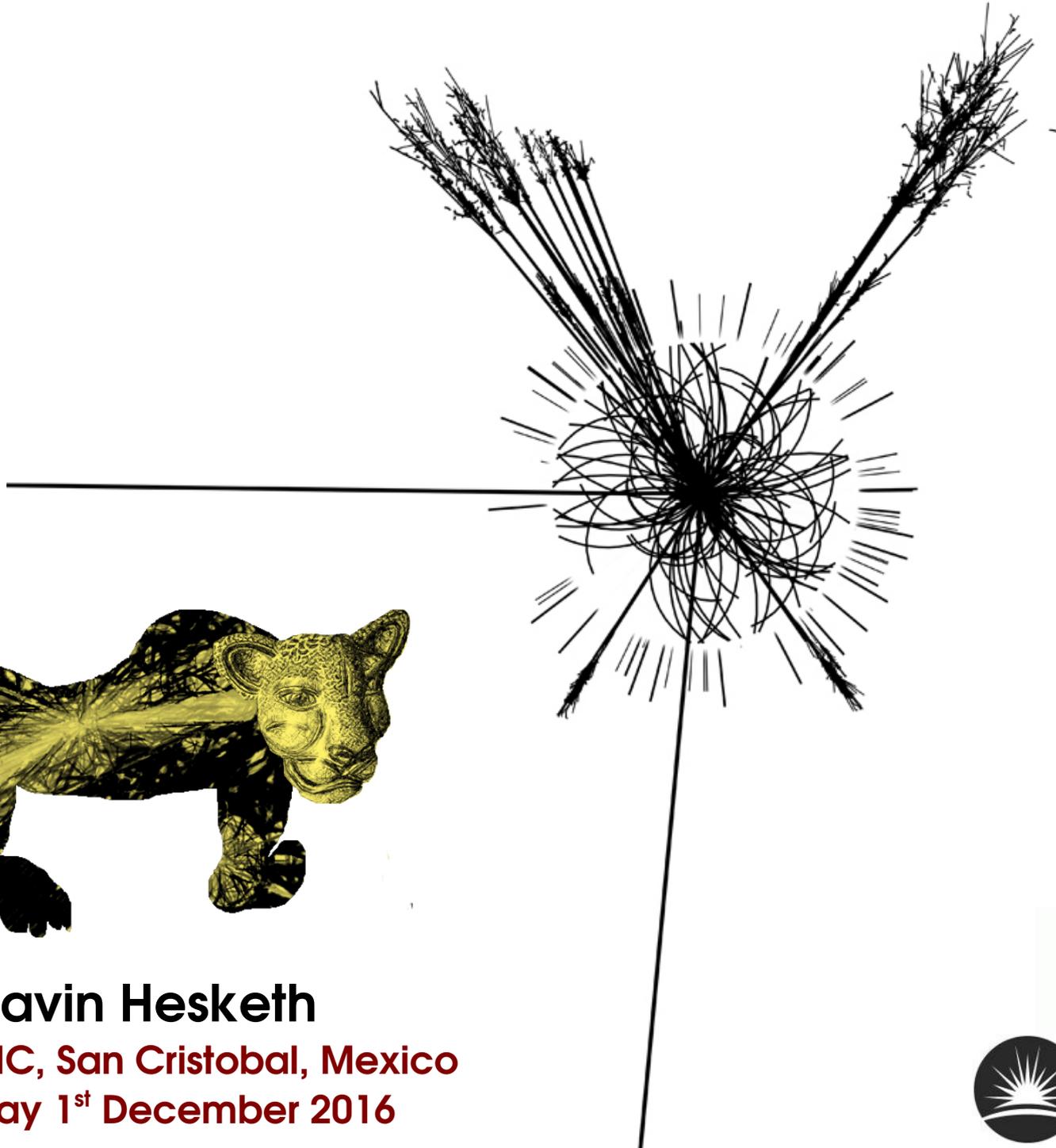


# Jet Veto Cross Section Measurements at ATLAS



**Gavin Hesketh**

**8<sup>th</sup> MPI@LHC, San Cristobal, Mexico**  
**Thursday 1<sup>st</sup> December 2016**



 **UCL**

 **THE ROYAL SOCIETY**

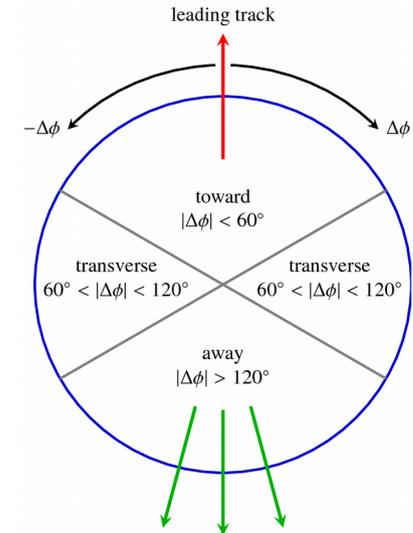


**Science & Technology**  
Facilities Council

**Jet vetoes allow a range of measurements:**

**Rapidity gaps can be used to study**

- diffraction (talk by Marek Tasevsky)
- BFKL vs DGLAP QCD evolution (no new results)

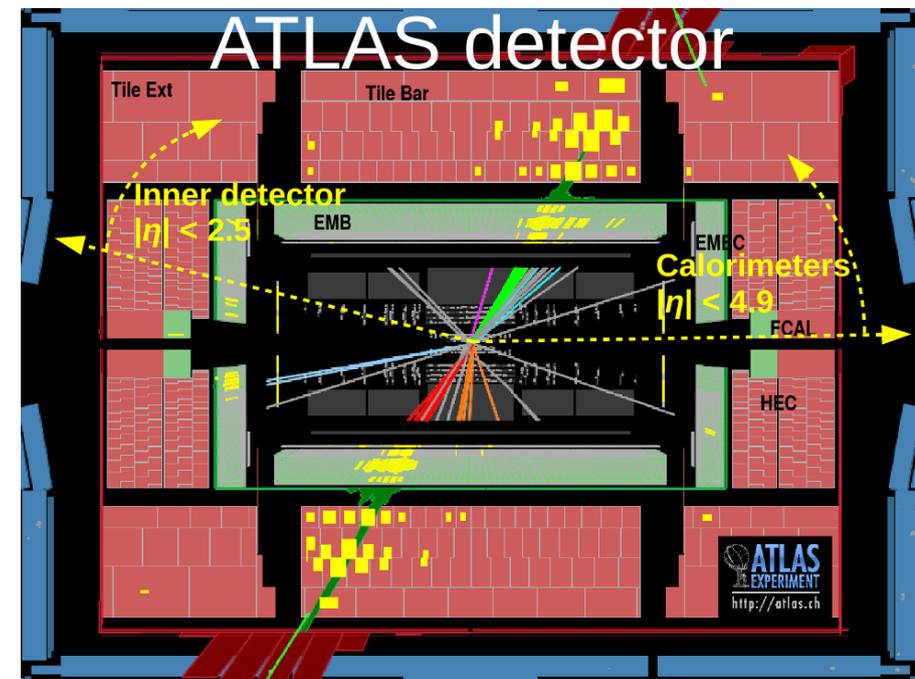


**Jet vetoes provide a tool to study “soft” physics**

- see talks on underlying event

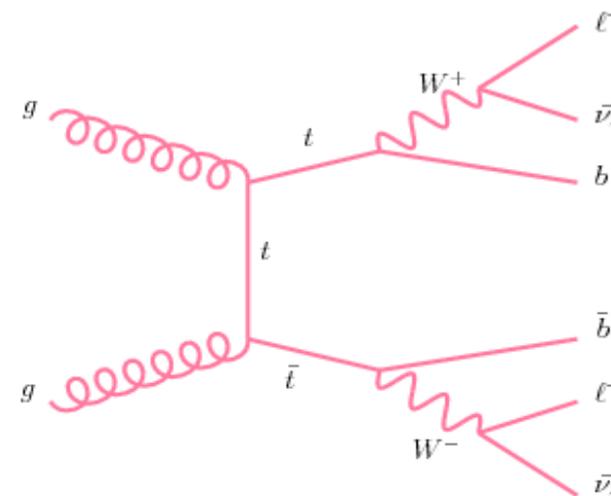
**Look for additional activity in events**

- MPI
- ISR
- underlying event
- what fraction of events pass a jet veto?

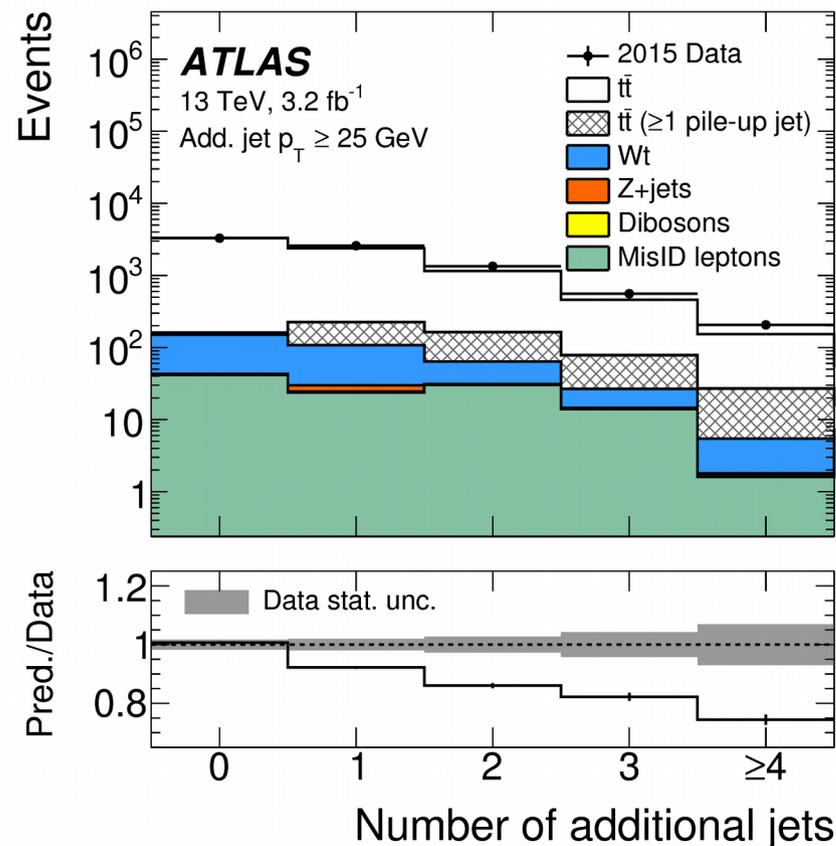
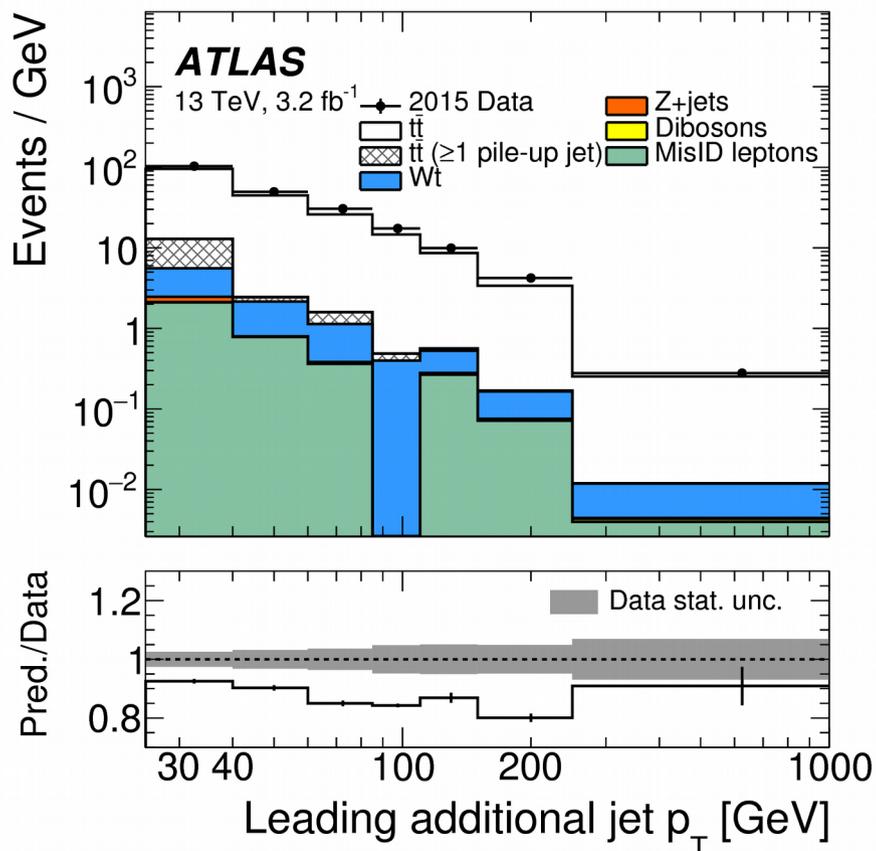


## Measurement of additional jets in top pair production

- use e+mu channel
- require 2 b-jets
- additional jets with  $p_T > 25$  GeV,  $|\eta| < 2.5$



JHEP 12 (2015) 105

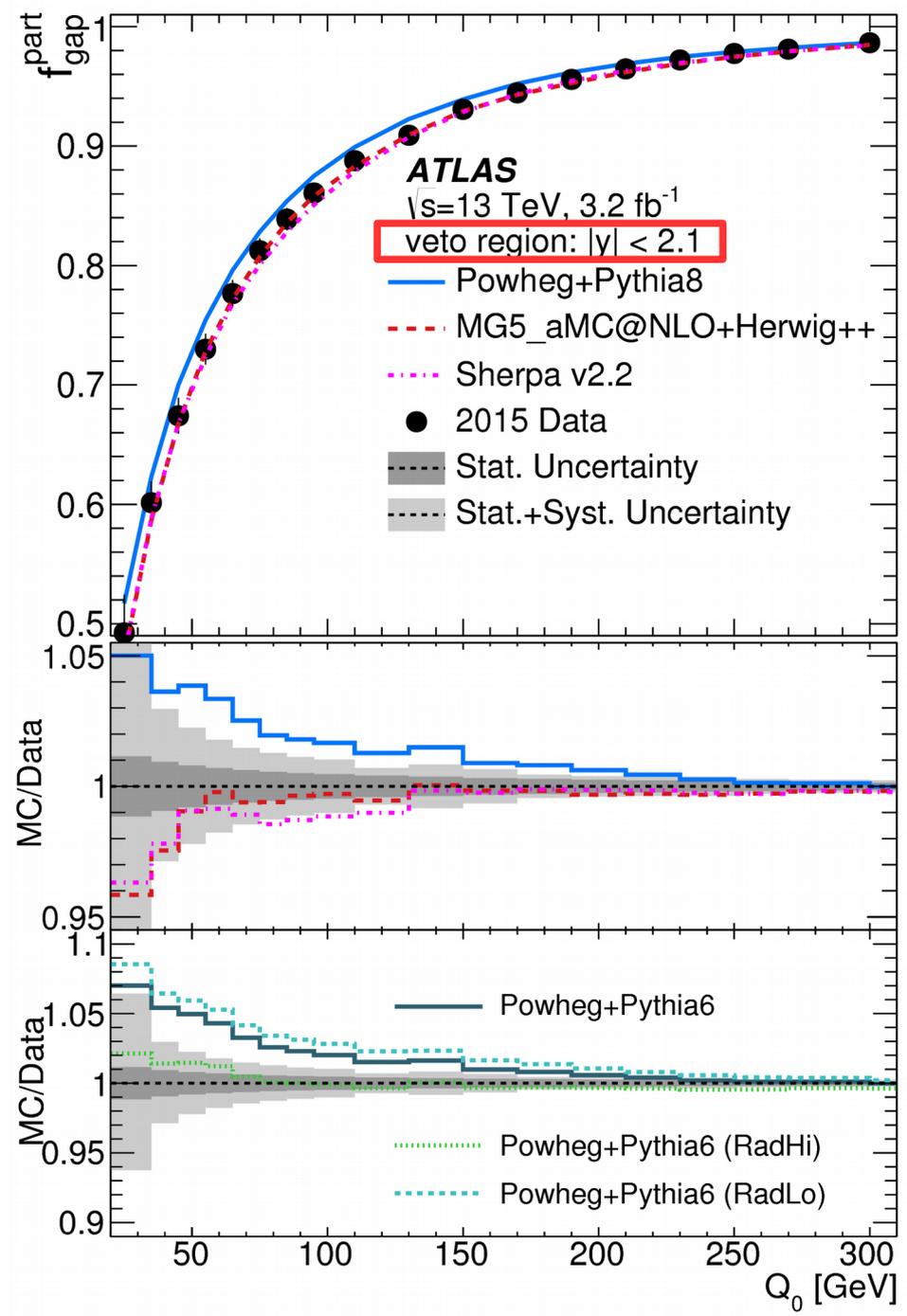


Define gap fraction based on jet pT cut,  $Q_0$

$$f_{\text{gap}}(Q_0) = \frac{n(Q_0)}{N_{t\bar{t}}}$$

Also defined as cut on sum of additional jets,  $Q_{\text{sum}}$   
 And as a function of  $M(e\mu b\bar{b})$   
 → see paper

**JHEP 12 (2015) 105**

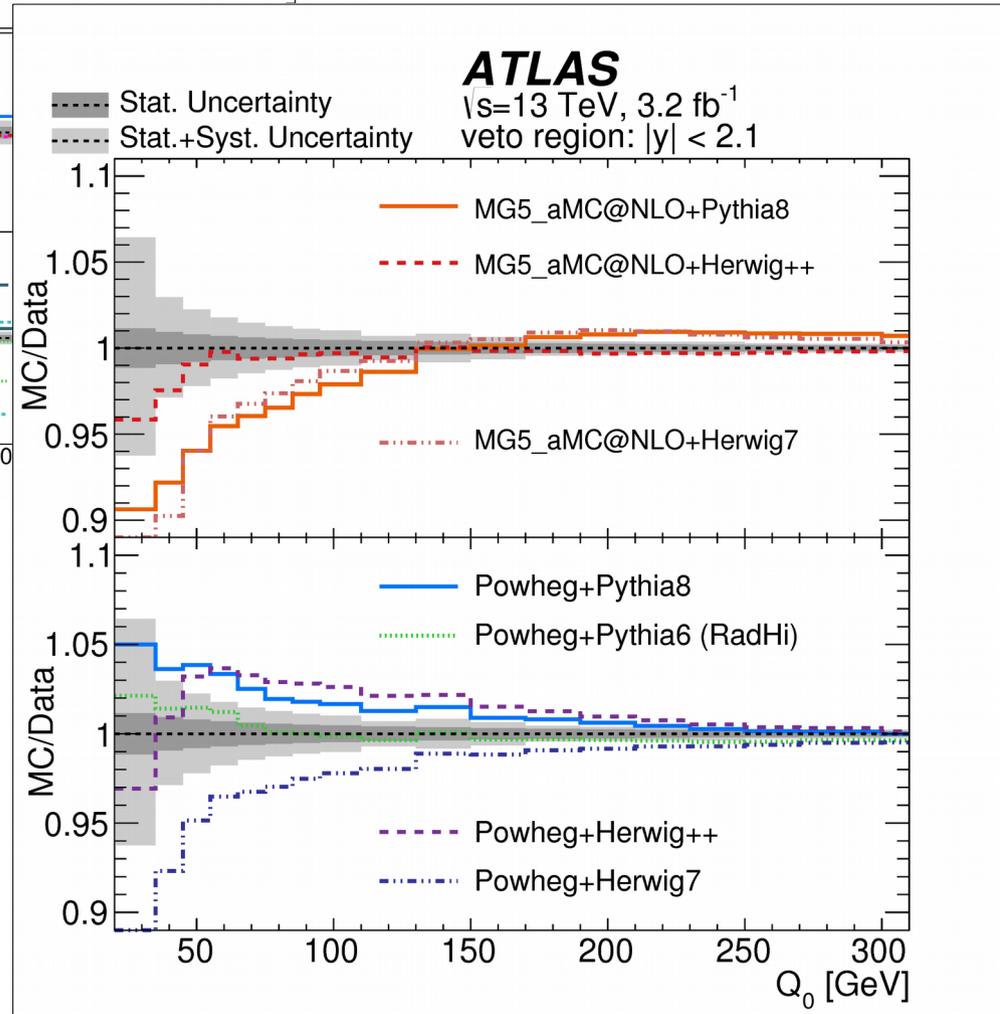
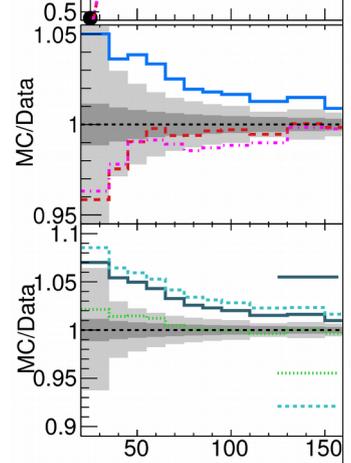
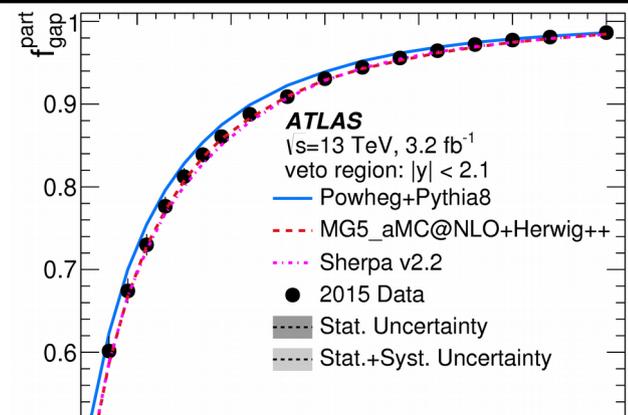


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**JHEP 12 (2015) 105**





# And now...



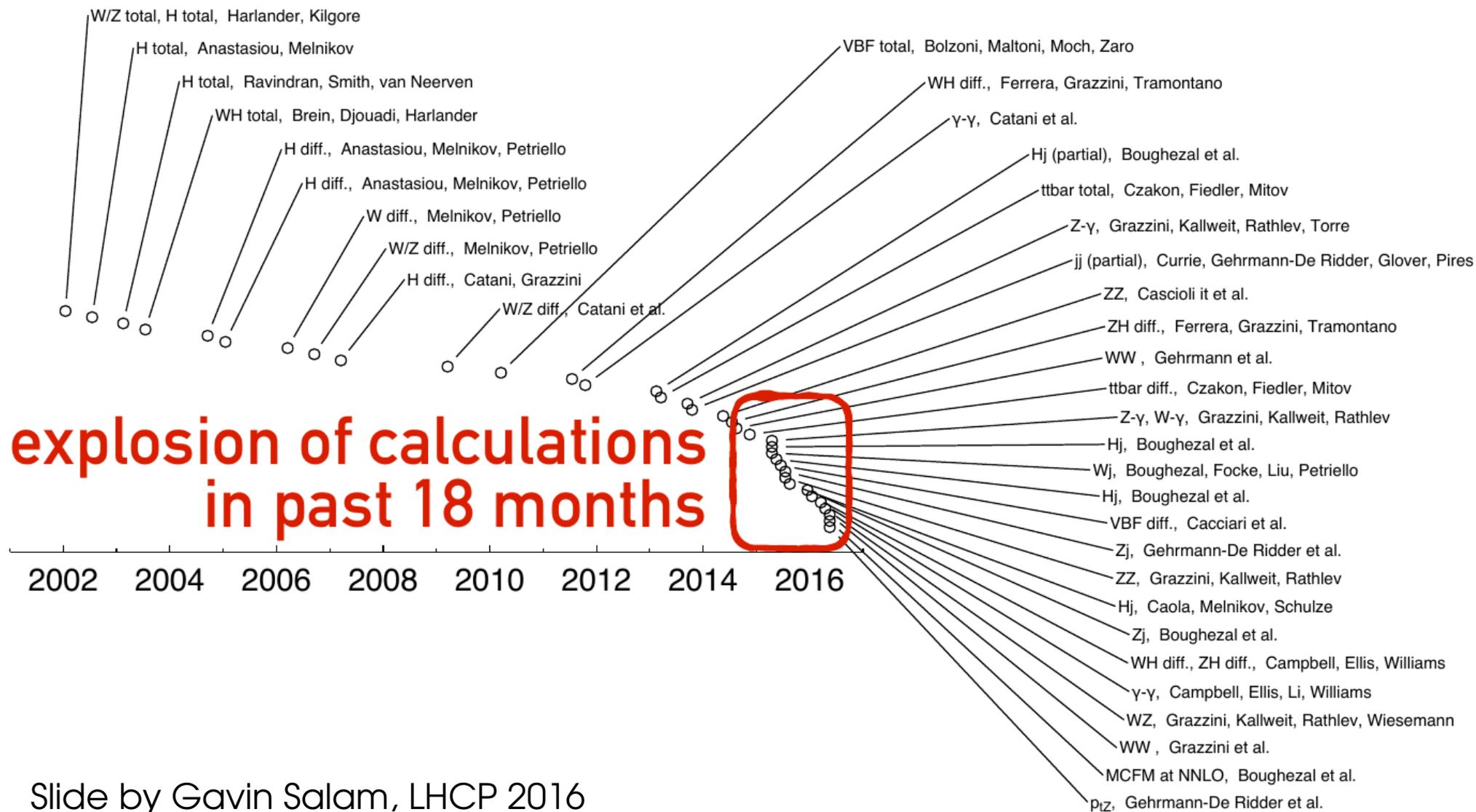
## Large LHC datasets make diboson (ZZ, WZ, WW) precision physics

- leptonic decay modes (e and mu)
  - low branching fractions, but experimentally clean
- entering the era of differential cross sections
- NNLO “revolution” producing new predictions

## NNLO hadron-collider calculations v. time

*let me know of any significant omissions*

Gavin Salam



## Large LHC datasets make diboson (ZZ, WZ, WW) precision physics

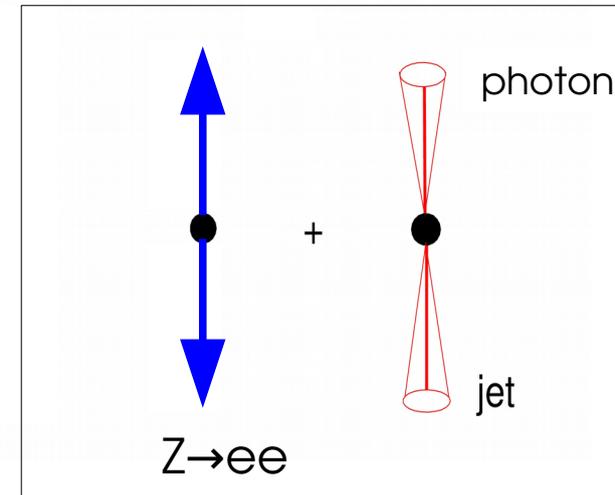
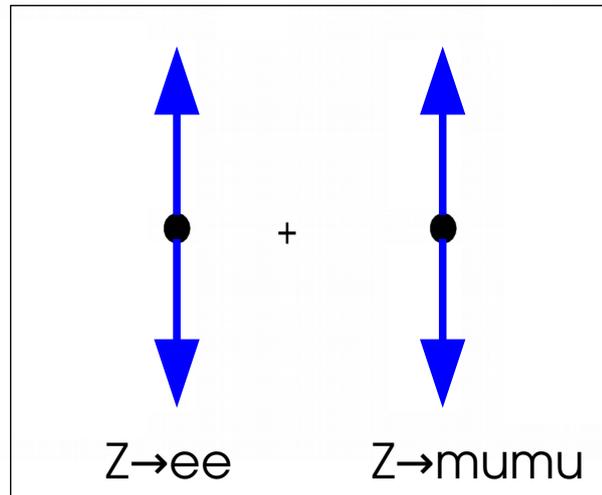
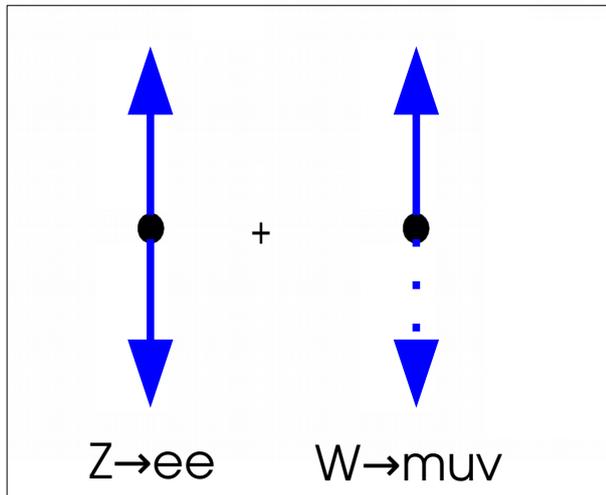
- leptonic decay modes (e and mu)
  - low branching fractions, but experimentally clean
- entering the era of differential cross sections
- NNLO "revolution" producing new predictions

## Test QCD predictions for diboson production

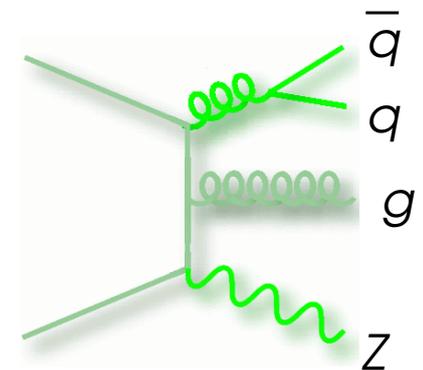
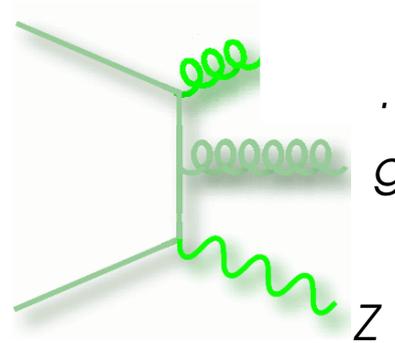
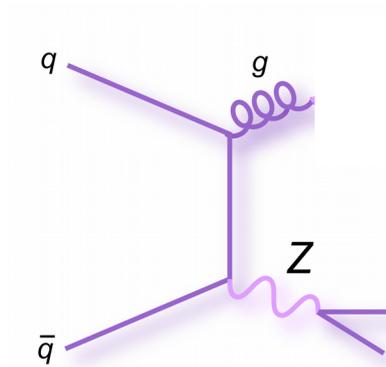
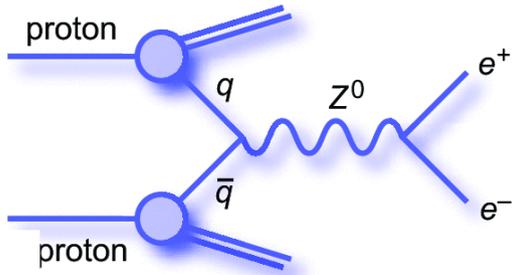
- and the electroweak gauge couplings of the Standard Model

## Also interesting targets for MPI studies

- veto additional jets to simplify



While **NNLO** represents the state of the art,  
many process are calculated using **merged (N)LO multi-leg** samples



### Complex events with several scales:

- vector boson mass
- jet  $p_T$

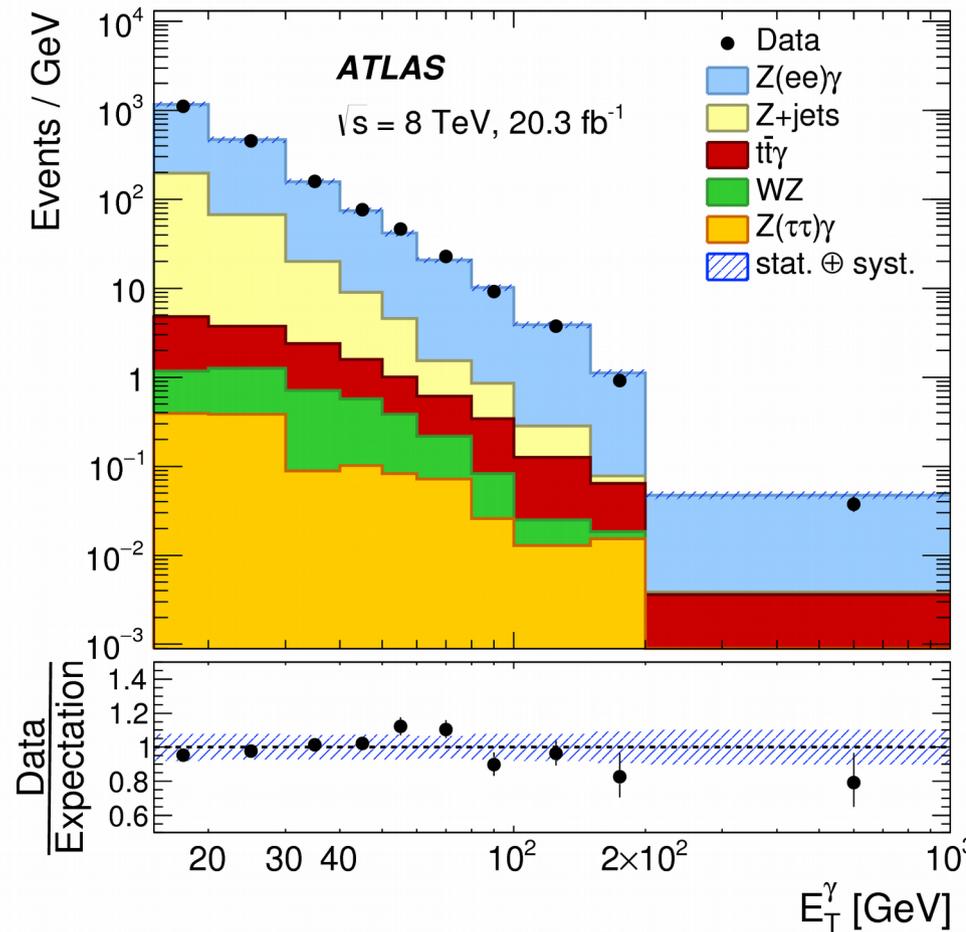
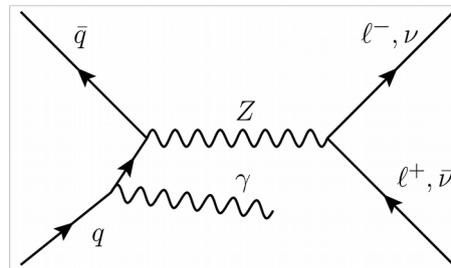
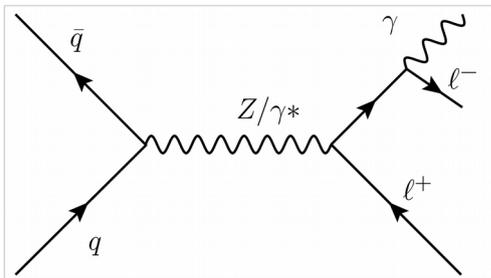
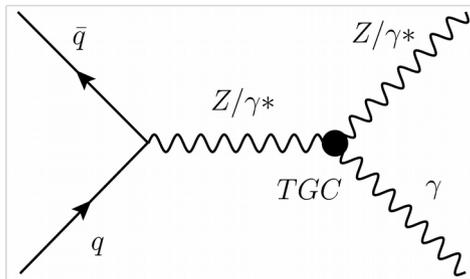
### Study exclusive jet bins:

- ie veto additional jets
- control the scales, test the models

## Measurement of Z( $\rightarrow$ ll/vv) + $\gamma/\gamma\gamma$

- Isolated photons,  $E_T > 15$  GeV
- Split into inclusive and zero-jet:
  - jets with  $p_T > 30$  GeV,  $|\eta| < 4.5$

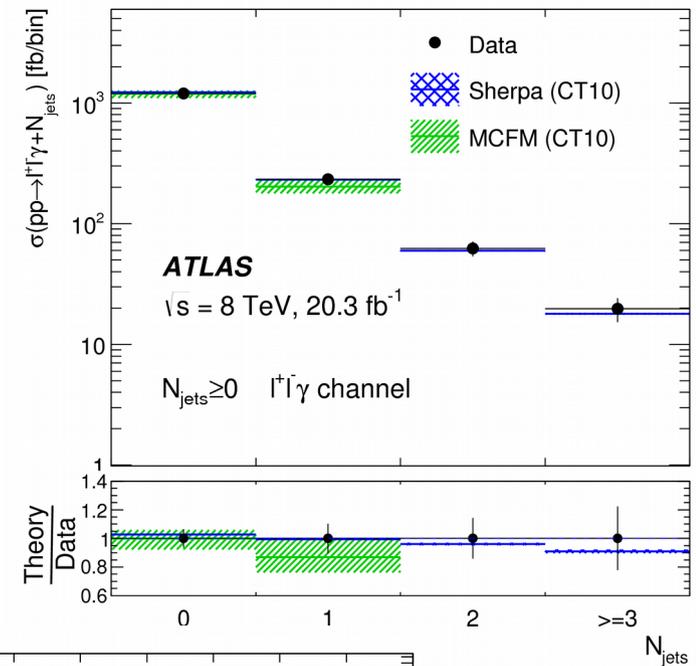
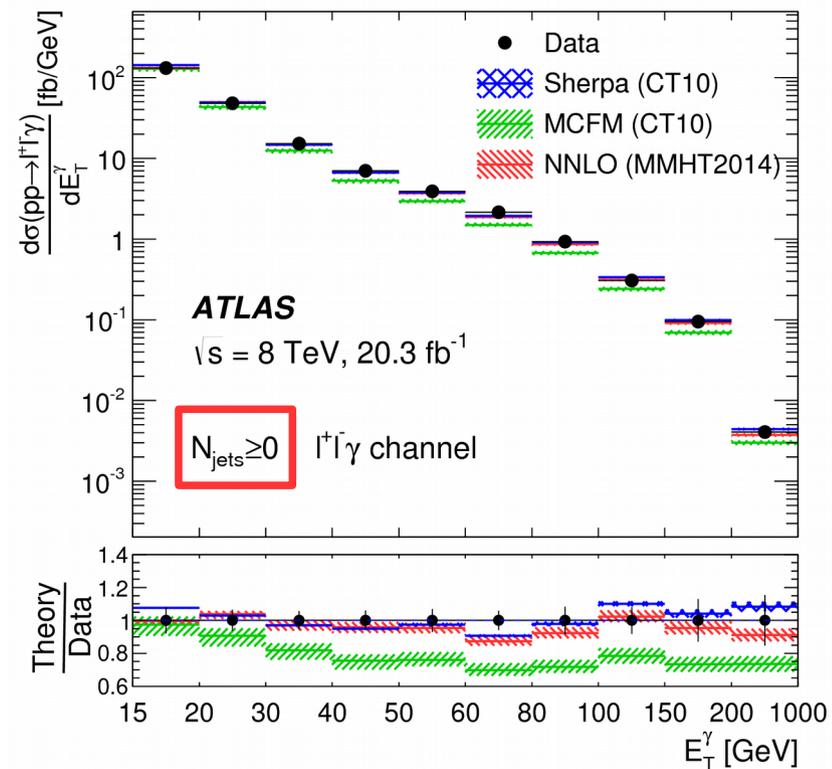
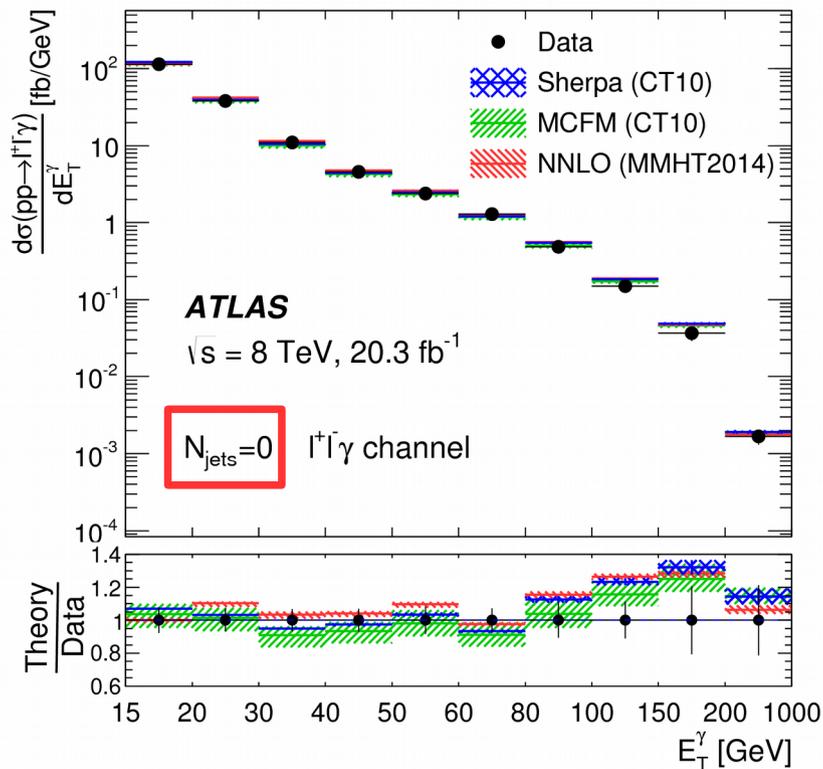
## Testing QCD and TGCs



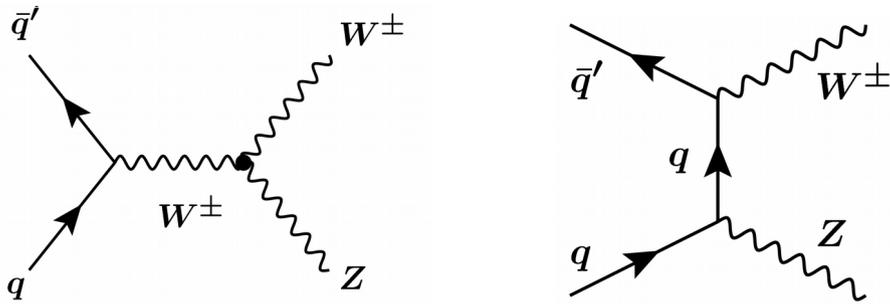
## Theoretical predictions from

- Sherpa 1.4 (LO merged 0-3 jets)
- MCFM NLO
- NNLO Grazzini, Kallweit & Rathlev, JHEP 1507 (2015) 085

Phys.Rev.D 93, 112002 (2016)



## Z+W diboson analysis at 13 TeV

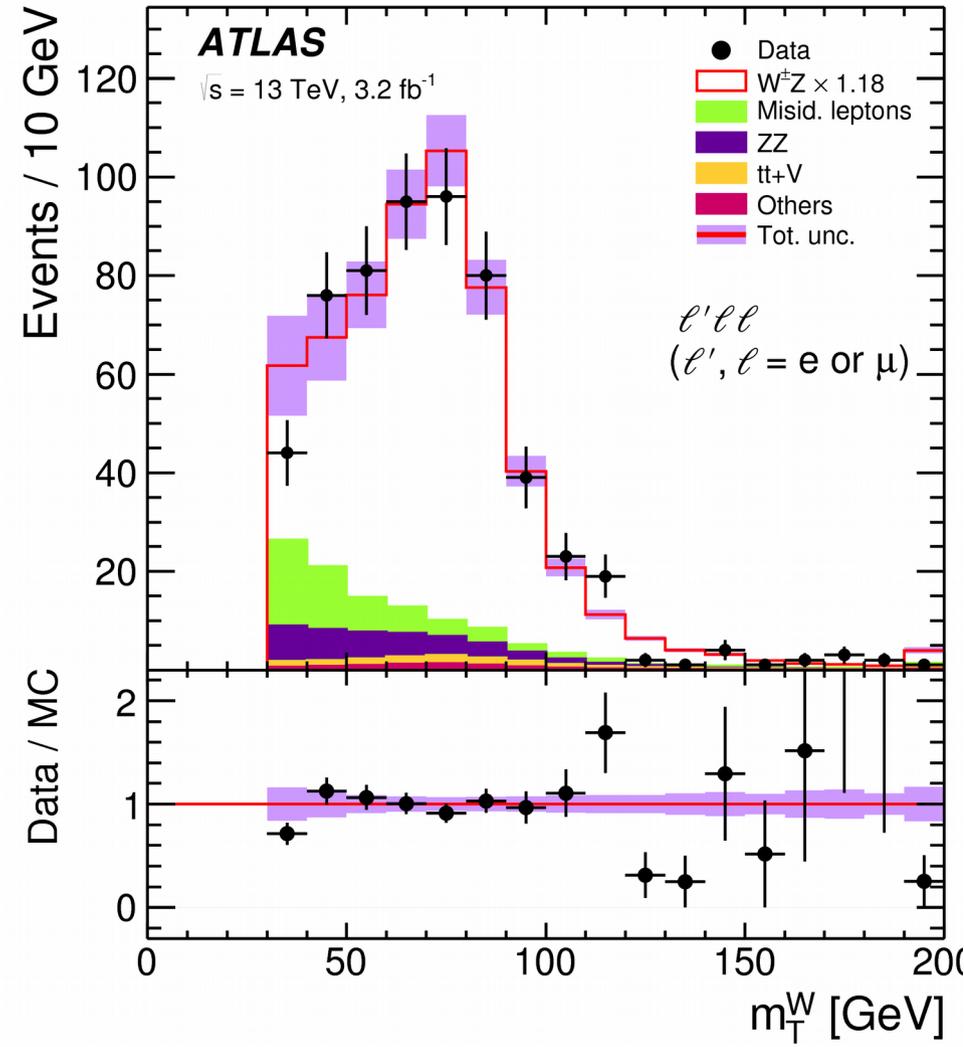


$Z \rightarrow ll$ : lepton  $p_T > 15$  GeV,  $81 < M_{ll} < 101$  GeV

$W \rightarrow lv$ : lepton  $p_T > 20$  GeV,  $M_T > 30$  GeV

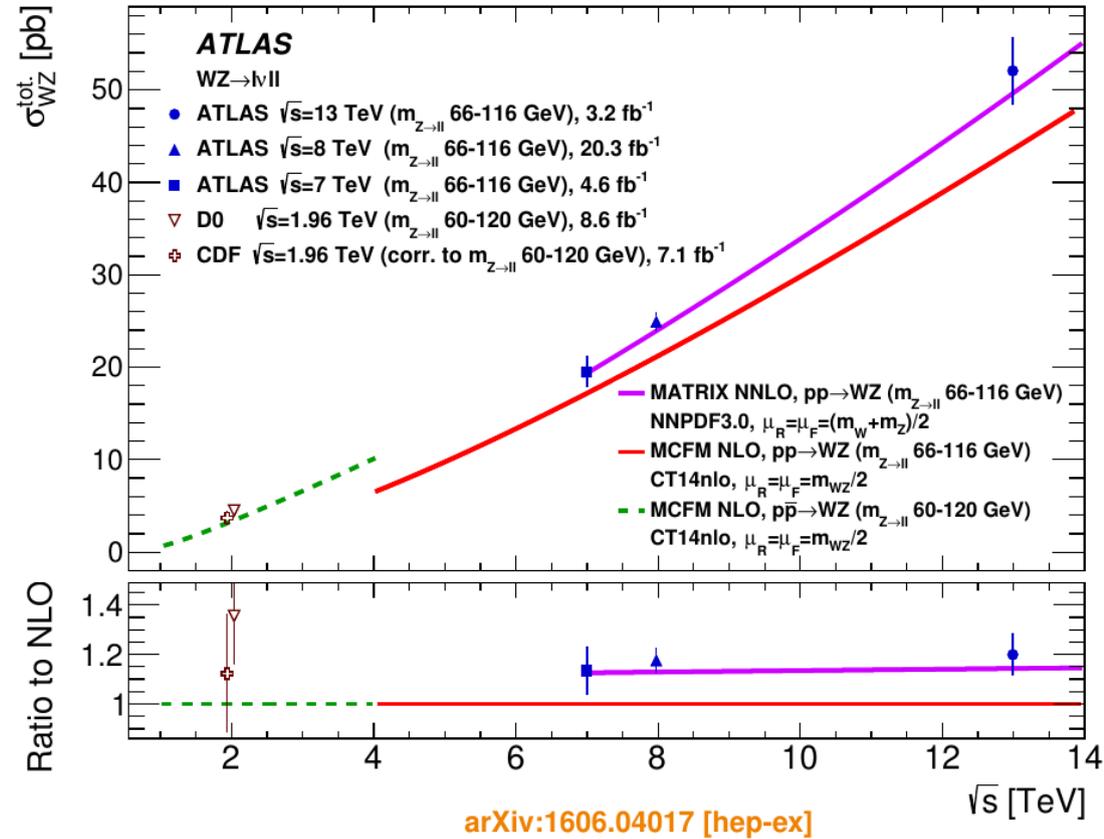
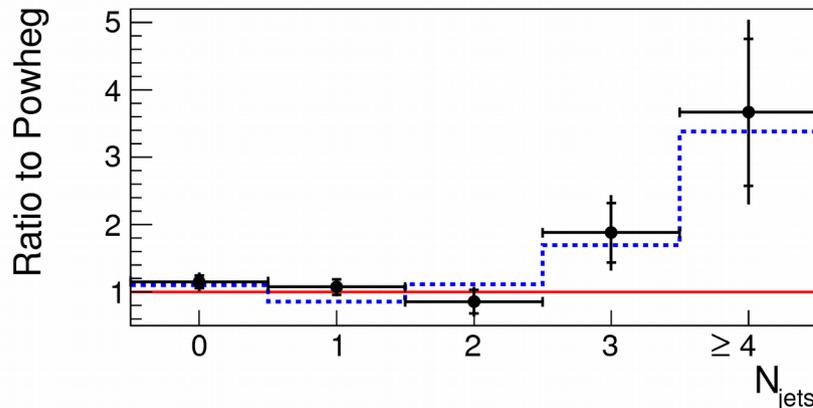
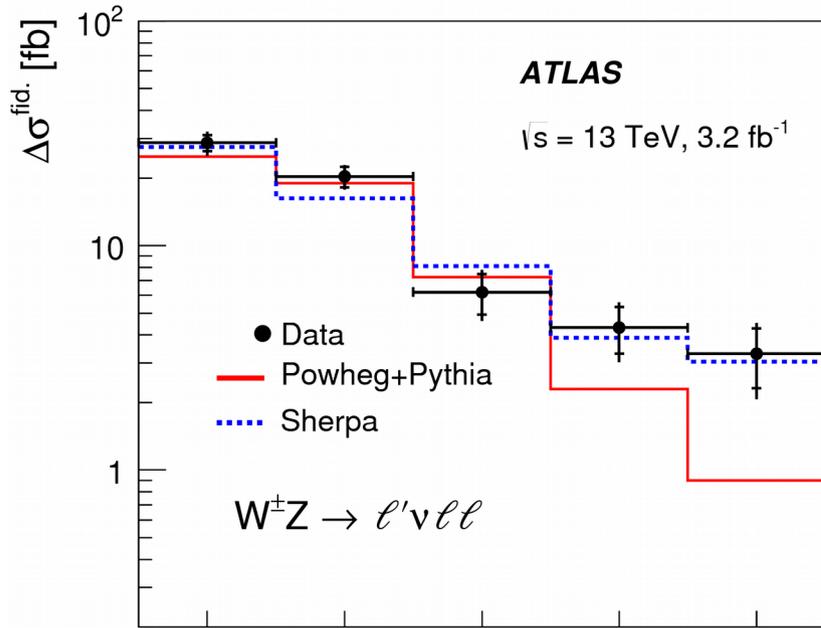
all lepton  $|\eta| < 2.5$

$\Delta R(l, l) > 0.2$  (0.3) for the Z (W and Z) leptons



New NNLO calculation agrees with data

Phys.Lett.B. 762 (2016) 1



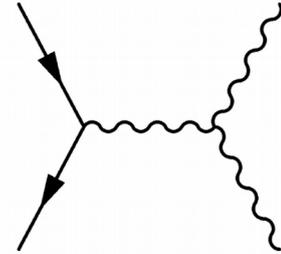
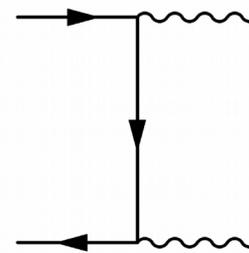
Measurement also broken into exclusive jet bins  
- jets with  $p_T > 25 \text{ GeV}$ ,  $|\eta| < 4.5$

Sherpa: WZ +  $\leq 3$  jets @ LO

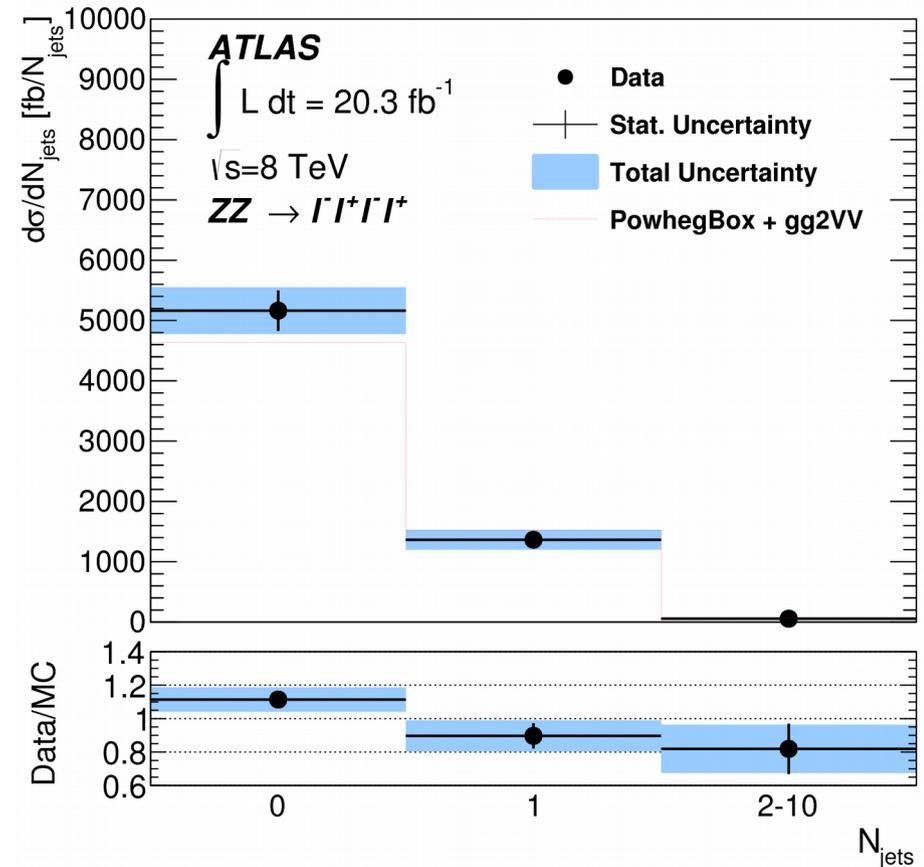
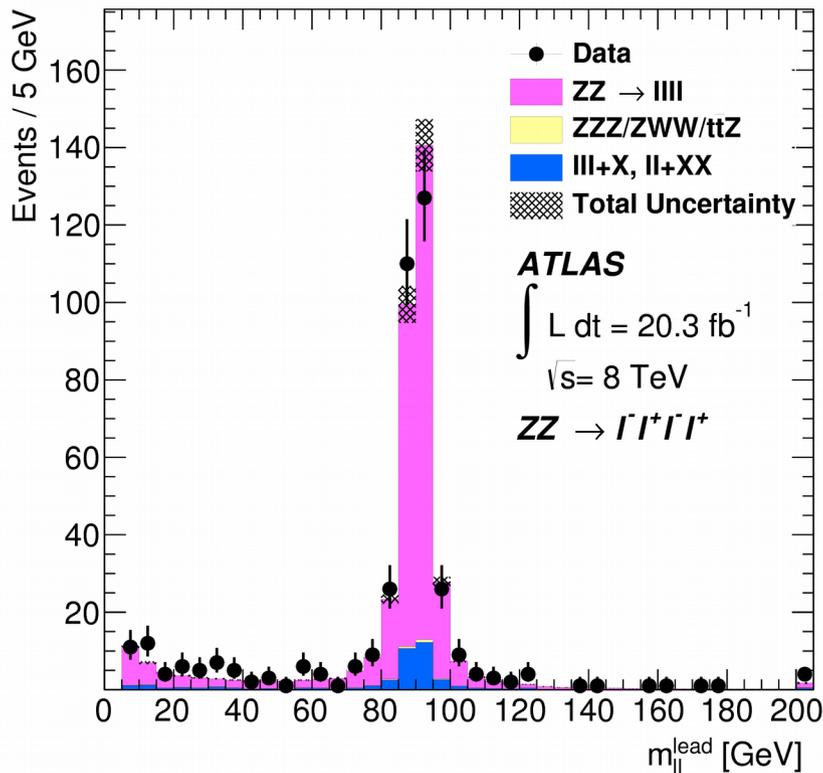
Powheg: WZ @ NLO

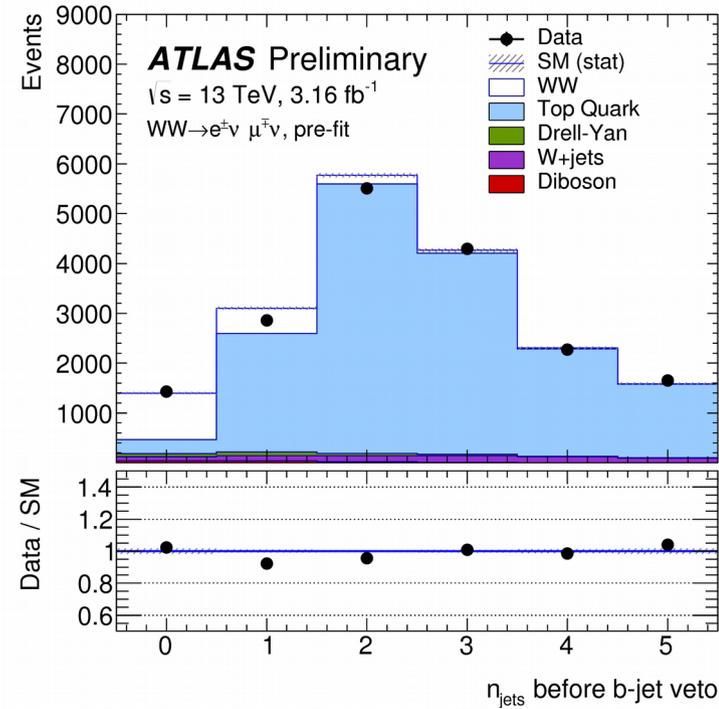
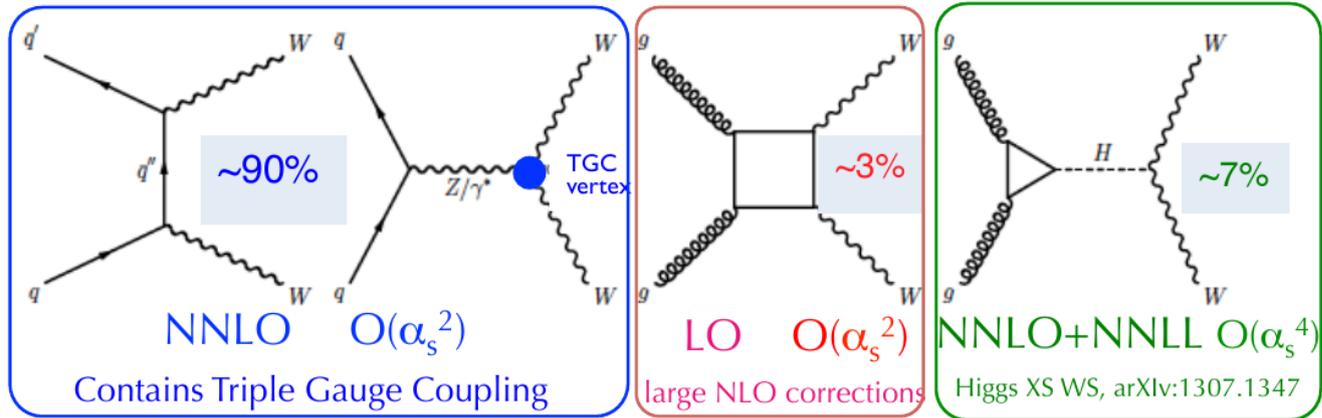
## Lowest stats, but very clean

- and fully reconstruct the Zs
- 4 leptons, dilepton masses 66-116 GeV
- also 2 lepton, 2 neutrino with jet veto
- jets with  $|\eta| < 4.5$ ,  $p_T > 25$  GeV



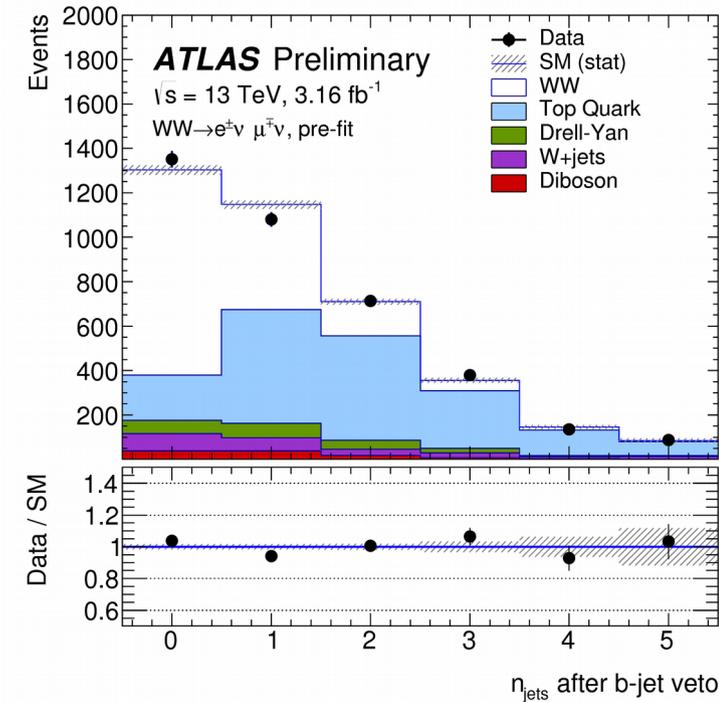
arXiv:1610.07585





## Leptonic decay modes:

Fiducial selection requirement	Cut value
$p_T^\ell$	$> 25 \text{ GeV}$
$ \eta_\ell $	$< 2.5$
$m_{e\mu}$	$> 10 \text{ GeV}$
Number of jets with $p_T > 25(30) \text{ GeV},  \eta  < 2.5(4.5)$	0
$E_{T, \text{Rel}}^{\text{miss}}$	$> 15 \text{ GeV}$
$E_T^{\text{miss}}$	$> 20 \text{ GeV}$



**Jet veto applied due to overwhelming top background!**

## Analysis of 8 TeV data

- broken down into exclusive jet bins

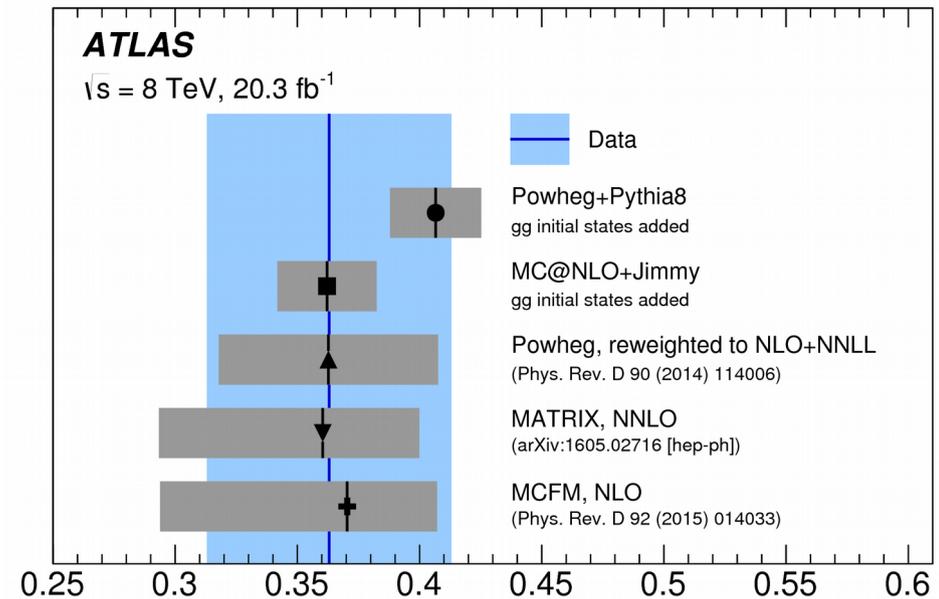
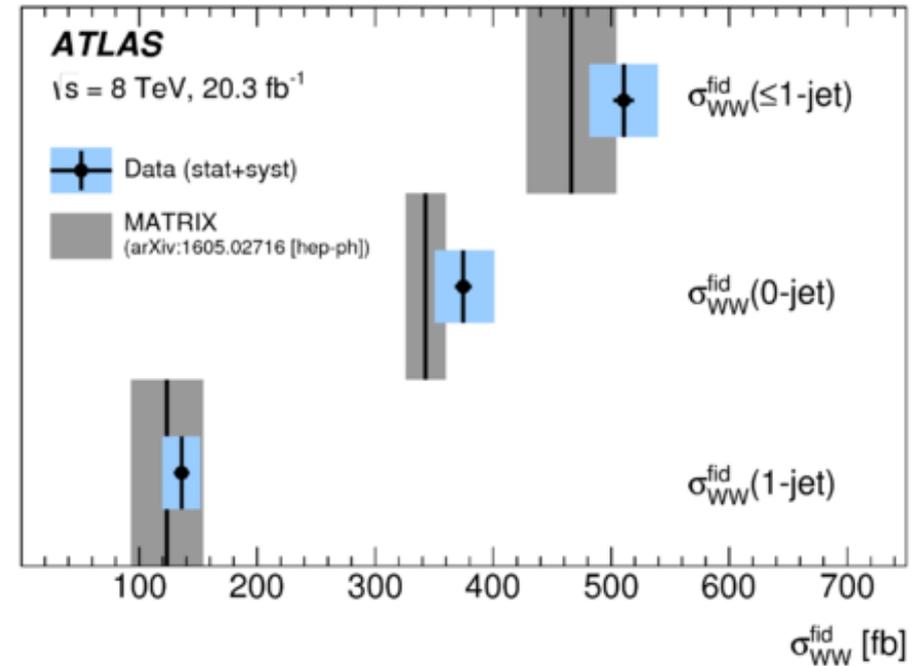
**Ratio:** cancellation of some systematics

## Particle level predictions from:

- Powheg + Pythia 8
- MC@NLO + Jimmy
- Powheg with reweighted  $p_T(WW)$

## Parton level predictions from:

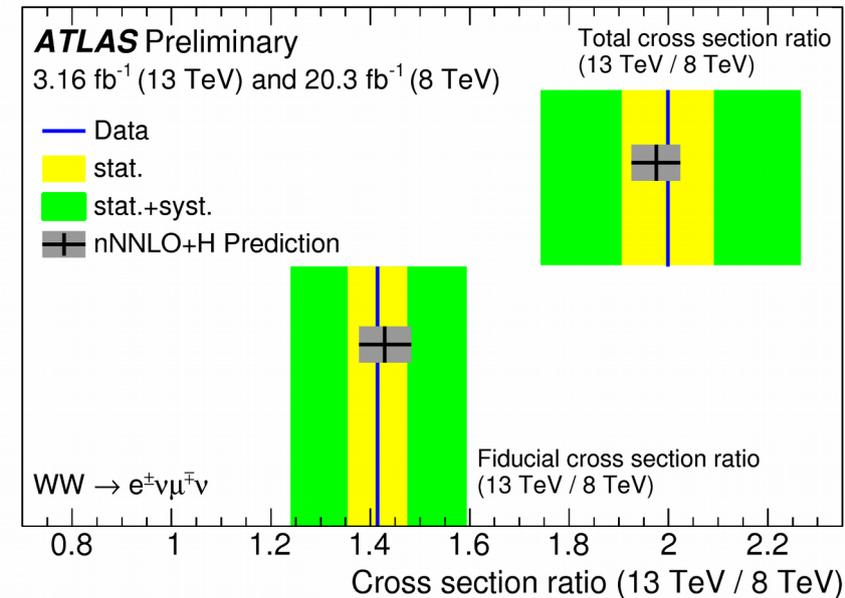
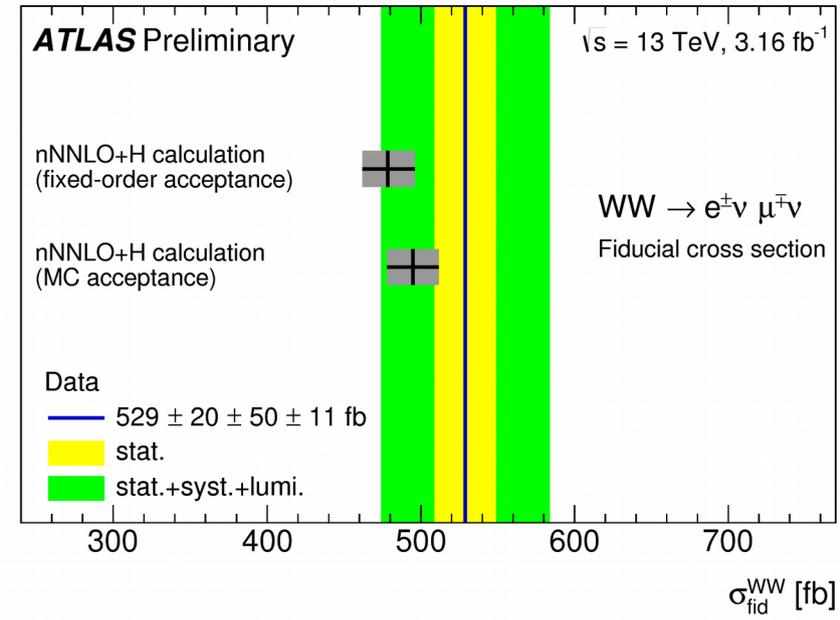
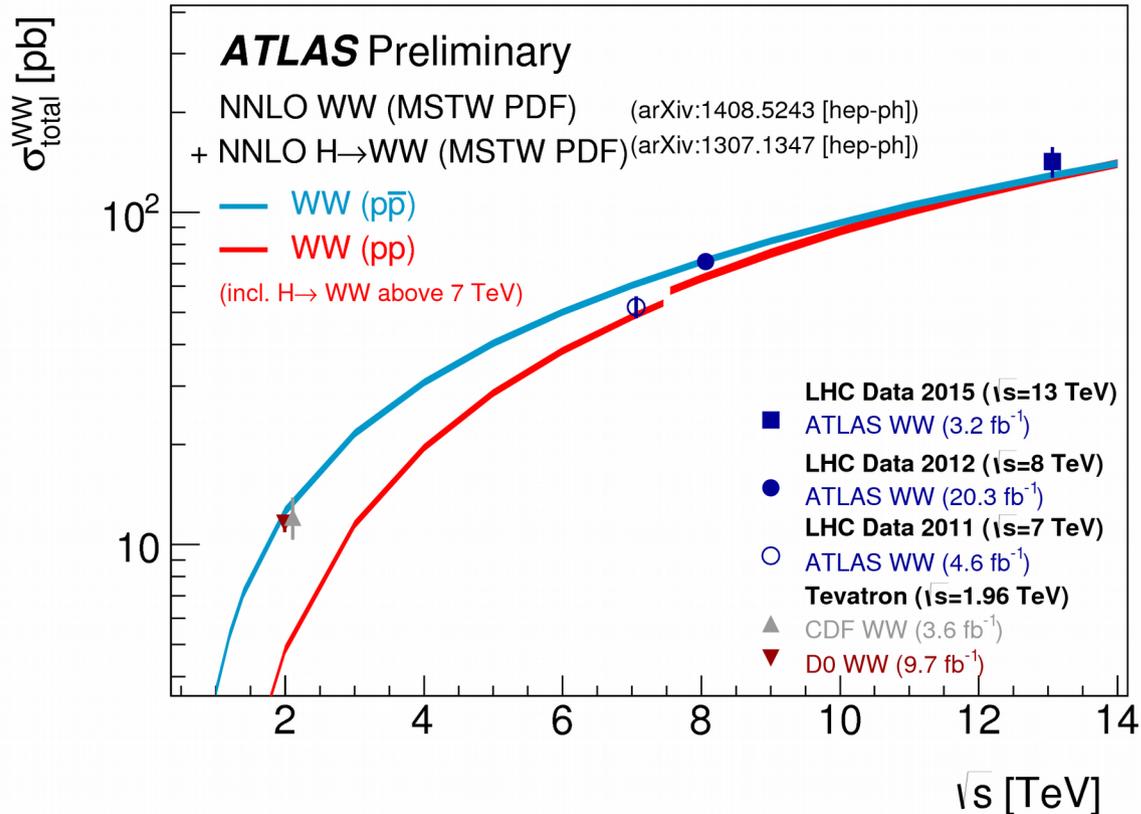
- Matrix NNLO
- MCFM NLO
- comparable result & uncertainties



## Preliminary analysis of 2015 13 TeV data

- require zero jets
- dominated by jet veto systematics

**Good description** of energy scaling  
and ratio 13 TeV / 8 TeV  
from NNLO calculation



## Jet vetoes open a broad range of physics for study

### Veto fraction in top pair

- additional activity in top events
- ISR, underlying event, ...

### Diboson differential cross sections are now possible at LHC

- currently testing the QCD modelling
- "jet veto" analyses already being done (exclusive zero jet bin)
- expect more differential results in the future
  - ideas for interesting tests with these signals?
- MPI dibosons in the future?



Thanks for your attention!

Define gap fraction based on jet pT cut,  $Q_0$

Shown for two veto regions

$|y| < 0.8$

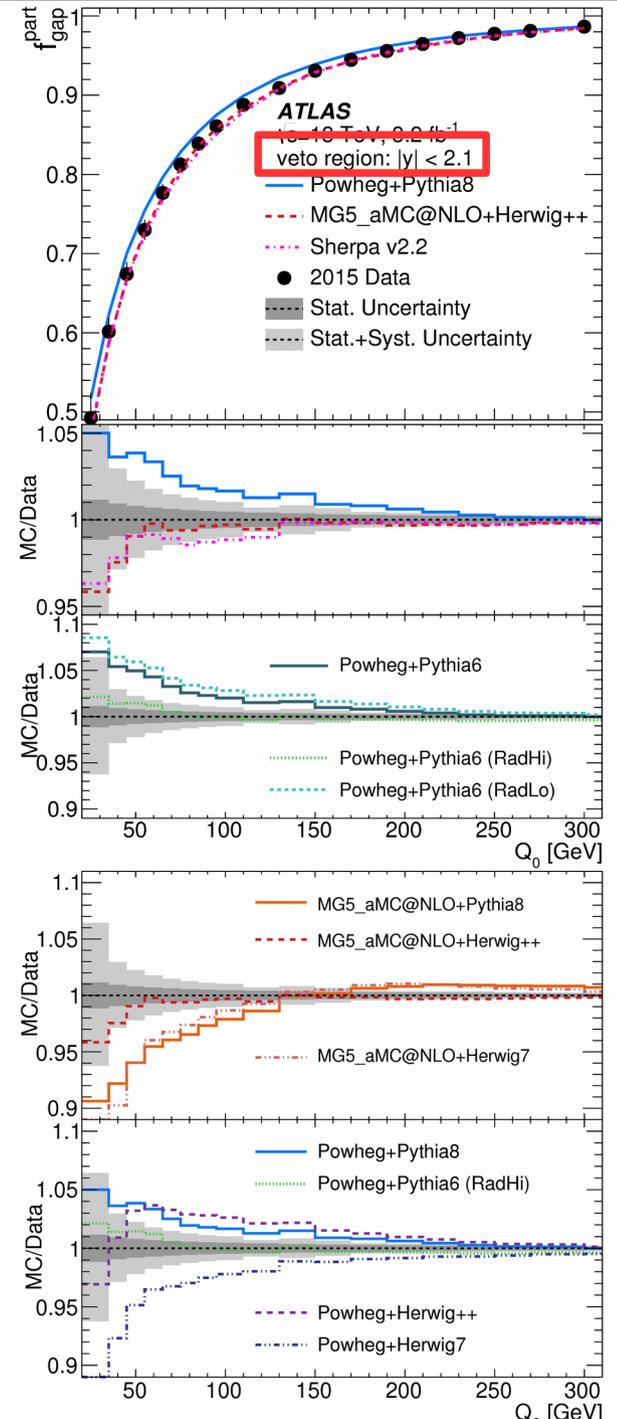
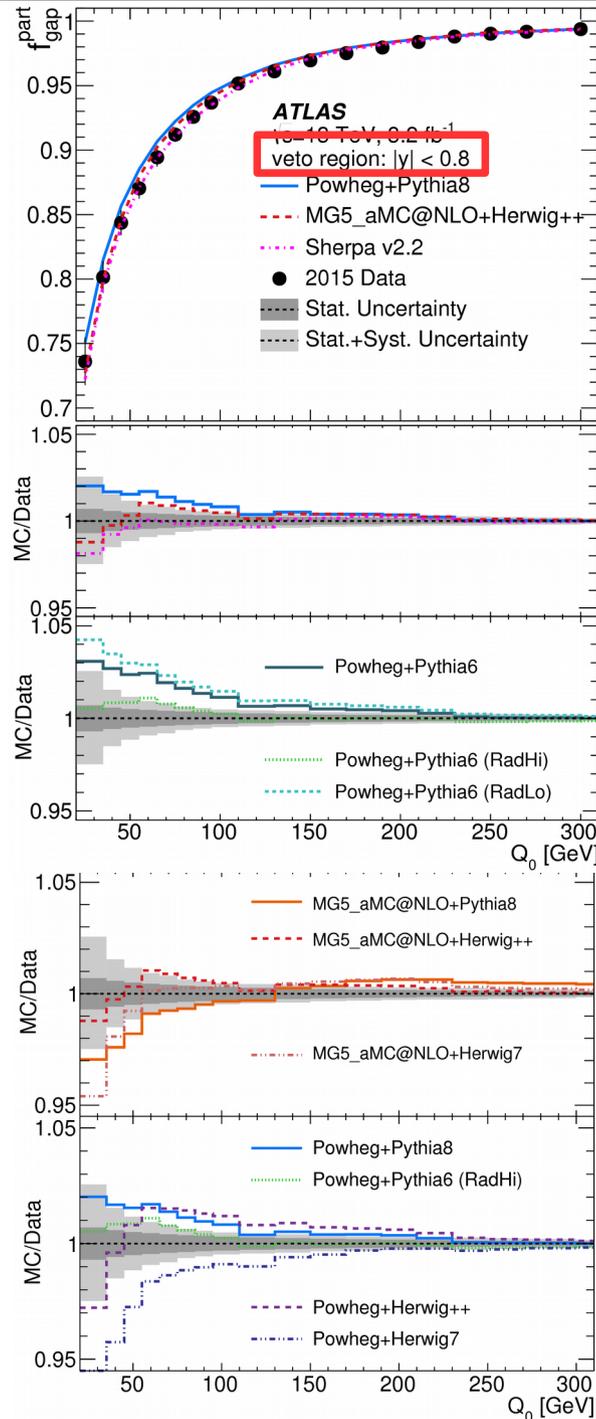
$|y| < 2.1$

Also defined as cut on sum of additional jets,  $Q_{\text{sum}}$

And as a function of  $M(e\mu b\bar{b})$

→ see backup

**JHEP 12 (2015) 105**



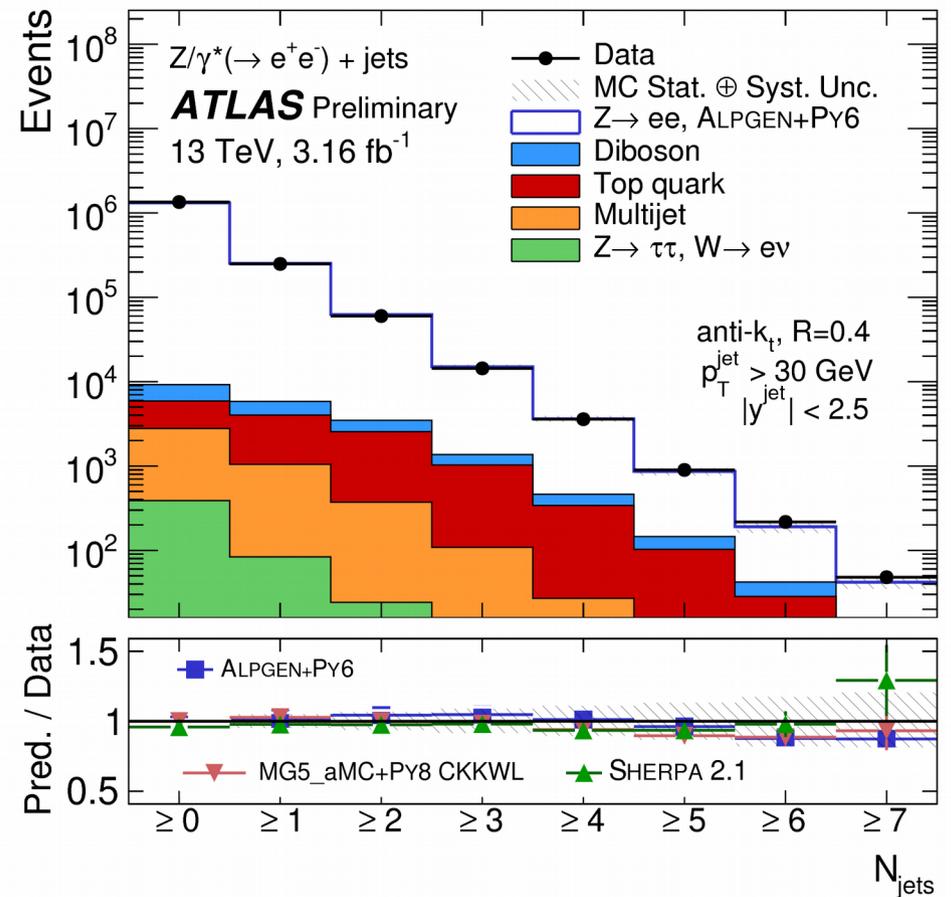
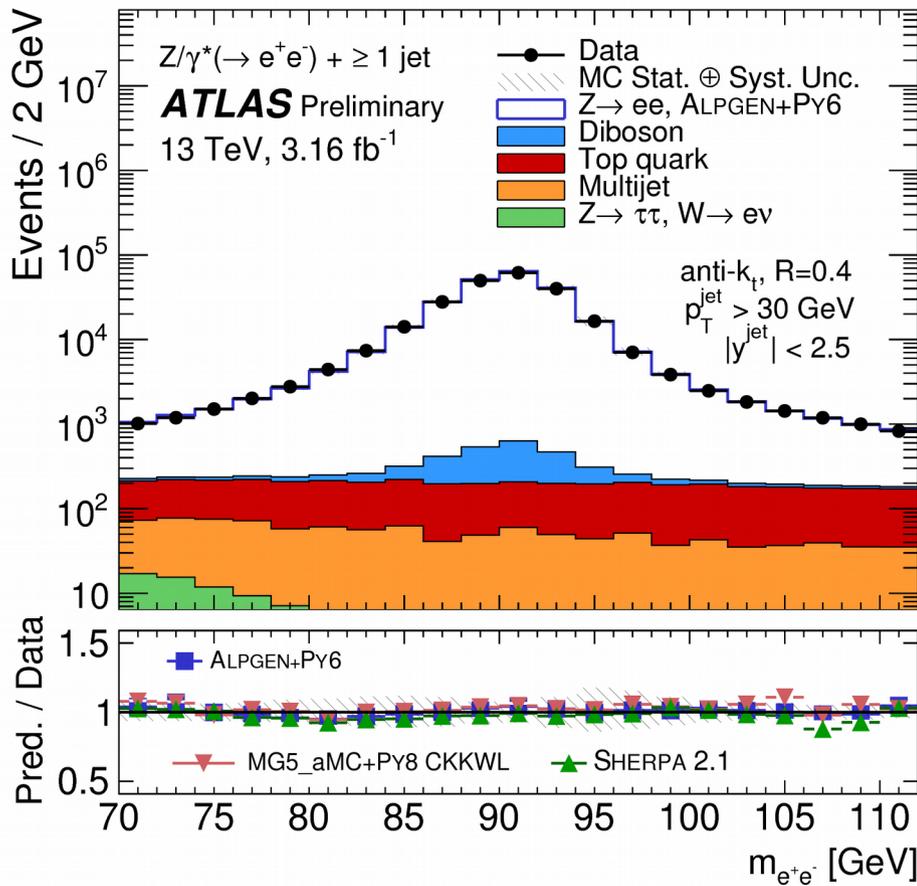
Use the Z as a colourless probe of the underlying process

Select leptons:  $p_T > 25$  GeV,  $|\eta| < 2.5$ ,  $66 < M_{ll} < 116$  GeV

Select jets:  $p_T > 30$  GeV,  $|\eta| < 2.5$

Extract many inclusive cross sections:

- number of jets, leading jet  $p_T$ , rapidity
- $H_T$ , mass(jet, jet),  $\Delta\phi$ (jet, jet)



**LO merged Z+4/5 jet:** Alpgen+Pythia6, MadGraph5\_aMC@NLO CKKWL

**NLO merged Z+2/3 jet:** Sherpa 2.2 (+LO up to 5 jet), Madgraph5\_aMC@NLO FxFx

**NLO parton level:** Blackhat + Sherpa

**NNLO Z + 1 jet** (Phys. Rev. Lett. 116 (2016) 152001)

**ATLAS-CONF-2016-046**

