pb)

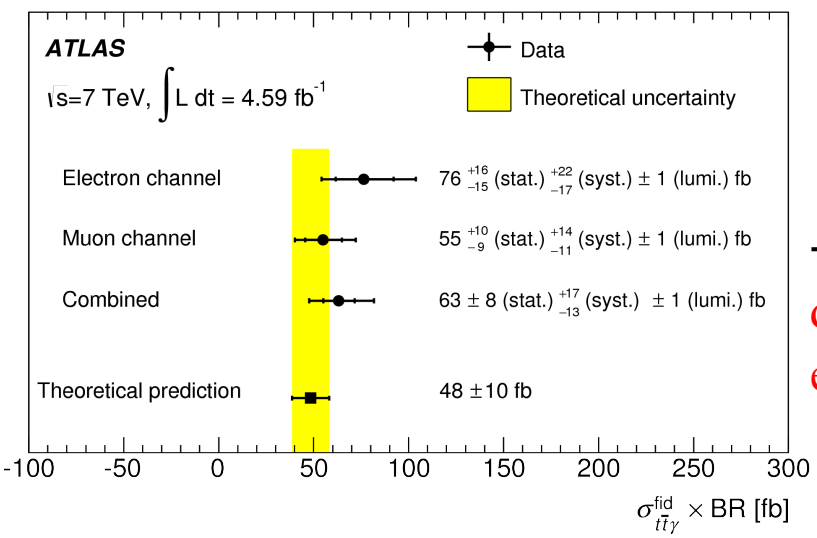


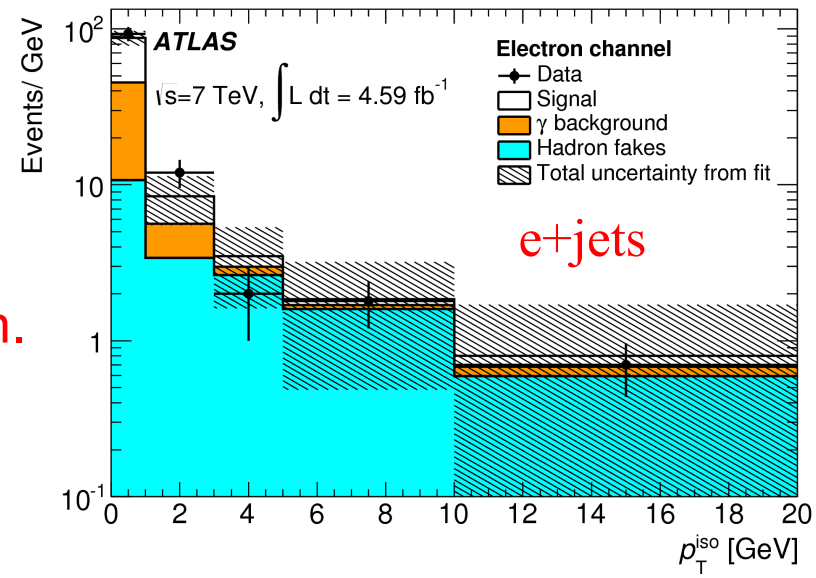
Measurement of $\sigma_{t\bar{t}\gamma}$ production $\sqrt{s}$=7 TeV

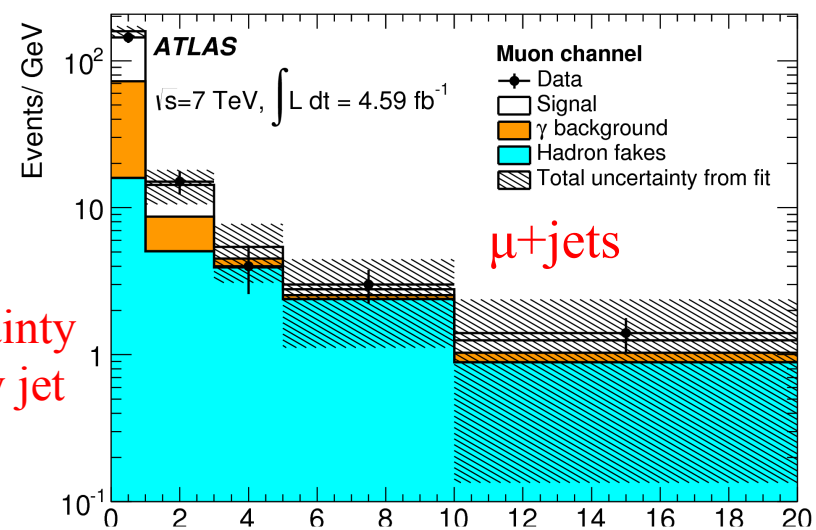
PR D91 072007

- Select isolated γ(pT>20GeV) in lep+jets.
- Sensitive to Top-γ coupling, BSM physics.
- Likelihood Fit $P_t^{iso}(\gamma)$ to extract signal and backgrounds that gives 5.3σ observation.

Contribution	Electron chan.	Muon chan.	Total
Signal	52 ± 14	100 ± 28	152 ± 31
Hadrons	38 ± 26	55 ± 38	93 ± 46
Prompt photons	41 ± 5	65 ± 9	106 ± 10
Total background	79 ± 26	120 ± 39	199 ± 47
Total	131 ± 30	220 ± 48	351 ± 59
Data candidates	140	222	362





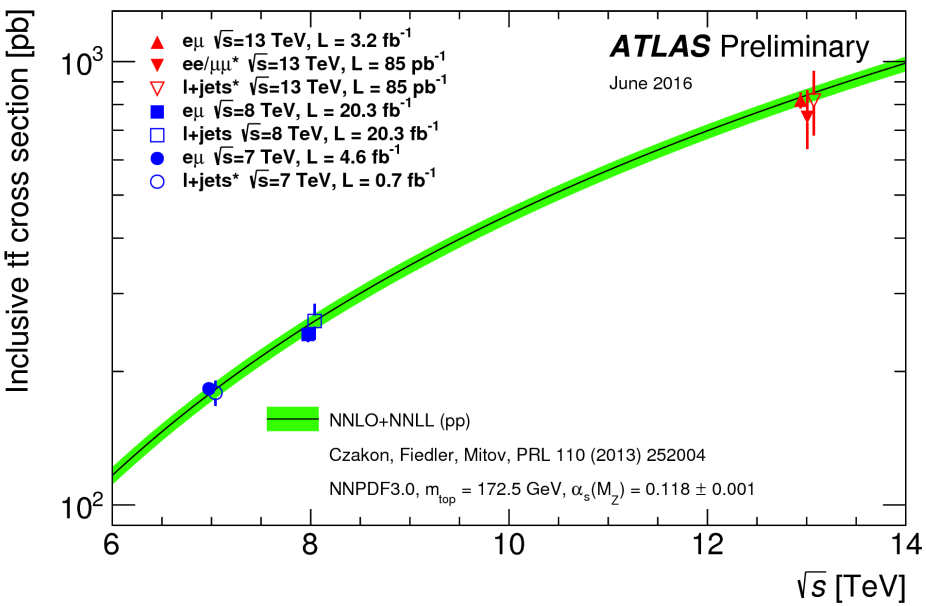


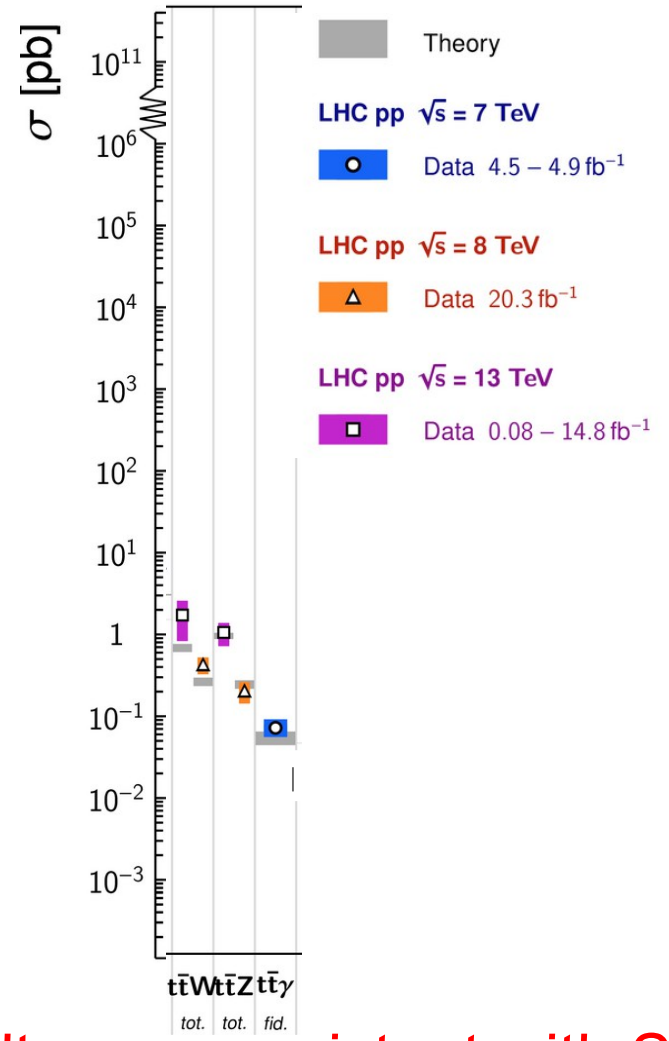
P_T^{iso}[GeV]= Σ P_t^{trk}(>1GeV) in ΔR=0.2

➔Syst uncertainty dominated by jet energy scale.

Conclusion

- Top-pair production at LHC:
  - Most are precisely measured, limited by systematic and luminosity uncertainties.
  - Ratio of $\sigma_{t\bar{t}}/\sigma_Z$ is more sensitive to PDFs.
  - Studies of $t\bar{t}$+jets, $t\bar{t}V$, $t\bar{t}\gamma$ can further constrain the higher-order corrections.





- Results are consistent with SM.
- Much more data available, stay tuned!