Recent highlights of Electroweak and QCD studies with ATLAS

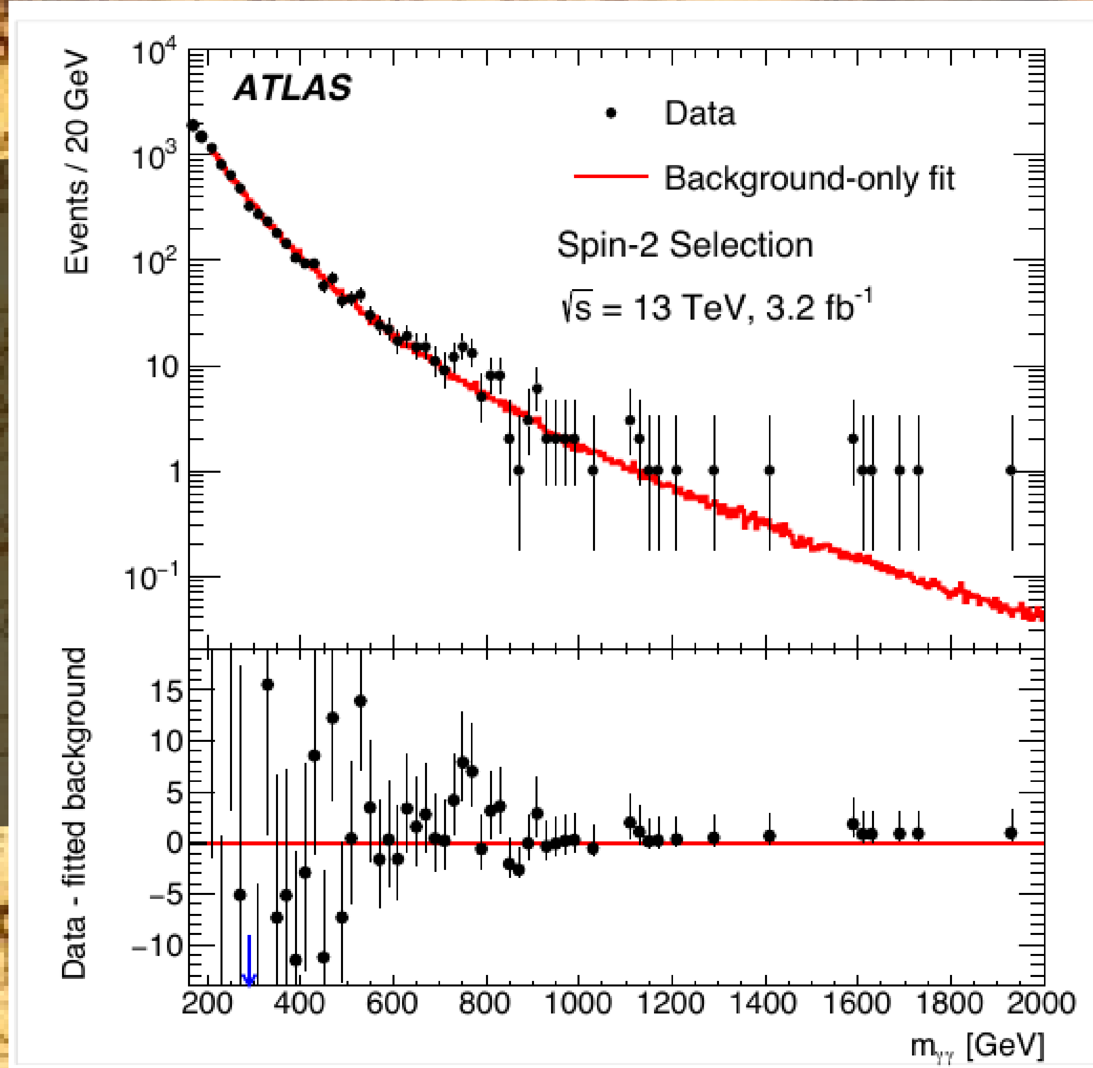
Gavin Hesketh
University College London

Corfu Summer Institute,
8/9/2016

THE ROYAL SOCIETY
Science & Technology Facilities Council
UCL

In 2015 the LHC went to 13 TeV

We may get lucky…



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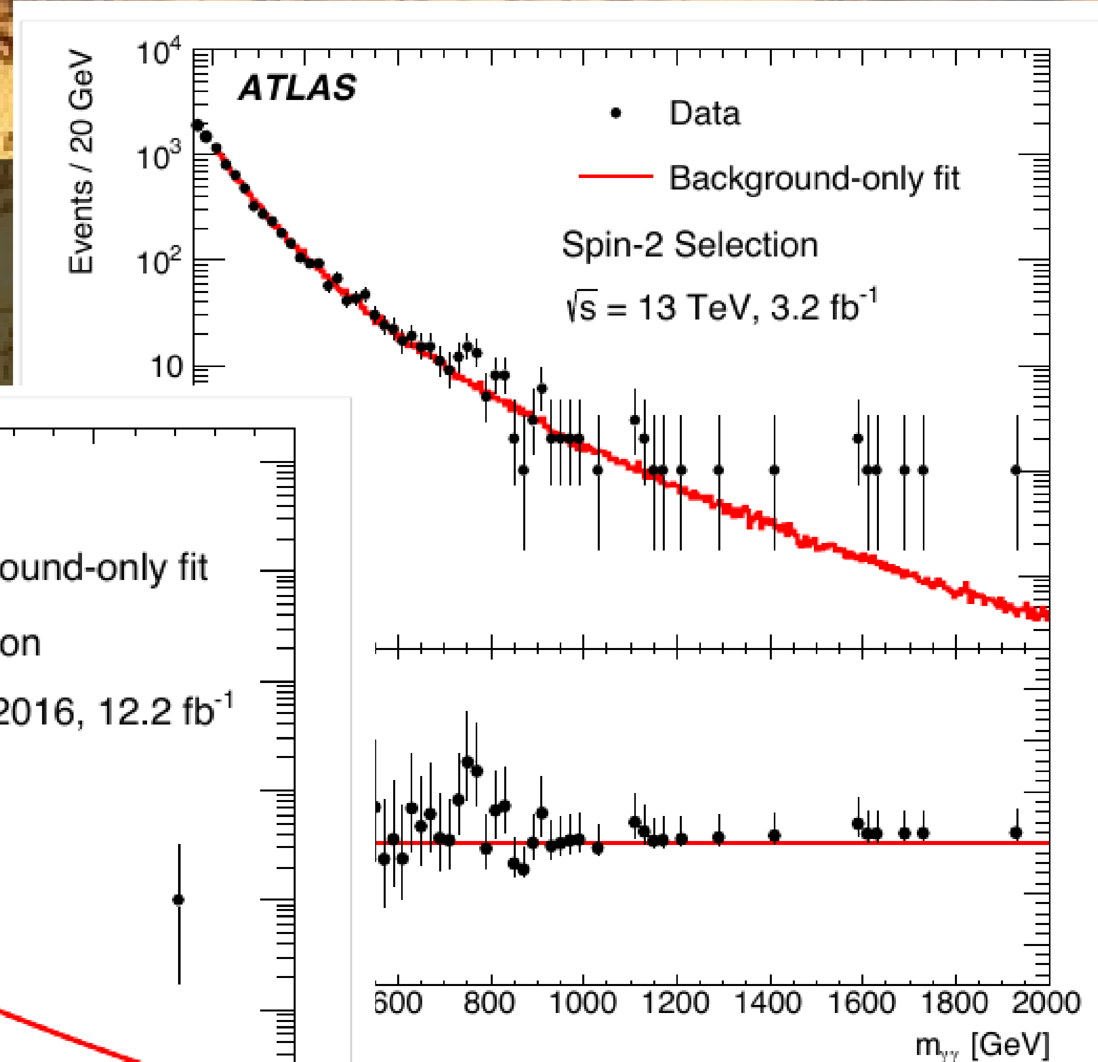
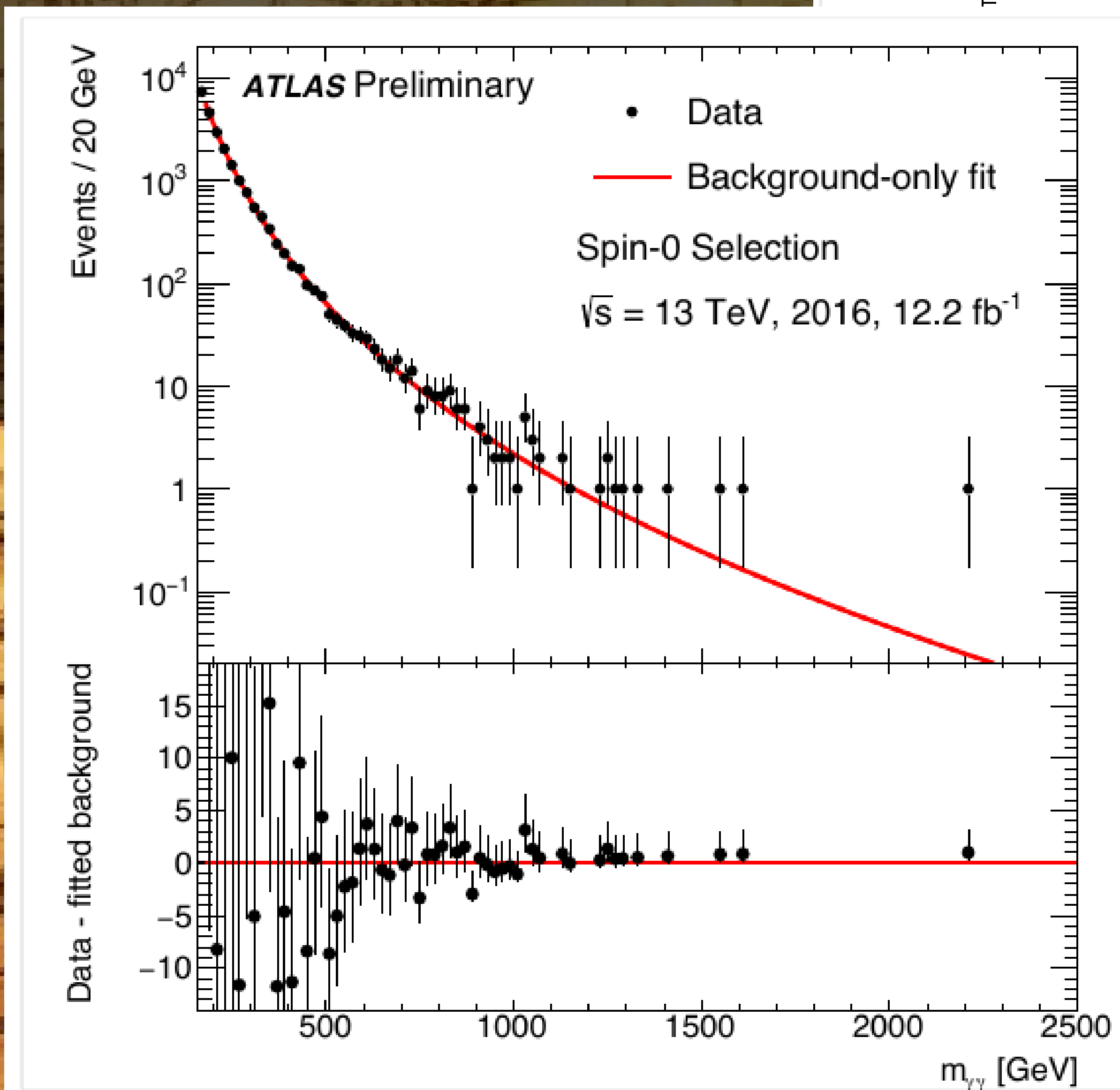




In 2015 the LHC went to 13 TeV

We may get lucky…

But we can also ask a different question:

- is the Standard Model still the right theory?
- are there any signs of different behaviour?

To answer this question, need precision measurements

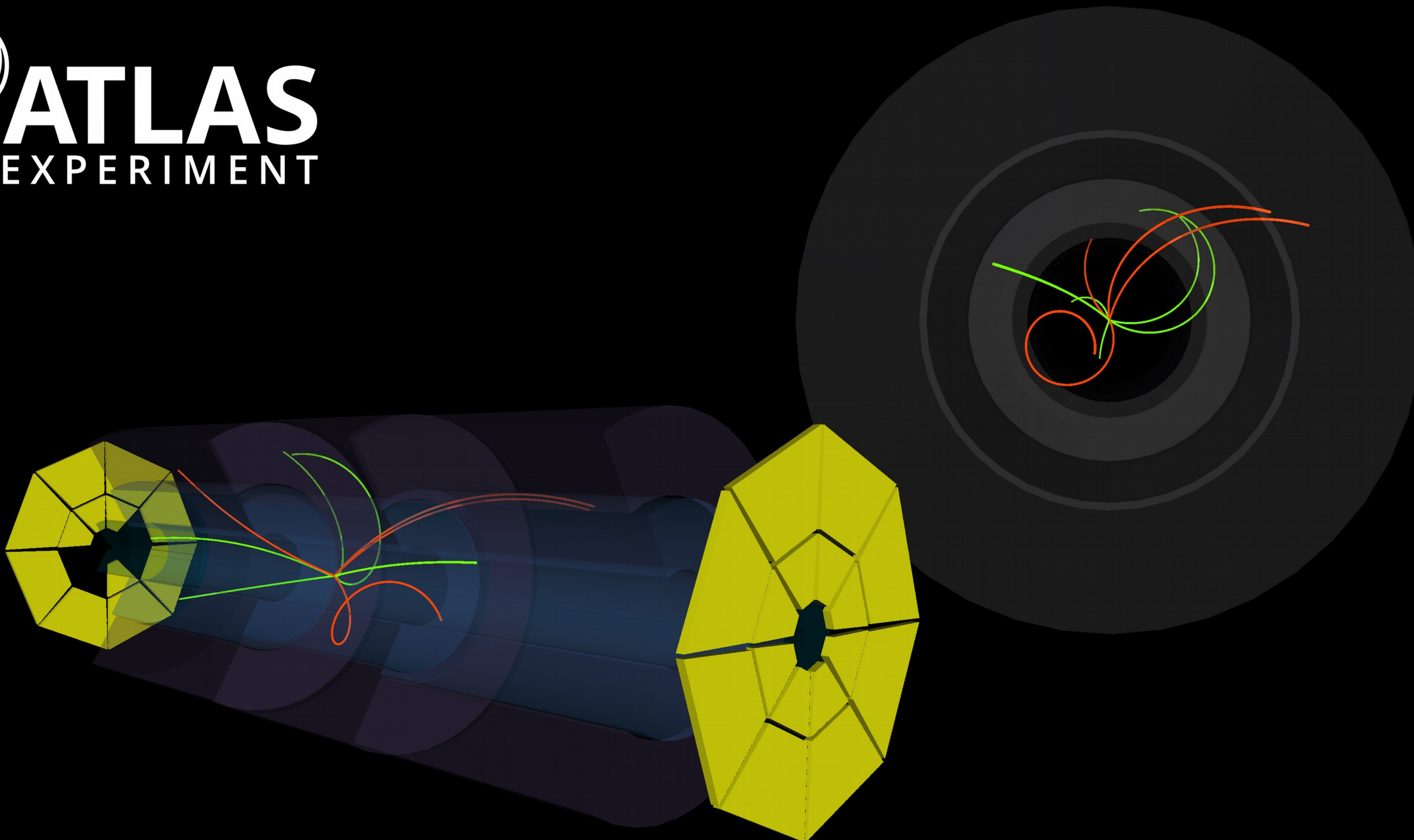
→ QCD and electroweak physics
(excluding top and Higgs)

rrere

Focus on 13 TeV results:

- total inelastic cross section
- min bias
- underlying event
- inclusive jets
- inclusive W, Z
- Z+jets
- dibosons

Total Inelastic σ



Showing tracks with pT>100 MeV

Run: 267358
Event: 7543551
2015-06-10 00:48:15 CEST

Total Inelastic σ

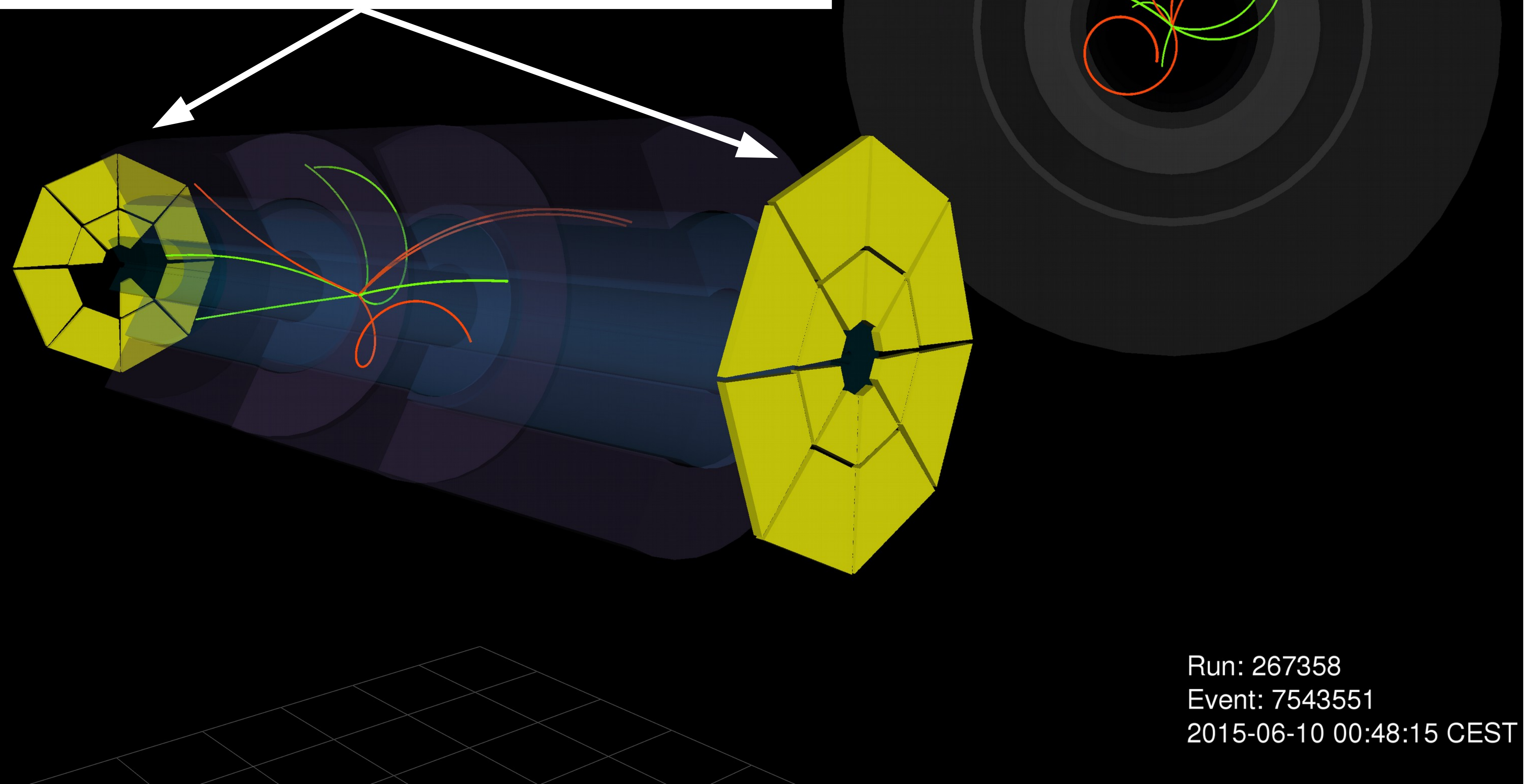
The majority of pp collisions are low Q^2

- non-perturbative QCD

Trigger using MBTS

- plastic scintillator 3.6 m from interaction region
- covers $2.07 < |\eta| < 3.86$

→ insensitive to elastic and low mass diffraction



Total Inelastic σ

New ATLAS measurement Consistent with expected rise in cross section

$$\sigma_{\text{inel}} = 79.3 \pm 0.6\,(\text{exp.}) \;\pm 1.3\,(\text{lum.}) \;\pm 2.5\,(\text{extrap.})\ \text{mb.}$$

Dataset:

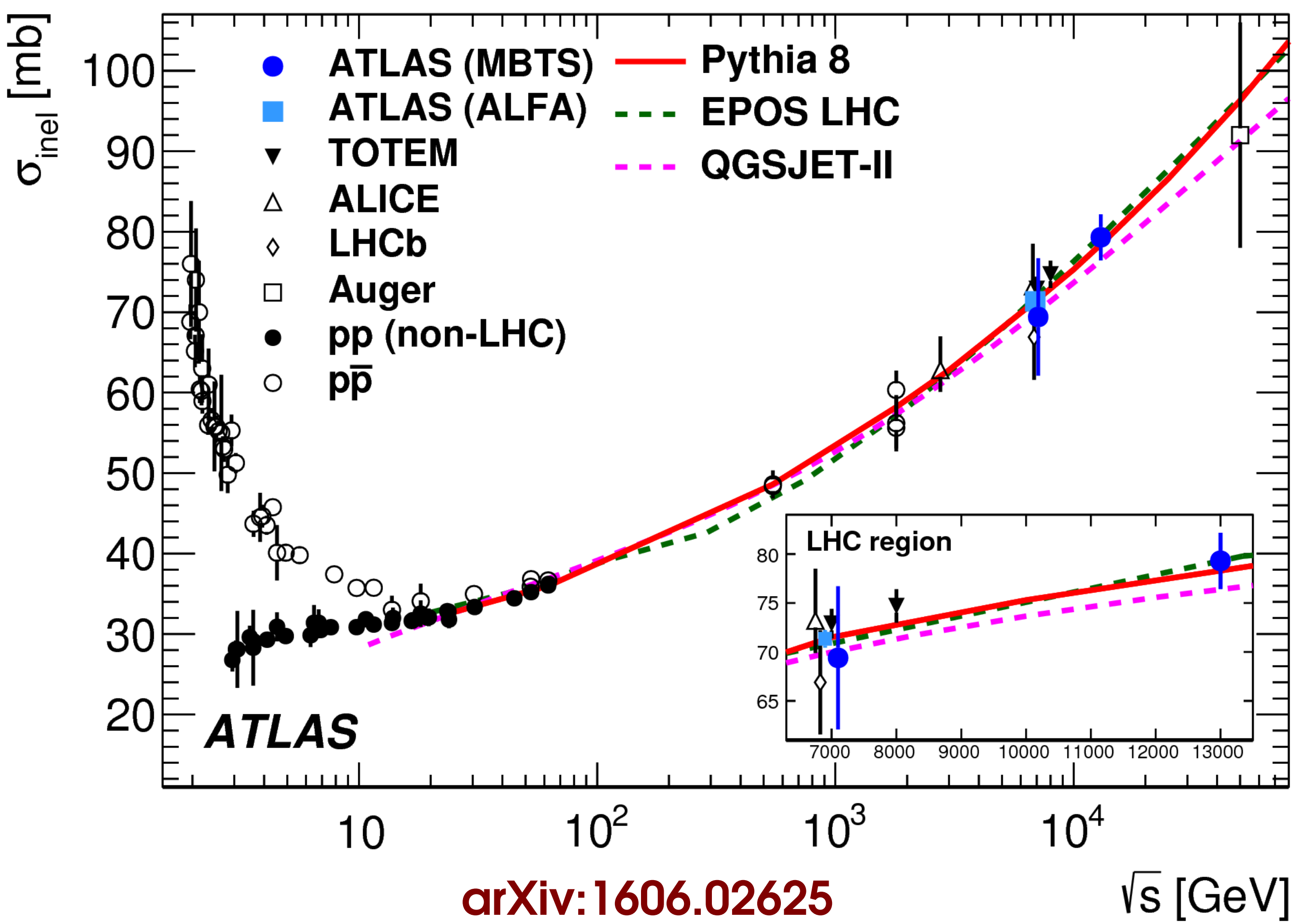
- 60 μb^{-1}, June 2015
- 0.0023 collisions per crossing

Test Pythia 8

- one of the LHC standards

EPOS LHC & QGSJET-II

- used for cosmic ray shower simulation



arXiv:1606.02625

Minimum Bias

To learn more about collisions:

Reconstruct charged tracks with

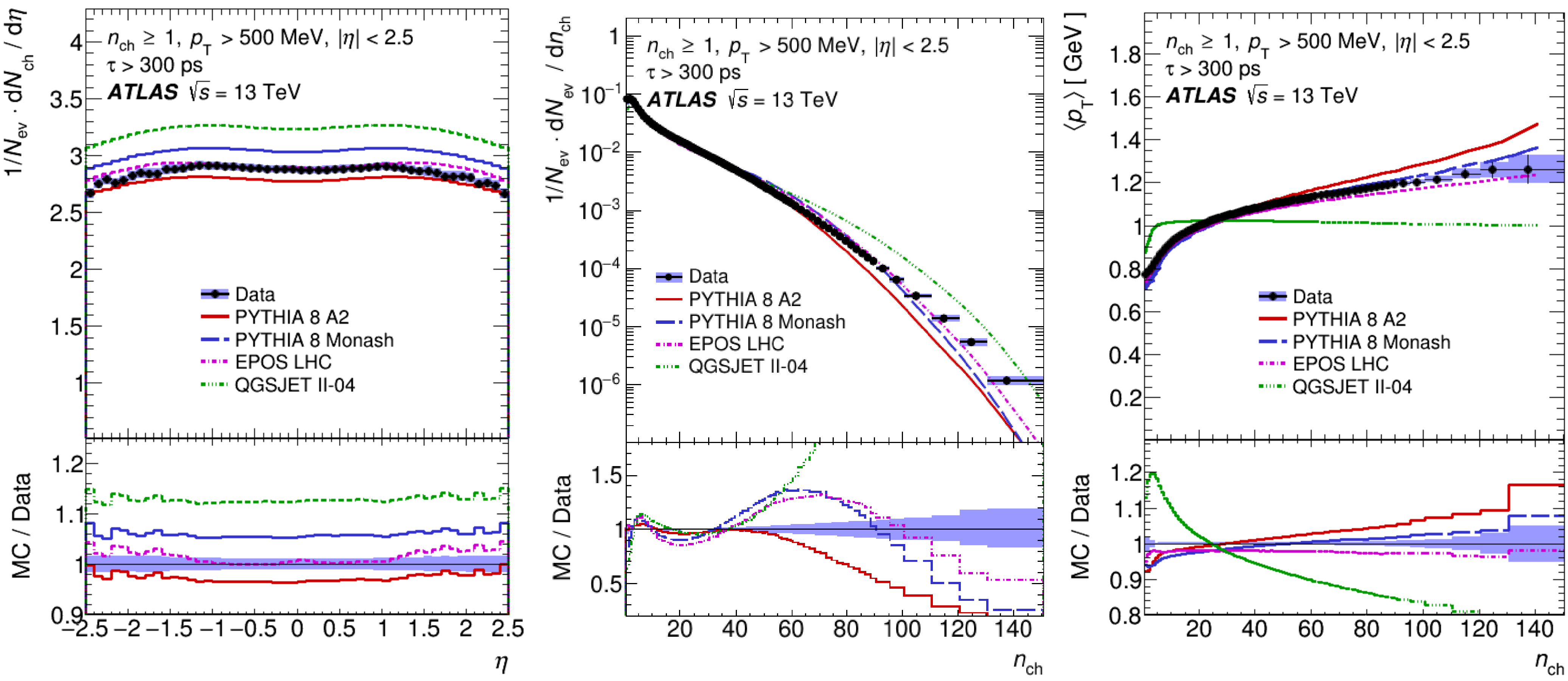
I eta I <2.5

pT>500 MeV

Correct to primary charged particles

Phys. Lett. B (2016), Vol 758, pp. 67-88

extended to pT>100 MeV: **arXiv: 1606.01133**



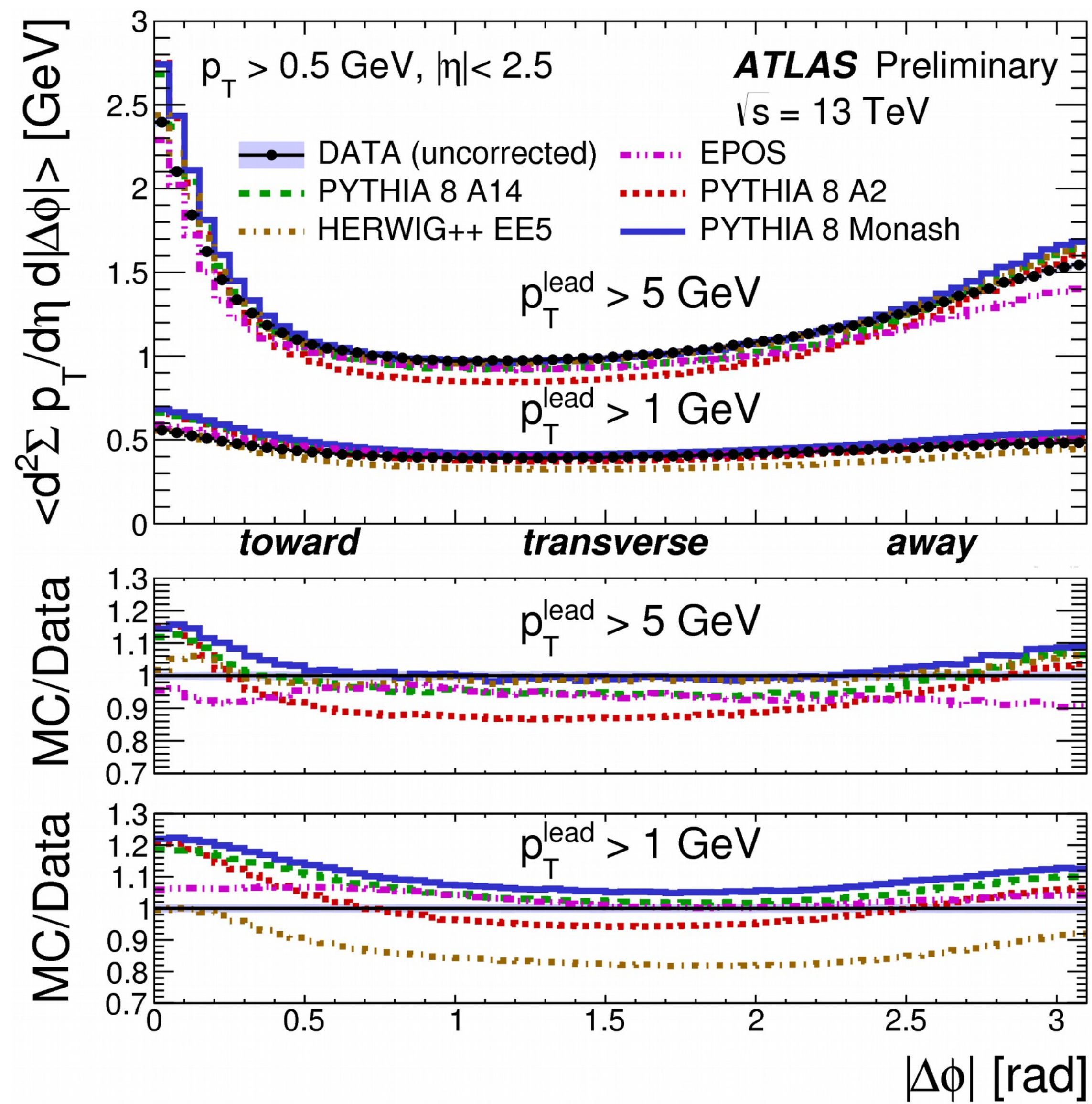
Underlying event

Using same data sample as minbias analysis
- tracks with pT > 500 MeV, I eta I <2.5

ATL-PHYS-PUB-2015-019

Select leading track, pT>1 GeV
- divide event relative to this track

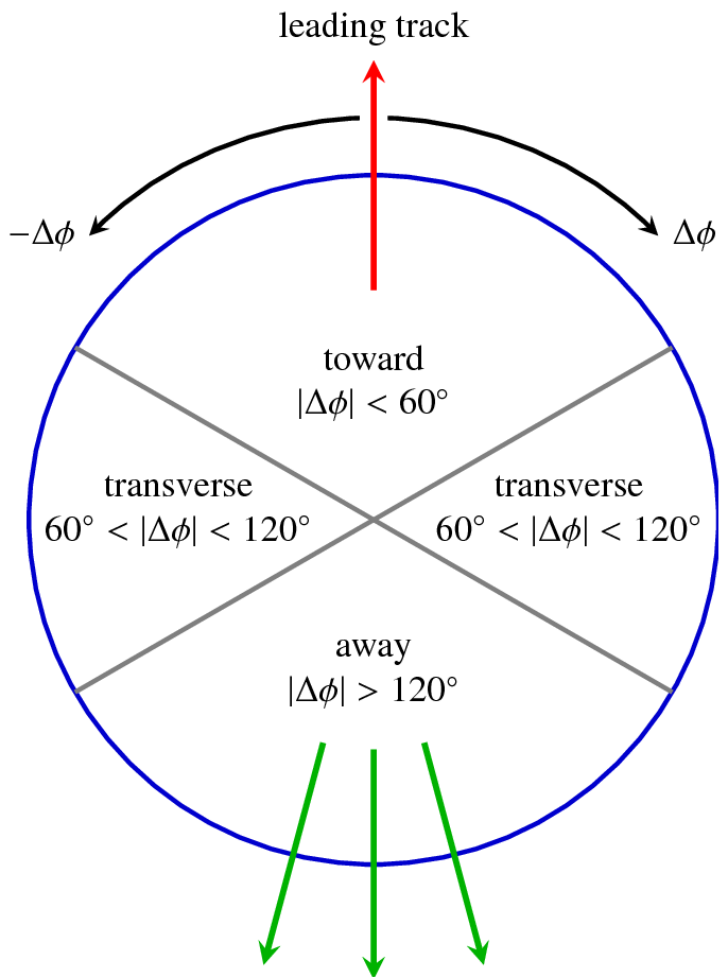
Further select beginnings of "hard" tail:
- require >=1 track with pT > 5 GeV
- beginning of jet formation
- "back-to-back" topology

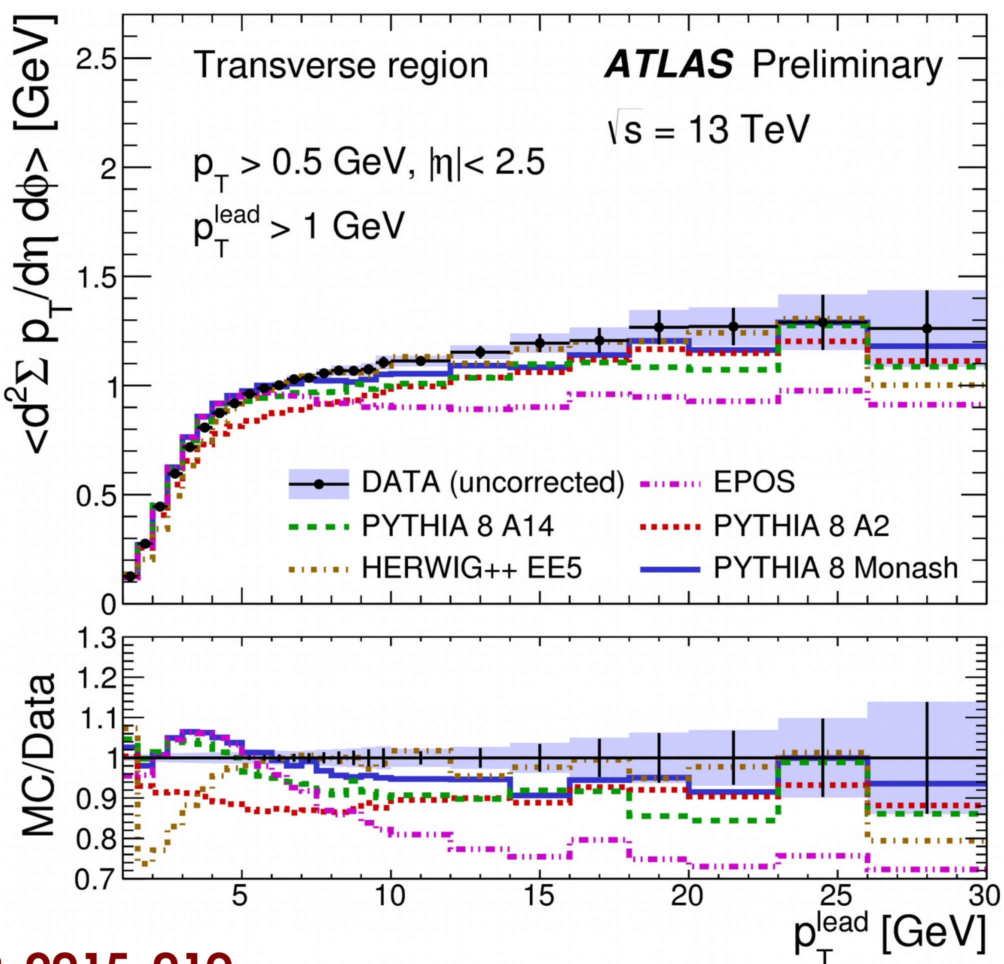


Underlying event

"Factorize" events into hard scatter and underlying event

- **Underlying event** ~independent of hard scatter as Q^2 increases
- **Present in all collisions** – important input for tuning non-perturbative models
  - along with jet fragmentation, min bias and multi-parton scatters

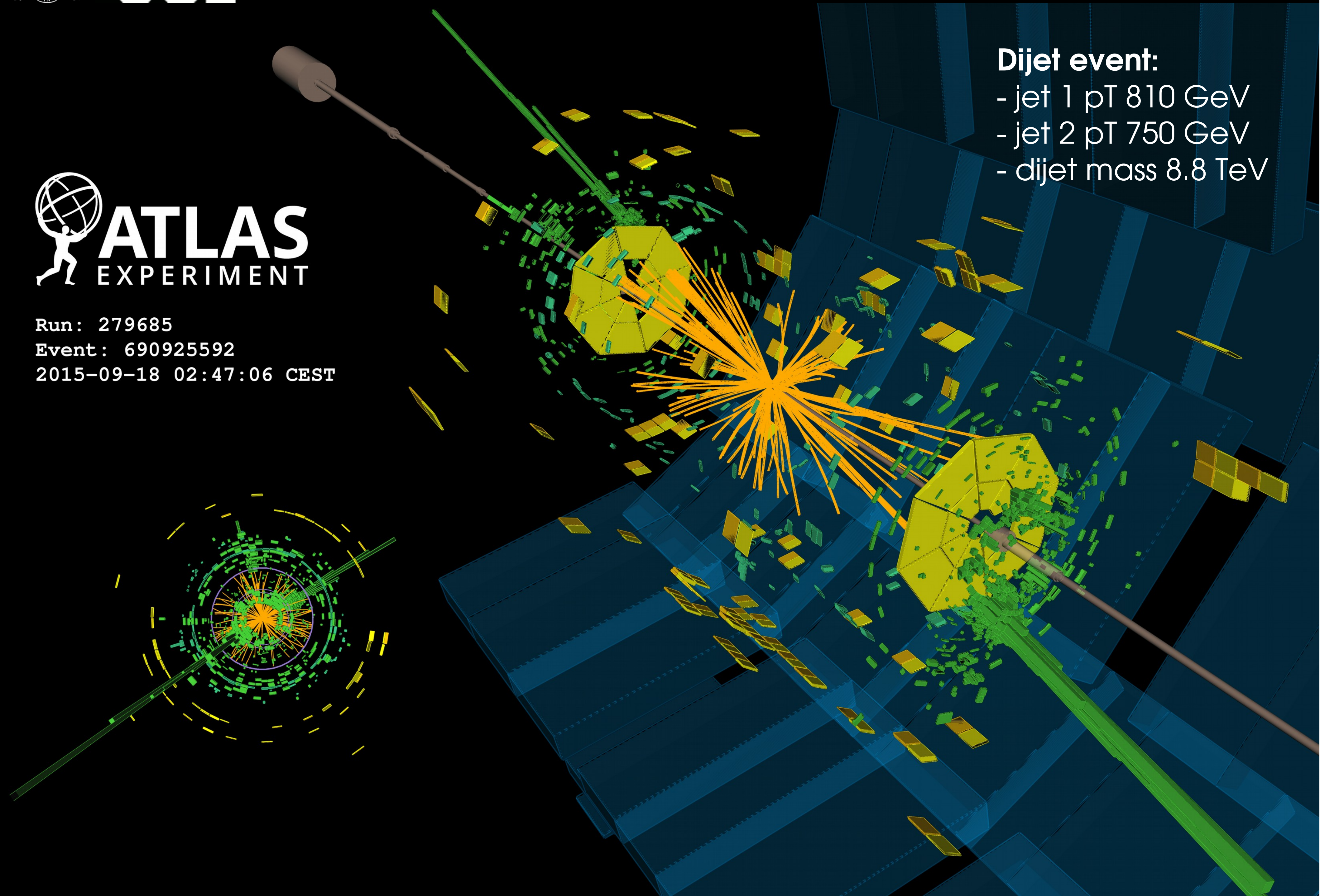




ATL-PHYS-PUB-2015-019

Inclusive Jets

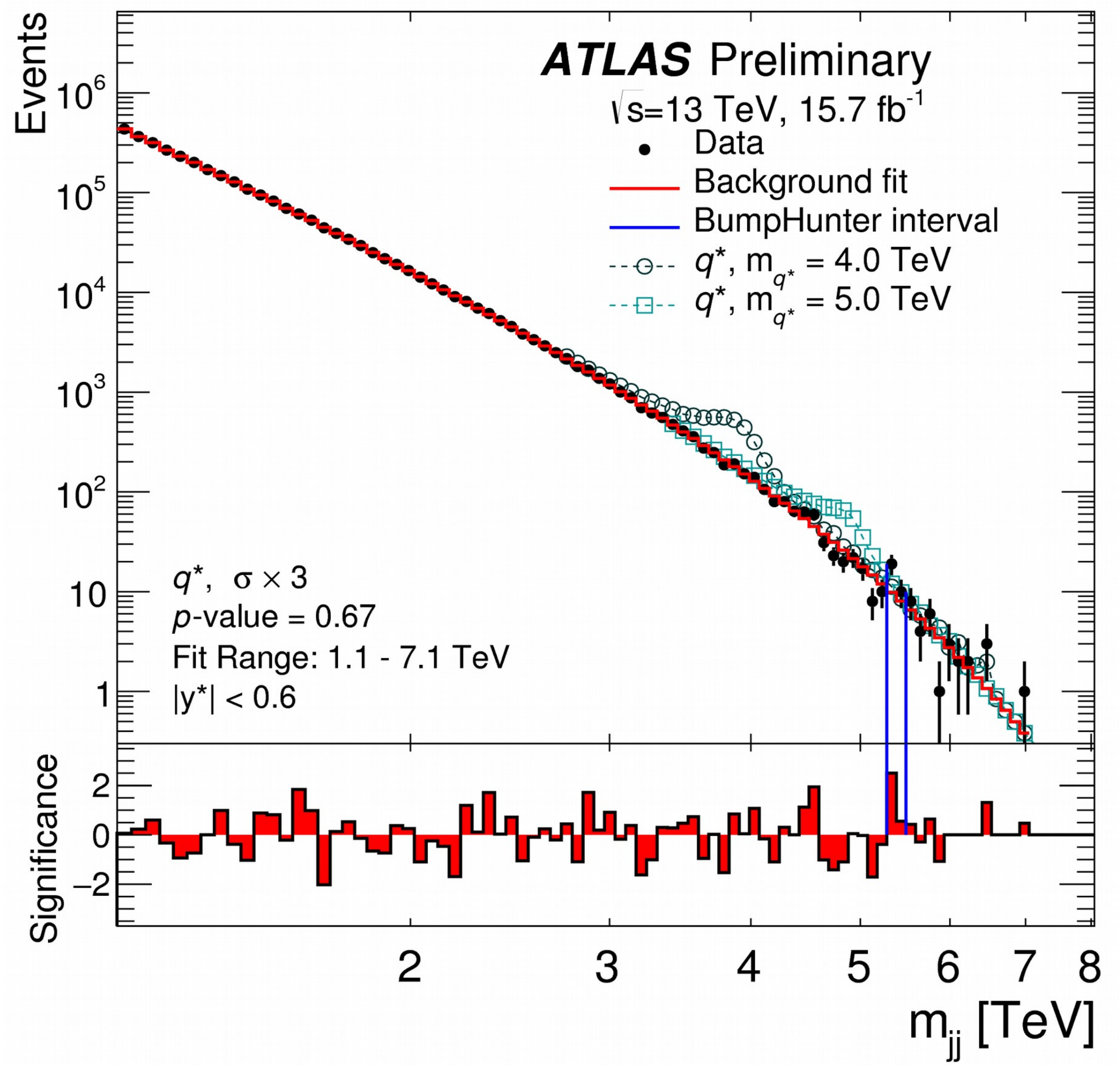
Dijet event:
- jet 1 pT 810 GeV
- jet 2 pT 750 GeV
- dijet mass 8.8 TeV



Inclusive Jets

Look at very high pT objects

- search for new interactions



ATLAS-CONF-2016-092

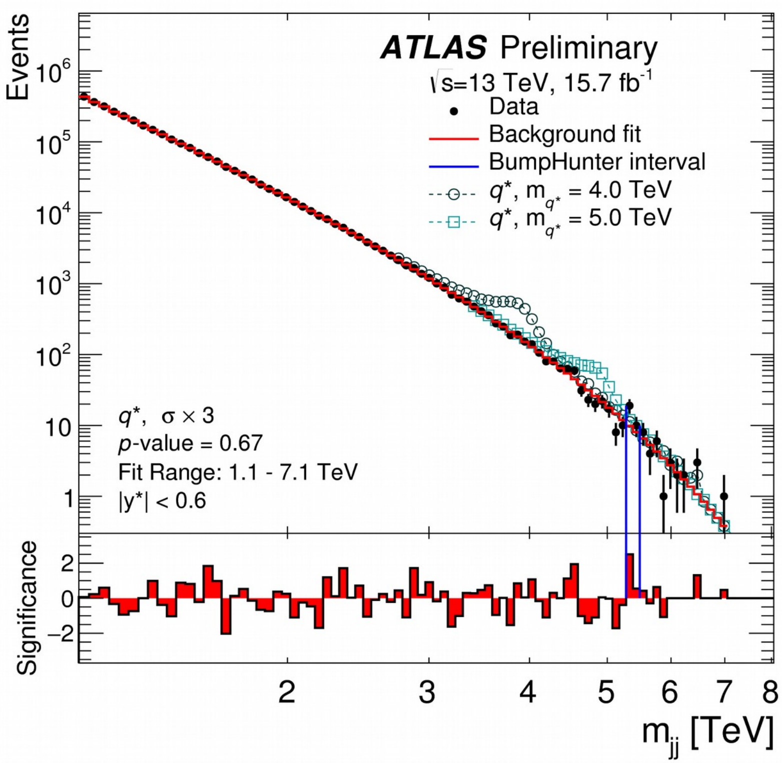
ATLAS-CONF-2016-069

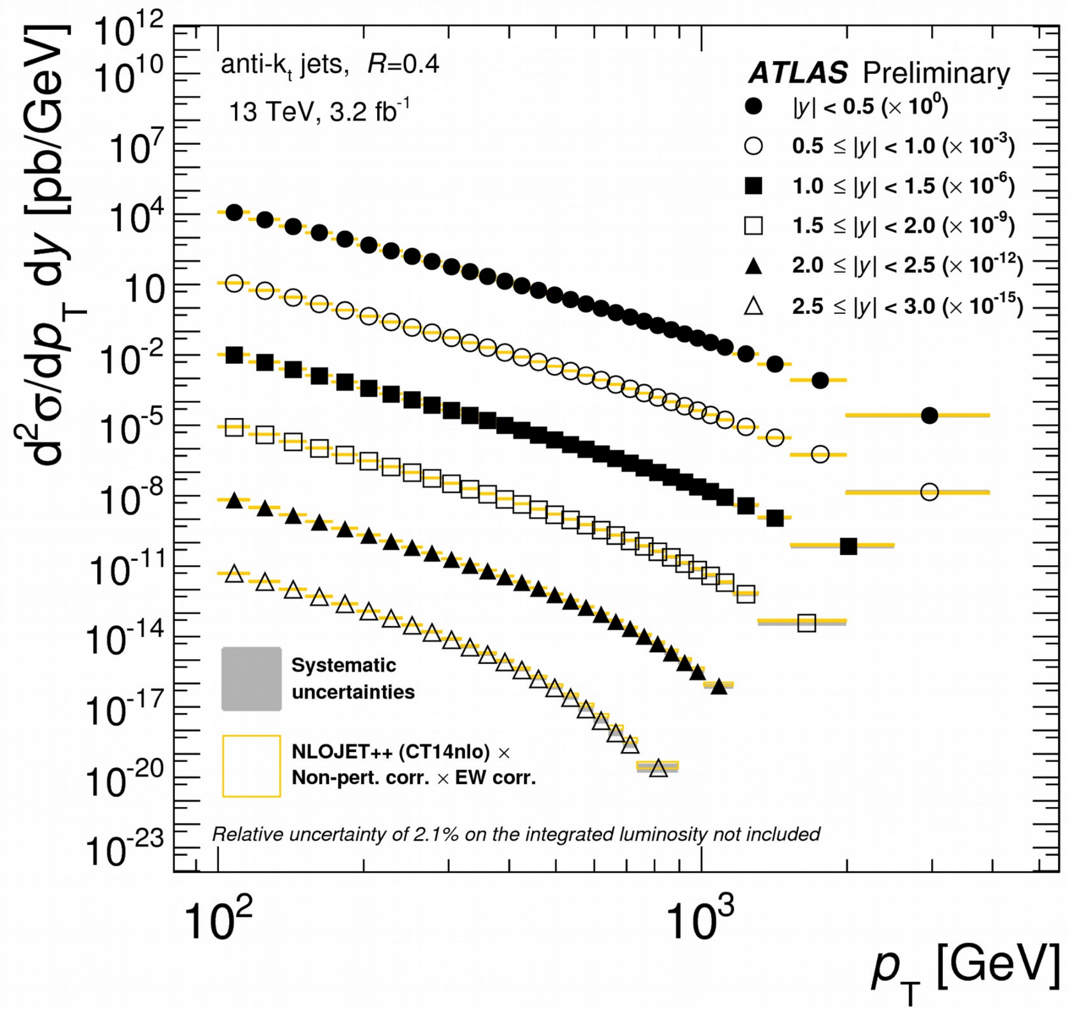
Inclusive Jets

Look at very high pT objects
- search for new interactions

→ Test perturbative QCD
Use a suite of single jet triggers
- pT > 55 → 360 GeV

Jet selection:
antikt R = 0.4 jets
pT > 100 GeV, | y | <3.2





ATLAS-CONF-2016-092

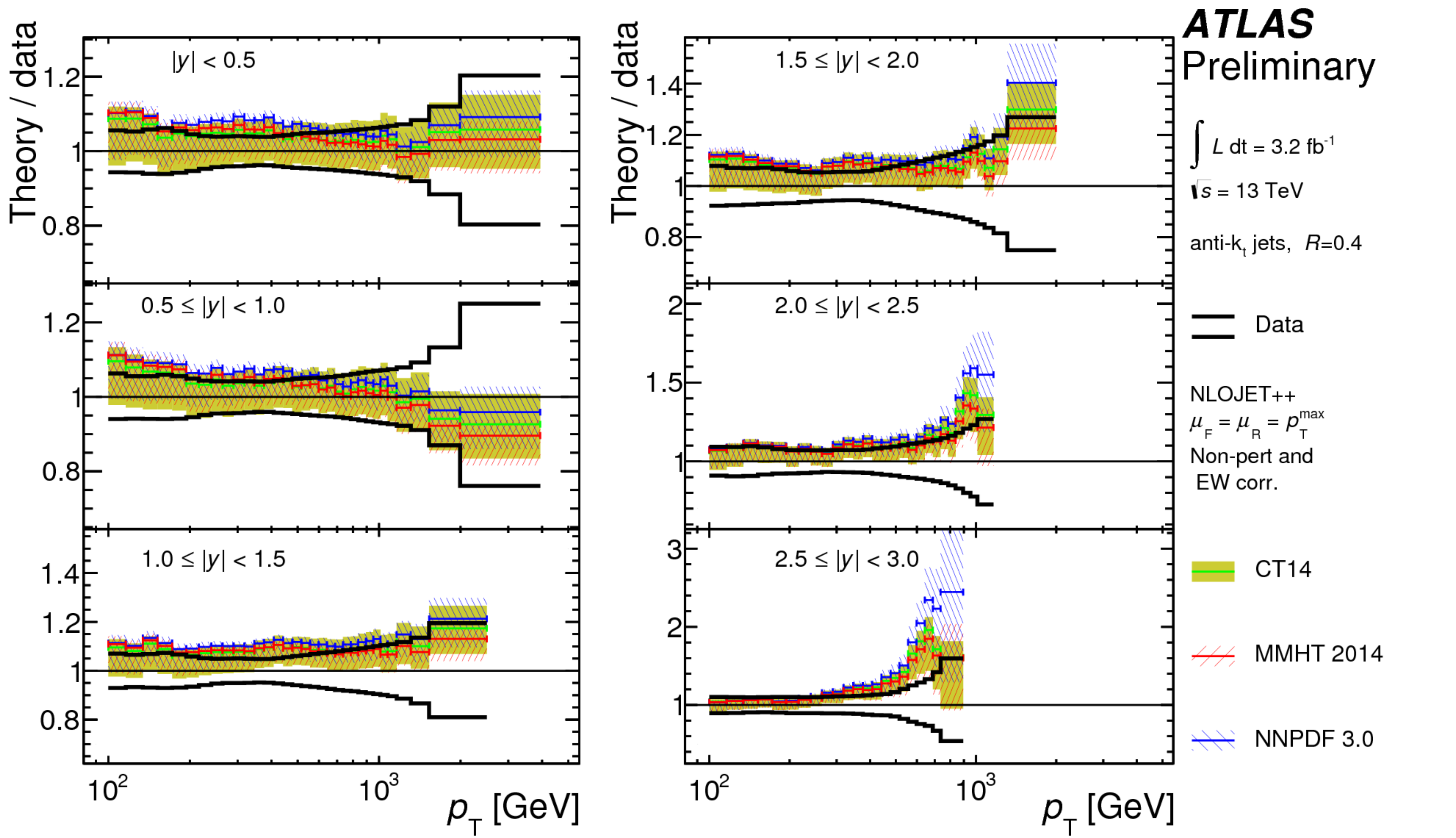
ATLAS-CONF-2016-069

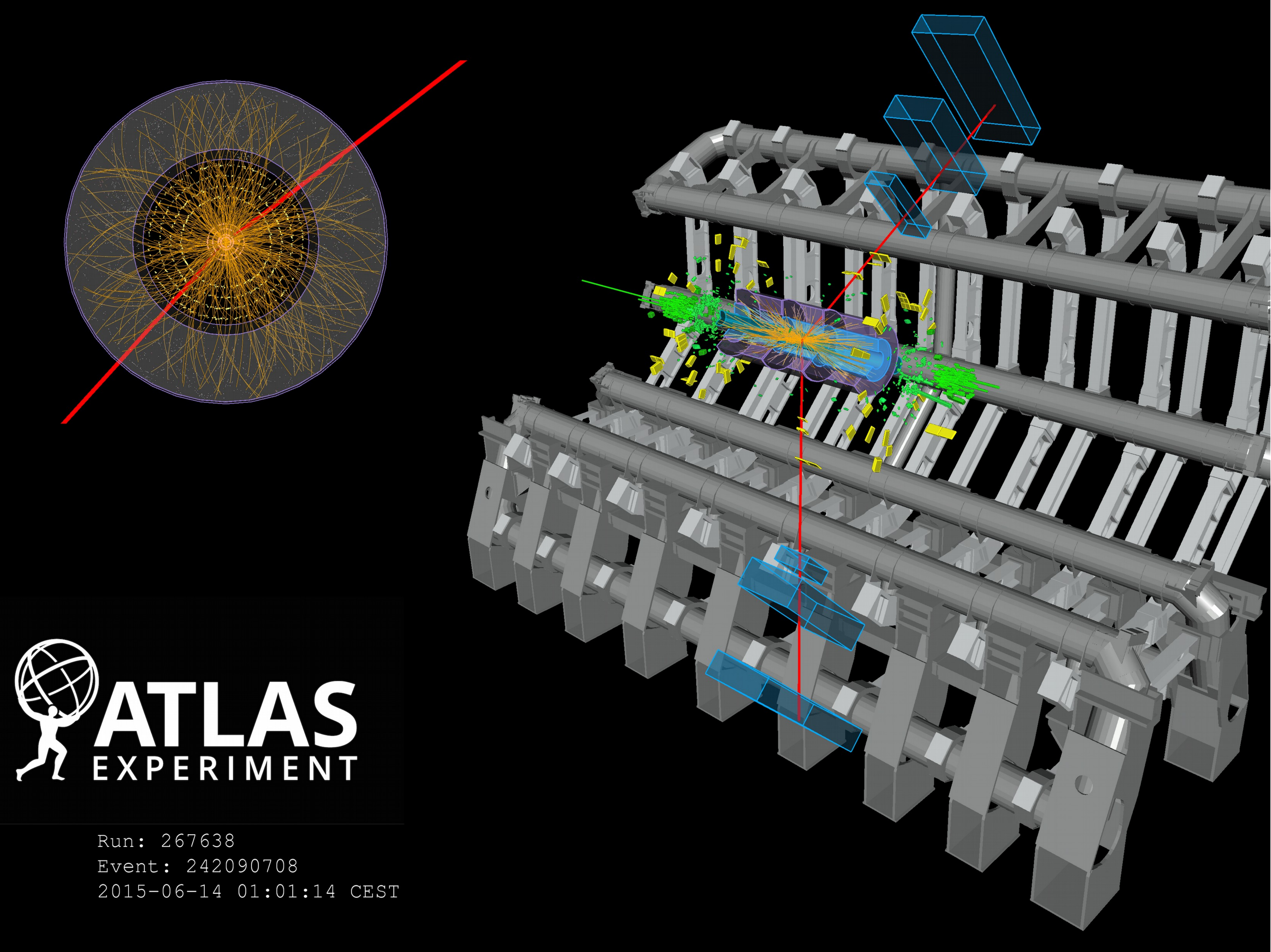
Inclusive Jets

NLO parton level prediction
with non-perturbative corrections

$$\sigma_{\rm pert}(\alpha_s) = \left(\sum_n \alpha_s^n c_n\right) \otimes f_1(\alpha_s) \otimes f_2(\alpha_s)$$

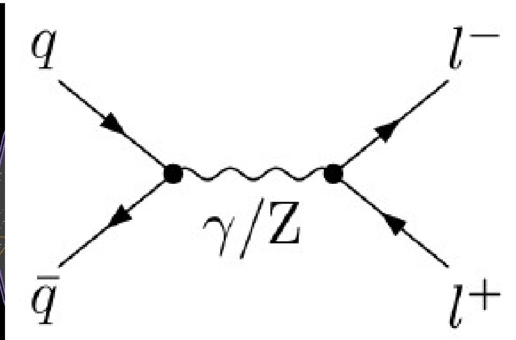
Precision of results (limited by JES)
puts constraints on PDFs

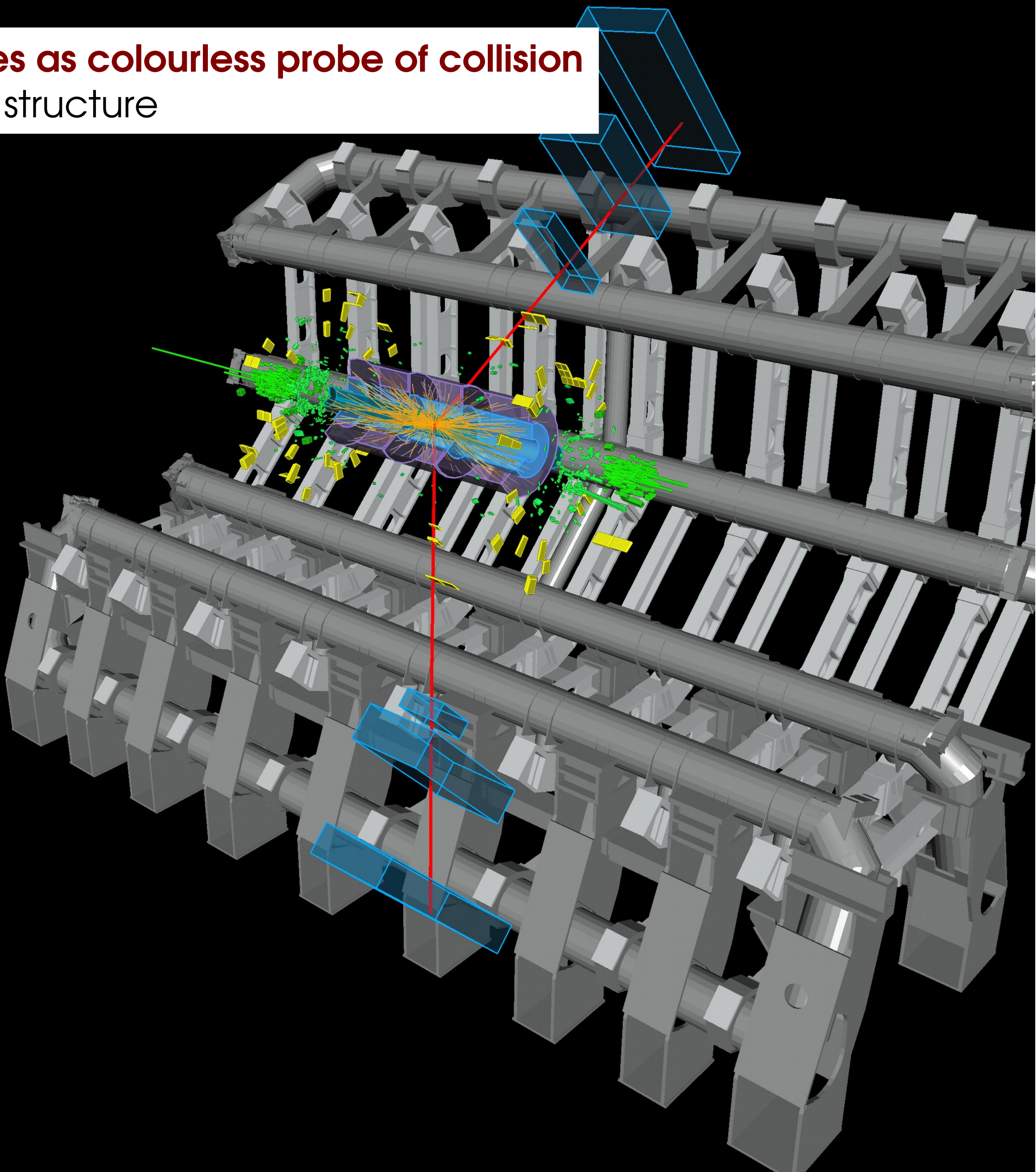



ATLAS
EXPERIMENT
Run: 267638
Event: 242090708
2015-06-14 01:01:14 CEST

Use electron & muon decay modes as colourless probe of collision

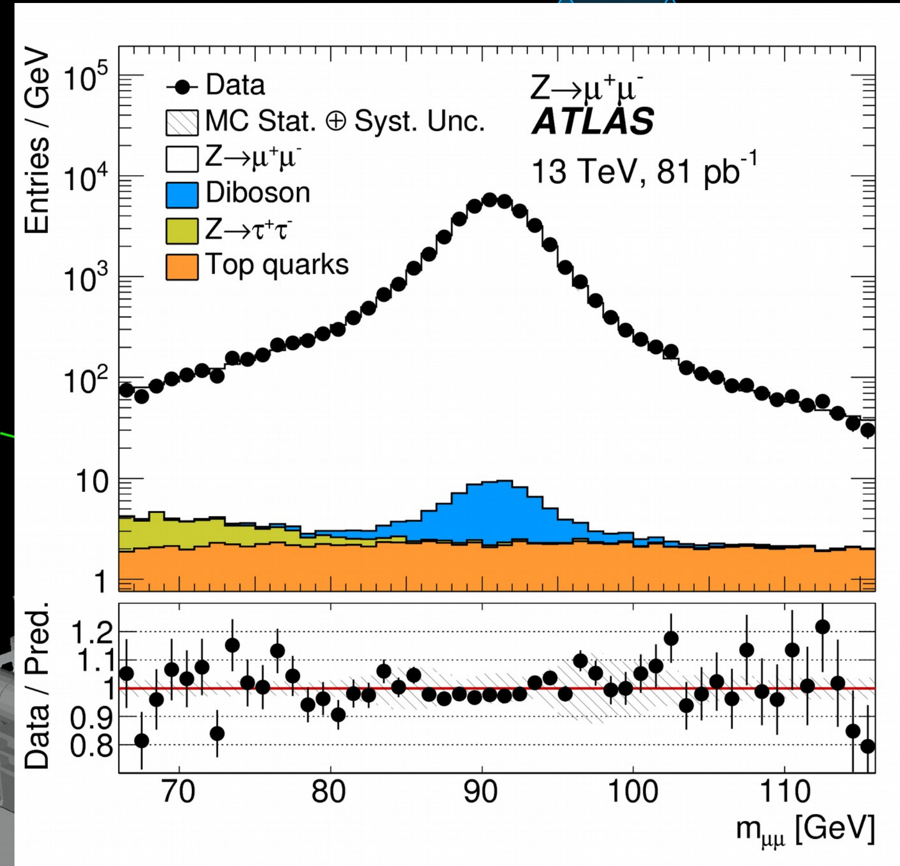
- test pQCD, constrain proton structure

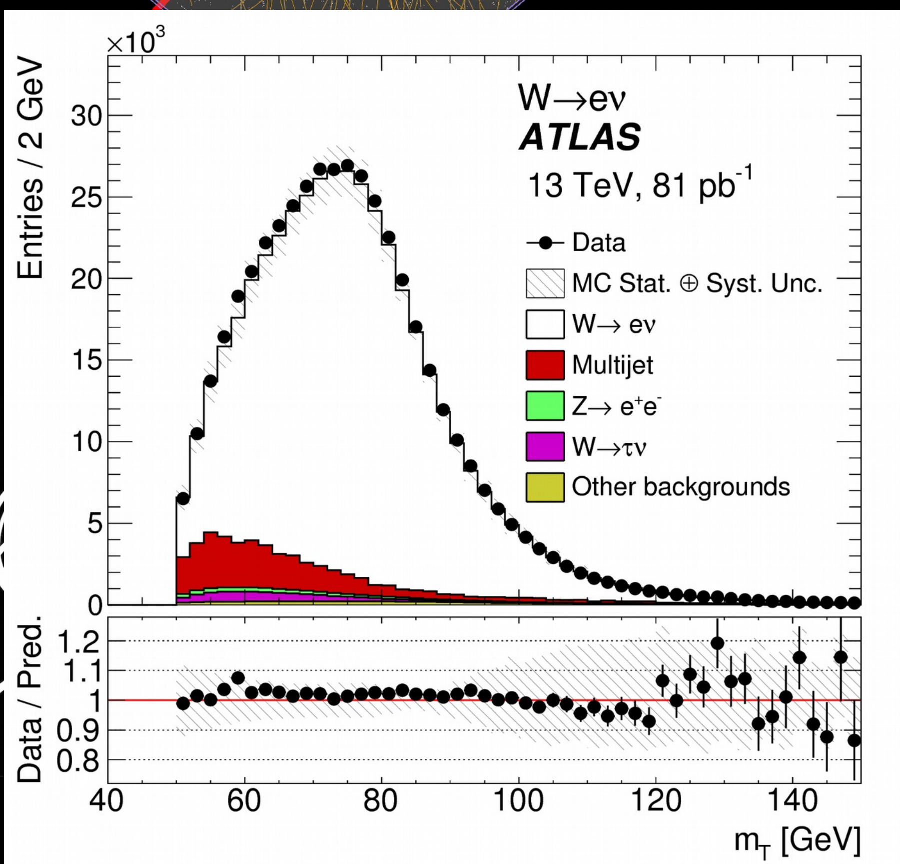


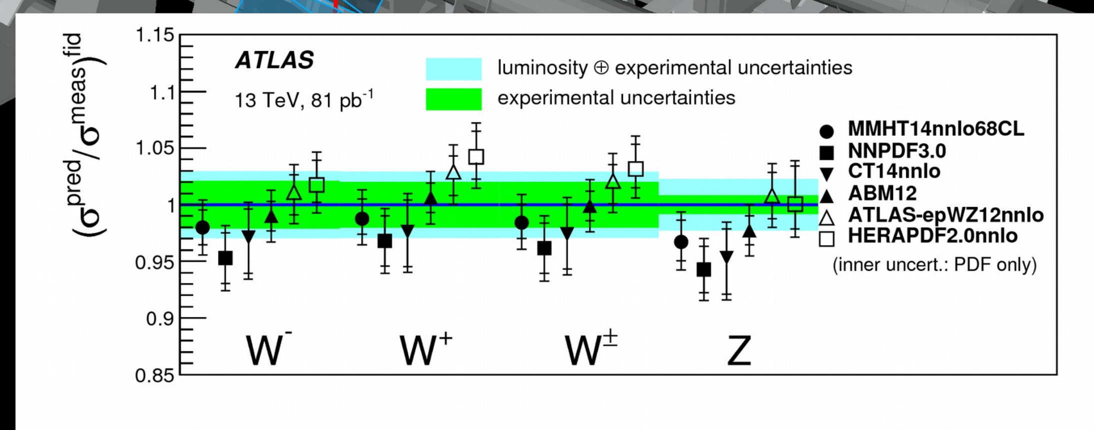


Run: 267638
Event: 242090708
2015-06-14 01:01:14 CEST

Lepton pT > 25 GeV
Lepton |η| < 2.5
Z: 66 < M_{ll} < 116 GeV
W: MET > 25 GeV
M_T > 50 GeV



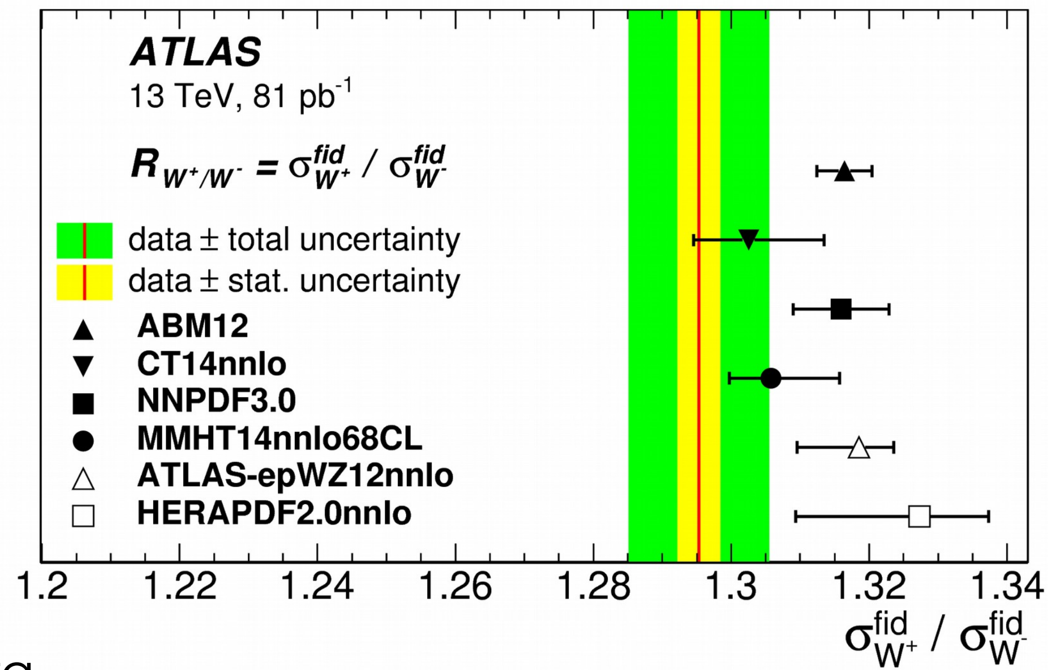




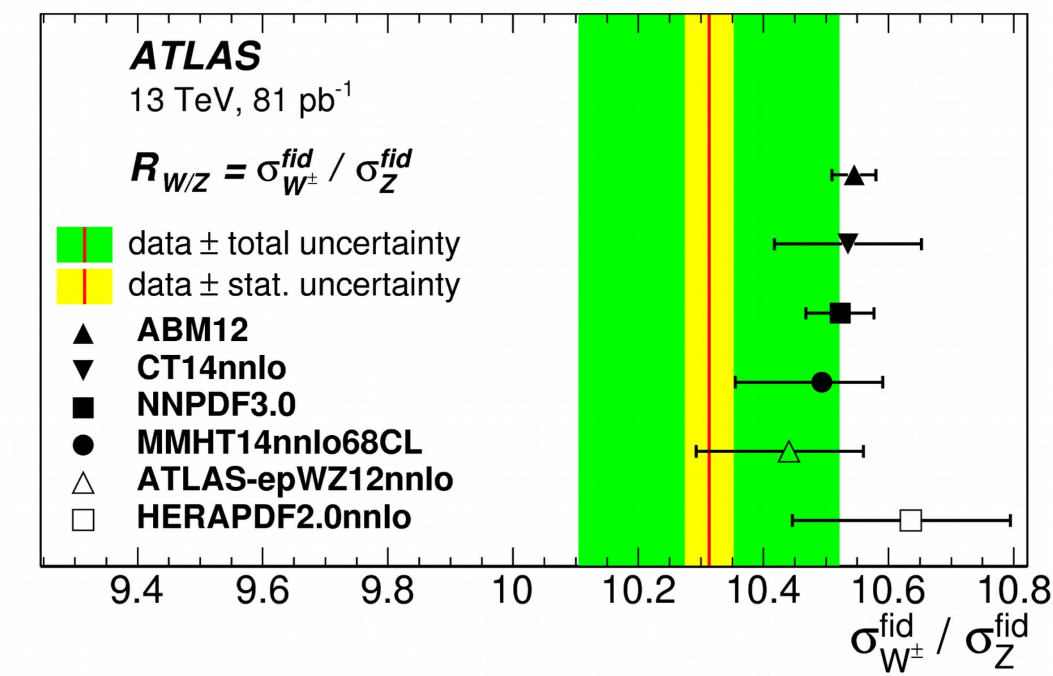
2015-06-14 01:01:14 CEST

Inclusive W/Z

NNLO pQCD predictions: DYNNLO & FEWZ
...with NLO EW corrections: FEWZ & SANC



Ratios provide PDF information
- ATLAS-eqWZ12nnlo PDF set used 7 TeV data

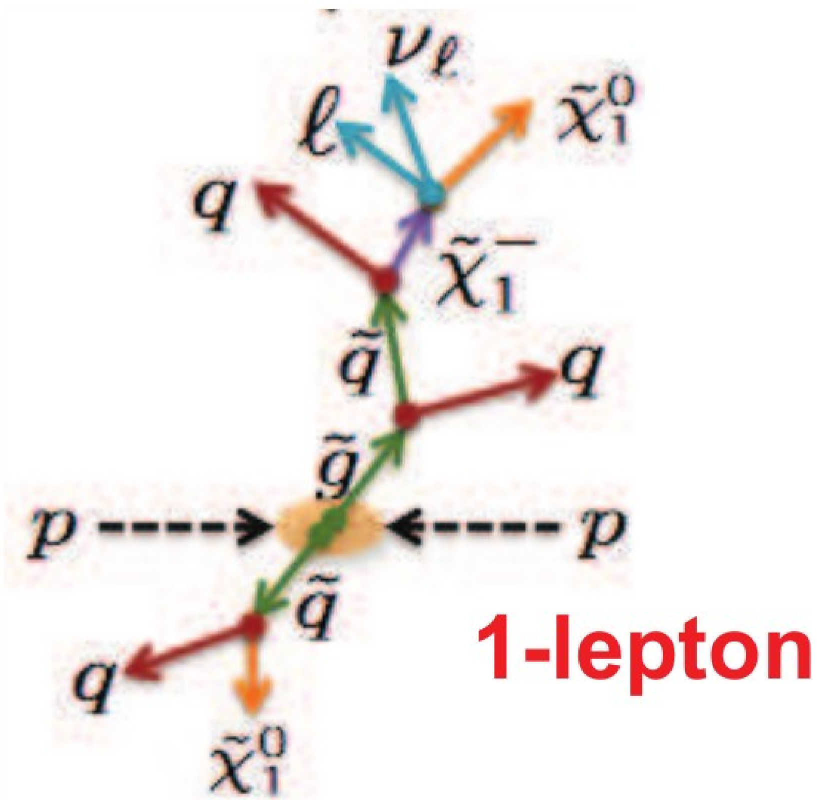


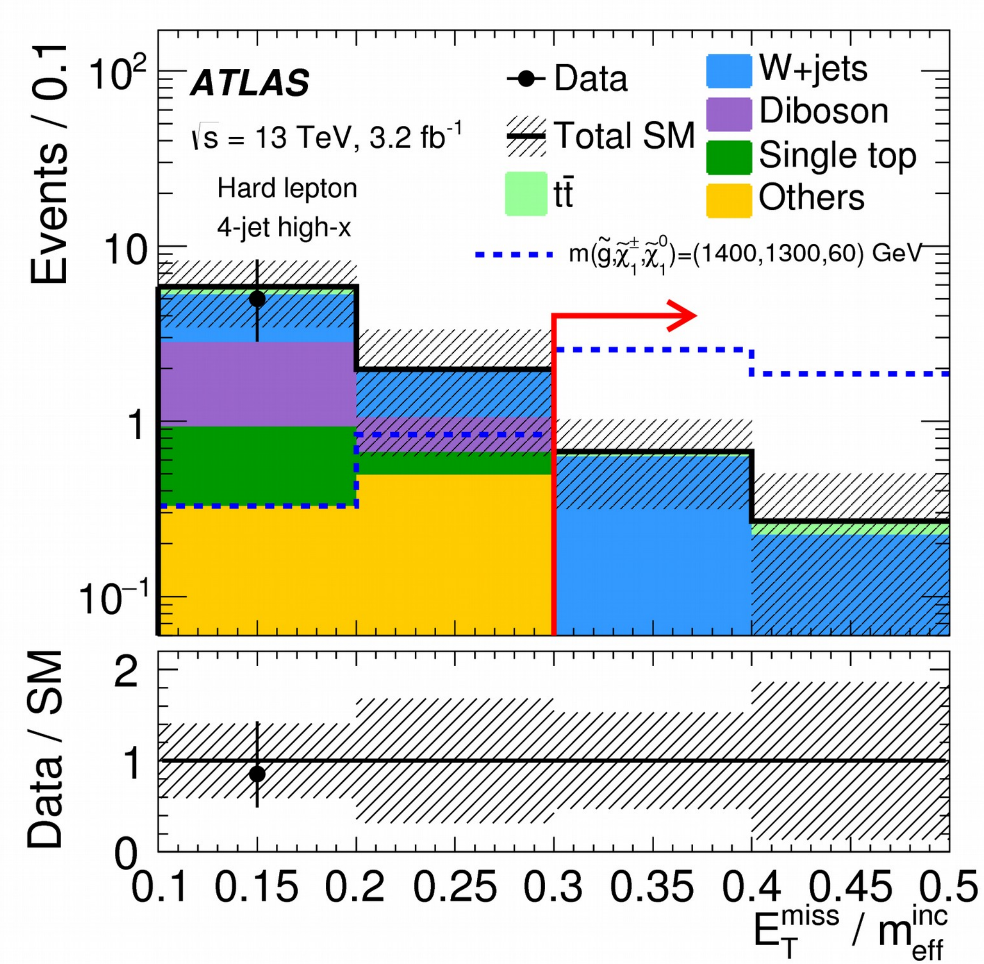
Phys. Lett. B 759 (2016) 601

Z + jets

Leptons + (missing energy) + jets is a common search signature

- eg SuSy decay cascade from Wolgang Hollik's “Introduction to SuSy/MSSM”



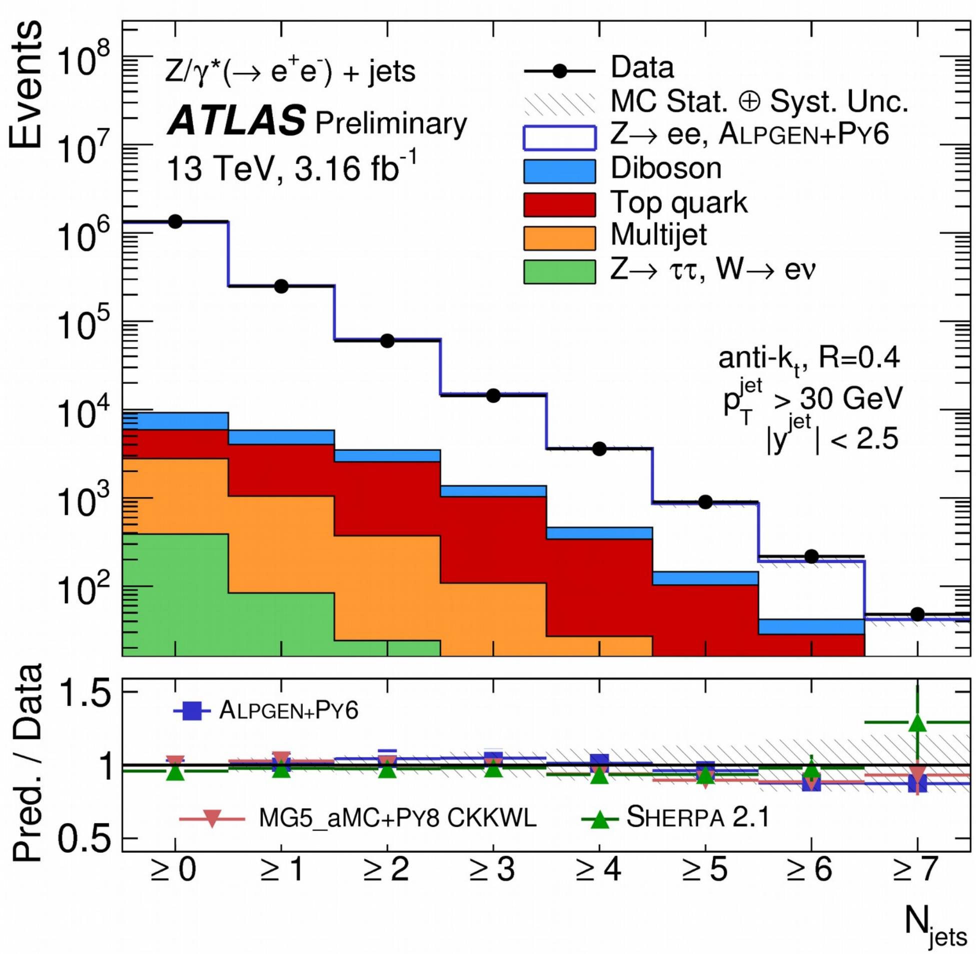


arXiv:1605.04285

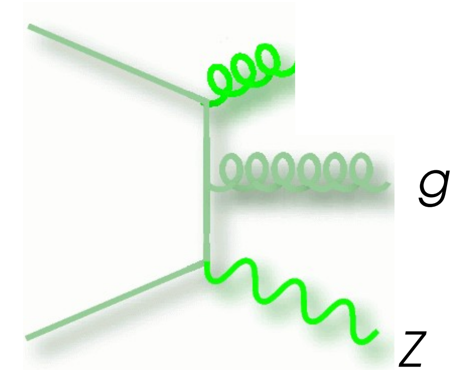
Z + jets

Also use W / Z events to test more complex final states

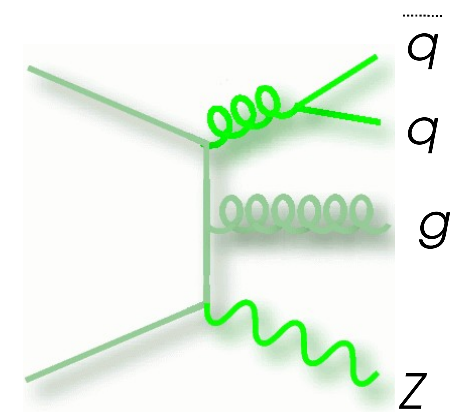
- jets with pT>30 GeV, |y|<2.5



Z+2-jets M.E



Z+3 jets matrix element



Test of pQCD modelling

- Z+{0,1,2,…} matrix elements, matched to parton shower
- then merged together, removing any overlaps

Z + jets

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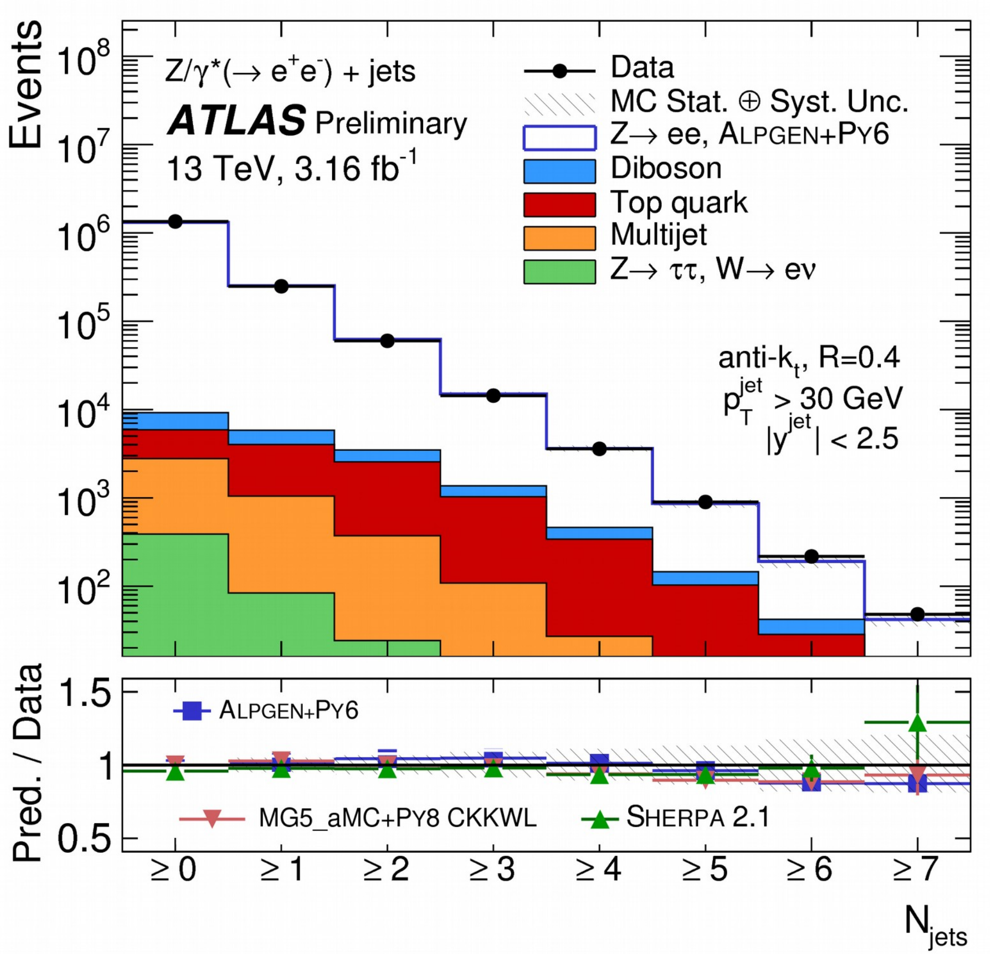
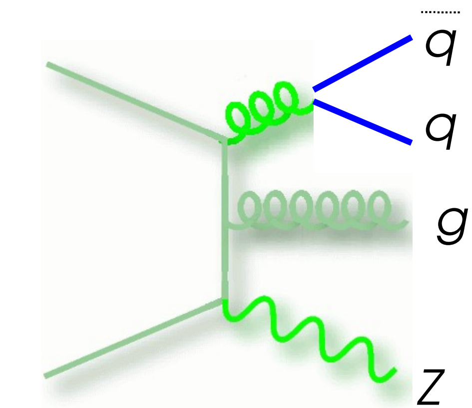


Z+2-jets M.E + parton shower



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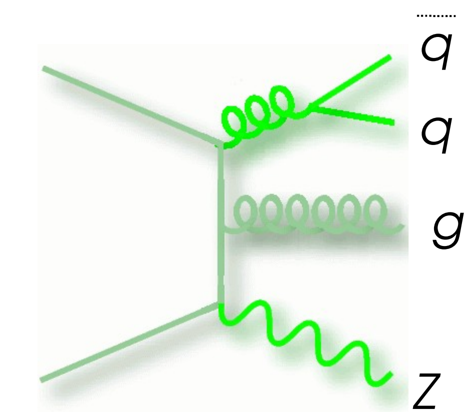

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Z + jets

Measure several distributions, compare to:

- LO MadGraph5_aMC@NLO + Pythia8 (CKKW-L), Alpgen + Pythia6 (MLM)
- NLO Sherpa (ME+PS@NLO), MadGraph5_aMC@NLO+Pythia8 (FxFx)
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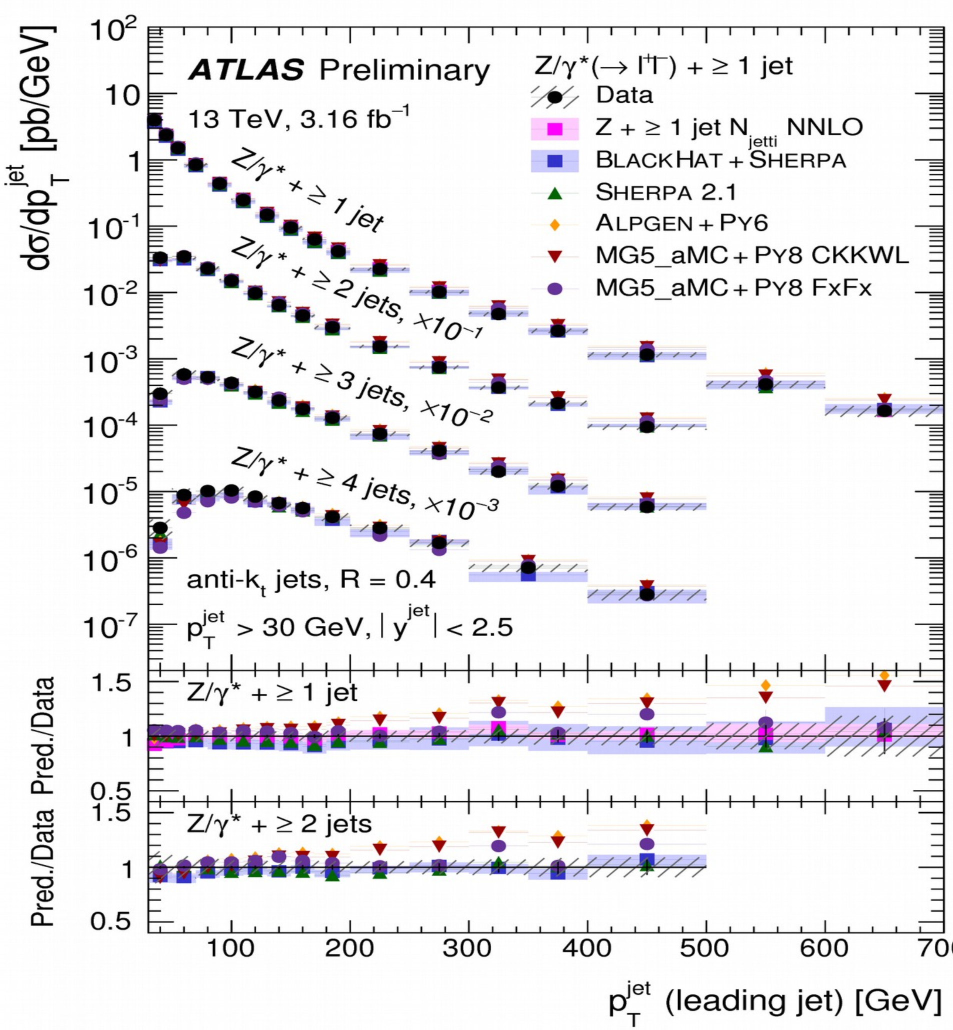
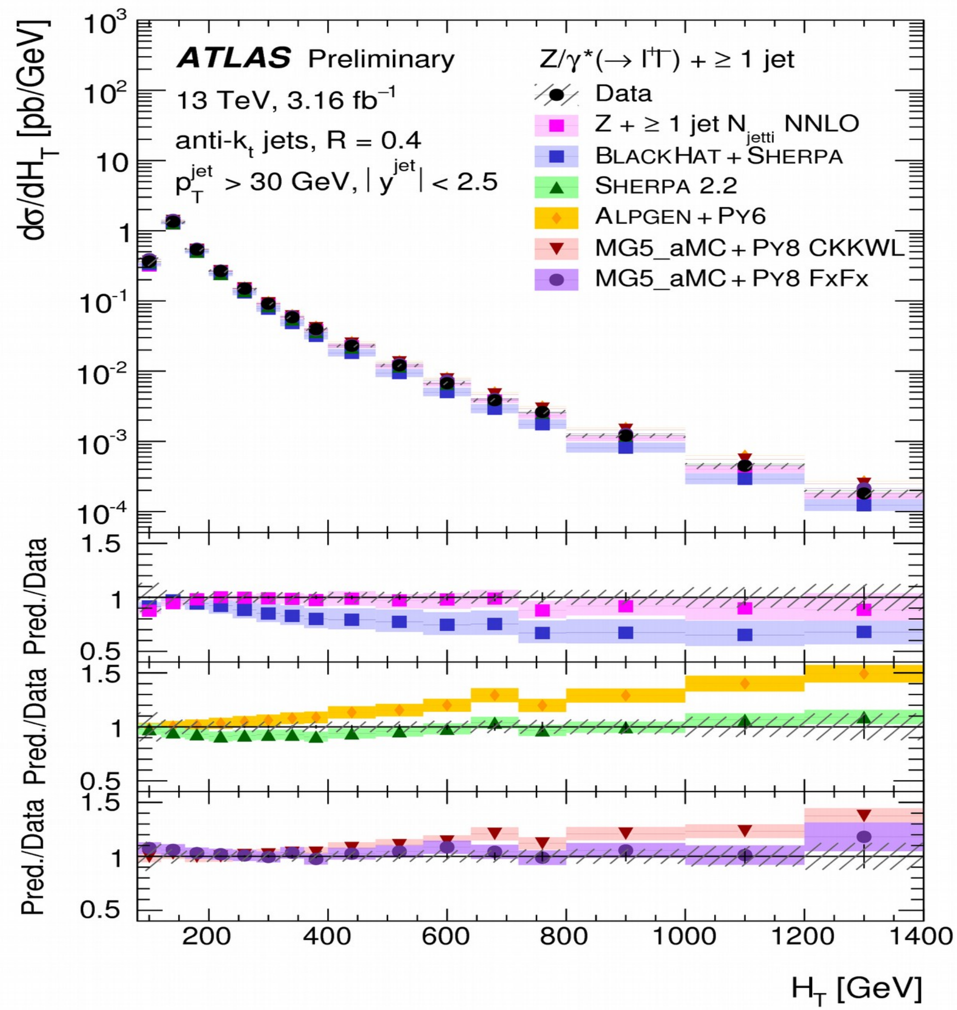
- NNLO Z + 1 jet (Phys. Rev. Lett. 116 (2016) 152001)





Z + jets

G. Hesketh

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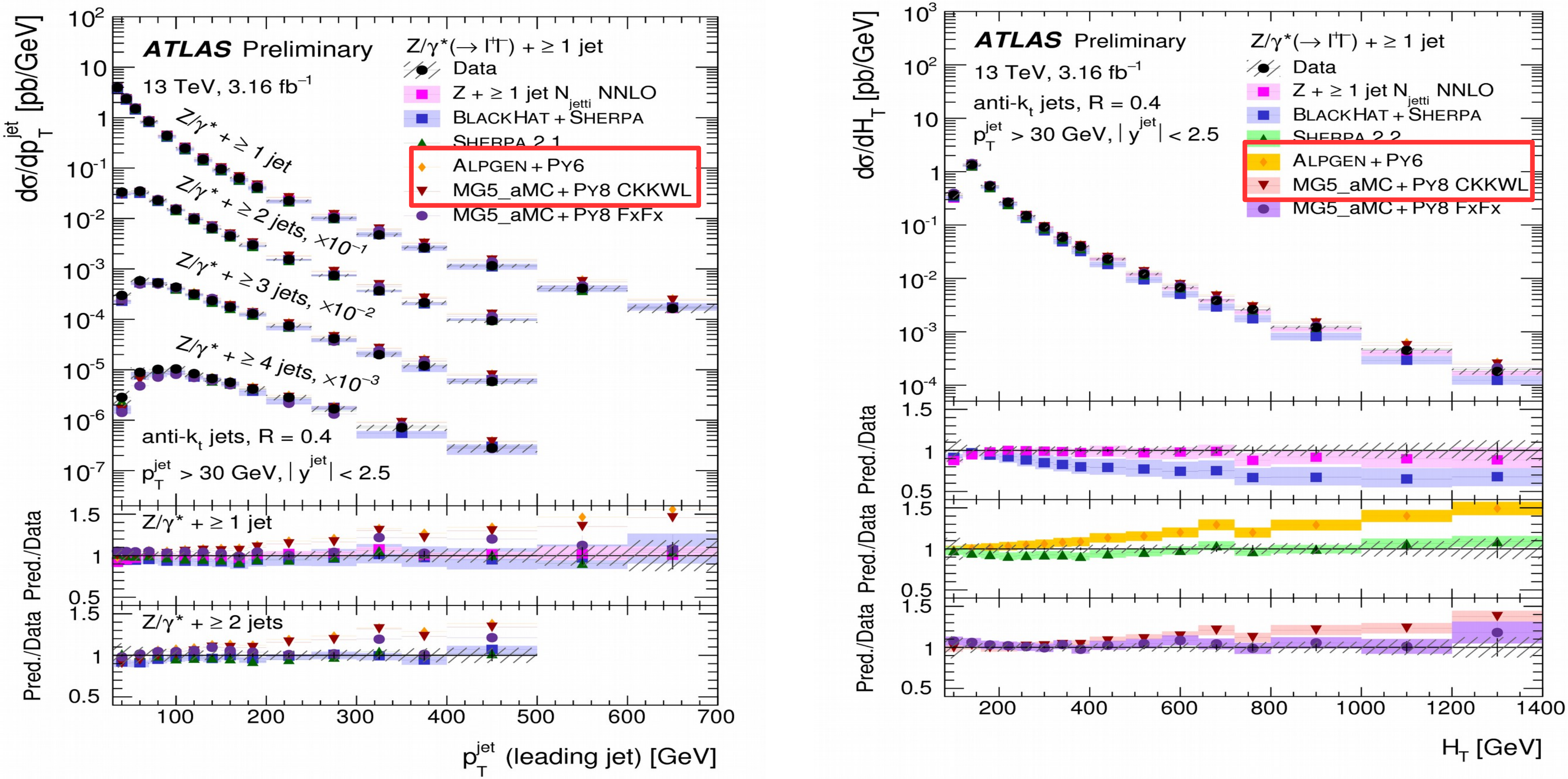

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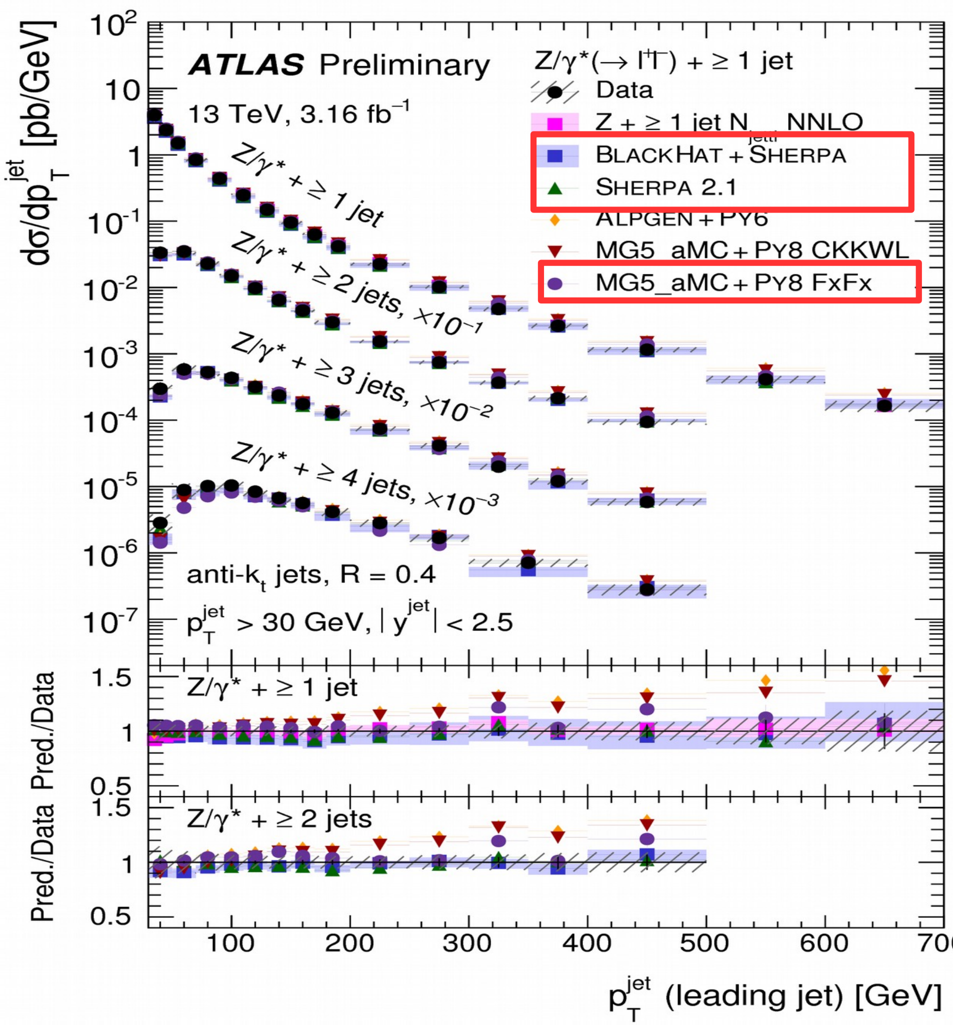

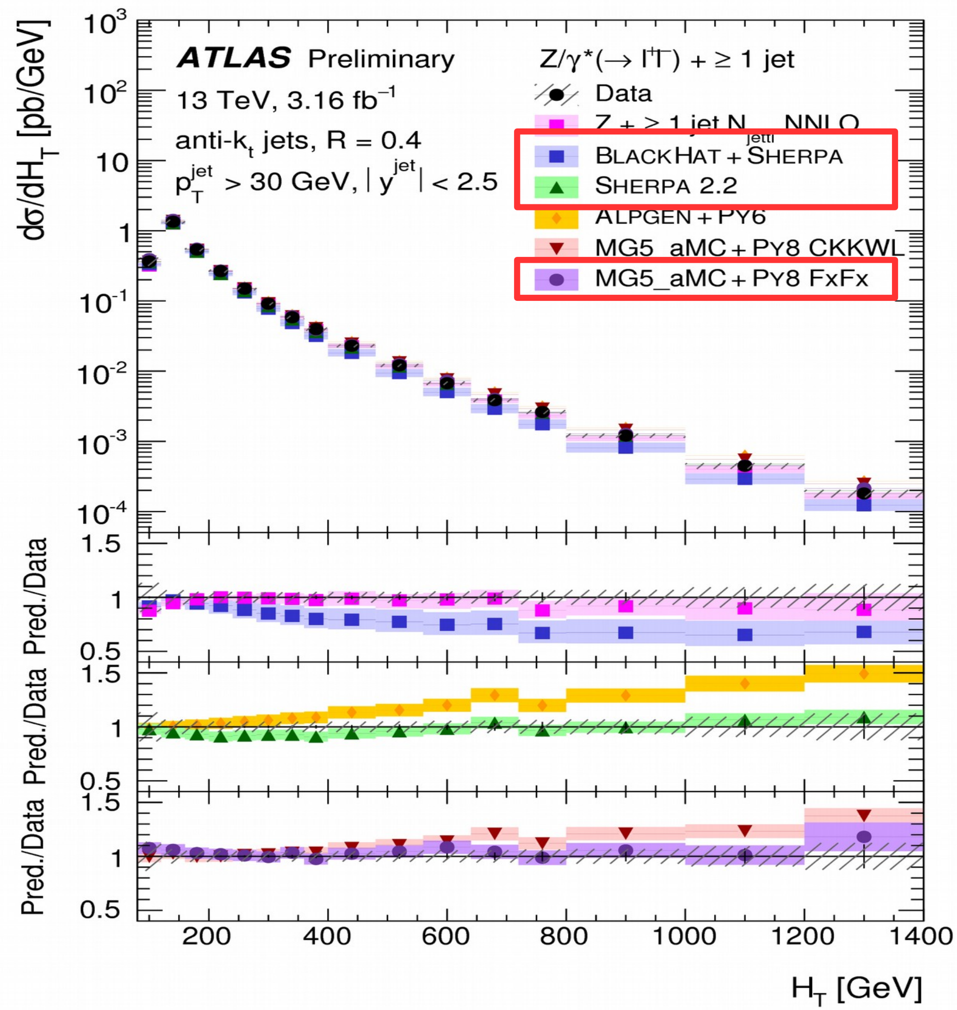

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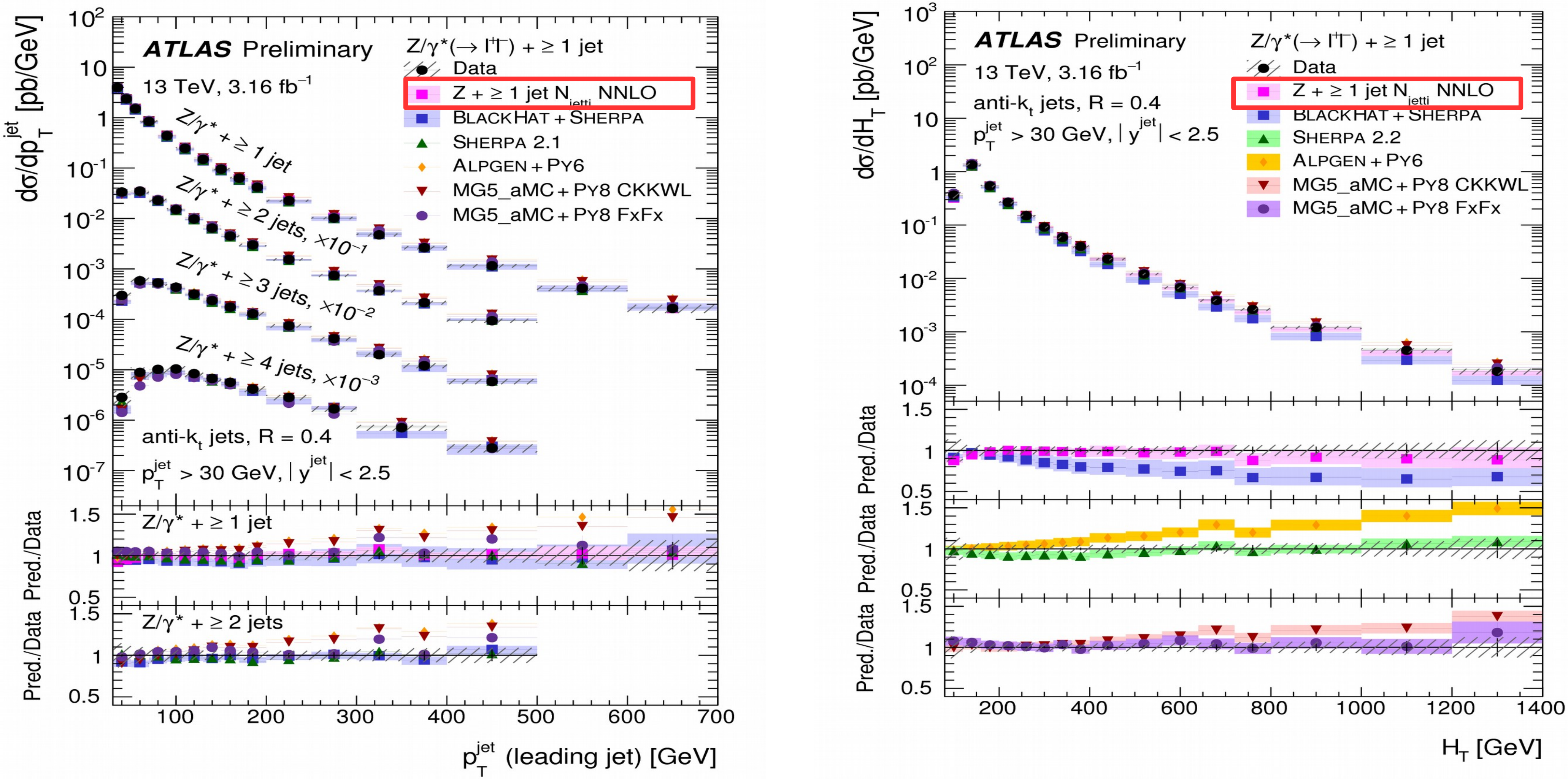
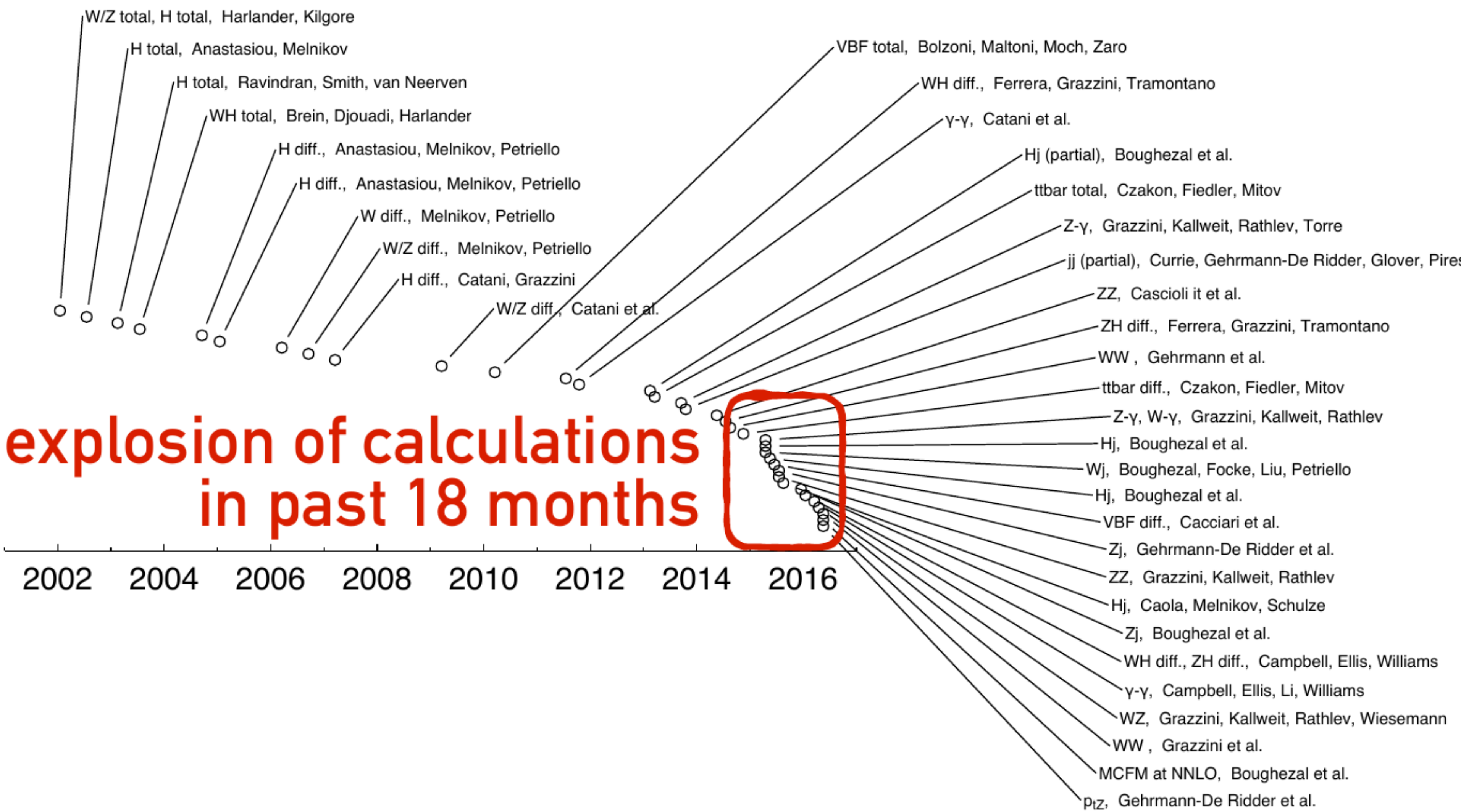


NNLO hadron-collider calculations v. time

Gavin Salam

let me know of any significant omissions

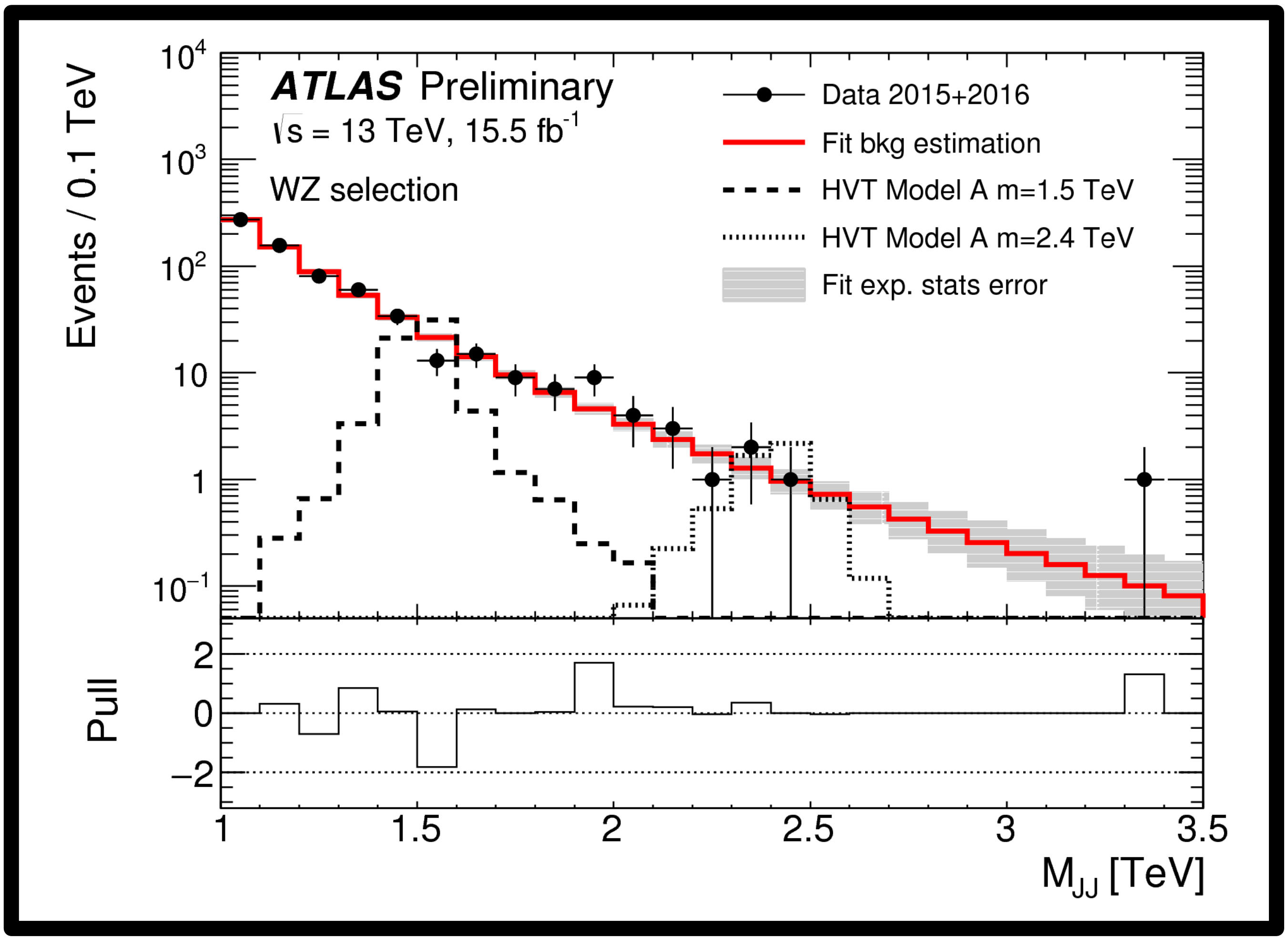


Slide by Gavin Salam, LHCP 2016

Dibosons

Disobons provide a different test:

- QCD and electroweak couplings
- one of the surviving small excesses:
  - W+Z → JJ, small excess ~ 2 TeV at end of Run 1, again in 2016



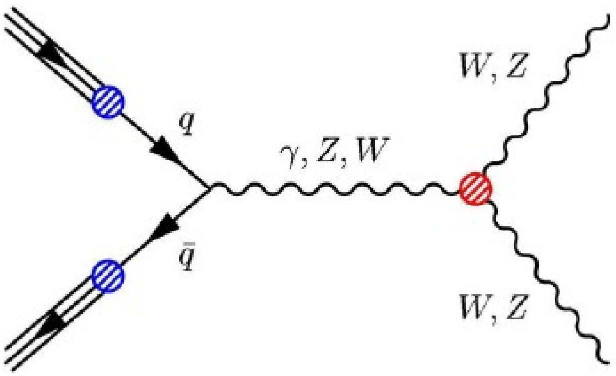
Dibosons

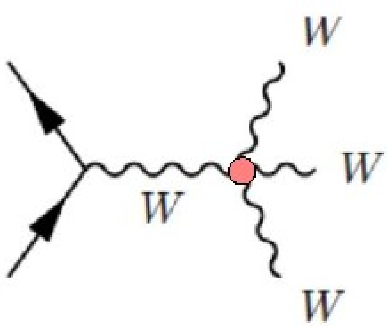
Disobons provide a different test

- QCD and electroweak couplings
- additional triple and quartic boson couplings

Use leptonic decays:

- WW: highest cross section, but 2 neutrinos
- ZZ lowest cross section, measure full system

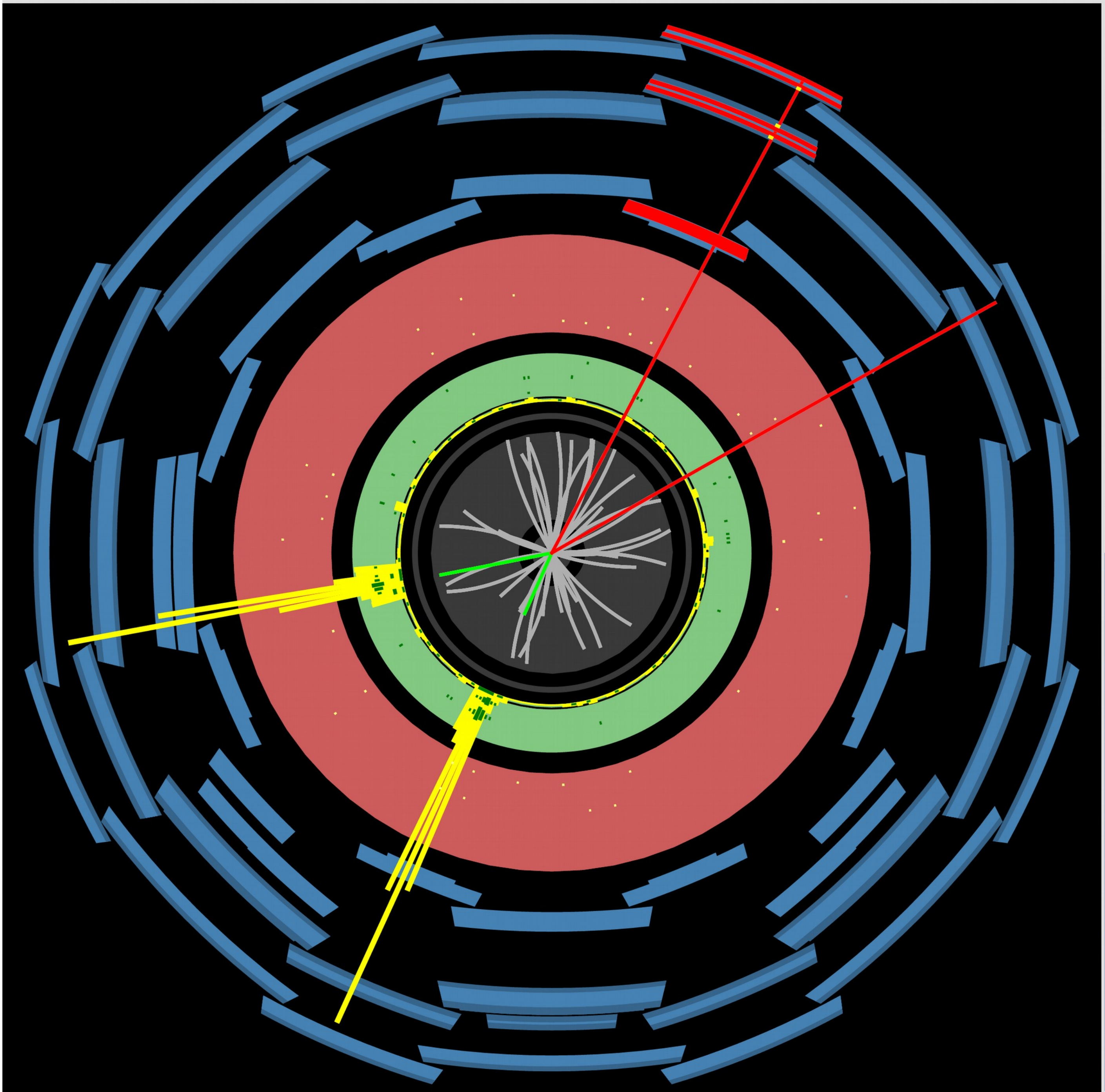




SM: $$\mathcal{L}^{gauge} = -\frac{1}{4}\mathbf{W}_{\mu\nu}\mathbf{W}^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$$

BSM: $$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = i\left[g_1^V(W_{\mu\nu}^\dagger W^\mu V^\nu - W_{\mu\nu}W^{\dagger\mu}V^\nu) + \kappa^V W_\mu^\dagger W_\nu V^{\mu\nu} + \frac{\lambda^V}{m_W^2}W_{\rho\mu}^\dagger W_\nu^\mu V^{\nu\rho}\right]$$

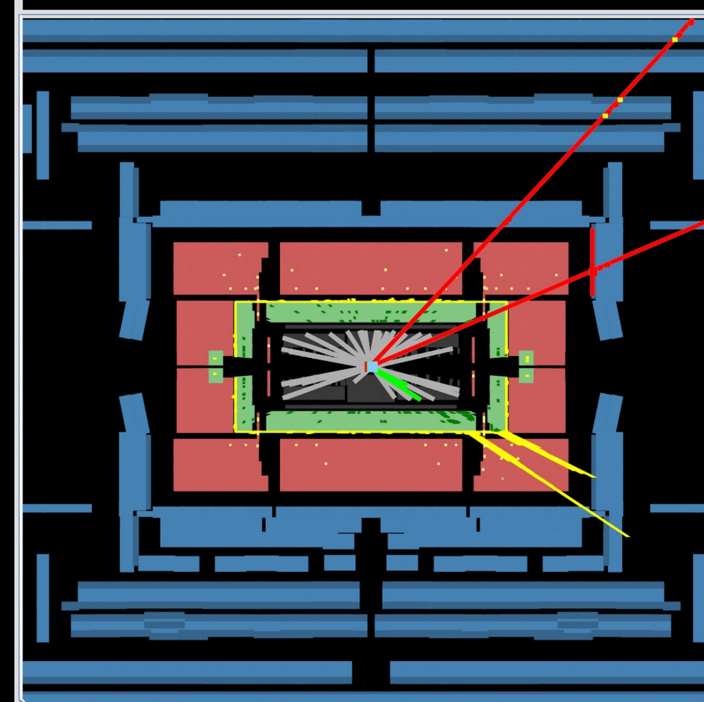
Z+Z



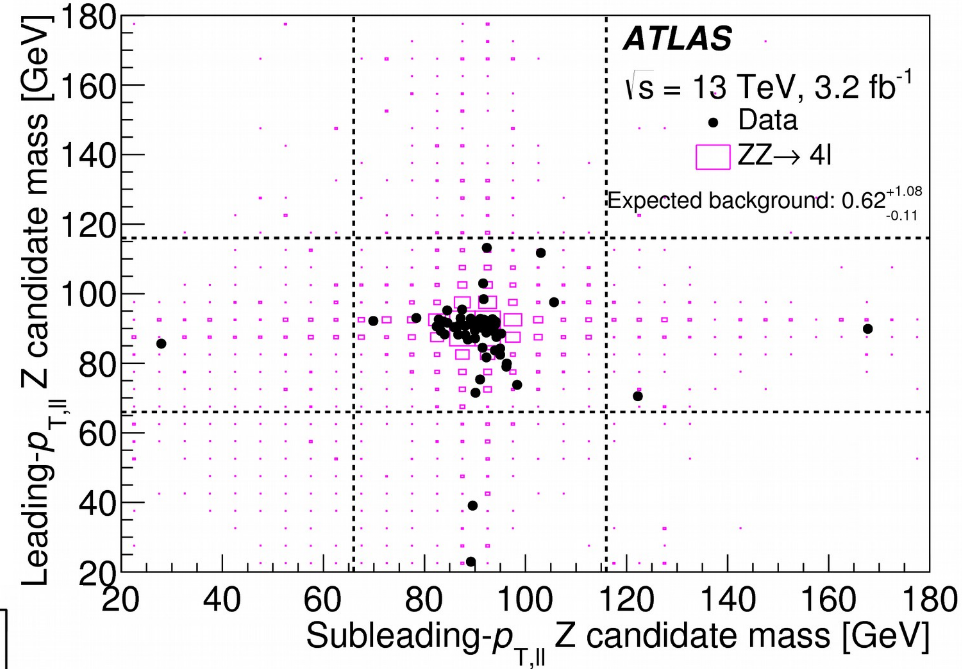
ATLAS EXPERIMENT

Run Number: 284285, Event Number: 4210157909

Date: 2015-11-01 14:56:38 CET



Z+Z



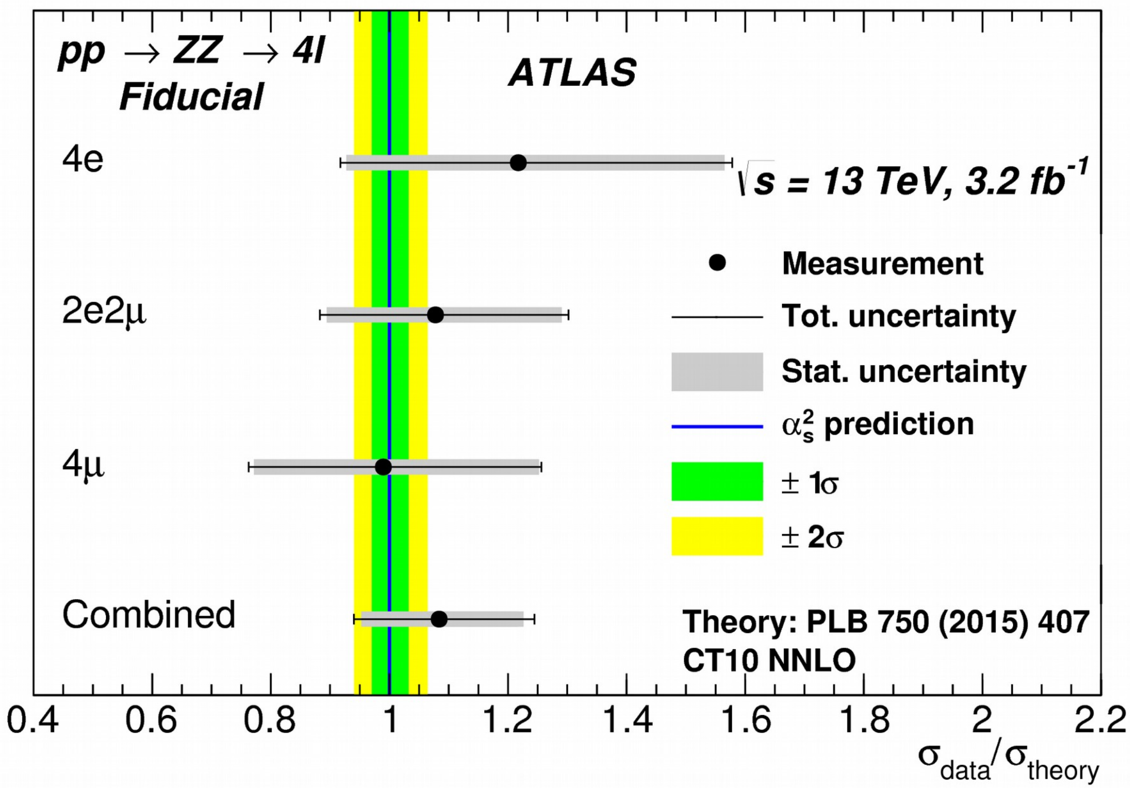
Use 3 channels:

eeee, $ee\mu\mu$, $\mu\mu\mu\mu$

Lepton pT>20 GeV, 66<M<116 GeV

Low cross section (63 candidates)

very pure (1% background)



Combined fiducial cross section:

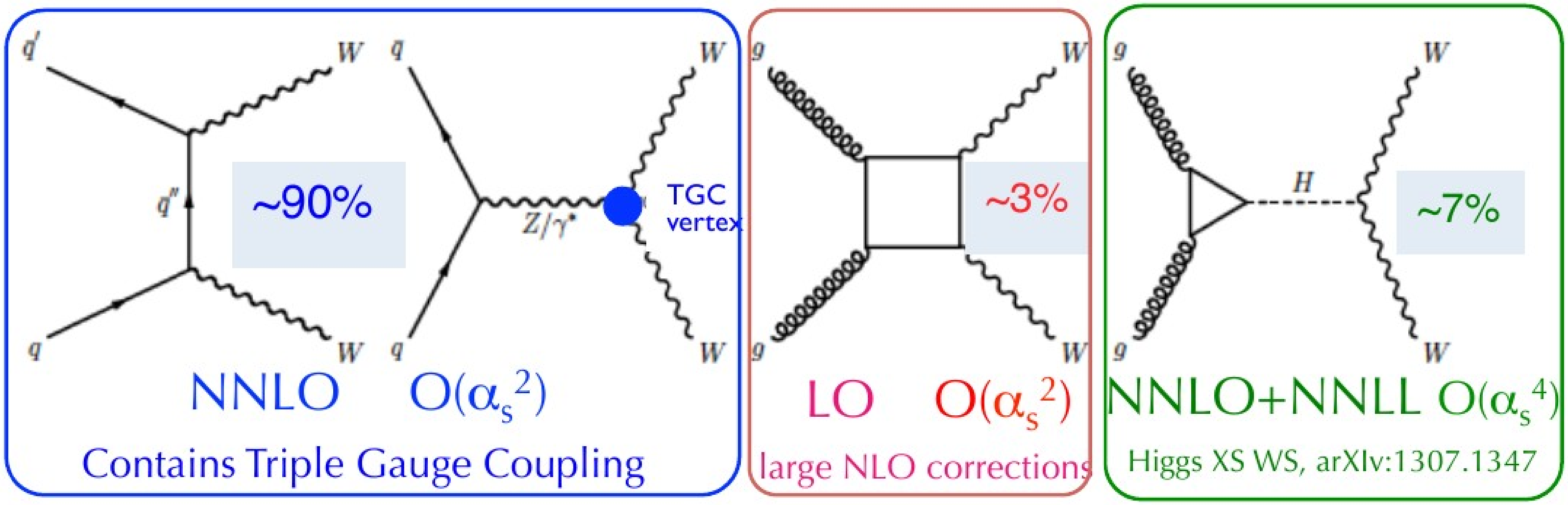
$$16.7\ ^{+2.2}_{-2.0}(\text{stat.})\ ^{+0.9}_{-0.7}(\text{syst.})\ ^{+1.0}_{-0.7}(\text{lumi.})\ \text{pb}$$

Phys. Rev. Lett. 116, 101801 (2016)

SM prediction (NNLO) (PLB 750 (2015) 407)

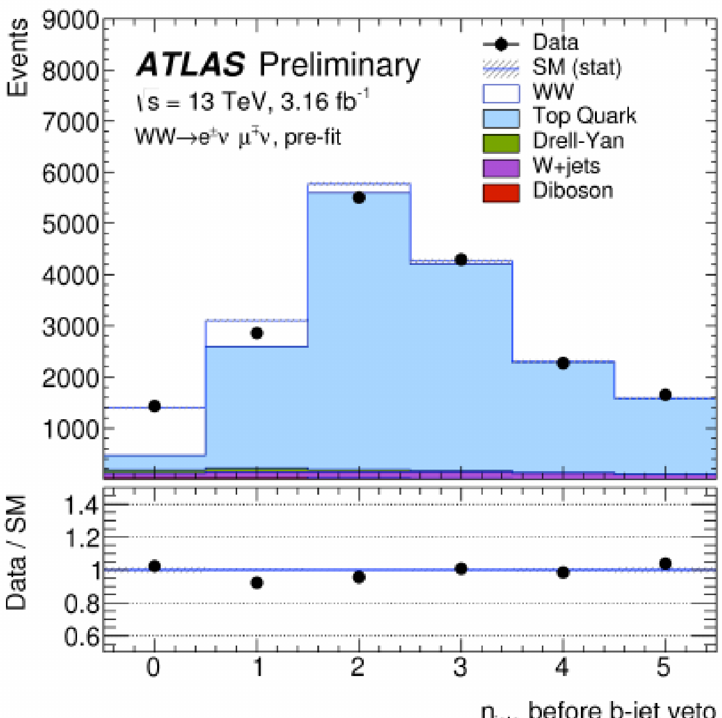
$$15.6^{+0.4}_{-0.4}\ \text{pb}$$

W+W



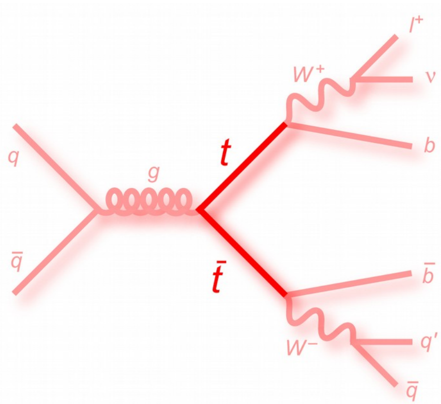
→ pp→WW =63pb

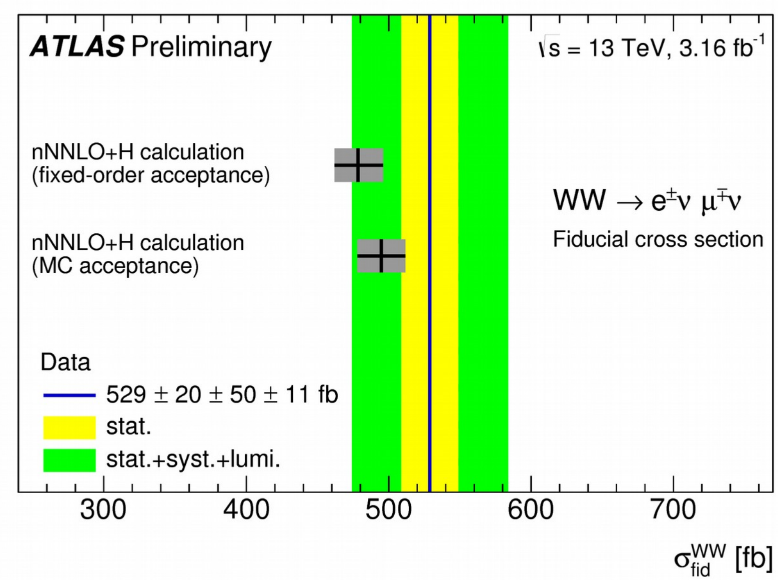
ATLAS-CONF-2016-090



Measure $W^+W^- \to l\nu l\nu$ (l=e, μ) + jet veto

- in fiducial phase space
- extrapolate to the total phase space

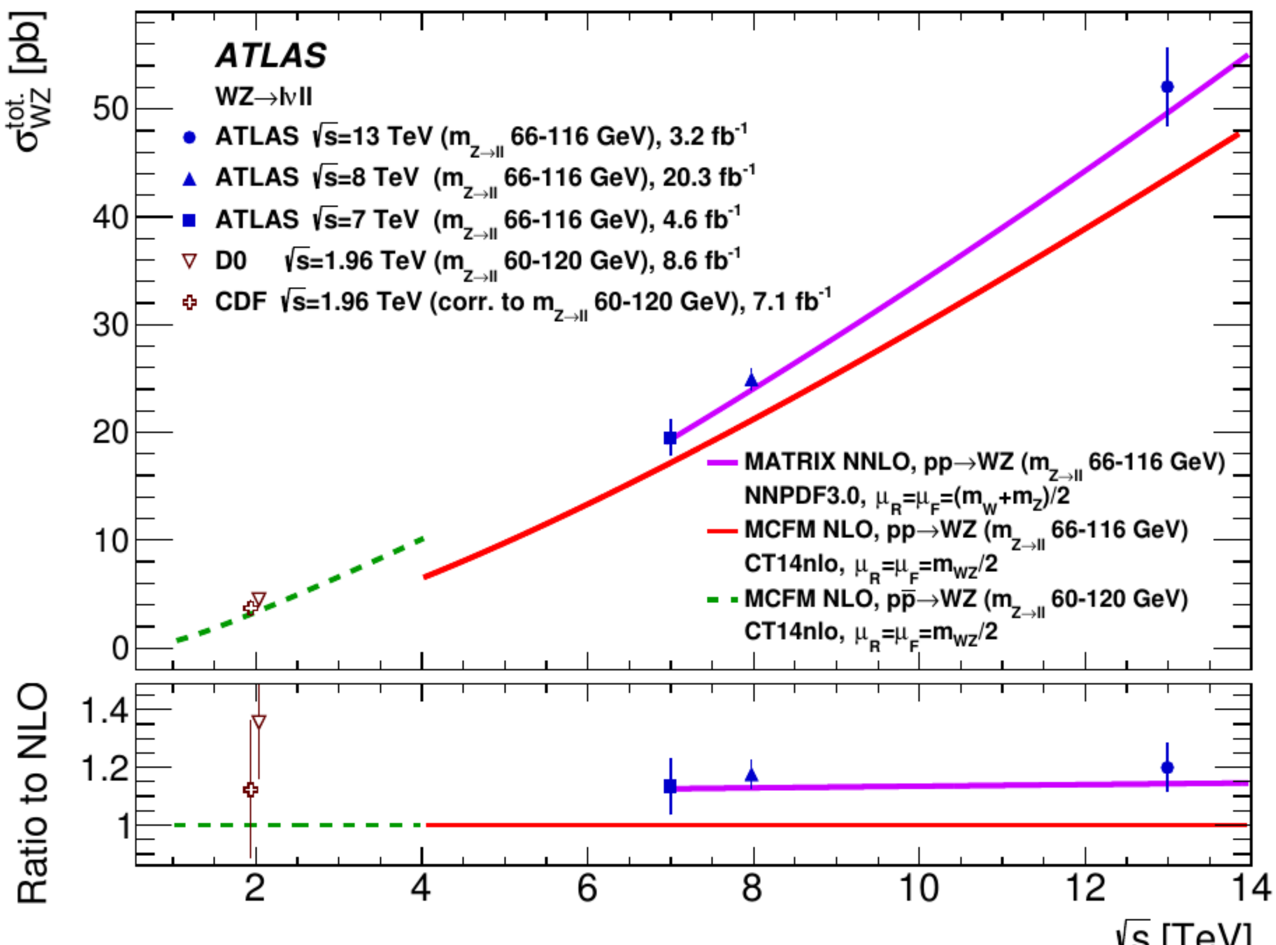


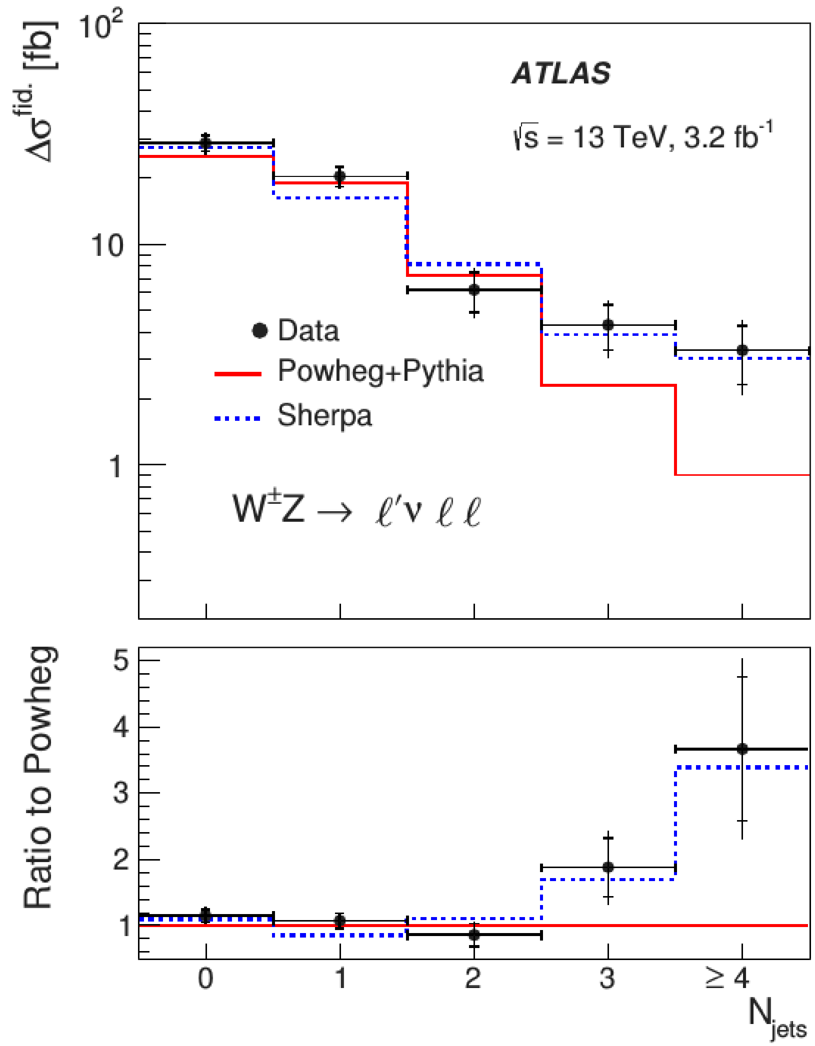


W+Z

Finally, WZ production
- inclusive cross section, and now differential

Disagreement with theory from Run 1
- explained by moving to NNLO





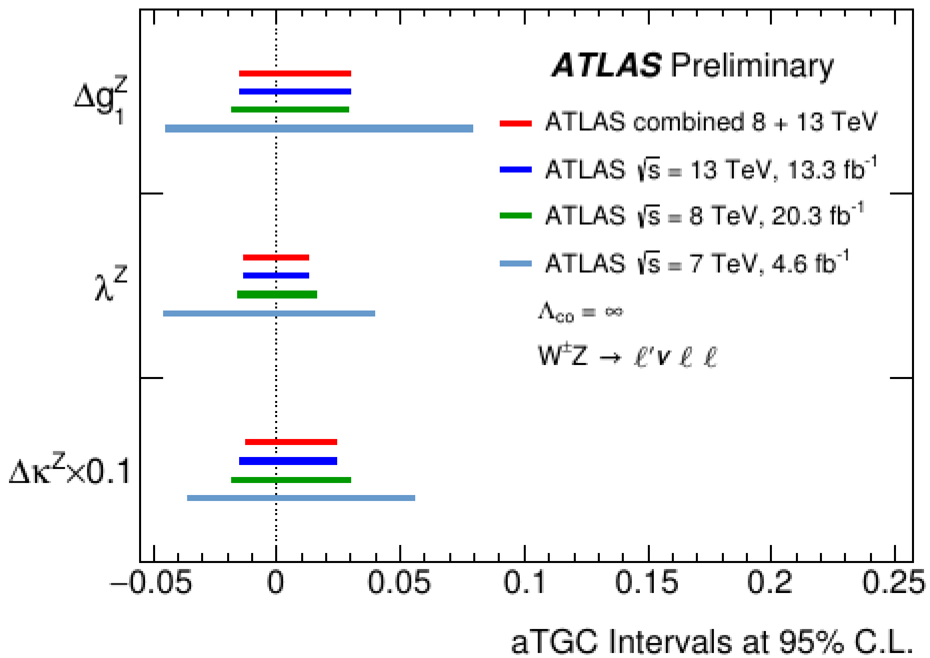
arXiv:1606.04017 [hep-ex]

aTGC

BSM: $$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = i\left[g_1^V\left(W^\dagger_{\mu\nu}W^\mu V^\nu - W_{\mu\nu}W^{\dagger\mu}V^\nu\right) + \kappa^V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda^V}{m_W^2} W^\dagger_{\rho\mu} W^\mu_\nu V^{\nu\rho}\right]$$

Similar sensitivity from 8 TeV and 13 TeV data

→ combine, 20% improvement in limits



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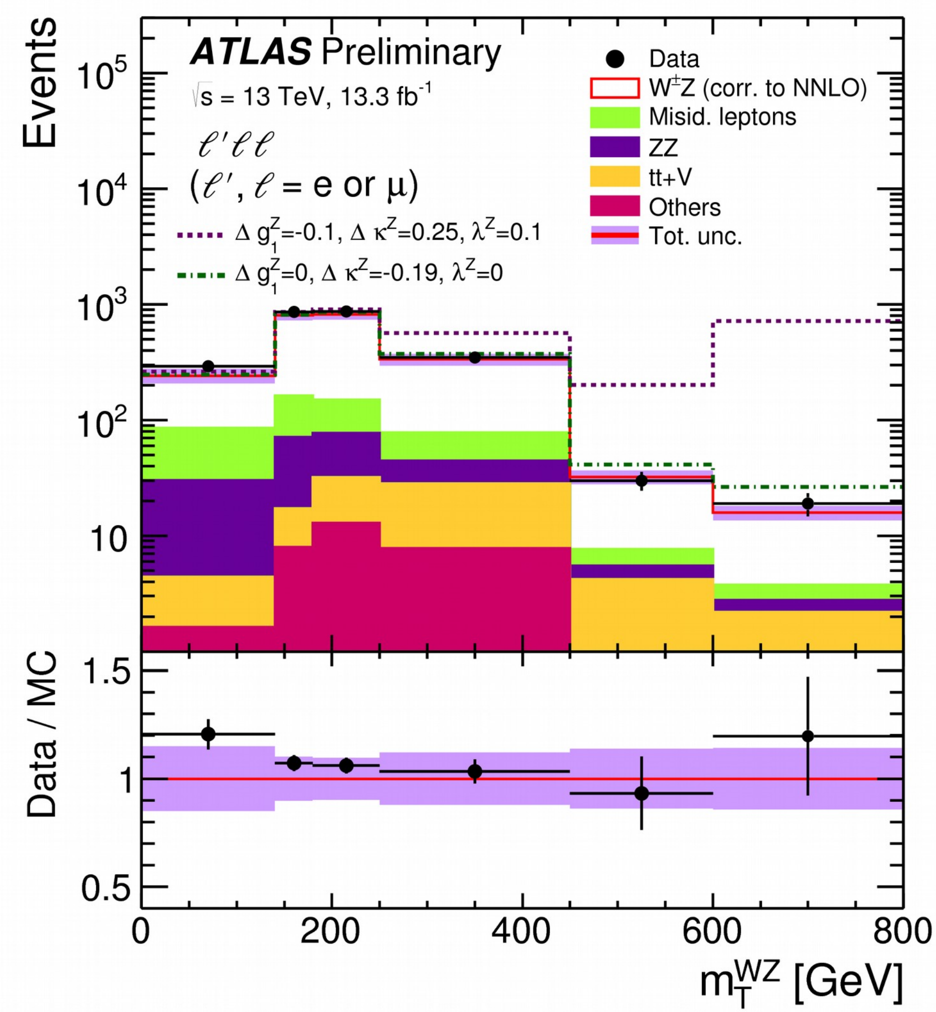
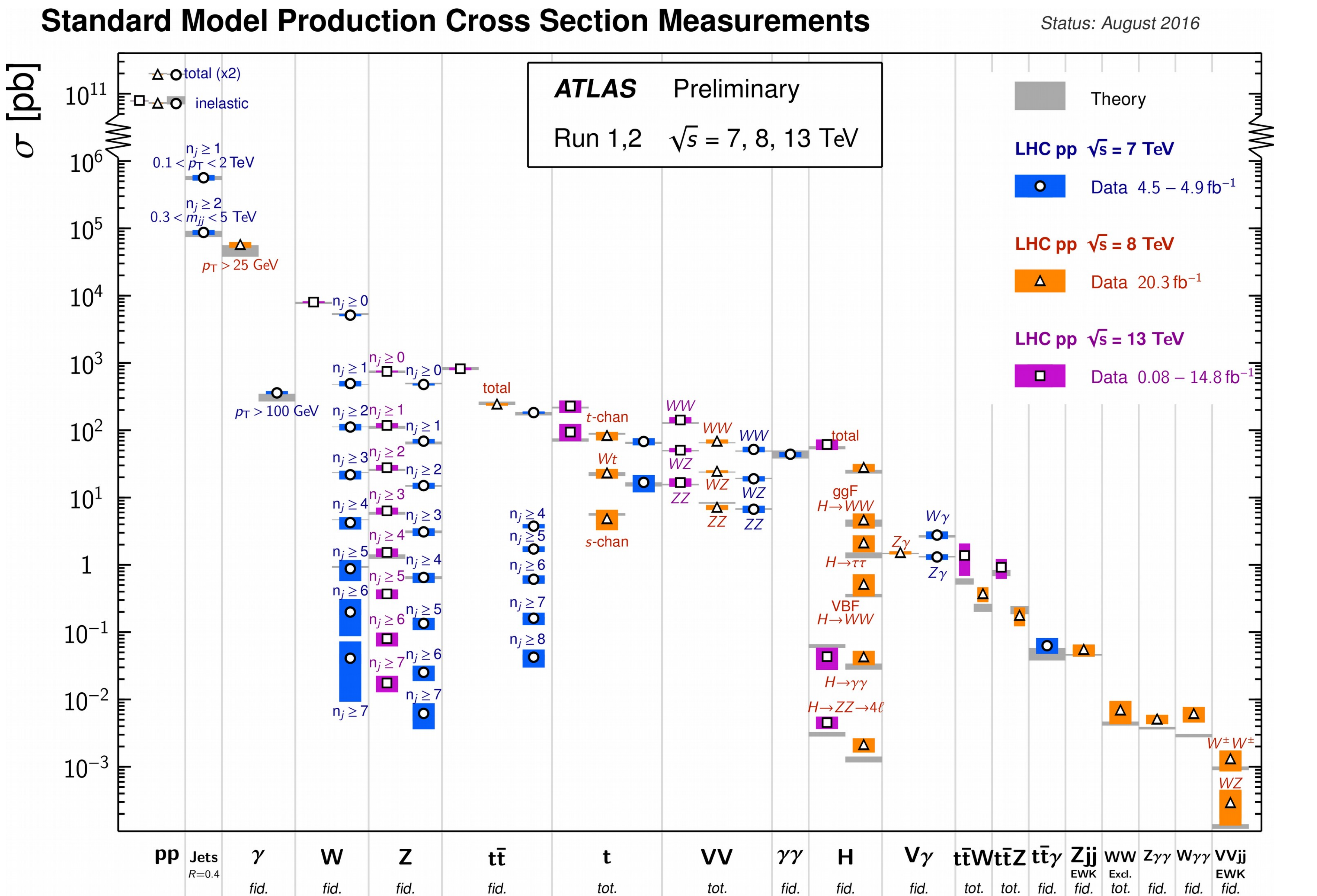
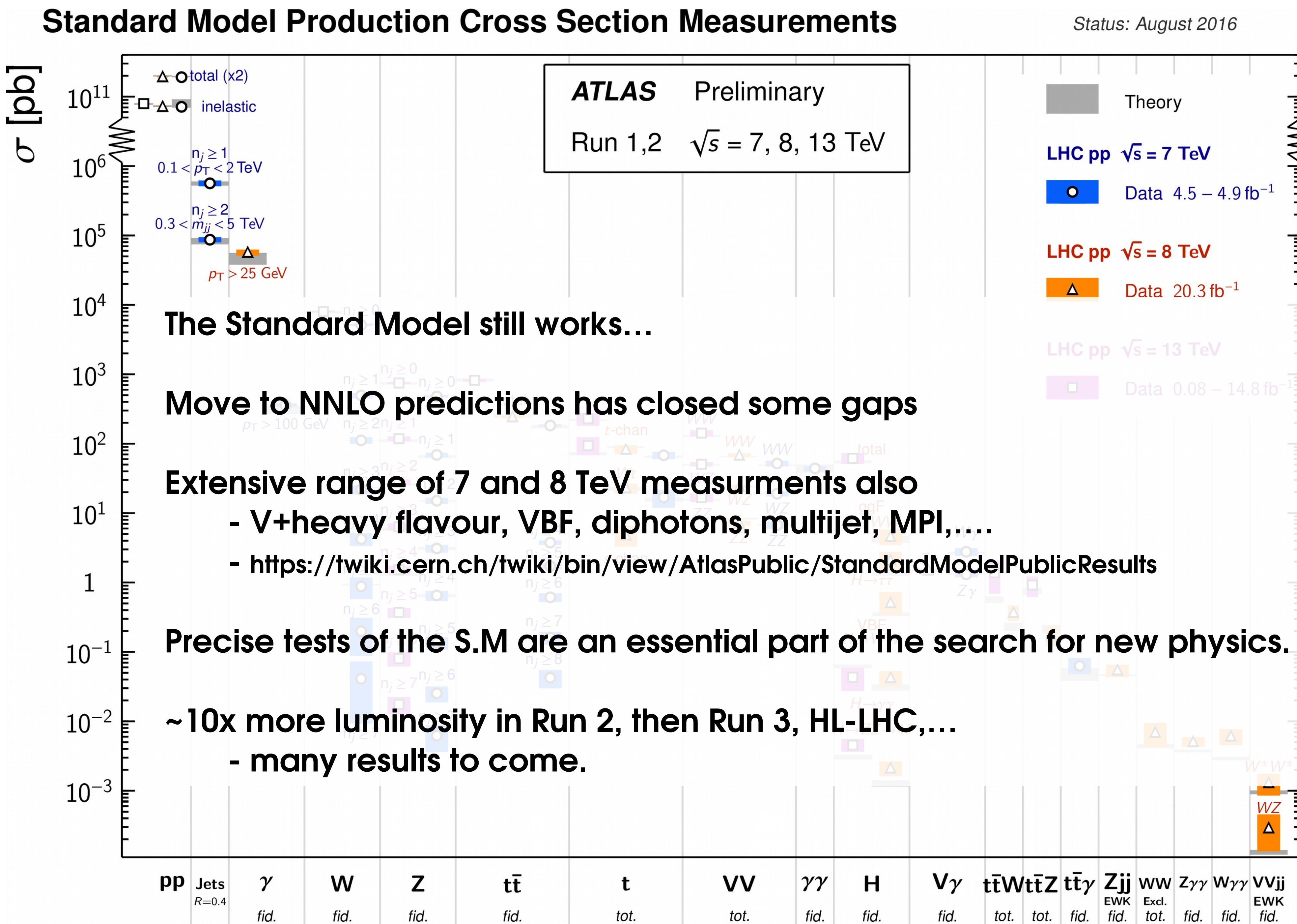



New physics?
The reach of the LHC?

Conclusion


Standard Model Production Cross Section Measurements
Status: August 2016
ATLAS Preliminary
Run 1,2 √s = 7, 8, 13 TeV
Theory
LHC pp √s = 7 TeV
Data 4.5 – 4.9 fb⁻¹
LHC pp √s = 8 TeV
Data 20.3 fb⁻¹
LHC pp √s = 13 TeV
Data 0.08 – 14.8 fb⁻¹
σ [pb]
total (x2)
inelastic
0.1 < pT < 2 TeV
0.3 < mjj < 5 TeV
pT > 25 GeV
pT > 100 GeV
total
t-chan
Wt
s-chan
WW
WZ
ZZ
ggF H→WW
H→ττ
VBF H→WW
H→γγ
H→ZZ→4ℓ
Wγ
Zγ
W±W±
pp
Jets R=0.4
γ fid.
W fid.
Z fid.
tt̄ fid.
t tot.
VV tot.
γγ fid.
H fid.
Vγ fid.
tt̄W tot.
tt̄Z tot.
tt̄γ fid.
Zjj EWK fid.
WW Excl. tot.
Zγγ fid.
Wγγ fid.
VVjj EWK fid.

Conclusion



The Standard Model still works…

Move to NNLO predictions has closed some gaps

Extensive range of 7 and 8 TeV measurments also
- **V+heavy flavour, VBF, diphotons, multijet, MPI,….**
- **https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults**

Precise tests of the S.M are an essential part of the search for new physics.

~10x more luminosity in Run 2, then Run 3, HL-LHC,…
- **many results to come.**

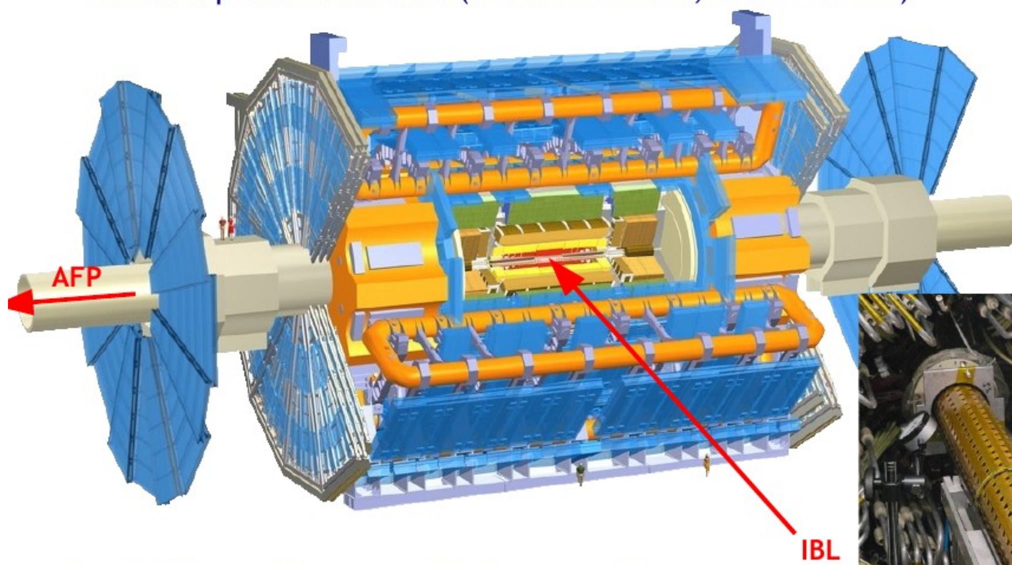
Upgraded

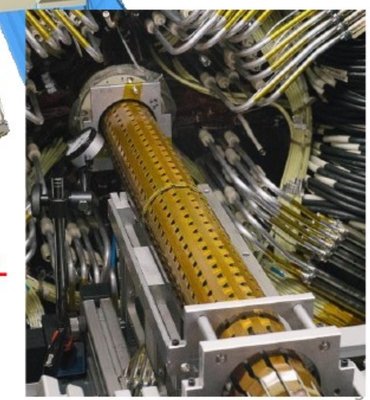
ATLAS EXPERIMENT

ATLAS in Run-2

New detectors in Run-2:

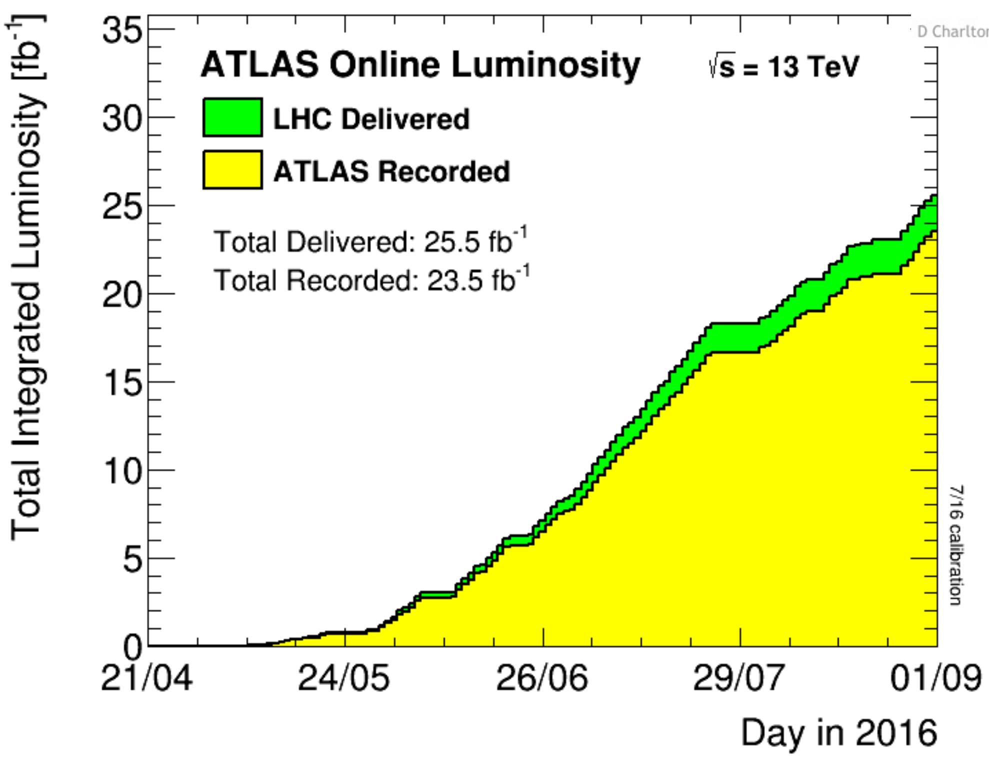
- Innermost pixel layer IBL, 3.4cm from interaction point
- Forward proton detectors (one arm in 2016, 210m from IP)





In addition, various consolidations provide improved running at high luminosities and rates

D Charlton / Birmingham - 8 August 2016, ICHEP Chicago



...and impressive LHC performance in 2016

Minimum Bias

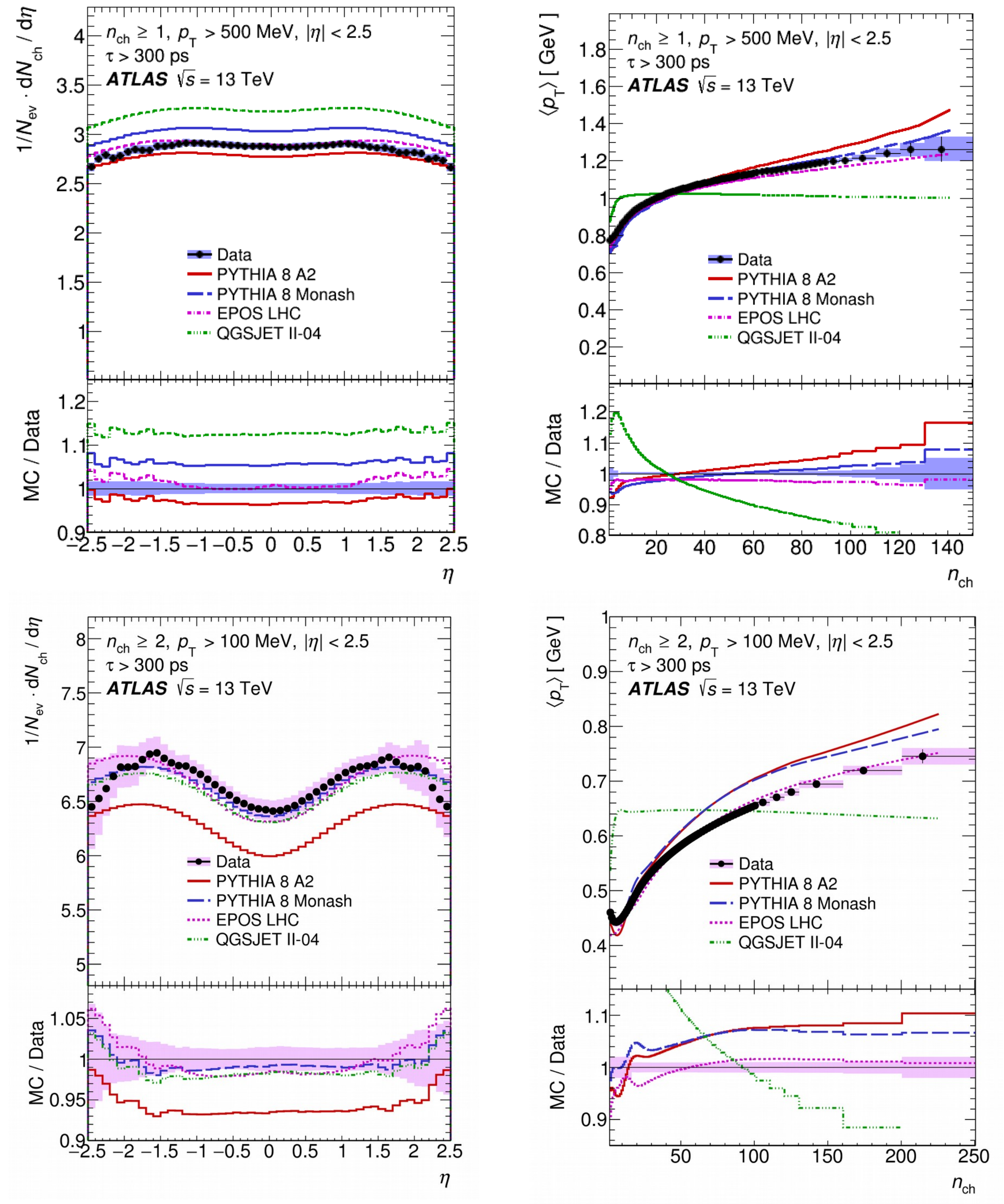
Study recently extended to lower pT:

pT>500 MeV → pT > 100 MeV

Highlights differences between models

Results will be used to tune models

arXiv: 1606.01133



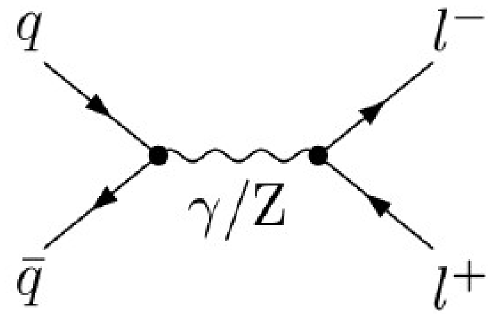
Inclusive W/Z

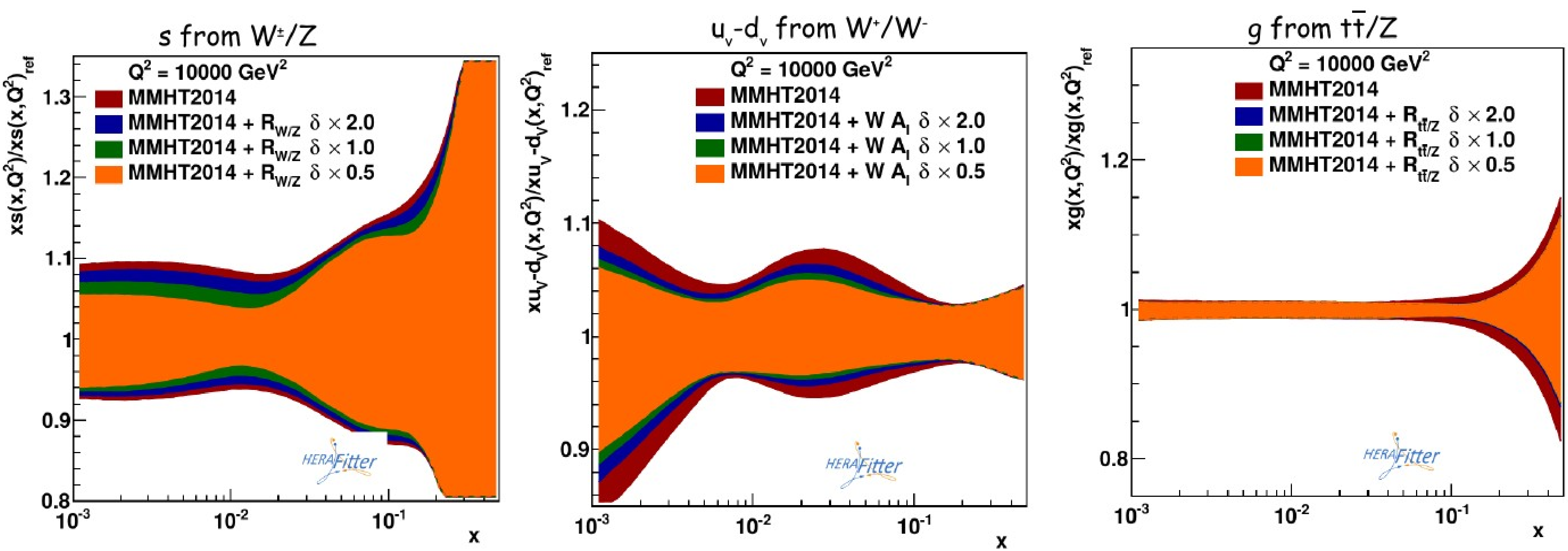
Use electron & muon decay modes as colourless probe of collision

- test pQCD, constrain proton structure

Measure cross-section ratios:

- fully cancel lumi uncertainties and partially systematics.
- precision < 2% will constrain PDFs

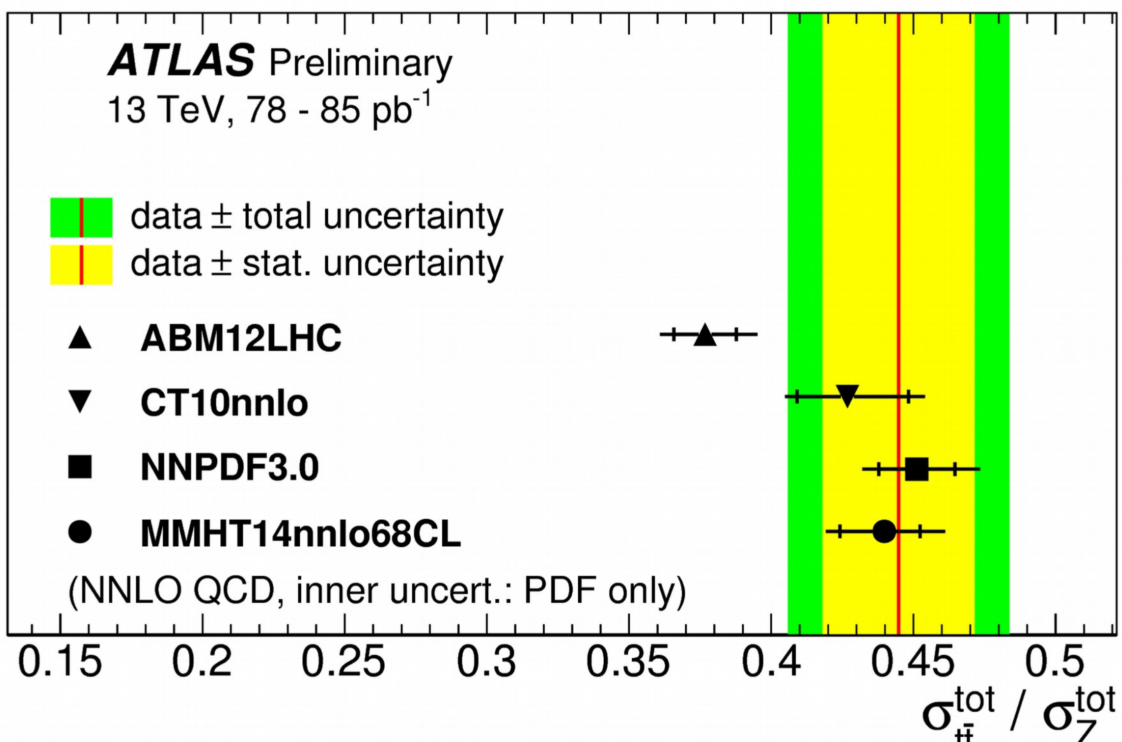




J. Rojo et al., J.Phys.G 42 (2015) 103103

Prediction		Fiducial cross section $pp \to WW \to \ell\ell\nu\nu$ [fb]
Measured $\sigma^{e\mu}_{\rm fid}(WW)$		$374 \pm 7({\rm stat})\ ^{+25}_{-23}({\rm syst})\ ^{+8}_{-7}({\rm lumi})$
$\sigma({\rm nNLO}_{{\rm fid},e\mu})$	PowHeg+Pythia8~NLO+NLL	311 ± 15
$\sigma({\rm approx.\ NNLO}_{{\rm fid},e\mu})$	NNLO	335 ± 18
$\sigma({\rm approx.\ (NNLO + NNLL)}_{{\rm fid},e\mu})$	Quoted from arXiv:1410.4745	358 ± 14
$\sigma({\rm NNLO}\ p_{\rm T}\text{-Resum}_{{\rm fid},e\mu})$	MC reweighted to NNLL resummed $p_T(WW)$	349 ± 19

- nNLO = NLO qq→WW + NNLO gg→H→WW + LO gg→WW
  NNLO= **NNLO** qq→WW + NNLO gg→H→WW + LO gg→WW



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