



CMS Experiment at LHC, CERN
Data recorded: Tue May 25 06:24:04 2010 CEST
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Lumi section: 348



Standard Model physics results from ATLAS and CMS

Milos Dordevic (CERN)

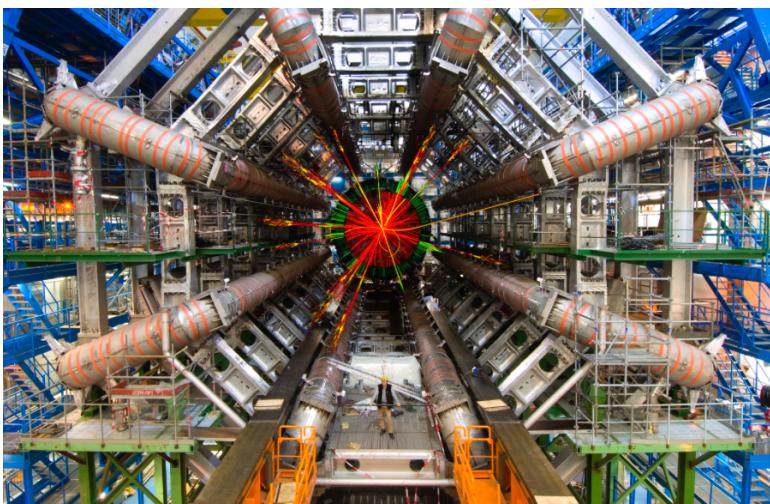
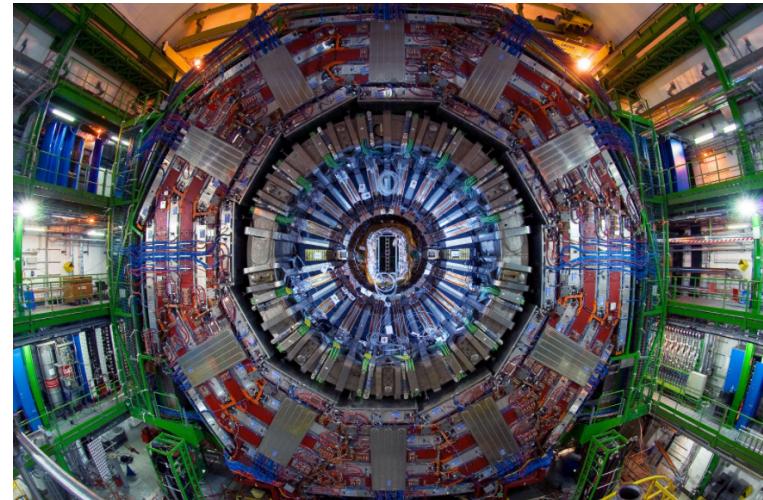
on behalf of ATLAS and CMS Collaborations

XXX-th International Workshop on High Energy Physics “**Particle and Astroparticle Physics, Gravitation and Cosmology: Predictions, Observations and New Projects**”

June 23-27, 2014, Protvino, Moscow region, Russia

Outline

- **Vector Boson Studies**
 - W and Z Boson Production
 - Drell-Yan Differential Cross Sections
- **Vector Boson + Jets Studies**
 - W/Z + Jets Differential Cross Sections
 - W + Charm Production
 - Z+b(b) Production
 - EWK $W^\pm W^\pm jj$ Production
 - EWK Zjj Production

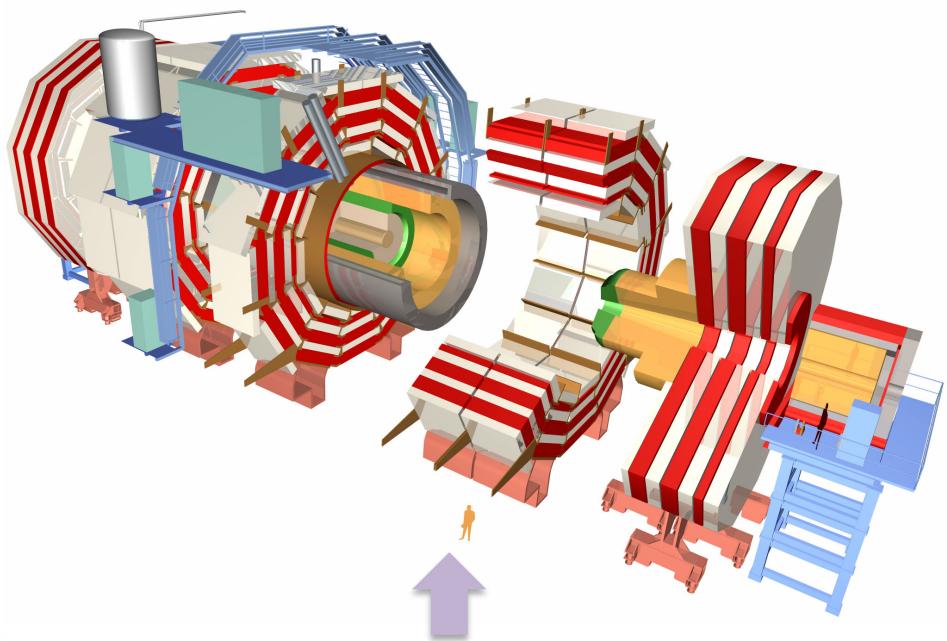
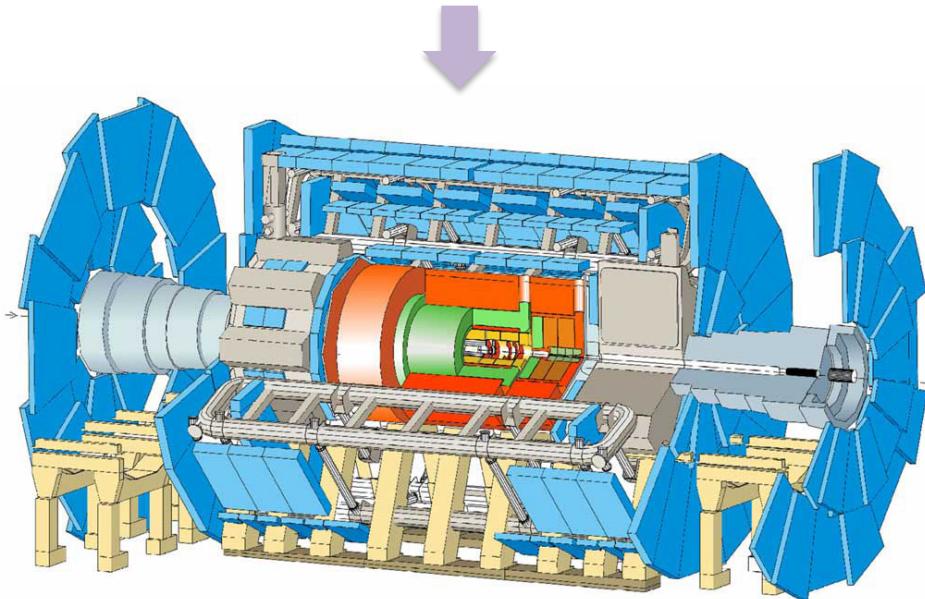


- **Multiboson Studies**
 - ZZ->4l Production
 - VZ (Z to bb) Production
 - Anomalous Triple and Quartic Couplings
- **Jet Physics Studies**
 - Jet Production Cross Sections
 - Constraints on PDFs and α_s

ATLAS and CMS Experiments



- Inner Solenoid (2 T), outer Toroid magnet.
- Silicon + TRT tracker, pT resolution $\sim 2.5\%$.
- Sampling ECAL (Lead, Steel, Liquid Argon).
- HCAL made of Steel with Scintillating tiles.
- Large Muon Spectrometer in Toroid field.

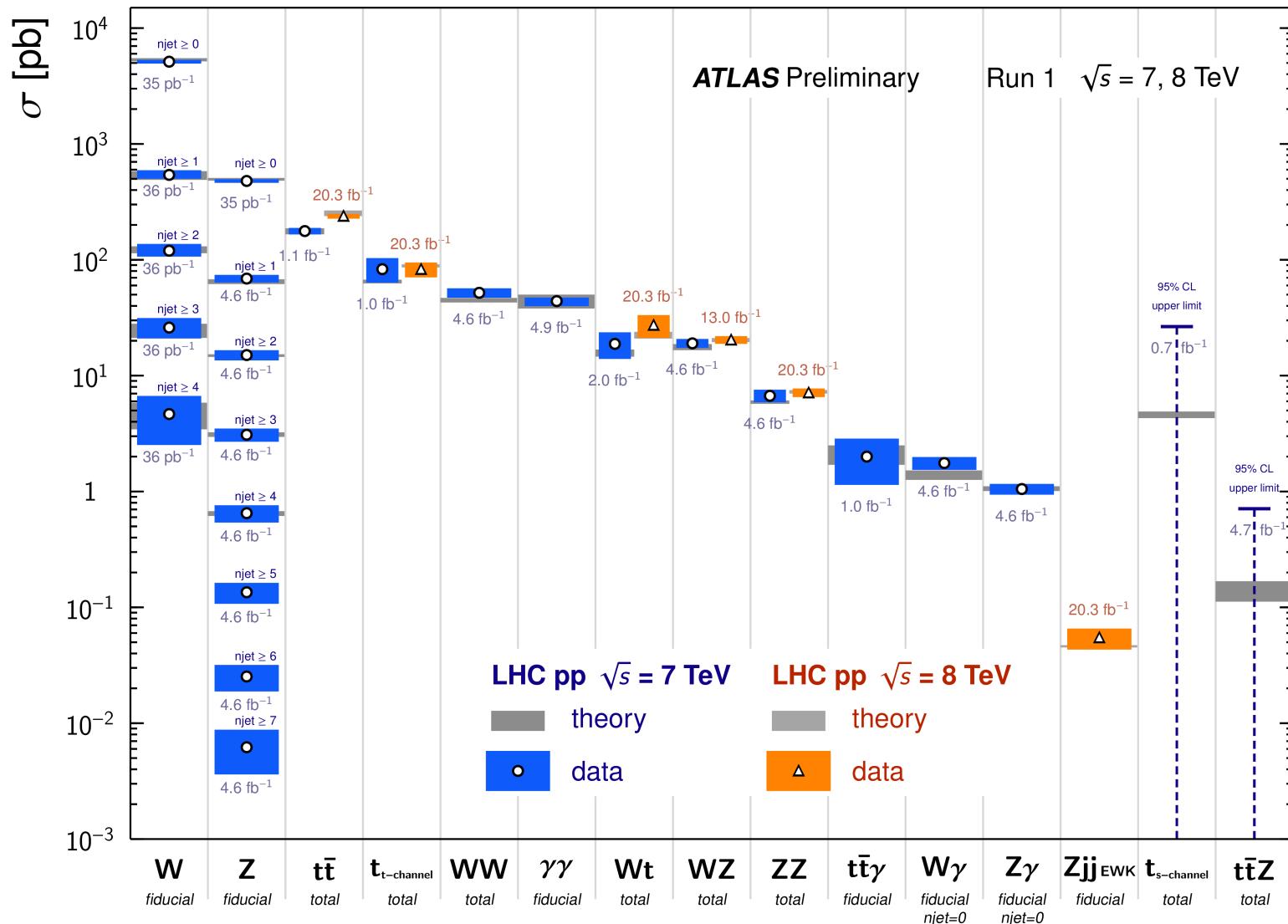


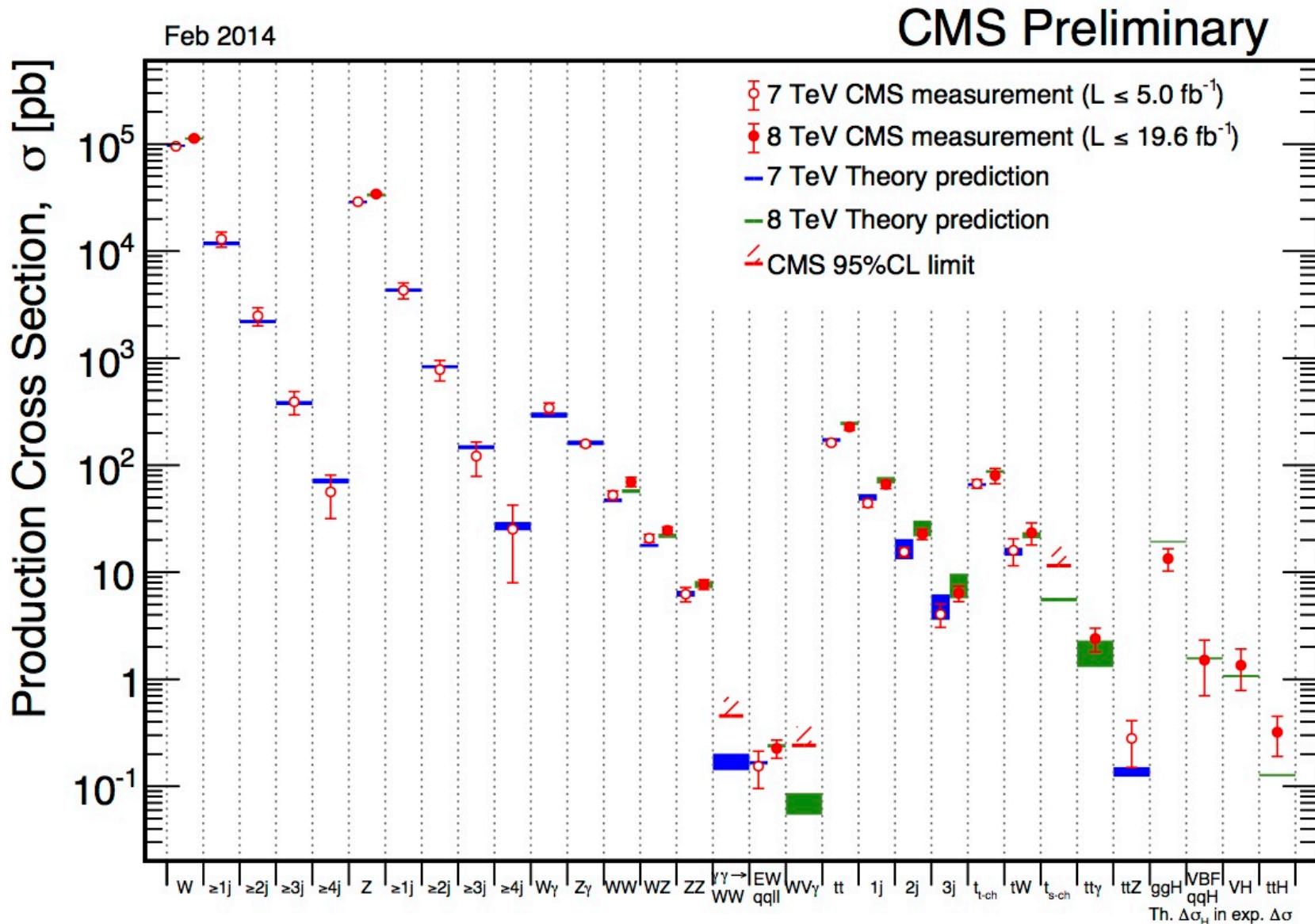
- Largest Solenoid, magnetic field of 4 T.
- Silicon tracker, track pT resolution $\sim 1\%$.
- ECAL made of Lead Tungstate crystals.
- Sampling HCAL (Brass and Scintillator).
- Large Muon System inside Return Yoke.

Standard Model Cross Sections at ATLAS

Standard Model Production Cross Section Measurements

Status: March 2014





Inclusive W/Z Boson Cross Section at $\sqrt{s} = 8$ TeV (CMS)

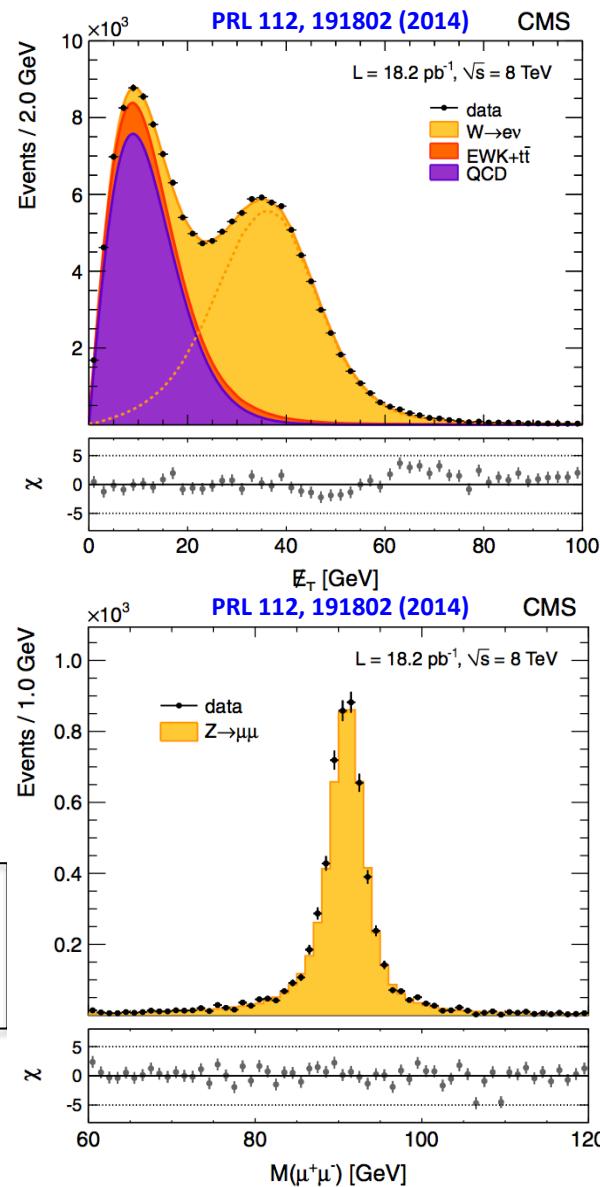


- Precise measurement that provides tests of pQCD and validate theory predictions of higher order corrections.
- Low pileup sample with an average of 4 interactions per bunch crossing, compared to an average of 21 in 2012.
- W and Z reconstructed via their electron and muon decays.
- The W boson signal and background yields extracted from MET distributions using a binned maximum-likelihood fit.
- The Z boson yield obtained by counting events in the dilepton mass window (3% from γ^* , 0.4% background).

$$\sigma(pp \rightarrow WX) \times B(W \rightarrow l\nu) = 12.21 \pm 0.03(\text{stat}) \pm 0.24(\text{syst}) \pm 0.32(\text{lum}) \text{ nb}$$

$$\sigma(pp \rightarrow ZX) \times B(Z \rightarrow l^+l^-) = 1.15 \pm 0.01(\text{stat}) \pm 0.02(\text{syst}) \pm 0.03(\text{lum}) \text{ nb}$$

- In agreement with NNLO QCD cross section calculations.

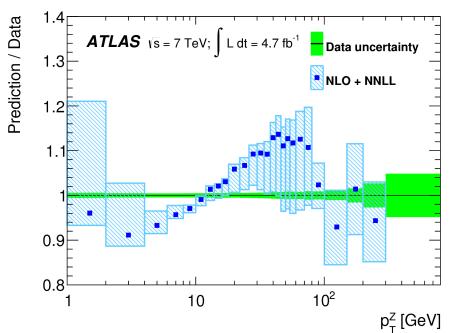
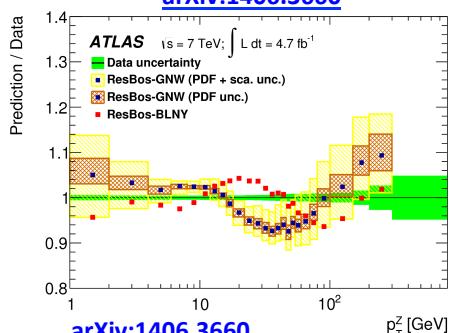
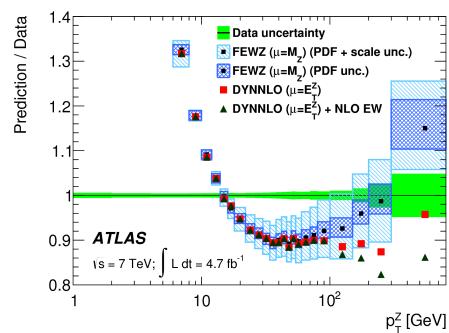


Measurement of the Z/γ^* boson p_T distribution (ATLAS)

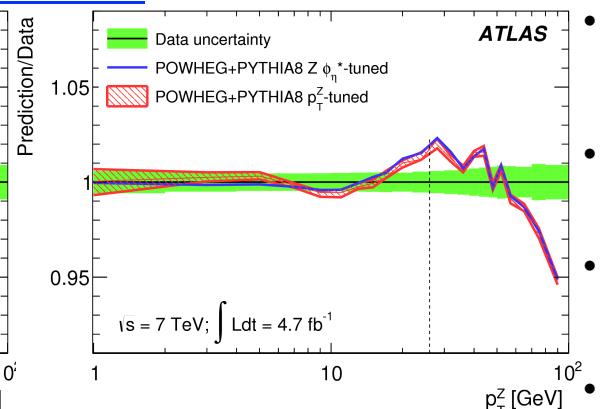
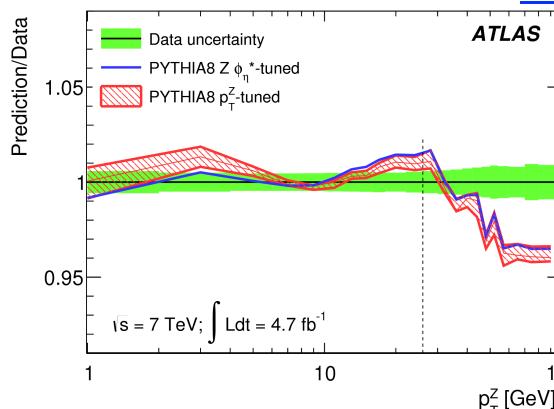
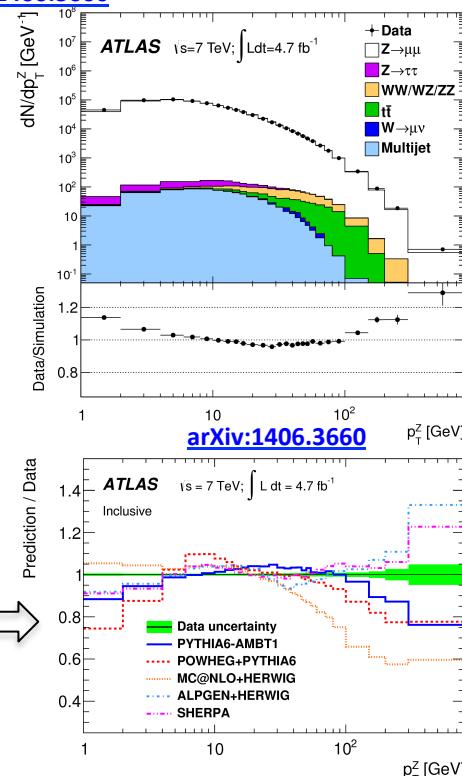


- Traditional probe of strong interaction dynamics.
- p_T spectrum measured in $Z/\gamma^* \rightarrow e^+e^-$ & $Z/\gamma^* \rightarrow \mu^+\mu^-$, inclusive in rapidity, also in three rapidity ranges.
- Fine binning in p_T^Z , with uncertainty from 1% to 5%.
- CS measurements compared to pQCD and resummed predictions (FEWZ, DYNNLO, RESBOS, NLO+NNLL).

[arXiv:1406.3660](#)

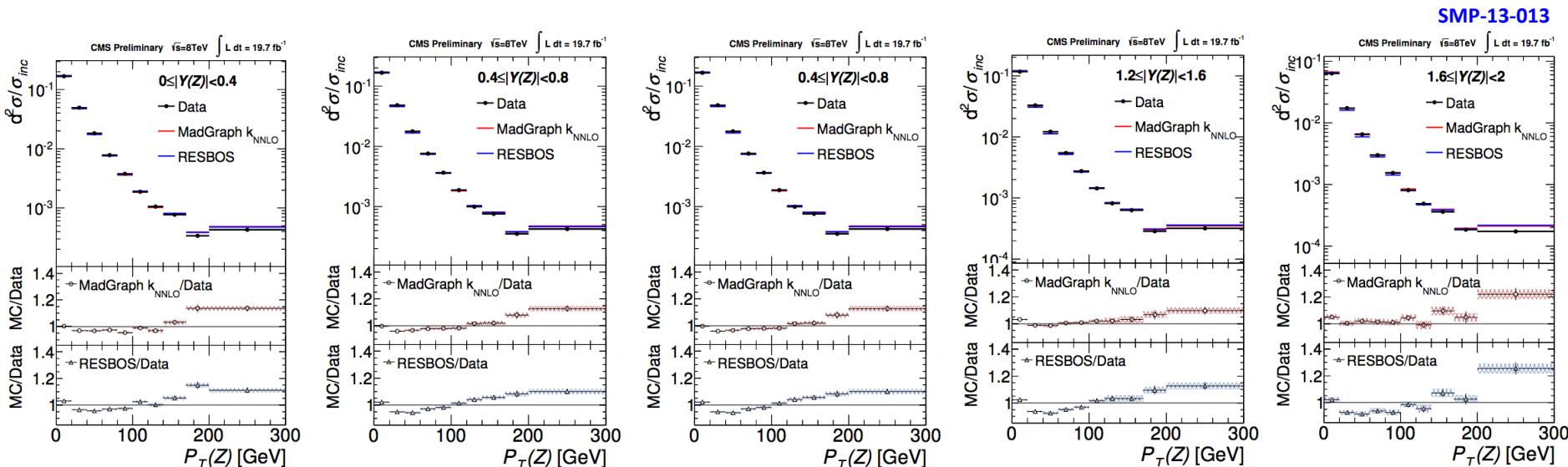


[arXiv:1406.3660](#)



- Comparison to different MC generators.
Phys. Lett. B 720 (2013) 32-51
(see backup slides)
- p_T^Z and ϕ_η^* measurements were used to tune PYTHIA8 and POWHEG+PYTHIA8.
- Both measurements can be interpreted consistently in terms of p_T^Z distribution.
- Similar sensitivity to PS model parameters.

- Measurement of fiducial DY to muons cross section at Z peak, double differentially in $pT(Z)$ and $|Y(Z)|$.
- Enables testing the QCD dynamics over large kinematic range with high granularity and high precision.
- Z production at high $pT(Z)$ is dominated by gluon-quark production: gluon PDF constraints for $gg \rightarrow H$.
- A pair of opposite charge muons selected with mass between 81 and 101 GeV and $|Y(\mu\mu)| < 2$.
- Small backgrounds, $t\bar{t}$, $DY \rightarrow \tau\tau$, WW , tW , $t\bar{W}$ and $W+jets$ estimated from data (flavour universality).



- Both generators overshoot the data for $pT(Z) > 120$ GeV by 10-20%, increase of $|Y(Z)|$ for MadGraph.
- Full covariance matrix will be made available for possible usage of the sample in gluon PDF fits.

High pT Z->bb Production at 8 TeV (ATLAS)

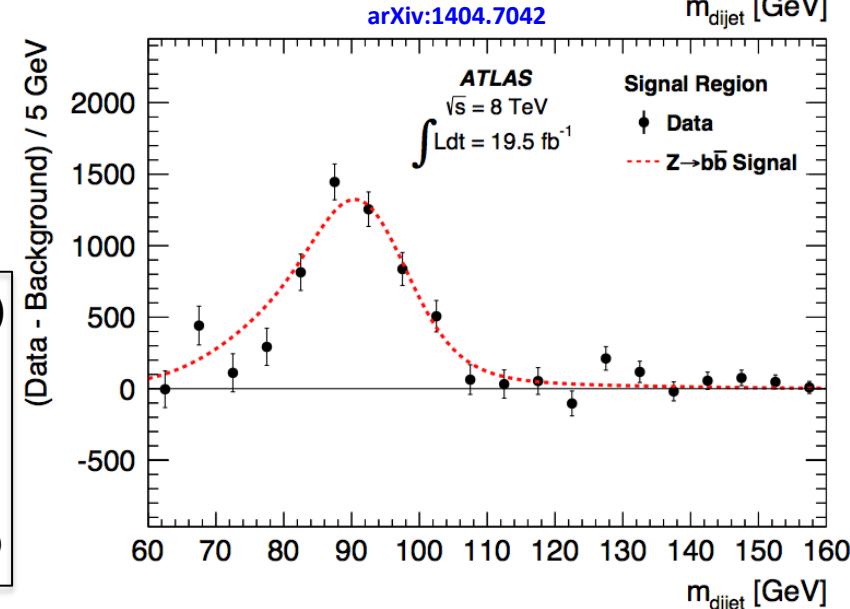
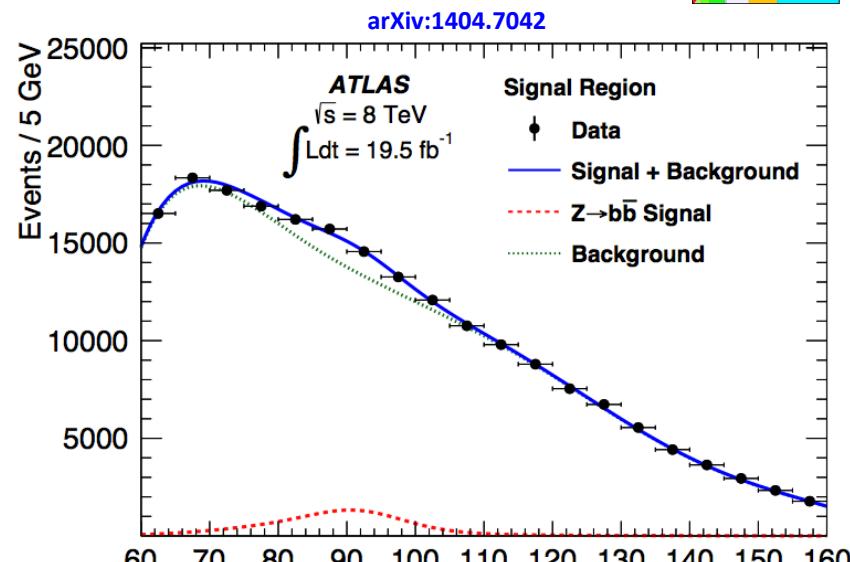


- Observation and cross section measurement.
- Important for H->bb search in high pT range, as well as for ZZ, ZH, HH (bbbb) resonances.
- Dominant background comes from multi-jets, smaller contributions from tt, Z->cc and W->qq.
- Two sets of events: Signal and Control Regions.
- η_{dijet} and $\Delta\eta(\text{dijet, balancing jet})$ input to ANN.
- Signal extracted by fitting simultaneously the m_{dijet} distribution in SR and CR (binned EML fit).

$$\sigma_{Z \rightarrow b\bar{b}}^{\text{fid}} = 1.98^{+0.16}_{-0.08} (\text{scales}) \pm 0.03 (\text{PDF}) \text{ pb (aMC@NLO)}$$

$$\sigma_{Z \rightarrow b\bar{b}}^{\text{fid}} = 2.02^{+0.25}_{-0.19} (\text{scales})^{+0.03}_{-0.04} (\text{PDF}) \text{ pb (POWHEG)}$$

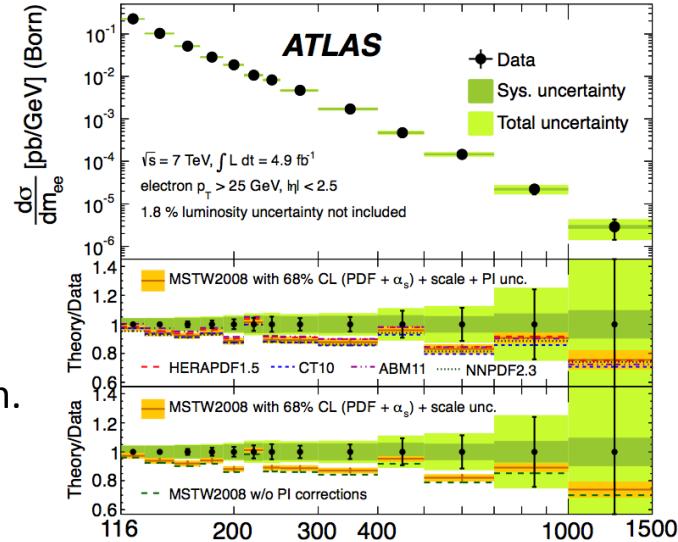
$$\sigma_{Z \rightarrow b\bar{b}}^{\text{fid}} = 2.02 \pm 0.20 (\text{stat.}) \pm 0.25 (\text{syst.}) \pm 0.06 (\text{lumi.}) \text{ pb}$$



Drell-Yan Differential Cross Sections (ATLAS)

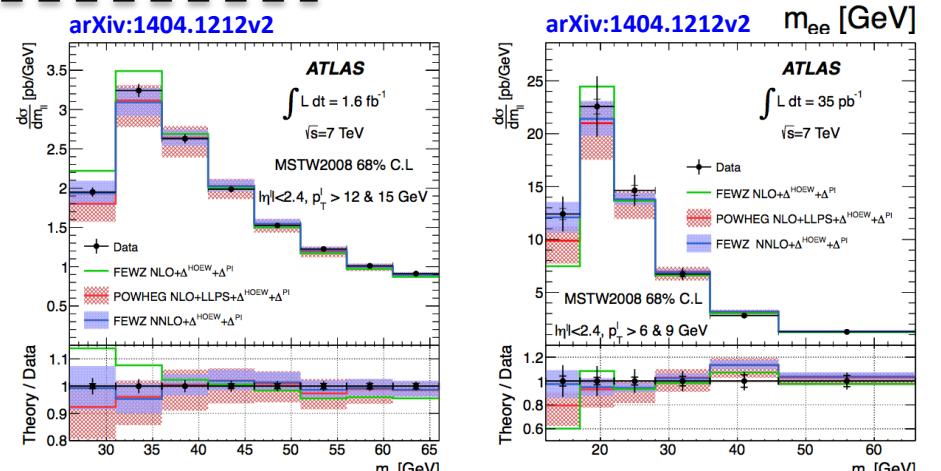


Phys. Lett. B 725 (2013)



- Measurements of the Drell-Yan differential cross section at 7 TeV as a function of m_{ee} , in the wide range of $116 < m_{ee} < 1500$ GeV.
- Tests of pQCD at NNLO, sensitive to PDFs, source of background.
- Dijets and W+jets backgrounds estimated using fake rate method.
- MC predictions consistent with shape of measured m_{ee} distribution.
- PDFs consistent with measured cross section, data above theory.

- Measurements of the Drell-Yan differential cross section in the low-mass range ($26 < m_{ll} < 66$ GeV).
- Multijet background estimated from data (OS - SS).
- The analysis extended to 12 GeV using 2010 data.
- More stringent multijet background suppression.
- FEWZ NLO give poor description, POWHEG NLO+LLPS and FEWZ NNLO significantly more compatible.
- Results supported by QCD analysis, PDFs fitted also to DIS data from HERA:



NNLO fit gives significantly better description of data than NLO fit.

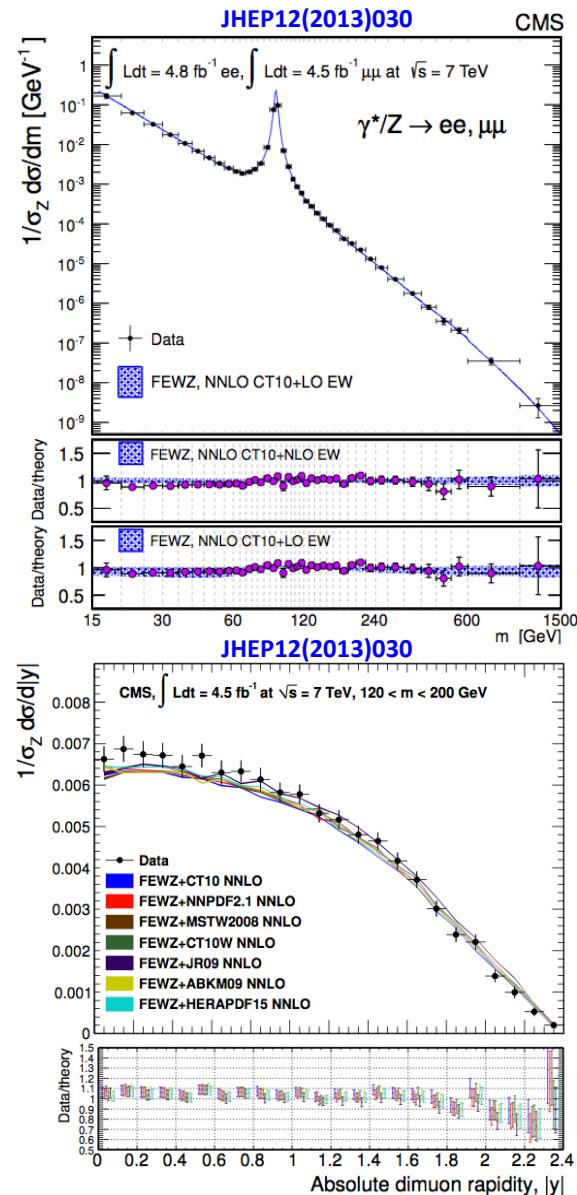
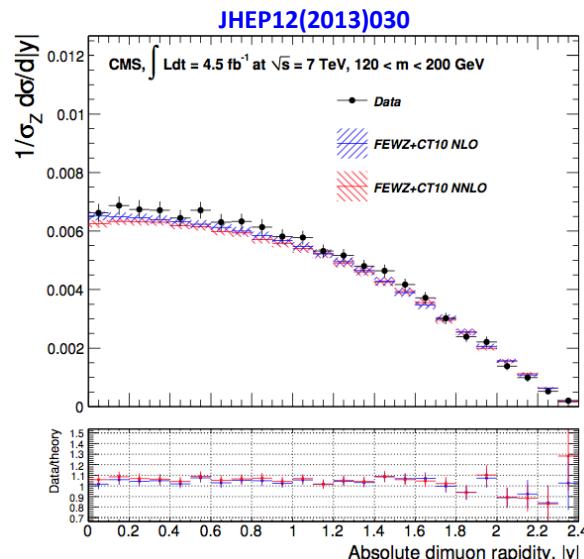
Drell-Yan Differential Cross Sections (CMS)



- Measurement of the differential and double-differential Drell-Yan cross section at 7 TeV in a wide range of dilepton invariant mass.
- Differential cross section, $d\sigma/dm$, measured in the dimuon and dielectron channels, normalized to the Z peak region (60-120 GeV).
- The measured inclusive cross section in Z peak region is found to be:

$$\sigma(l\bar{l}) = 986.4 \pm 0.6(\text{stat.}) \pm 5.9(\text{exp. syst.}) \pm 21.7(\text{th. syst.}) \pm 21.7(\text{lum.}) \text{ pb}$$

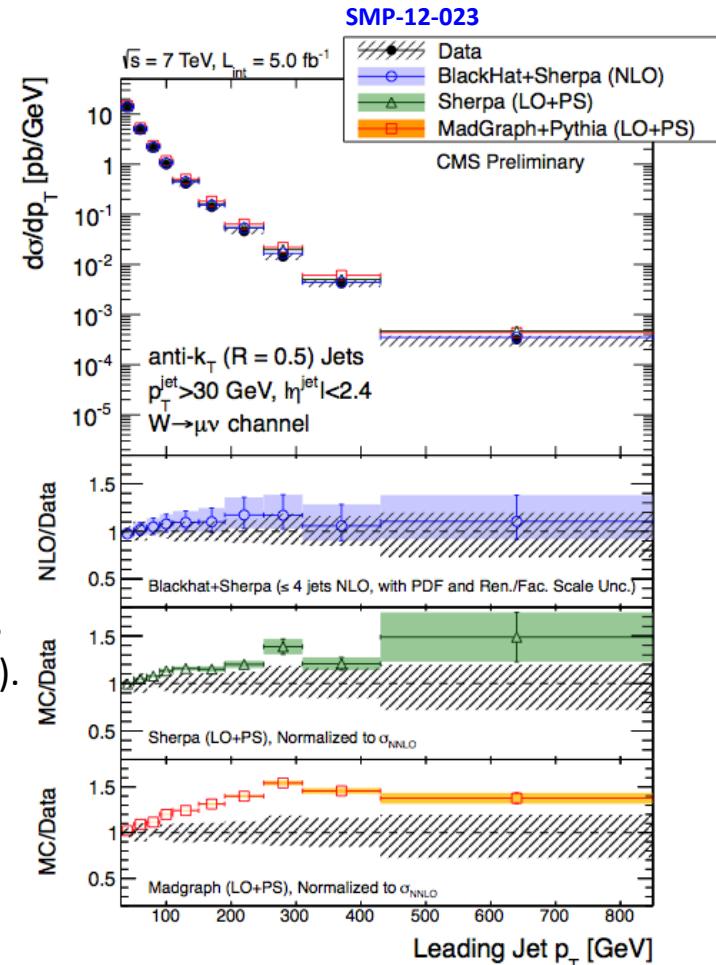
- The results are in good agreement with the SM predictions at NNLO.
- Measurement of $d^2\sigma/dmd|y|$ is compared to the N(N)LO prediction from FEWZ using the CT10 PDFs.
- The predictions of various existing PDF sets are rather different, in particular in the low and high mass.
- Can be used to calculate new PDFs.



W+Jets Differential Cross Sections (CMS)



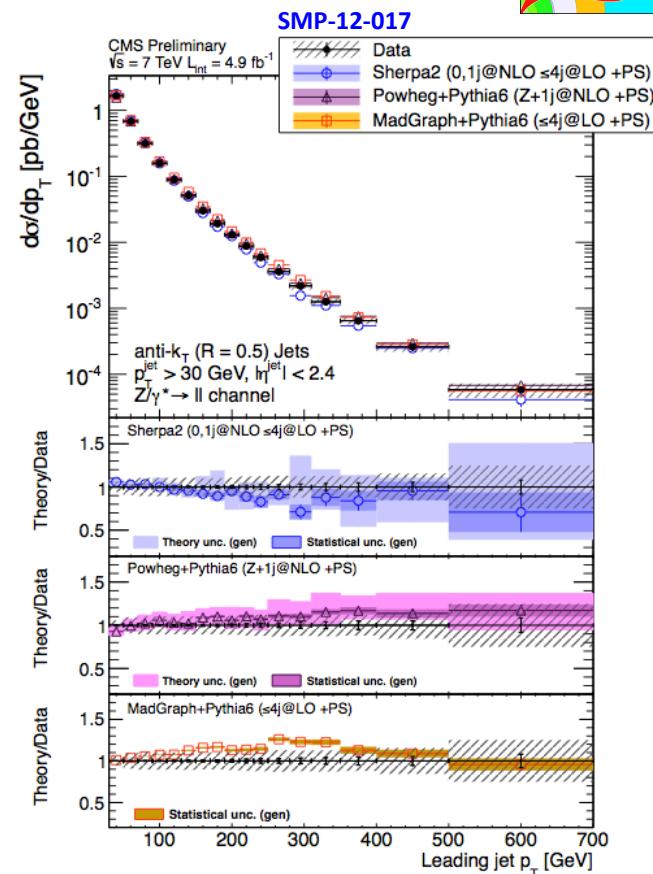
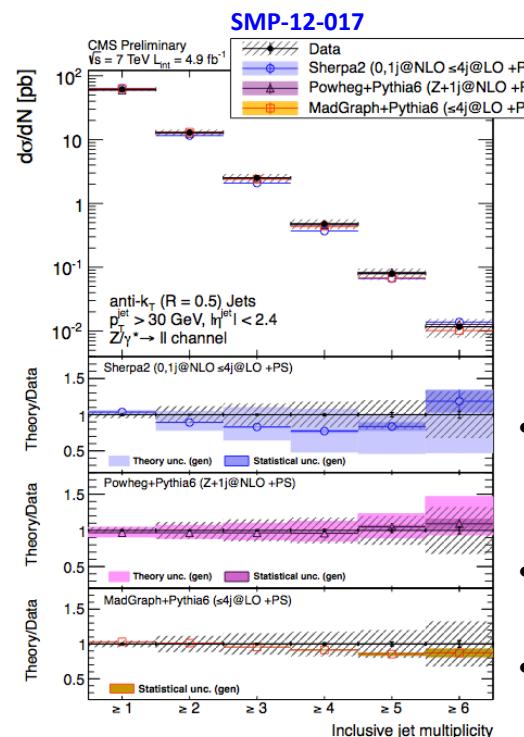
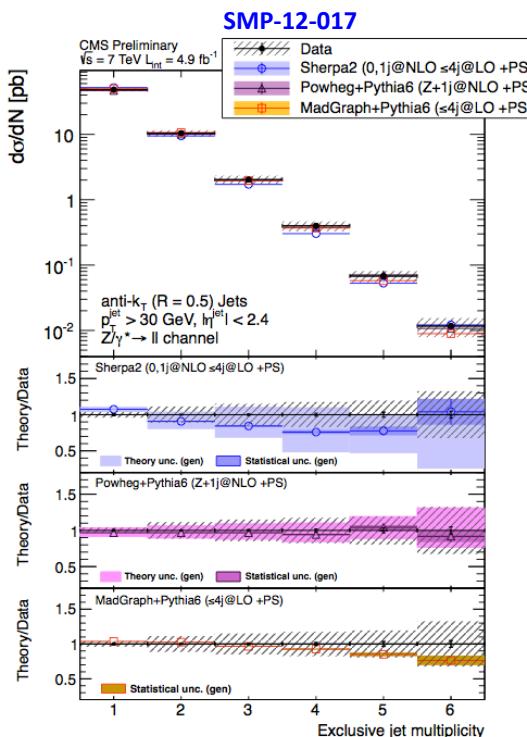
- Fundamental test of pQCD, background for Higgs and BSM.
- Production of W+jets, W decays into a muon and neutrino.
- Backgrounds: tt, single t, Z/ γ^* +jets, VV+jets, QCD multijets.
- Measured W+jets cross sections compared to the predictions from several generators, normalized to the NNLO with FEWZ.
- MadGraph and Sherpa: LO ME calculations for each N_{jet} , combined into inclusive samples by matching the ME partons to particle jets.
- BlackHat+Sherpa: fixed-order predictions at the level of ME partons of W+njets at NLO accuracy up to 4 jets (PDF uncertainties included).
- Sherpa and BlackHat+Sherpa predictions agree with measurement within systematic uncertainties, MadGraph gives an over-estimate.
- Similar observation hold for MadGraph in the jet H_T distributions.
- MadGraph+Pythia, Sherpa and NLO BlackHat+Sherpa describe the jet multiplicity reasonably well up to 6 jets.
- NLO BlackHat+Sherpa perform especially well at higher N_{jet} , MadGraph gives an over-estimate at high jet pT.



Z+Jets Differential Cross Sections (CMS)



- Production of Z+jets, Z decays into a pair of electrons or muons.
- Dilepton invariant mass selected within the 71 - 111 GeV window.
- Production cross section of Z+jet events measured as a function of the jet inclusive and exclusive multiplicities.
- Differential cross section measured as function of pT and η of the 4 leading jets, H_T measured as a function of inclusive jet multiplicity.



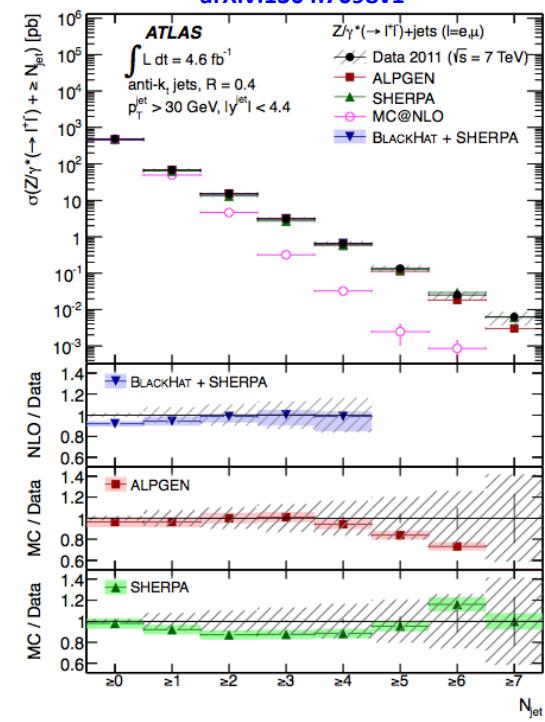
- Overall satisfactory agreement with the predictions from MadGraph and Sherpa.
- Reasonable agreement for Powheg as well.
- Limited agreement for 2nd leading jet pT, due to parton shower-based description.

Z+Jets Differential Cross Sections (ATLAS)

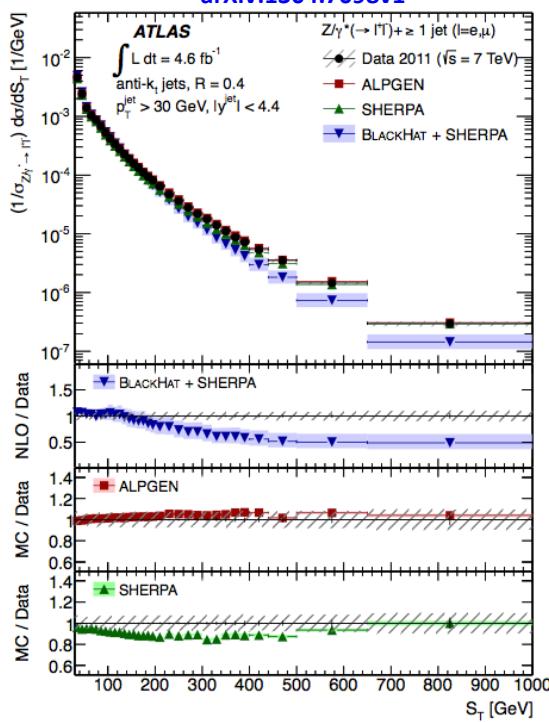


- Z+jets studies, Z boson decays into a pair of electrons or muons.
- Dilepton invariant mass selected within the 66 - 116 GeV window.
- Cross sections as a function of the inclusive and exclusive jet multiplicities, differential cross sections as function of jet pT, η , angular separation between leading jets and H_T and S_T variables.
- MC@NLO fails to model higher jet multiplicities and leading jet pT.

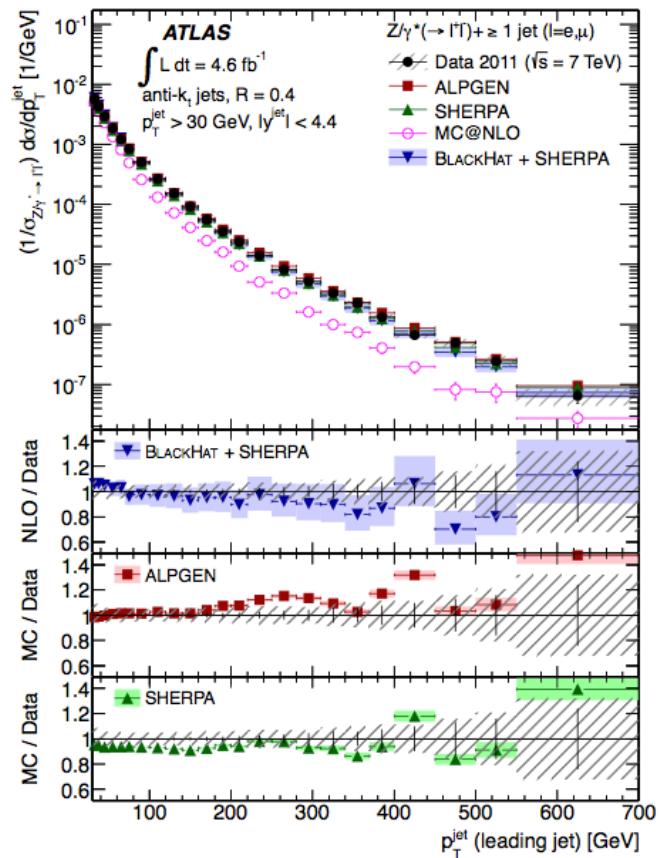
arXiv:1304.7098v1



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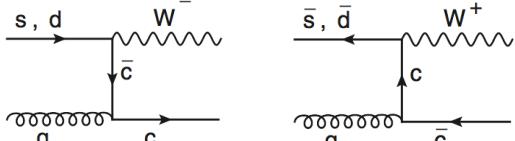


- Predictions of ME+PS generators at fixed order are generally consistent with data.
- H_T and S_T predicted by BlackHat+Sherpa fixed order NLO deviate by several σ from measured spectra in hard H_T and S_T regime.

W+D/D*/Charm – Jet Production (CMS)



- Provides direct access to strange (anti)quark PDFs.



- Main diagrams:

- Jets originating from c(c) partons using 3 signatures:

$$1 : D^+ \rightarrow K^-\pi^+\pi^+, D^- \rightarrow K^+\pi^-\pi^-$$

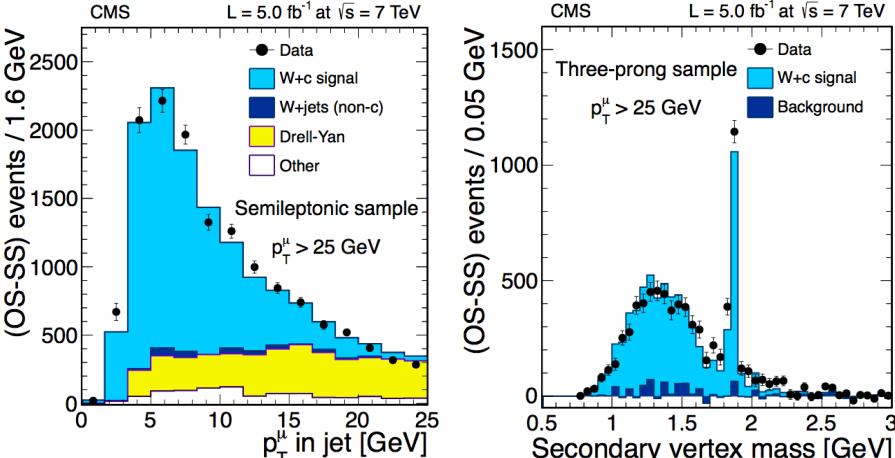
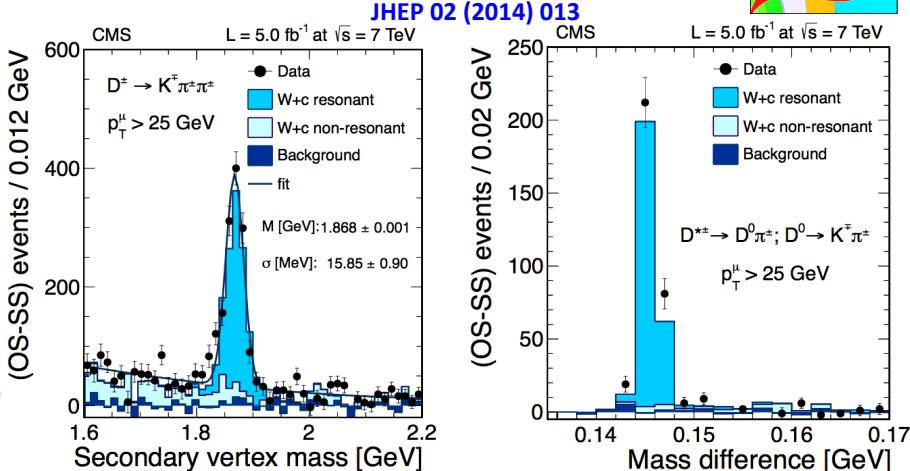
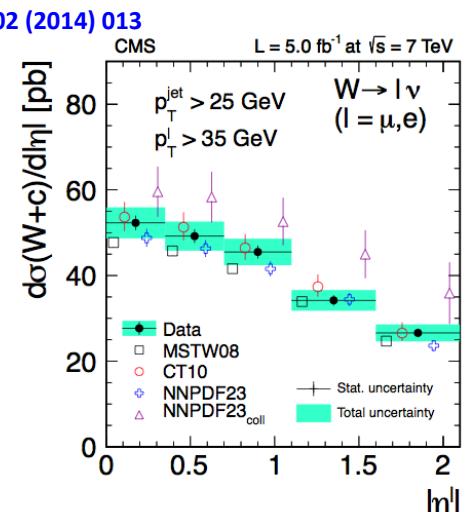
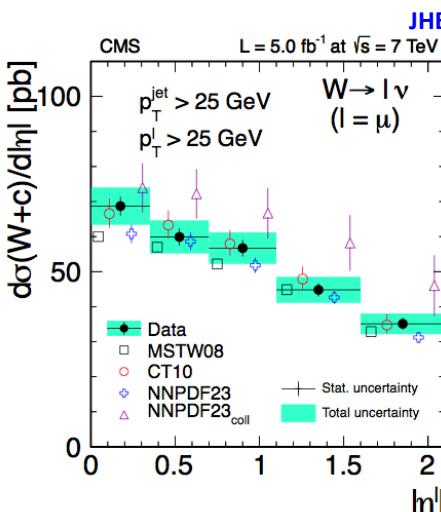
$$2 : D^0 \rightarrow K^-\pi^+(\bar{D}^0 \rightarrow K^+\pi^-), D^{*+}(2010) \rightarrow D^0\pi^+(D^{*-}(2010) \rightarrow \bar{D}^0\pi^-)$$

$$3 : c \rightarrow l\nu + X$$

- W+c+X background estimated with OS - SS method.

$$\sigma(pp \rightarrow W + c + X) \times \mathcal{B}(W \rightarrow \mu\nu)(p_T^\mu > 25 \text{ GeV}) = 107.7 \pm 3.3 \text{ (stat.)} \pm 6.9 \text{ (syst.) pb}$$

$$\sigma(pp \rightarrow W + c + X) \times \mathcal{B}(W \rightarrow \ell\nu)(p_T^\ell > 35 \text{ GeV}) = 84.1 \pm 2.0 \text{ (stat.)} \pm 4.9 \text{ (syst.) pb}$$



$$\begin{aligned} \sigma(pp \rightarrow W^+ + \bar{c} + X) (p_T^\mu > 25 \text{ GeV}) &= 0.954 \pm 0.025 \text{ (stat.)} \pm 0.004 \text{ (syst.)} \\ \sigma(pp \rightarrow W^- + c + X) & \\ \sigma(pp \rightarrow W^+ + \bar{c} + X) (p_T^\ell > 35 \text{ GeV}) &= 0.938 \pm 0.019 \text{ (stat.)} \pm 0.006 \text{ (syst.)} \\ \sigma(pp \rightarrow W^- + c + X) & \end{aligned}$$

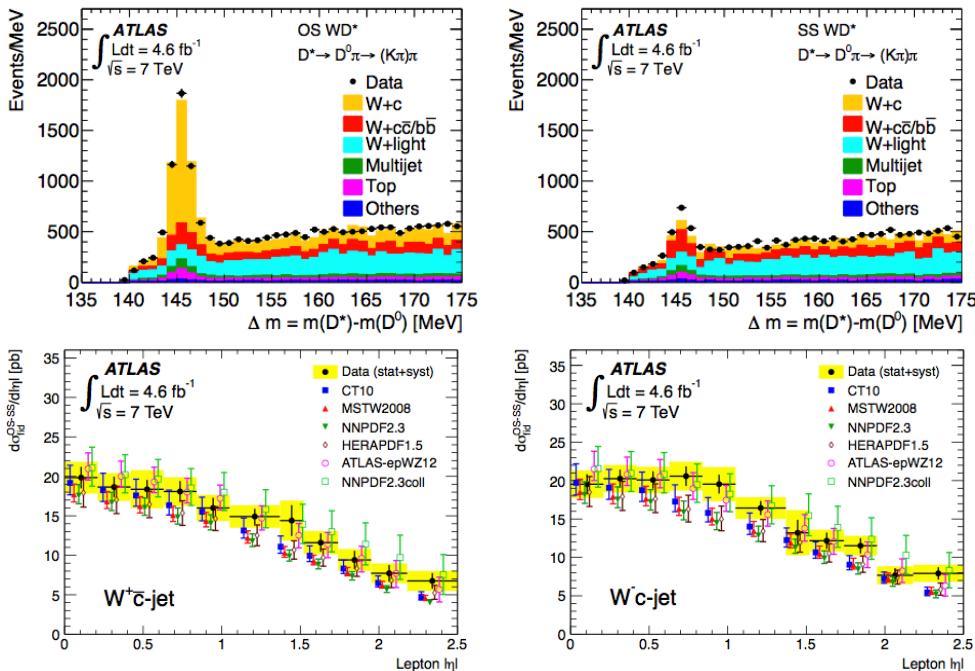
- Differential cross section shapes in agreement with the measured results (W- yield a bit larger).

W+D/D*/Charm – Jet Production (ATLAS)



arXiv:1402.6263v1

- Determine W+c yields by measuring the number of OS – SS events, exploiting flavor symmetry.
- Measure integrated and differential cross sections.
- Two measurement strategies: presence of a muon from semileptonic charm decay within a hadronic jet or presence of a charged D^(*) (D or D*) meson.
- The two methods are sensitive to different c-quark kinematic regions, different dominant systematics.
- Large overlap of 68% CL contours for the ratios of the measured cross section (aMC@NLO, CT10 PDF).



$$\sigma_{fid}^{OS-SS}(W^+\bar{c}\text{-jet}) = 33.6 \pm 0.9 \text{ (stat)} \pm 1.8 \text{ (syst)} \text{ pb}$$

$$\sigma_{fid}^{OS-SS}(W^-c\text{-jet}) = 37.3 \pm 0.8 \text{ (stat)} \pm 1.9 \text{ (syst)} \text{ pb}$$

$$\sigma_{fid}^{OS-SS}(W^+D^-) = 17.8 \pm 1.9 \text{ (stat)} \pm 0.8 \text{ (syst)} \text{ pb}$$

$$\sigma_{fid}^{OS-SS}(W^-D^+) = 22.4 \pm 1.8 \text{ (stat)} \pm 1.0 \text{ (syst)} \text{ pb}$$

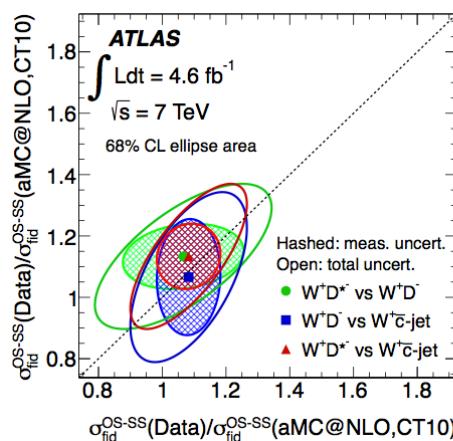
$$\sigma_{fid}^{OS-SS}(W^+D^{*-}) = 21.2 \pm 0.9 \text{ (stat)} \pm 1.0 \text{ (syst)} \text{ pb}$$

$$\sigma_{fid}^{OS-SS}(W^-D^{*+}) = 22.1 \pm 0.8 \text{ (stat)} \pm 1.0 \text{ (syst)} \text{ pb}$$

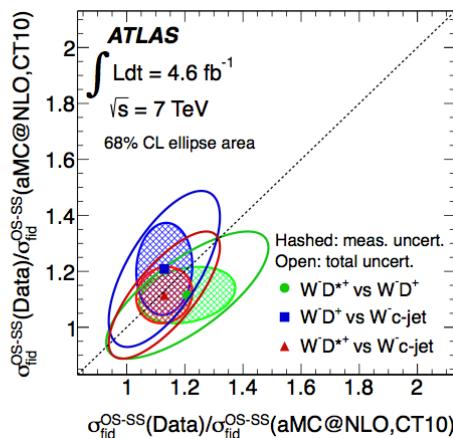
$$R_c^\pm(Wc\text{-jet}) = \frac{\sigma_{fid}^{OS-SS}(W^+\bar{c}\text{-jet})}{\sigma_{fid}^{OS-SS}(W^-c\text{-jet})} = 0.90 \pm 0.03 \text{ (stat)} \pm 0.02 \text{ (syst)}$$

$$R_c^\pm(WD^{(*)}) = \frac{\sigma_{fid}^{OS-SS}(W^+D^{*-})}{\sigma_{fid}^{OS-SS}(W^-D^{*+})} = 0.92 \pm 0.05 \text{ (stat)} \pm 0.01 \text{ (syst)}$$

- Data consistent with wide range of PDFs, but show a preference for PDFs with an SU(3) light-quark sea.



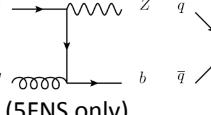
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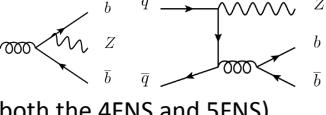
Z+b(b) Production (ATLAS)



- Possibilities to probe the pQCD predictions of associated heavy flavour production and dynamics with b-hadrons.
- Z+b-jets LO Feynman diagrams

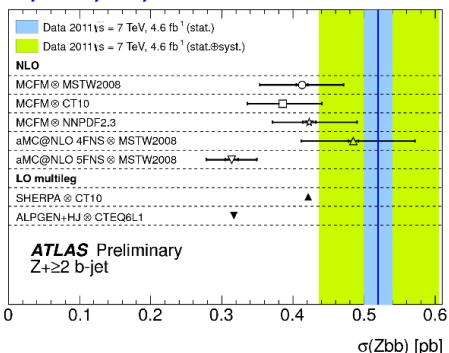
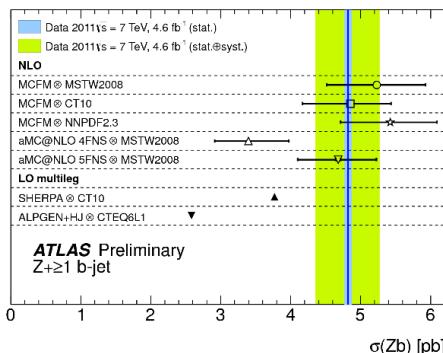


(5FNS only)

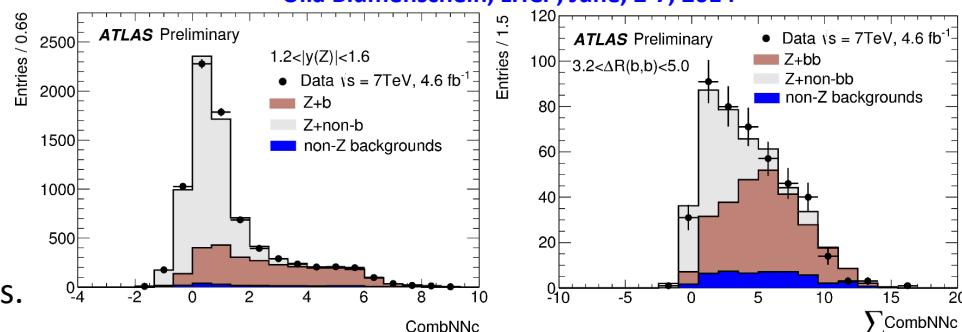


(both the 4FNS and 5FNS)
- Background to ZH ($H \rightarrow b\bar{b}$) and BSM signatures with b-jets.

Ulla Blumenschein, LHCP, June, 2-7, 2014

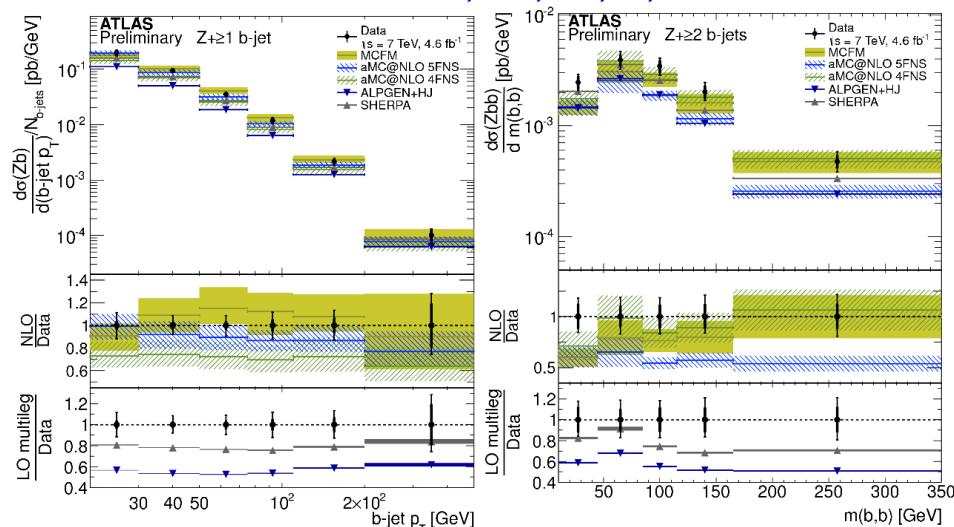


- ALPGEN+HERWIG+JIMMY and SHERPA under the data.
- A good description of b-jet pT shape by all generators.
- Discrepancies in other kinematic variables (see backup).
- Z+bb: all predictions give reasonable description of data.
- Some disagreement at low m_{bb} and low ΔR_{bb} (see backup).



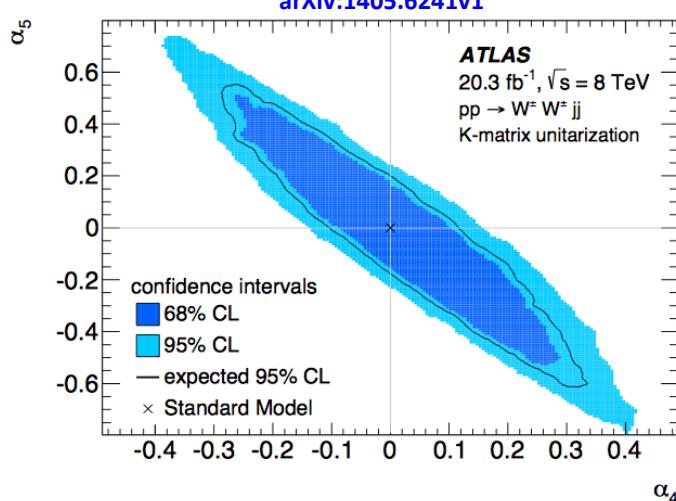
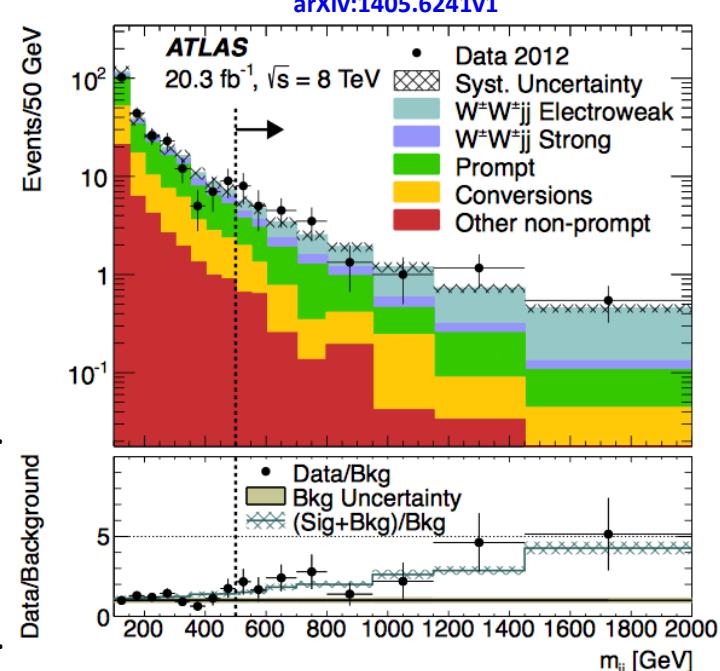
- Measurement of differential Z+b and Z+bb cross-sections.
- Dilepton mass required in the range of $76 < m_{ll} < 106$ GeV.
- MCFM (NLO, 5NFS) agrees with data within uncertainties.
- aMC@NLO: 5FNS suits Z+b, Z+bb prefers 4FNS scheme.

Ulla Blumenschein, LHCP, June, 2-7, 2014



Electroweak Production of $W^\pm W^\pm jj$ (ATLAS)

- A key process to probe the nature of EWK symmetry breaking.
- Higgs discovery suggests which mechanism could unitarize VBS.
- Many scenarios predict enhancements in the VBS production.
- No previous evidence for a process involving a VVVV vertex.
- Two classes of VVjj processes: pure EWK and strong (with EWK).
- “Inclusive region” (strong) and “VBS region” (EWK, $|\Delta y_{jj}| > 2.4$).
- Signal: two SS leptons ($e^\pm e^\pm$, $e^\pm \mu^\pm$ and $\mu^\pm \mu^\pm$) and at least two jets.



- An excess of events over background observed in both signal regions in all three channels: 4.5σ in the inclusive region and 3.6σ in the VBS region (expected 3.4σ and 2.8σ , respectively).
- Fiducial cross section for strong $W^\pm W^\pm jj$ in the inclusive region:

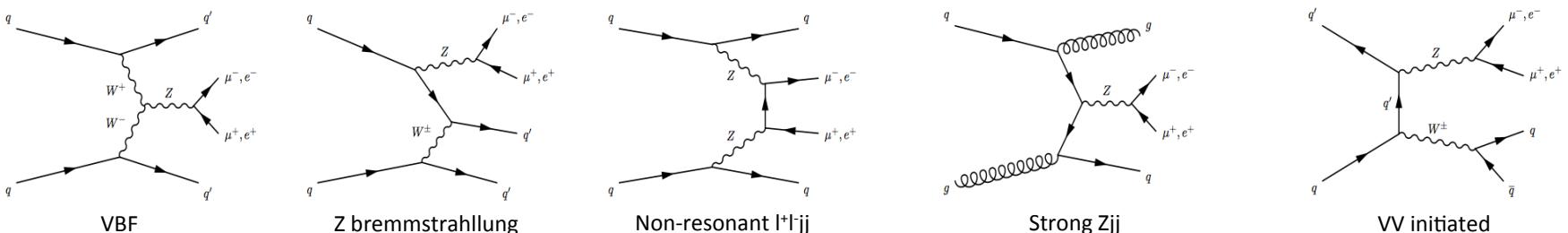
$$\sigma^{\text{fid}} = 2.1 \pm 0.5(\text{stat}) \pm 0.3(\text{syst}) \text{ fb}$$
 (SM exp. 1.52 ± 0.11 fb)
- Fiducial cross section for EWK $W^\pm W^\pm jj$ in the VBS region:

$$\sigma^{\text{fid}} = 1.3 \pm 0.4(\text{stat}) \pm 0.2(\text{syst}) \text{ fb}$$
 (SM exp. 0.95 ± 0.06 fb)
- First limits on the $\alpha_{4,5}$ aQGC parameters are set (VBS region).

Electroweak Zjj Production (ATLAS)



- Dominant mechanism for Zjj production at the LHC is via DY process, t-channel exchange of EWK boson is rare.
- Fiducial cross sections and differential distributions of inclusive Zjj, observation of EWK Zjj with more than 5σ .

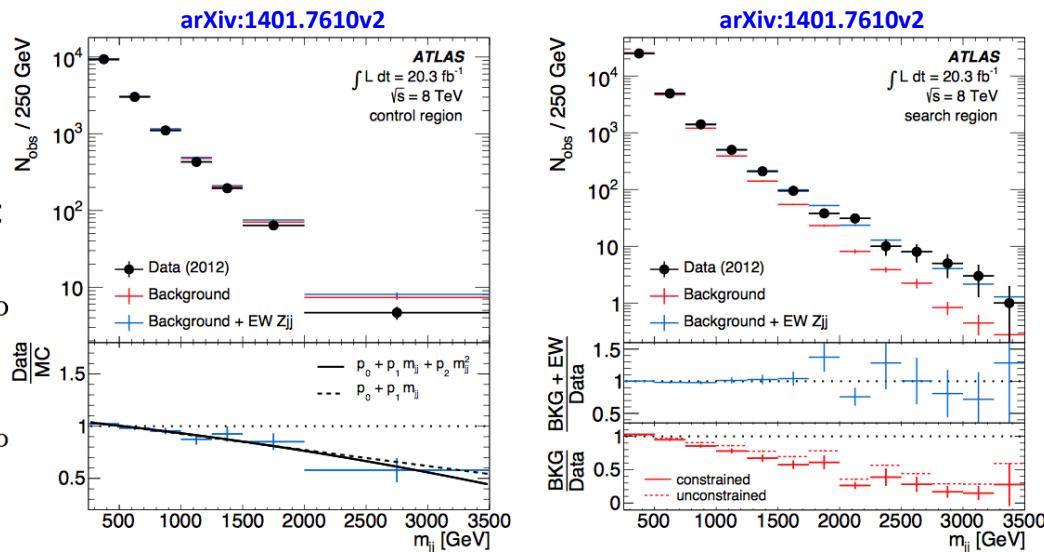


- Good agreement with SM expectation, limits have been set on anomalous triple gauge boson couplings (ATGC).
- The cross sections measurements are in good agreement with the prediction from POWHEG for Zjj production.
- Differential distributions sensitive to EWK Zjj.

$$\left. \begin{array}{l} \sigma_{EW}^{ee} = 67.2 \pm 6.9 \text{ (stat)} \pm 12.7 \text{ (syst)} \pm 1.9 \text{ (lumi)} \text{ fb} \\ \sigma_{EW}^{\mu\mu} = 45.6 \pm 6.1 \text{ (stat)} \pm 9.1 \text{ (syst)} \pm 1.3 \text{ (lumi)} \text{ fb} \end{array} \right\} \text{ combined:}$$

$$\sigma_{EW} (m_{jj} > 1 \text{ TeV}) = 10.7 \pm 0.9 \text{ (stat)} \pm 1.9 \text{ (syst)} \pm 0.3 \text{ (lumi)} \text{ fb}$$

$$\text{POWHEG: } 9.38 \pm 0.05 \text{ (stat)} \pm 0.15 \text{ (scale)} \pm 0.24 \text{ (PDF)} \pm 0.09 \text{ (model)} \text{ fb}$$



Electroweak Zjj Production (CMS)



- The EWK Zjj signal characterized by a large Δn_{jj} , large M_{jj} , Z boson central in rapidity gap distance region.
- Two methods of signal extraction applied in order to confirm and cross-check the presence of the signal:
 - MVA analysis (BDT), exploiting distinct discrimination, mainly with respect to the QCD Zjj process;
 - Data-driven prediction of QCD background based on $\gamma+jj$ sample, using dijet Fisher discriminant.
- Overall reasonable agreement observed for the distributions of discriminators used in the two methods.

- Inclusive production cross sections:

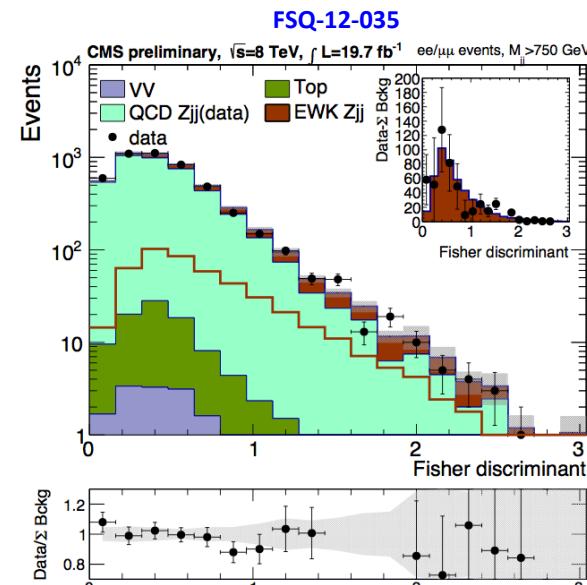
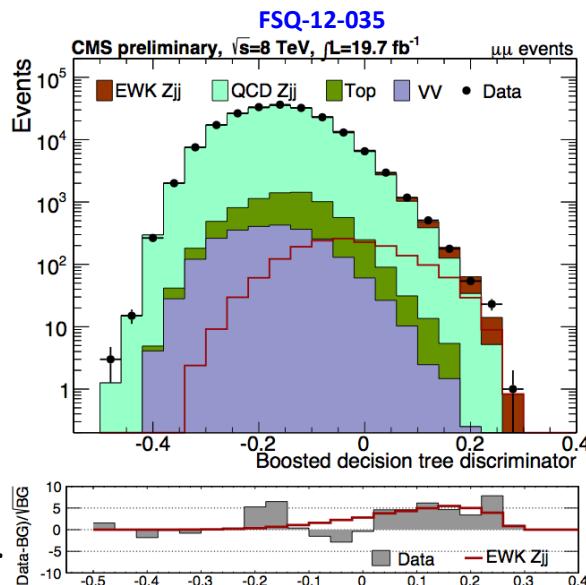
$$\sigma(\text{EWK } \ell\ell + jj)_I = 191 \pm 29_{\text{stat}} \pm 39_{\text{syst}} \text{ fb}$$

$$\sigma(\text{EWK } \ell\ell + jj)_{II} = 303 \pm 29_{\text{stat}} \pm 57_{\text{syst}} \text{ fb}$$

- Results were combined using BLUE:

$$\sigma(\text{EWK } \ell\ell jj) = 226 \pm 26_{\text{stat}} \pm 35_{\text{syst}} \text{ fb}$$

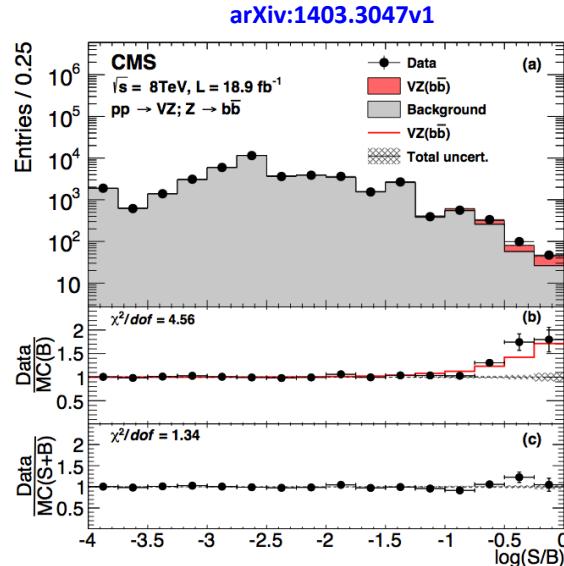
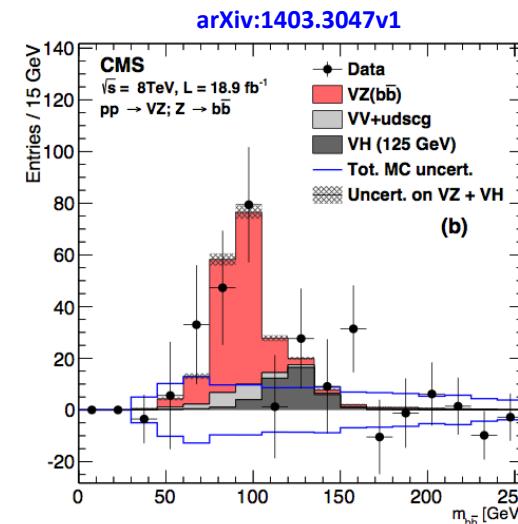
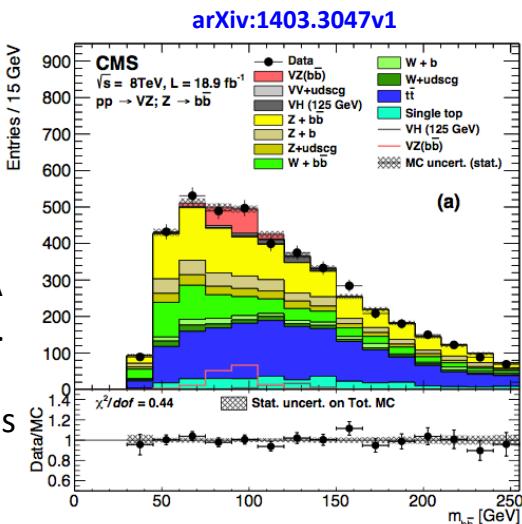
- Theoretical (NLO) prediction: 239 fb.



WZ and ZZ Production using Z->bb Decays (CMS)



- Important test of SM, backgrounds for VH(bb).
- Leptonic decays: $W \rightarrow e\nu, \mu\nu$; $Z \rightarrow e^+e^-, \mu^+\mu^-$, vv.
- Analysis of final states with the 0, 1 or 2 leptons.
- Two methods: first using fit to the output of MVA discriminant, second takes fit of the two jet mass.
- MVA (BDT): events classified into different regions of W/Z pT, then sorted by the expected S/B ratio.
- Two-jet mass analysis: more restrictive selection.



- Total cross sections determined from simultaneous fit to all final states.
- MVA analysis: 6.3σ (5.9σ expected); m_{bb} analysis: 4.1σ (4.6σ expected).
- Measured cross sections ($60 < M_Z < 120\text{ GeV}$) consistent with SM@NLO:

$$\sigma(pp \rightarrow WZ) = 30.7 \pm 9.3 (\text{stat.}) \pm 7.1 (\text{syst.}) \pm 4.1 (\text{th.}) \pm 1.0 (\text{lum.}) \text{ pb}$$

$$\sigma(pp \rightarrow WZ) = 22.3 \pm 1.1 \text{ pb}$$

$$\sigma(pp \rightarrow ZZ) = 6.5 \pm 1.7 (\text{stat.}) \pm 1.0 (\text{syst.}) \pm 0.9 (\text{th.}) \pm 0.2 (\text{lum.}) \text{ pb}$$

$$\sigma(pp \rightarrow ZZ) = 7.7 \pm 0.4 \text{ pb}$$

ZZ->4l Production (CMS)



- The studies of diboson production, such as ZZ, provide an important test of the non-Abelian structure of the Standard Model Lagrangian.
- There is no SM contribution to the ZZ production from ZZZ and ZZ γ .
- Inclusive and differential ZZ->ll'l' cross sections ($l = e, \mu$; $l' = e, \mu, \tau$).
- Mutually exclusive sets of 4e, 4 μ , 2e2 μ and ll $\tau\tau$, with $60 < m_Z < 120$.
- Backgrounds WZ+jets, Z+jets and ttbar, control data samples used.
- Simultaneous fit to include all final states in cross section calculation.
- Differential cross section measured, 4e, 4 μ , 2e2 μ decays combined.
- Improved limits on anomalous ZZZ and ZZ γ couplings are established.

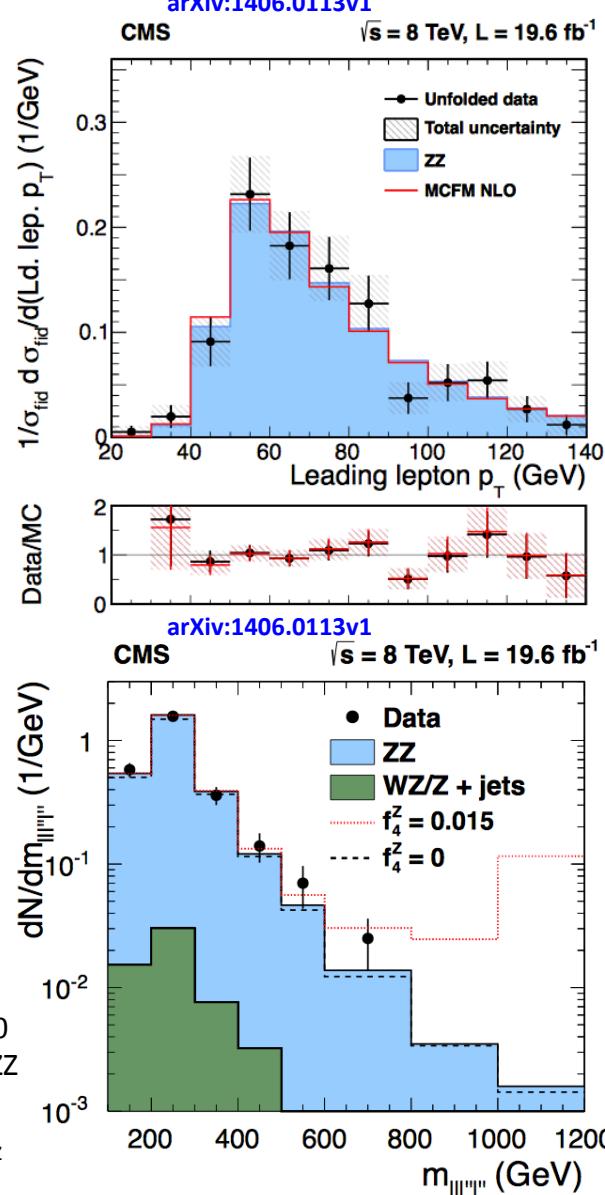
[arXiv:1406.0113v1](#)

Decay channel	Total cross section, pb
4e	$7.2^{+1.0}_{-0.9}$ (stat.) $^{+0.6}_{-0.5}$ (syst.) ± 0.4 (th.) ± 0.2 (lum.)
4 μ	$7.3^{+0.8}_{-0.8}$ (stat.) $^{+0.6}_{-0.5}$ (syst.) ± 0.4 (th.) ± 0.2 (lum.)
2e2 μ	$8.1^{+0.7}_{-0.6}$ (stat.) $^{+0.6}_{-0.5}$ (syst.) ± 0.4 (th.) ± 0.2 (lum.)
ll $\tau\tau$	$7.7^{+2.1}_{-1.9}$ (stat.) $^{+2.0}_{-1.8}$ (syst.) ± 0.4 (th.) ± 0.2 (lum.)
Combined	7.7 ± 0.5 (stat.) $^{+0.5}_{-0.4}$ (syst.) ± 0.4 (th.) ± 0.2 (lum.)

Theoretical value of

$$7.7 \pm 0.6 \text{ pb}$$

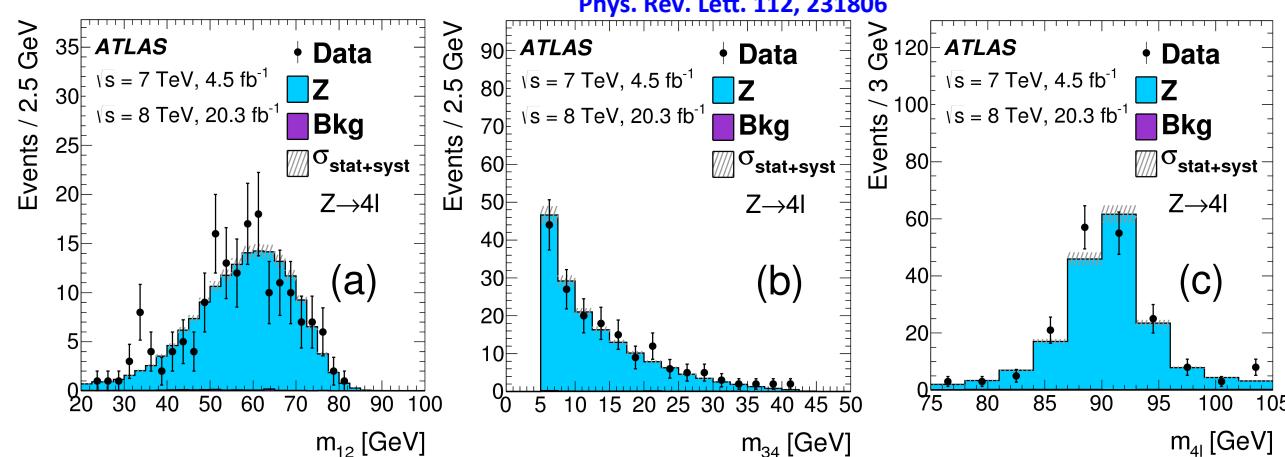
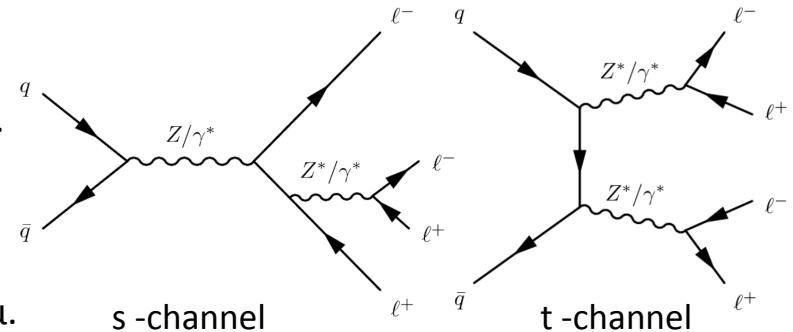
calculated with MCFM 6.0
at NLO qq->ZZ & LO gg->ZZ
with MSTW2008 PDF and
scales set to $\mu_R = \mu_F = m_Z$



ZZ->4l Production (ATLAS)



- Study of inclusive production of 4l ($l = e, \mu$) at the Z resonance.
- The dominant production of 4l in SM occurs through s-channel.
- Cross-check of the detector response to 4l from Higgs decay.
- Inclusive 4l production measured separately in 4e, 4 μ and 2e2 μ .



- The Z->4l branching fraction was determined by subtracting the non-resonant contributions to the selected events and normalizing the resulting yield to the observed number of the Z-> $\mu\mu$ events in the same dataset.

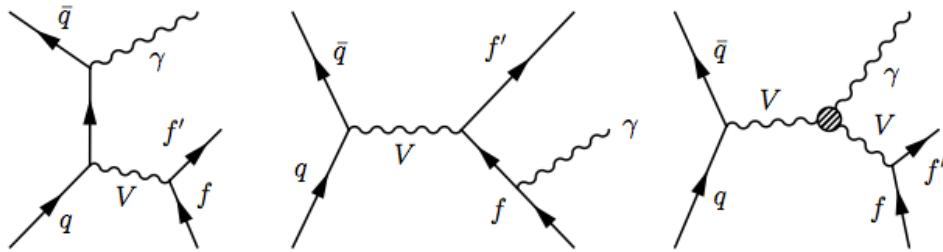
$$\Gamma_{Z \rightarrow 4\ell} / \Gamma_Z = (3.20 \pm 0.25 \text{ (stat)} \pm 0.13 \text{ (syst)}) \times 10^{-6}$$

- Z->4l follows closely H->ZZ*->4l analysis with loosened muon pT and dilepton mass requirements to increase the Z->4l acceptance.
- Measured fiducial cross sections were extrapolated to the final phase-space region defined by $m_{ll} > 5 \text{ GeV}$ & $80 < m_{4l} < 100 \text{ GeV}$.

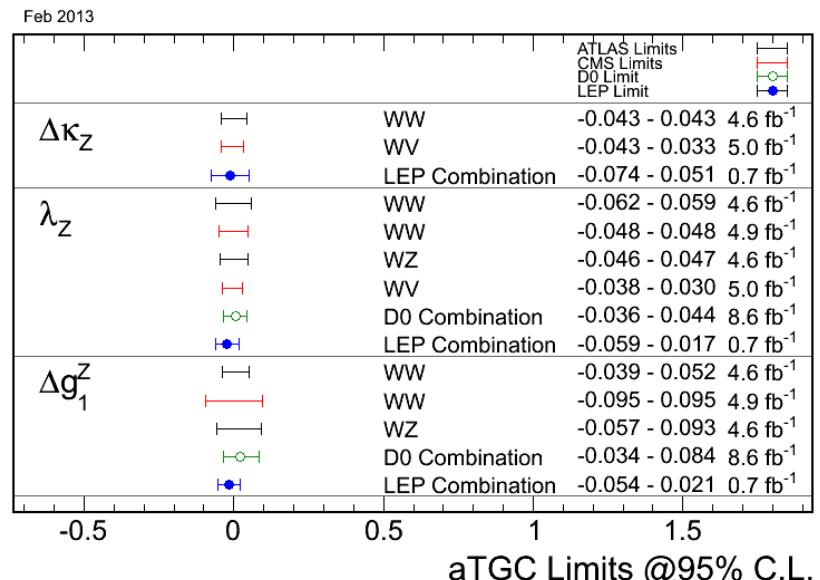
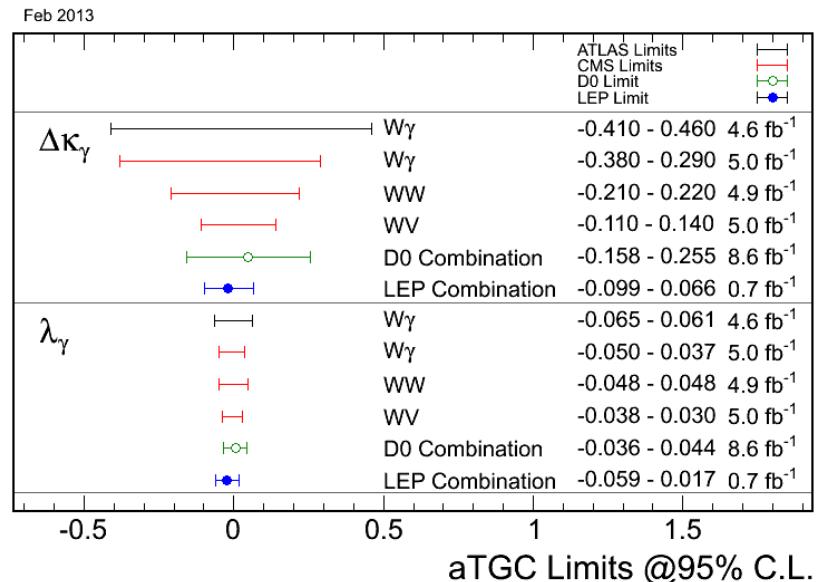
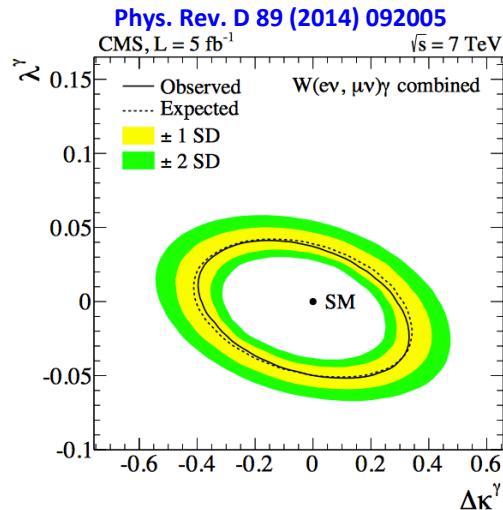
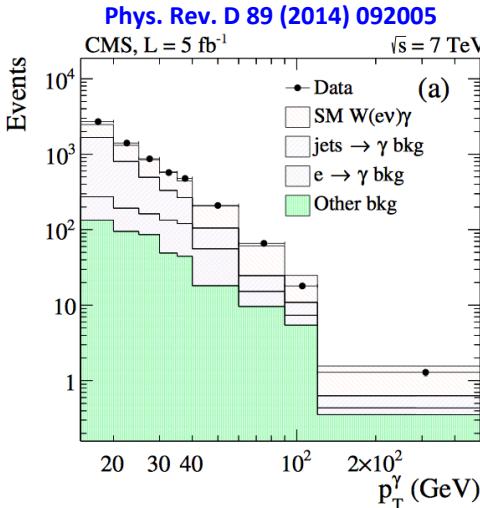
\sqrt{s}	4 ℓ state	$N_{4\ell}^{\text{obs}}$	$N_{4\ell}^{\text{exp}}$	$N_{4\ell}^{\text{bkg}}$	$C_{4\ell}$	$\sigma_{Z4\ell}^{\text{fid}} \text{ [fb]}$	$A_{4\ell}$	$\sigma_{Z4\ell} \text{ [fb]}$	
7 TeV	$ee + ee$	1	1.8 ± 0.3	0.12 ± 0.04	21.5%	$0.9^{+1.4}_{-0.7} \pm 0.14 \pm 0.02$	7.5%	$\left. \begin{array}{l} 4e, 4\mu \\ 2e2\mu \end{array} \right\}$	$\left. \begin{array}{l} 32 \pm 11 \pm 1.0 \pm 0.6 \\ 44 \pm 14 \pm 3.3 \pm 0.9 \\ 76 \pm 18 \pm 4 \pm 1.4 \end{array} \right\}$
	$\mu\mu + \mu\mu$	8	11.3 ± 0.5	0.08 ± 0.04	59.2%	$3.0^{+1.2}_{-0.9} \pm 0.07 \pm 0.05$	18.3%		
	$ee + \mu\mu$	7	7.9 ± 0.4	0.18 ± 0.09	49.0%	$3.1^{+1.4}_{-1.1} \pm 0.16 \pm 0.05$	15.8%		
	$\mu\mu + ee$	5	3.3 ± 0.3	0.07 ± 0.04	36.3%	$3.0^{+1.6}_{-1.2} \pm 0.30 \pm 0.06$	8.8%		
	combined	21	24.2 ± 1.2	0.44 ± 0.14					
8 TeV	$ee + ee$	16	14.4 ± 1.4	0.14 ± 0.03	36.1%	$2.2^{+0.6}_{-0.5} \pm 0.20 \pm 0.06$	7.3%	$\left. \begin{array}{l} 4e, 4\mu \\ 2e2\mu \end{array} \right\}$	$\left. \begin{array}{l} 56 \pm 6 \pm 1.8 \pm 1.6 \\ 52 \pm 7 \pm 2.4 \pm 1.5 \\ 107 \pm 9 \pm 4 \pm 3.0 \end{array} \right\}$
	$\mu\mu + \mu\mu$	71	68.8 ± 2.7	0.34 ± 0.05	71.1%	$4.9^{+0.7}_{-0.6} \pm 0.13 \pm 0.14$	17.8%		
	$ee + \mu\mu$	48	43.2 ± 2.1	0.32 ± 0.05	55.5%	$4.2^{+0.7}_{-0.6} \pm 0.16 \pm 0.12$	14.8%		
	$\mu\mu + ee$	16	19.3 ± 1.3	0.18 ± 0.04	46.2%	$1.7^{+0.5}_{-0.4} \pm 0.10 \pm 0.04$	7.9%		
	combined	151	146 ± 7	1.0 ± 0.11					

Anomalous (Charged) Triple Gauge Couplings

- The self-interaction of the electroweak gauge bosons present an important and sensitive probe of the SM.
- Any deviation would be an indication of new physics.



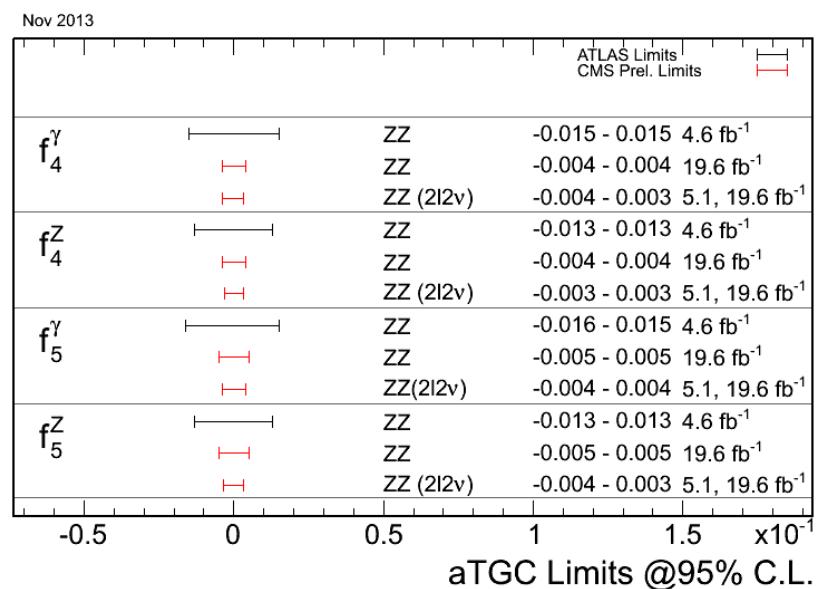
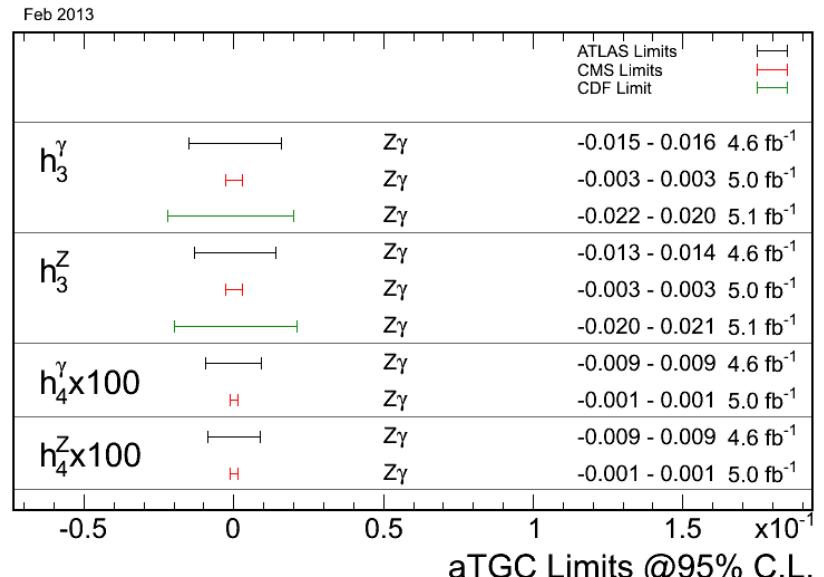
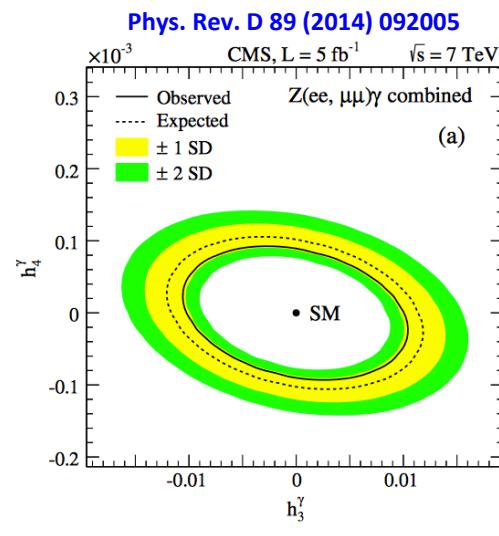
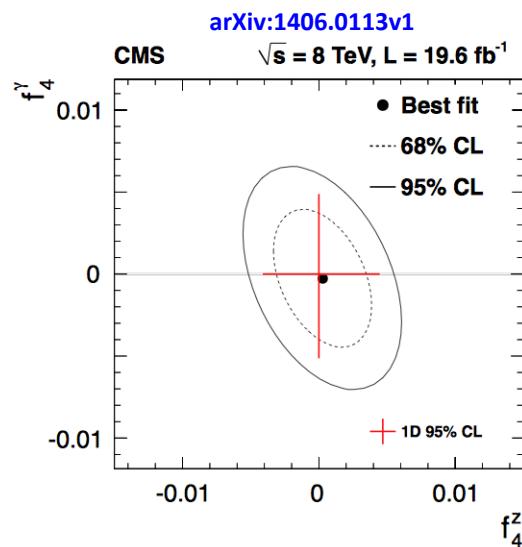
- Limits on the charged aTGC: WW γ and WWZ vertices.
- ATLAS and CMS results approaching sensitivity of LEP.



Anomalous (Neutral) Triple Gauge Couplings



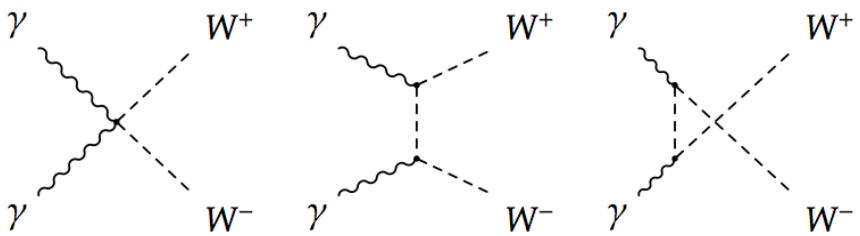
- Limits on the neutral aTGC: $ZZ\gamma$ and $Z\gamma\gamma$ vertices.
- In the SM neutral aTGC are equal to zero at tree level.
- The limits are set for aTGC parameters: h_3, h_4 and f_4, f_5 .
- Several limits are at the world-best in the sensitivity.
- Many analysis will be updated using the 8 TeV data.
- Possibilities to improve by combining the channels.



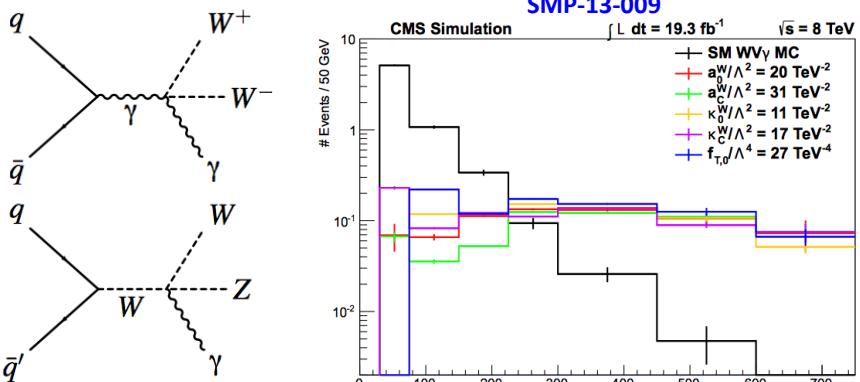
Anomalous Quartic Gauge Couplings (CMS)



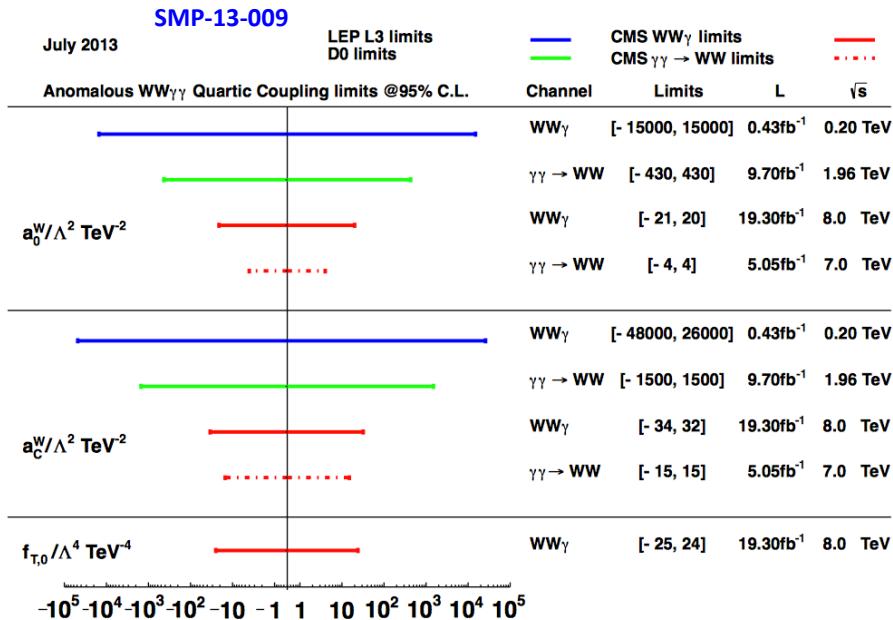
- Two photon production of a pair of W bosons is sensitive to anomalous quartic gauge couplings.



- Limits set by CMS are approximately two orders of magnitude more stringent than the LEP limits and about 20 times better than Tevatron results.
- Search for aQGC through WV γ production, where W boson decays to leptons and V(W or Z) to jets.



- First ever limits on anomalous WWZ γ couplings.



SMP-13-009

Observed Limits	Expected Limits
$-21 (\text{TeV}^{-2}) < a_0^W/\Lambda^2 < 20 (\text{TeV}^{-2})$	$-24 (\text{TeV}^{-2}) < a_0^W/\Lambda^2 < 23 (\text{TeV}^{-2})$
$-34 (\text{TeV}^{-2}) < a_C^W/\Lambda^2 < 32 (\text{TeV}^{-2})$	$-37 (\text{TeV}^{-2}) < a_C^W/\Lambda^2 < 34 (\text{TeV}^{-2})$
$-25 (\text{TeV}^{-4}) < f_{T,0}^W/\Lambda^4 < 24 (\text{TeV}^{-4})$	$-27 (\text{TeV}^{-4}) < f_{T,0}^W/\Lambda^4 < 27 (\text{TeV}^{-4})$
$-12 (\text{TeV}^{-2}) < K_0^W/\Lambda^2 < 10 (\text{TeV}^{-2})$	$-12 (\text{TeV}^{-2}) < K_0^W/\Lambda^2 < 12 (\text{TeV}^{-2})$
$-18 (\text{TeV}^{-2}) < K_C^W/\Lambda^2 < 17 (\text{TeV}^{-2})$	$-19 (\text{TeV}^{-2}) < K_C^W/\Lambda^2 < 18 (\text{TeV}^{-2})$

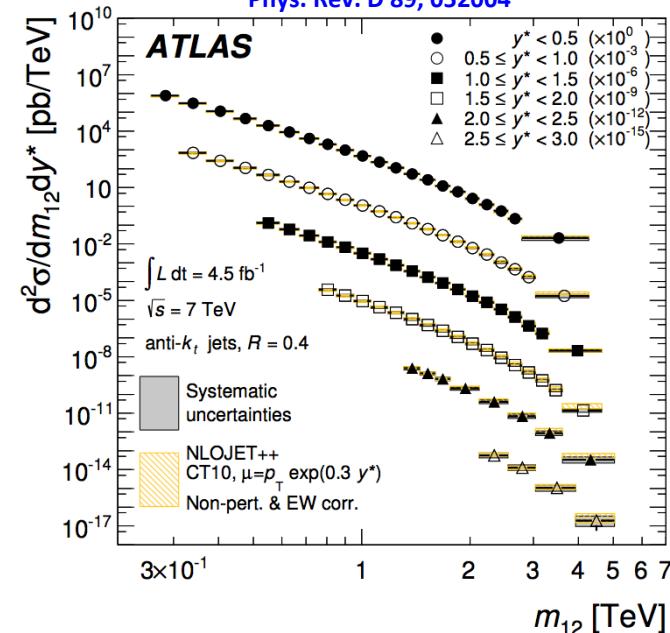
SMP-13-009

Observed Limits	Expected Limits
$-77 (\text{TeV}^{-4}) < f_{M,0}/\Lambda^4 < 81 (\text{TeV}^{-4})$	$-89 (\text{TeV}^{-4}) < f_{M,0}/\Lambda^4 < 93 (\text{TeV}^{-4})$
$-131 (\text{TeV}^{-4}) < f_{M,1}/\Lambda^4 < 123 (\text{TeV}^{-4})$	$-143 (\text{TeV}^{-4}) < f_{M,1}/\Lambda^4 < 131 (\text{TeV}^{-4})$
$-39 (\text{TeV}^{-4}) < f_{M,2}/\Lambda^4 < 40 (\text{TeV}^{-4})$	$-44 (\text{TeV}^{-4}) < f_{M,2}/\Lambda^4 < 46 (\text{TeV}^{-4})$
$-66 (\text{TeV}^{-4}) < f_{M,3}/\Lambda^4 < 62 (\text{TeV}^{-4})$	$-71 (\text{TeV}^{-4}) < f_{M,3}/\Lambda^4 < 66 (\text{TeV}^{-4})$

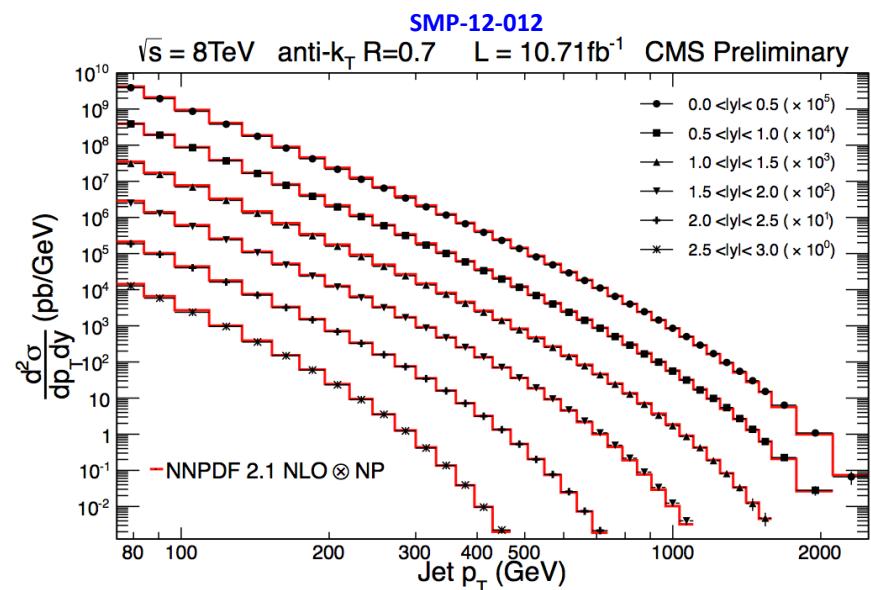
Jet Production Cross Sections



Phys. Rev. D 89, 052004



- Double differential cross sections as function of m_{jj} (up to 5 TeV), y separation of the two highest-pT jets (measured up to $y^* < 3.0$).
- Fixed order NLO QCD by NLOJet++ and POWHEG NLO ME to PS.
- Improved measurement in high dijet mass region can be used to constrain gluon PDFs at high momentum fraction.
- Good agreement found for CT10, NNPDF2.1 and MSTW 2008 PDF.
- Disagreement with HERAPDF1.5 and NLOJet++ using ABM11 PDF.



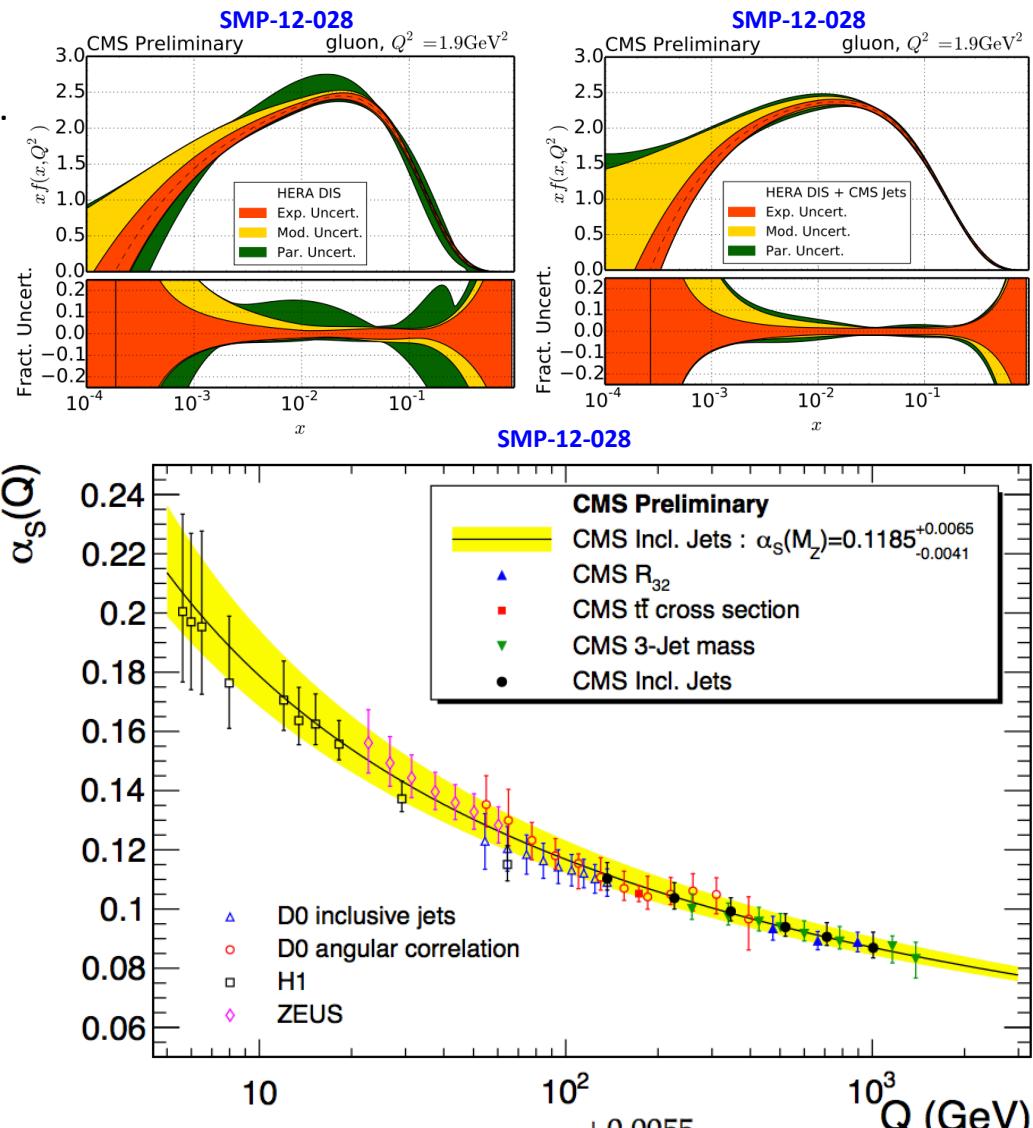
- Inclusive jet cross section, double-differential in jet pT and $|y|$, ranging up to $pT = 2.5$ TeV and $|y| < 3.0$.
- pQCD describes data well in wide range of pT and $|y|$.
- Good agreement in low pT region, except for ABM11.
- In high pT region only the CT10 is in good agreement.

Constraints on PDFs and α_s (CMS)



- Inclusive jet cross sections measured by CMS extend the accessible phase space in pT and $|y|$.
- The impact of the inclusive jet cross section measurements on PDFs using the HERAFitter.
- Adding the CMS inclusive jet data significantly reduces the uncertainty on gluon distribution for fractional parton momenta of $x \geq 0.01$.
- Strong coupling is fundamental QCD parameter
- Fitting the strong coupling as a free parameter in addition to PDFs is possible with CMS data.
- Results consistent with dedicated fits of $\alpha_s(M_Z)$:

$$\alpha_s(M_Z) = 0.1185 \pm 0.0019 \text{ (exp.)} \pm 0.0028 \text{ (PDF)} \pm 0.0004 \text{ (NP)}^{+0.0055}_{-0.0022} \text{ (scale)}$$

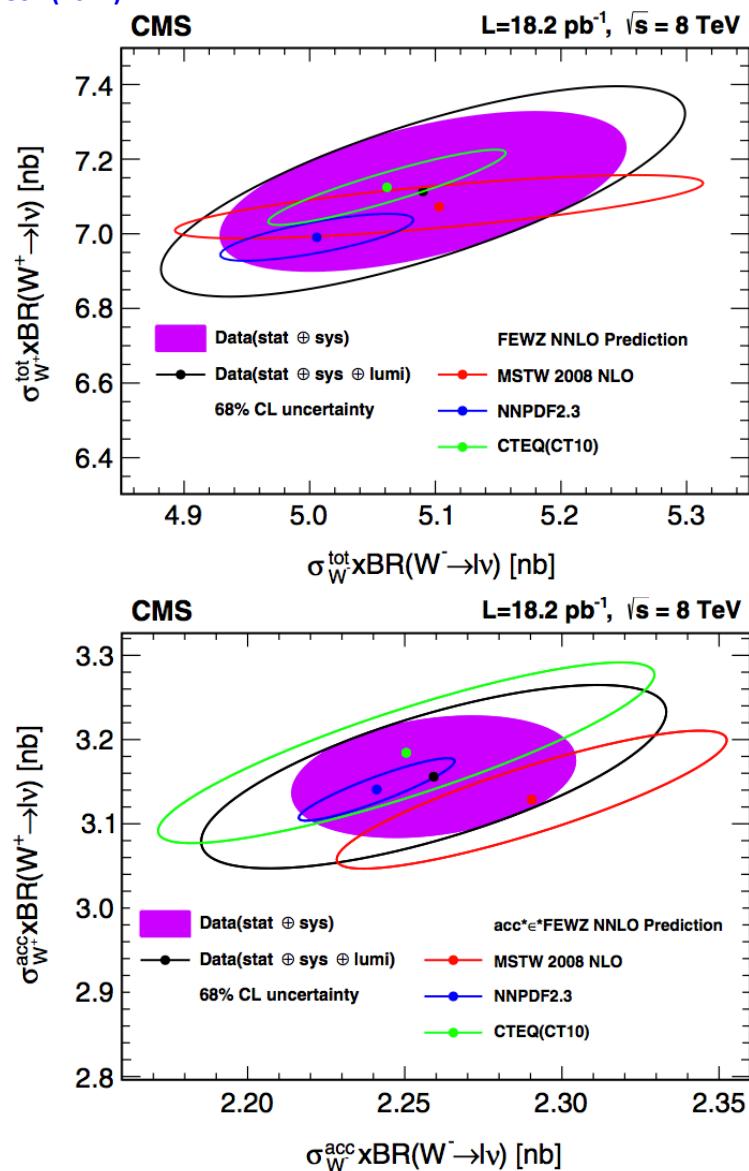
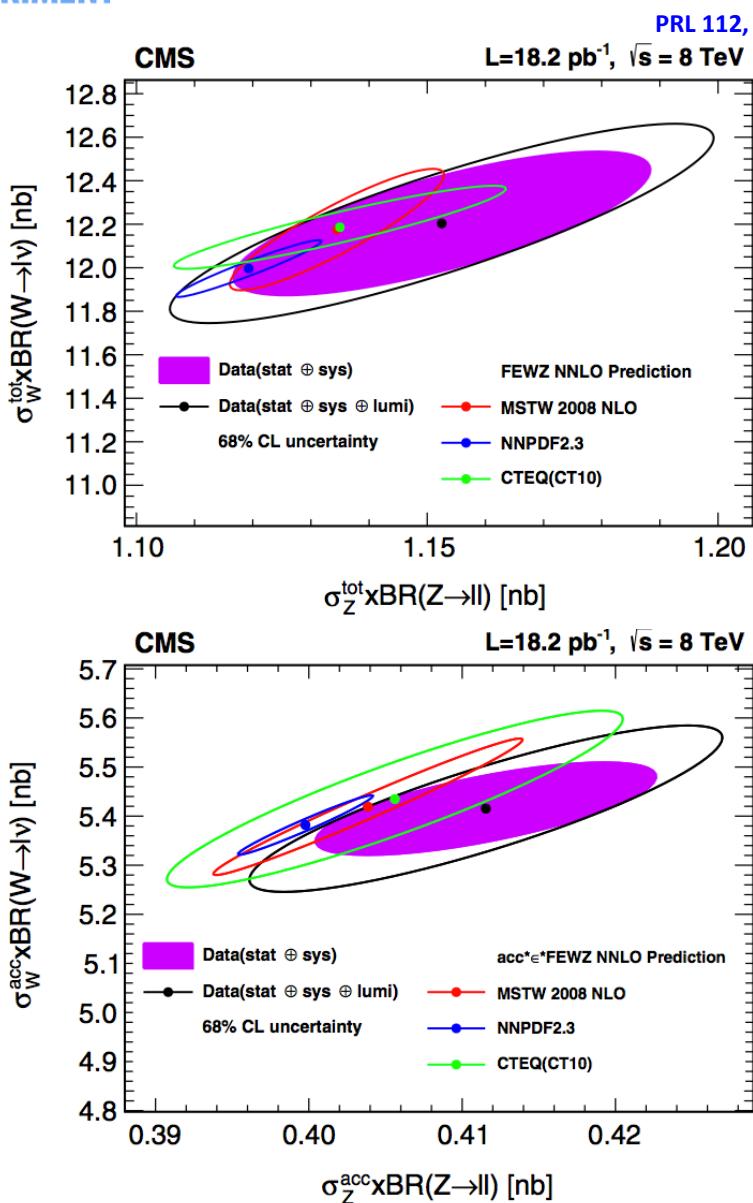


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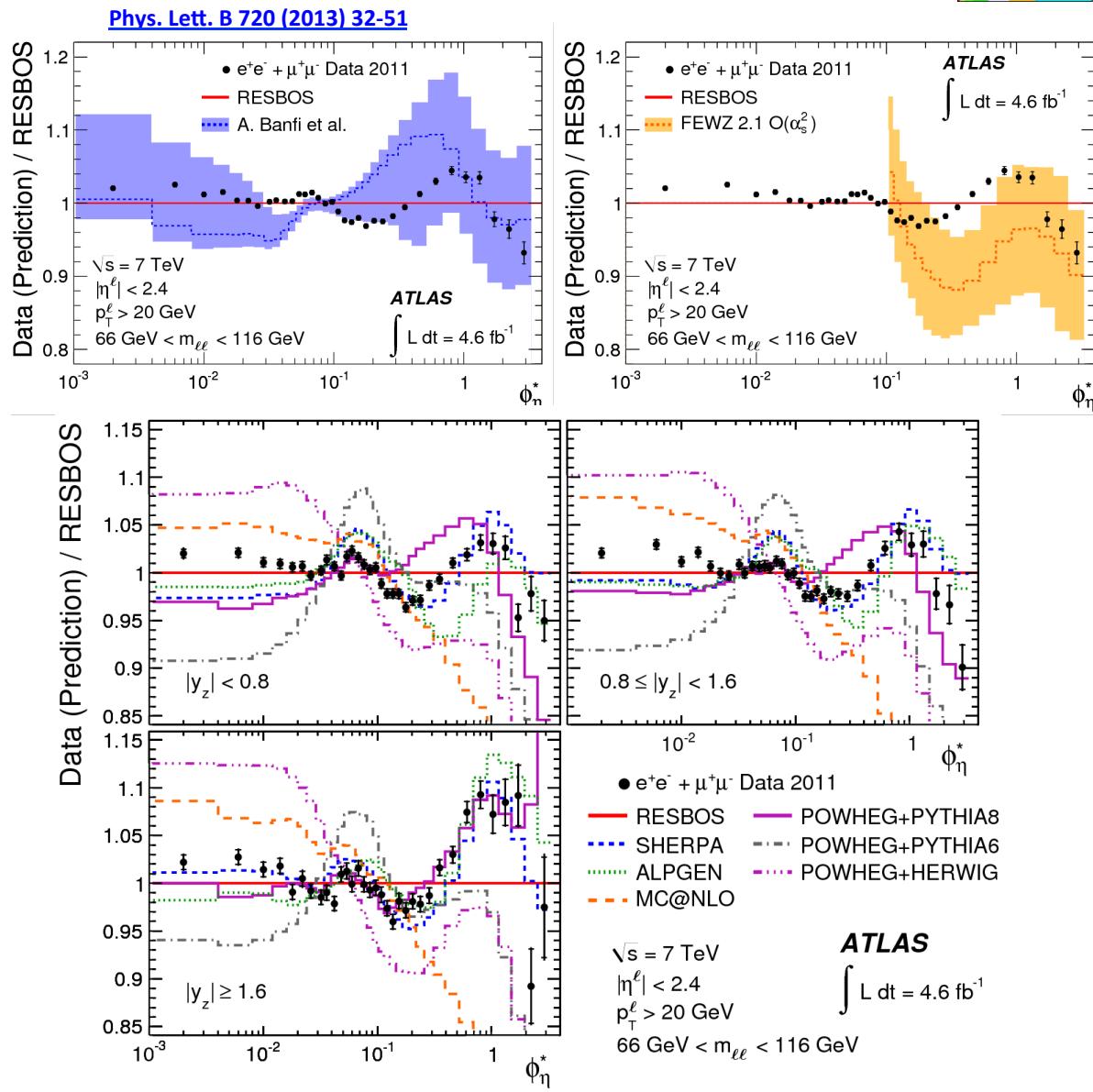
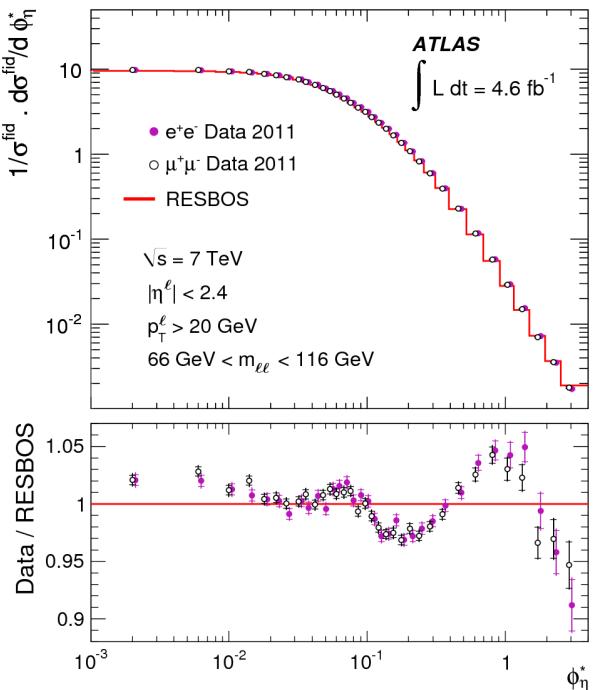
- Studies of the vector boson production showed unprecedented precision and enabled testing of the pQCD over large kinematic region that has never been probed before.
- Measurements of the vector boson plus jets production were improved, various MC generators have confirmed predictive capabilities of pQCD, new PDF constraints.
- The multiboson studies resulted with limits that are reaching the sensitivity of LEP, several of them are world-leading already, many 8 TeV analysis are expected to come.
- Inclusive jet cross section were measured in the extended phase space, significantly reduced the uncertainty on PDFs, strong coupling constant measurement improved.
- Standard Model results from ATLAS and CMS using the LHC Run 1 data have given us a possibility to perform extensive tests of the electroweak and strong interactions.
- Interesting times ahead as the preparations for LHC Run 2 are ongoing, with higher energies and luminosities, also higher pileup and more challenging trigger conditions.

Backup slides

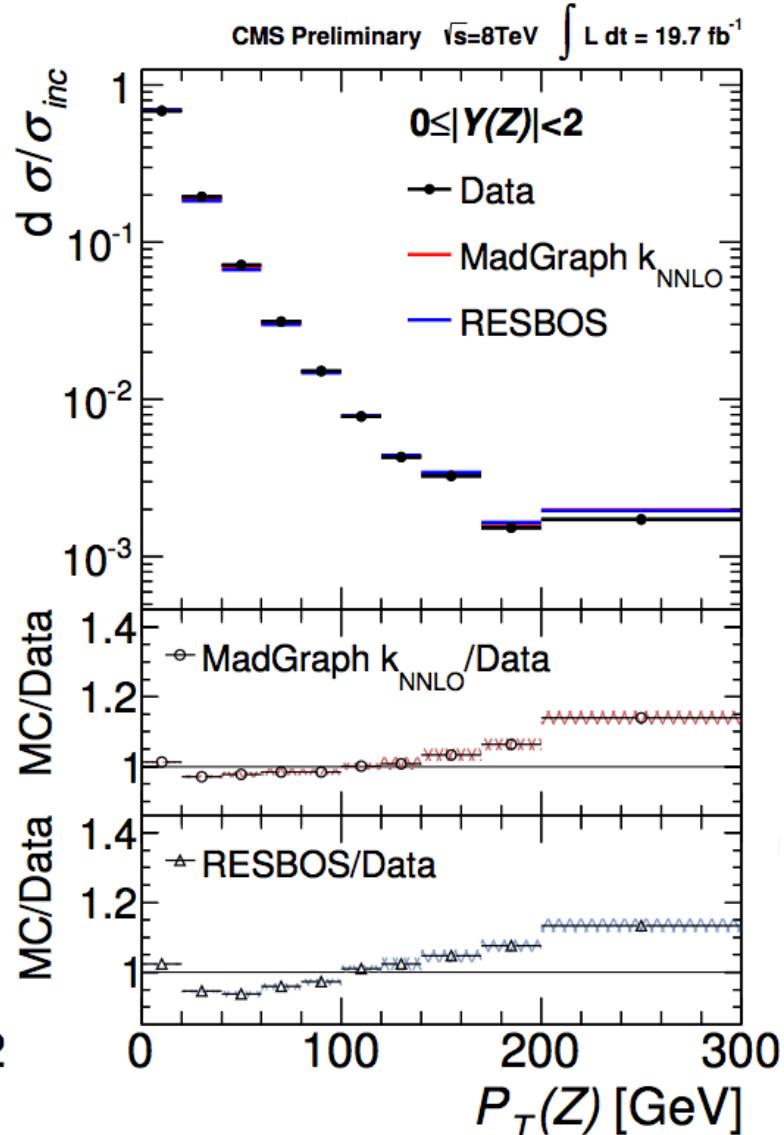
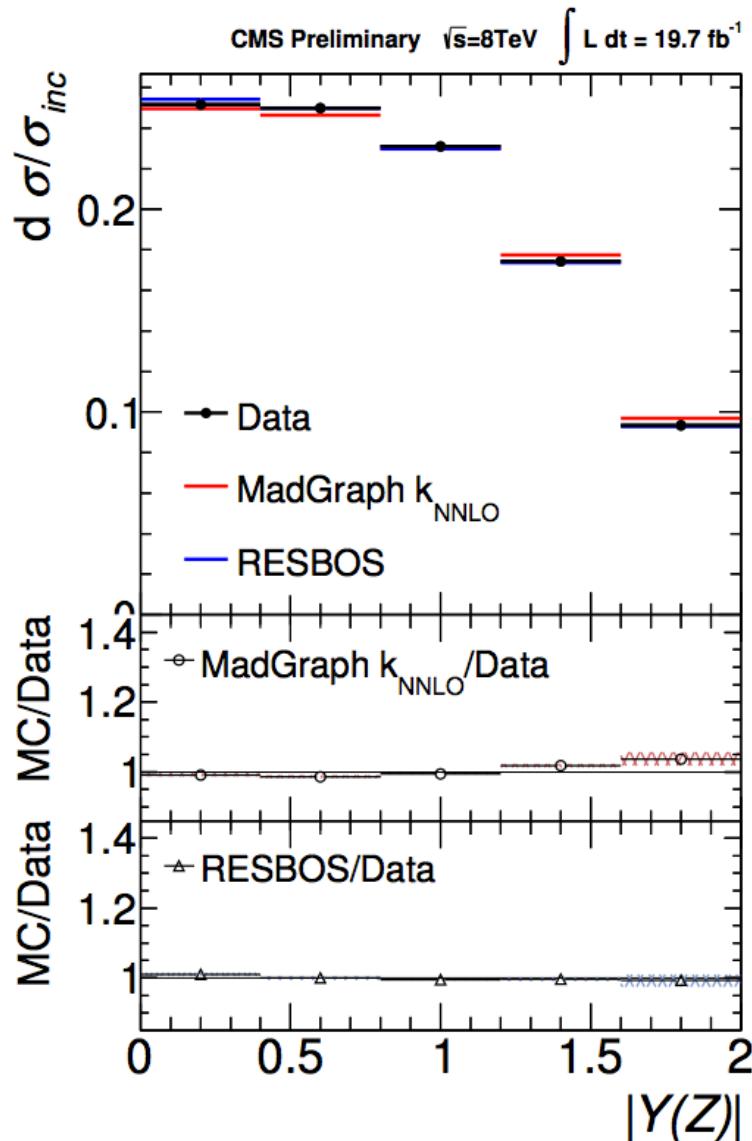
Inclusive W/Z Boson Cross Section at $\sqrt{s} = 8$ TeV (CMS)



- Measurement of angular correlations in DY to lepton pairs via ϕ_η^* observable.
- Probes the same physics as Z/ γ^* pT but with a better experimental resolution.
- Cross-section measurements compared to resummed QCD predictions combined with fixed-ordered pQCD calculations and also to predictions from different MC generators interfaced to a PS algorithm.



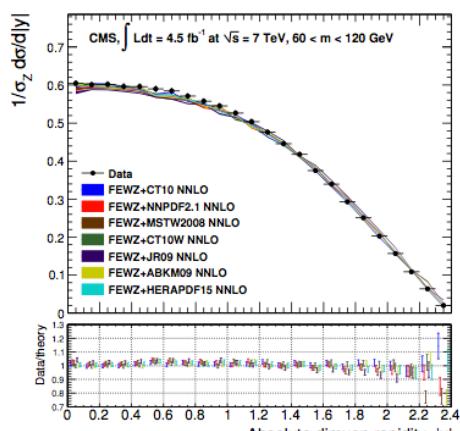
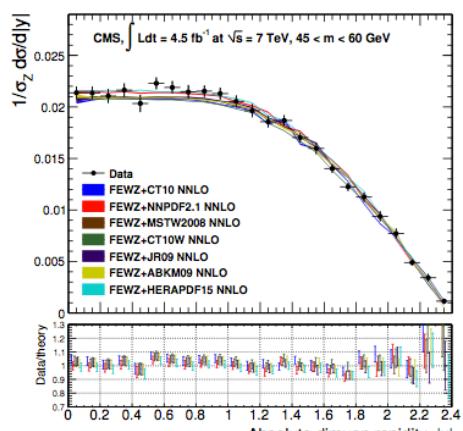
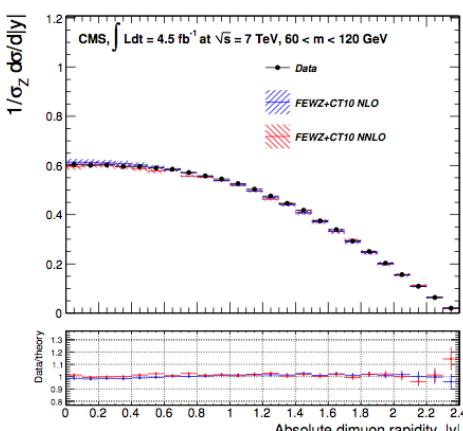
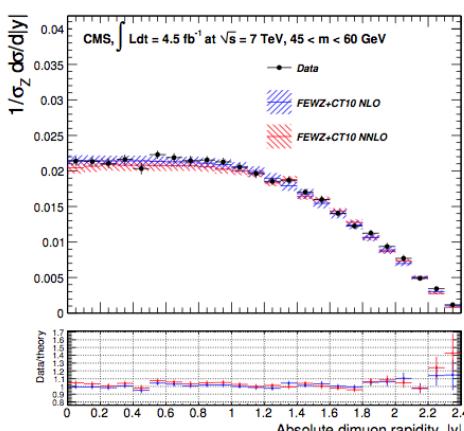
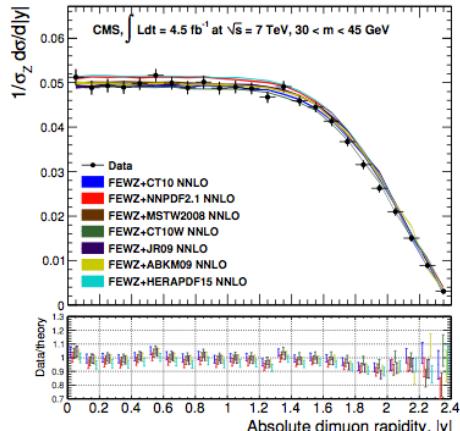
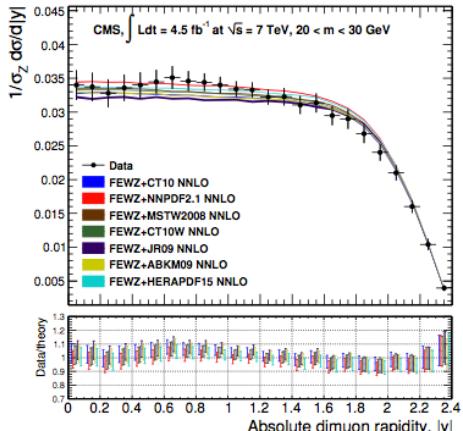
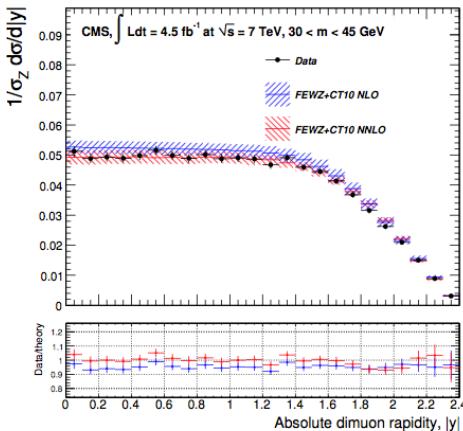
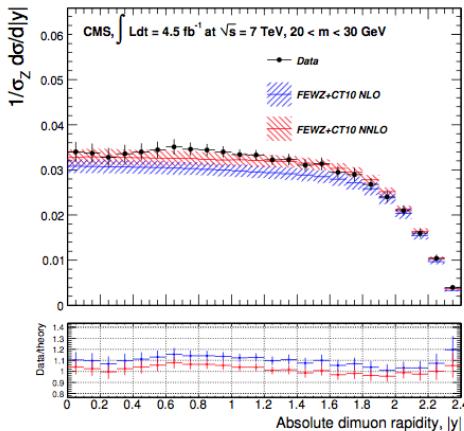
SMP-13-013



Drell-Yan Differential Cross Sections (CMS)



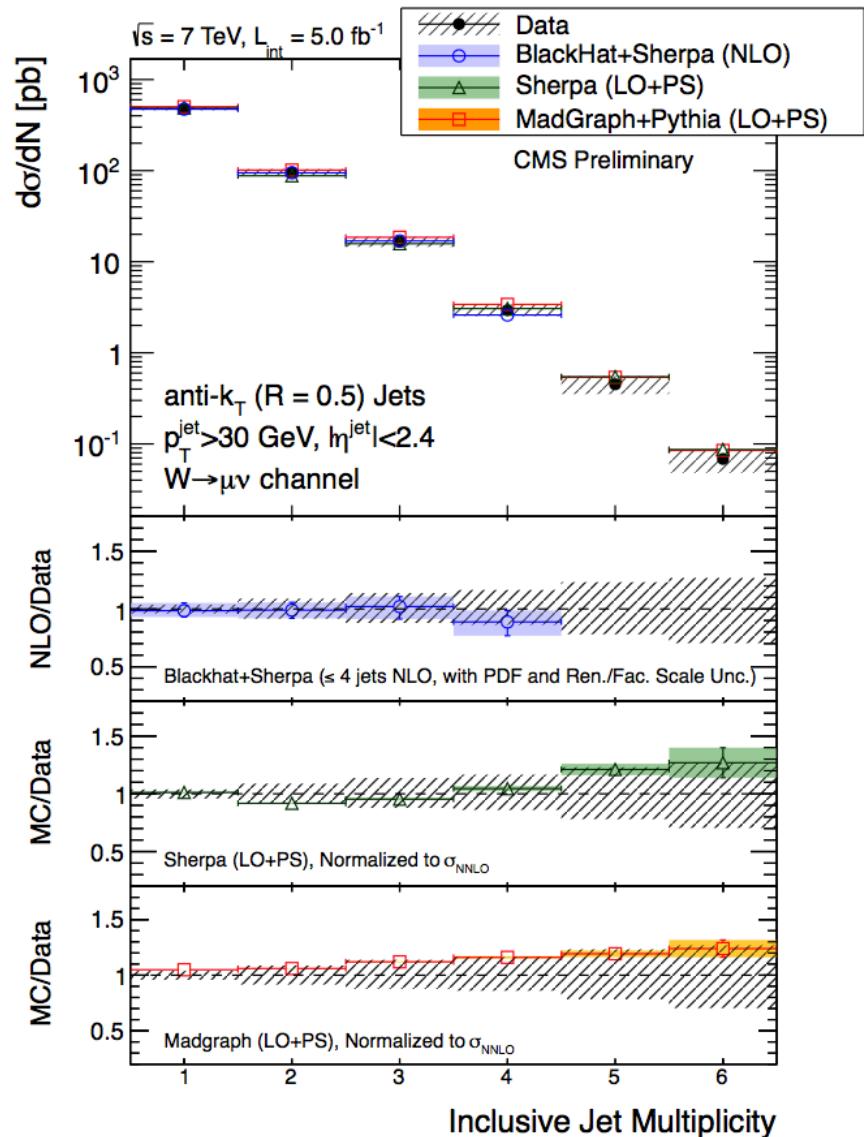
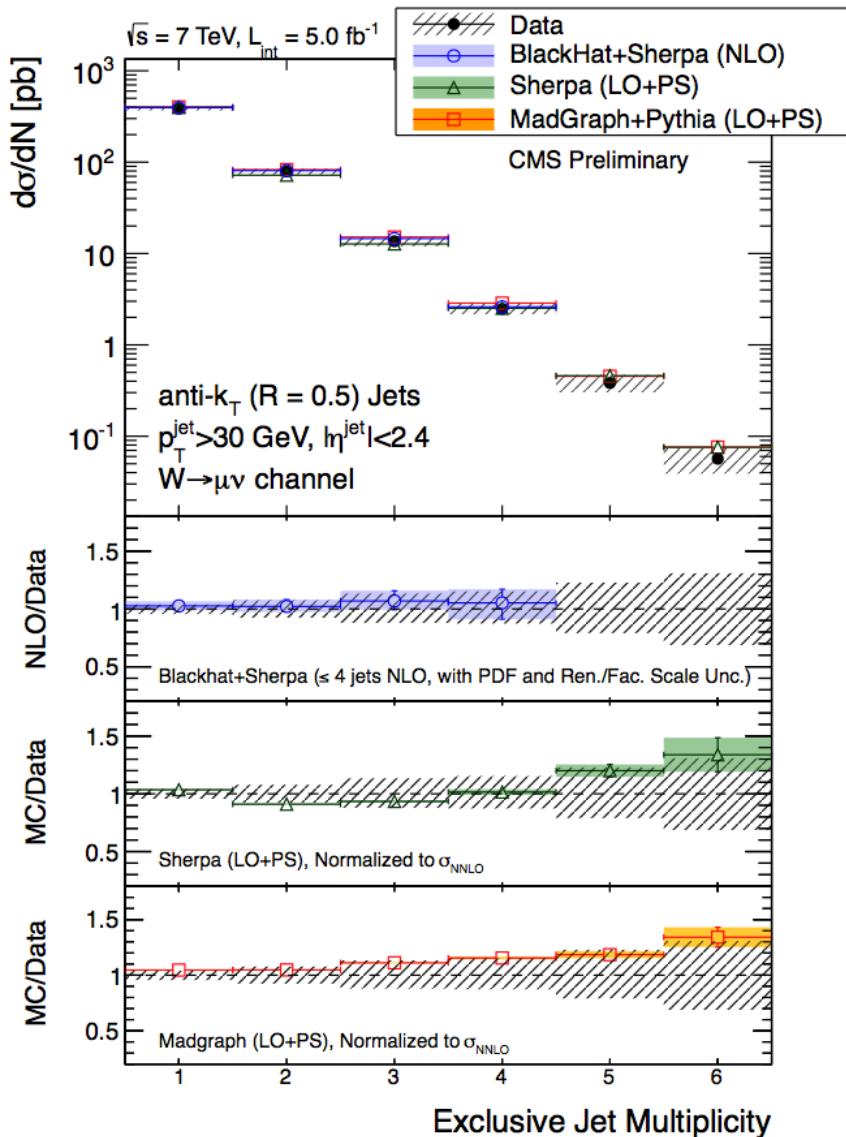
JHEP12(2013)030



W+Jets Differential Cross Sections (CMS)



SMP-12-023

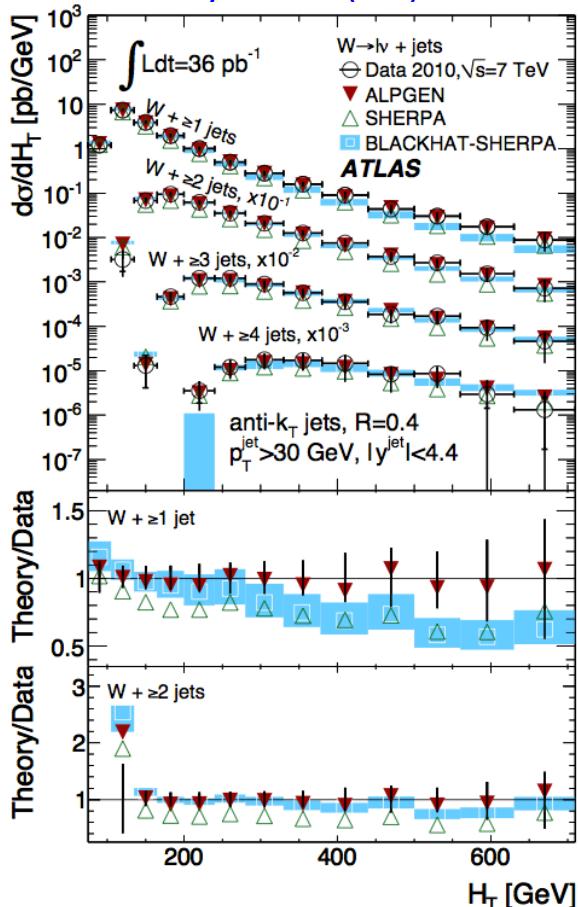


W+Jets Differential Cross Sections (ATLAS)

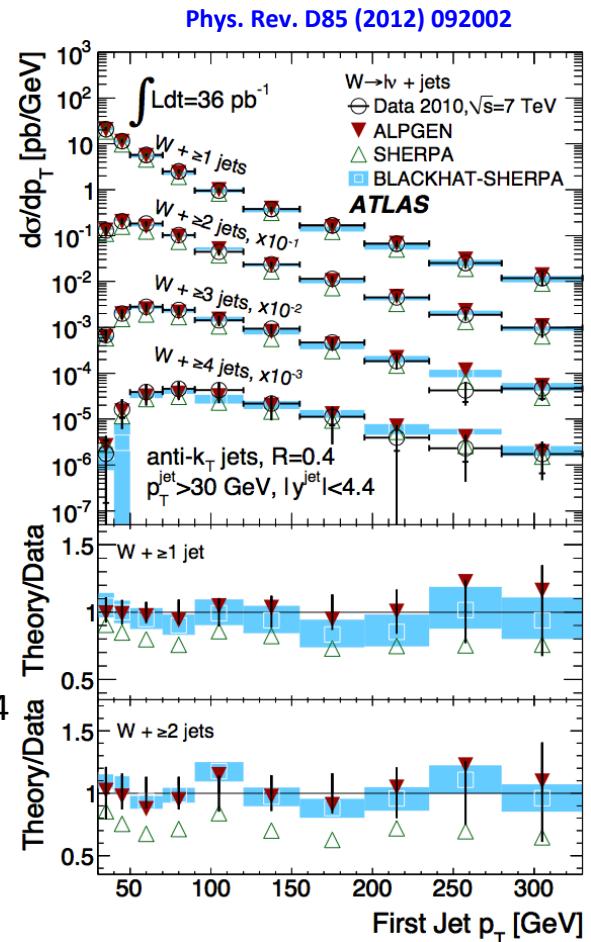


- Production of W+jets, W decays into a electron/muon and a neutrino.
- Results for the electron and muon channels were combined using BLUE.
- Predictions from Alpgen, Sherpa, Pythia, BlackHat-Sherpa and MCFM.

Phys. Rev. D85 (2012) 092002



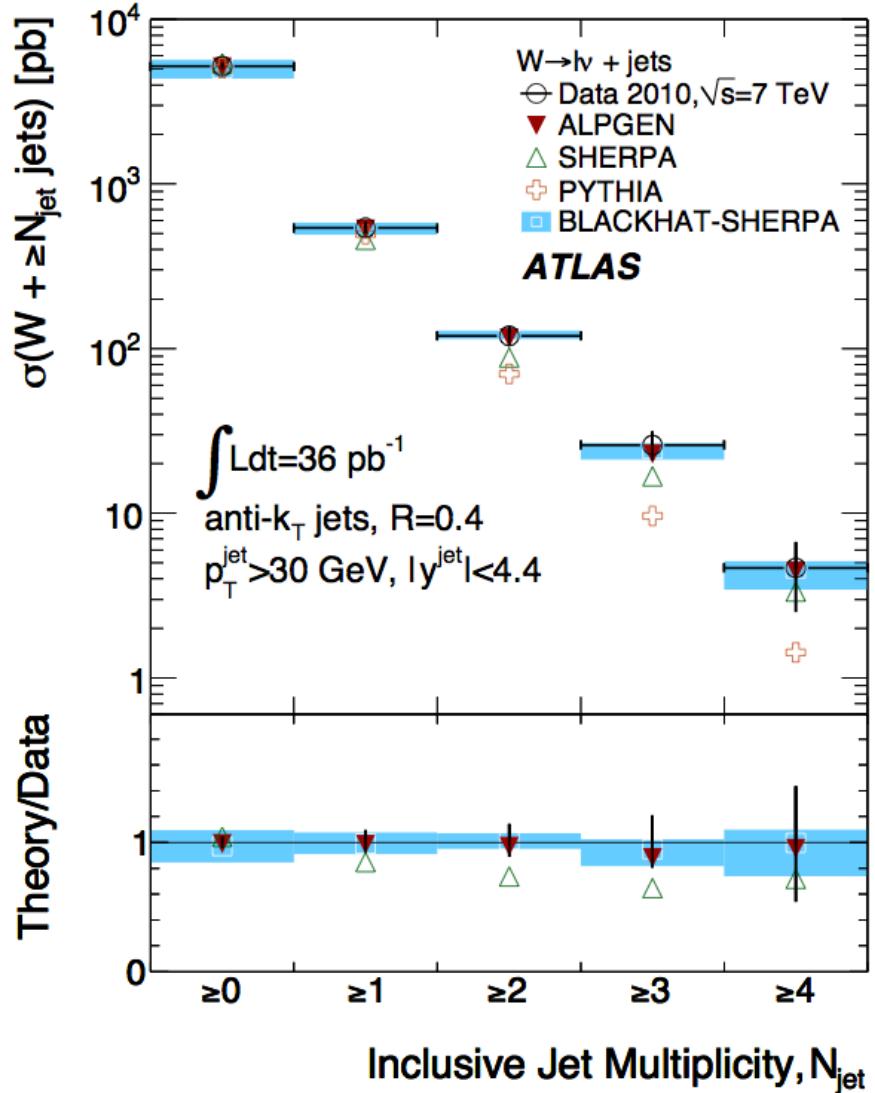
- H_T is scalar sum over p_T of lepton, neutrino and all jets in the event.
- Used to set the renormalization and factorization scale in the fixed order calculations, interesting for Data/MC.
- Modified BlackHat-Sherpa introduced, higher order NLO terms with 2, 3 and 4 real emissions added to the $N_{\text{jets}} \geq 1$.
- Prediction of H_T at NLO is challenging.
- Multiparton ME generator Alpgen in good agreement with measurement, Sherpa has slightly worse prediction, while NLO BlackHat-Sherpa has some deviations in the $d\sigma/dH_T$, $d\sigma/dy(\text{jet})$ and $d\sigma/d(y(l)-y(\text{jet}))$ distributions.



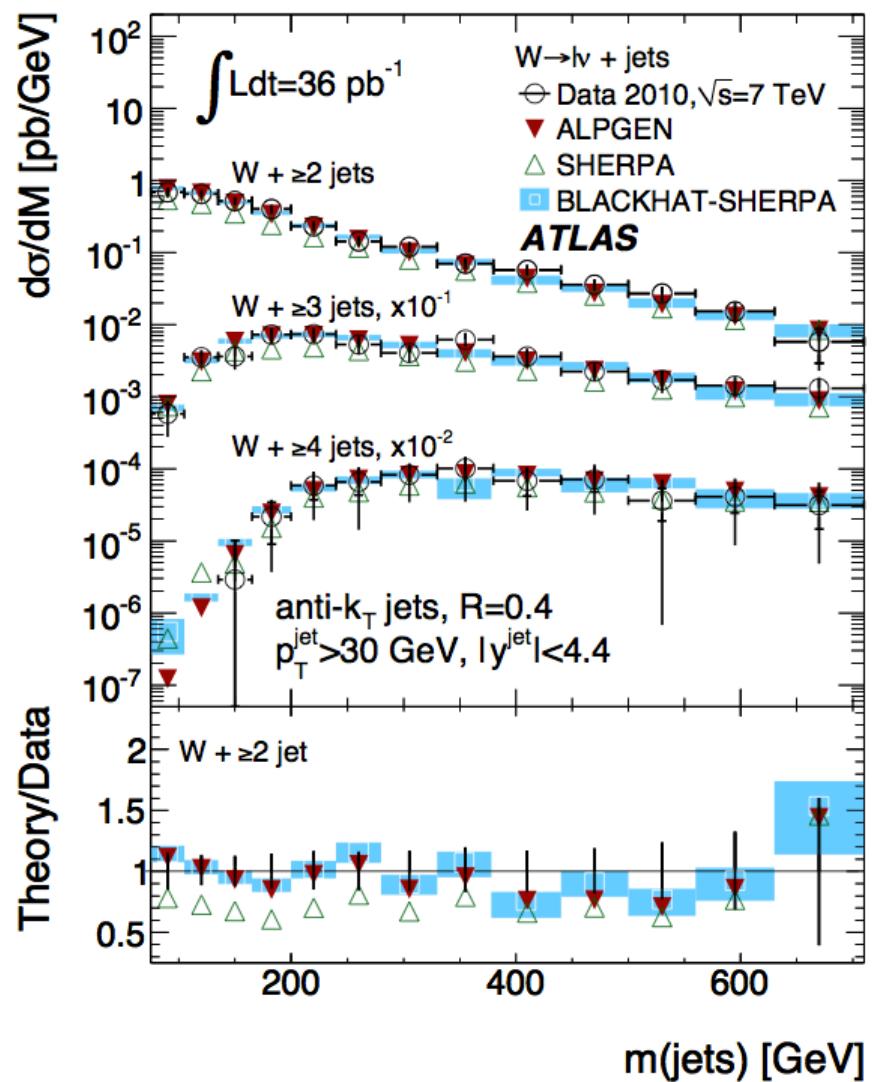
W+Jets Differential Cross Sections (ATLAS)



Phys. Rev. D85 (2012) 092002



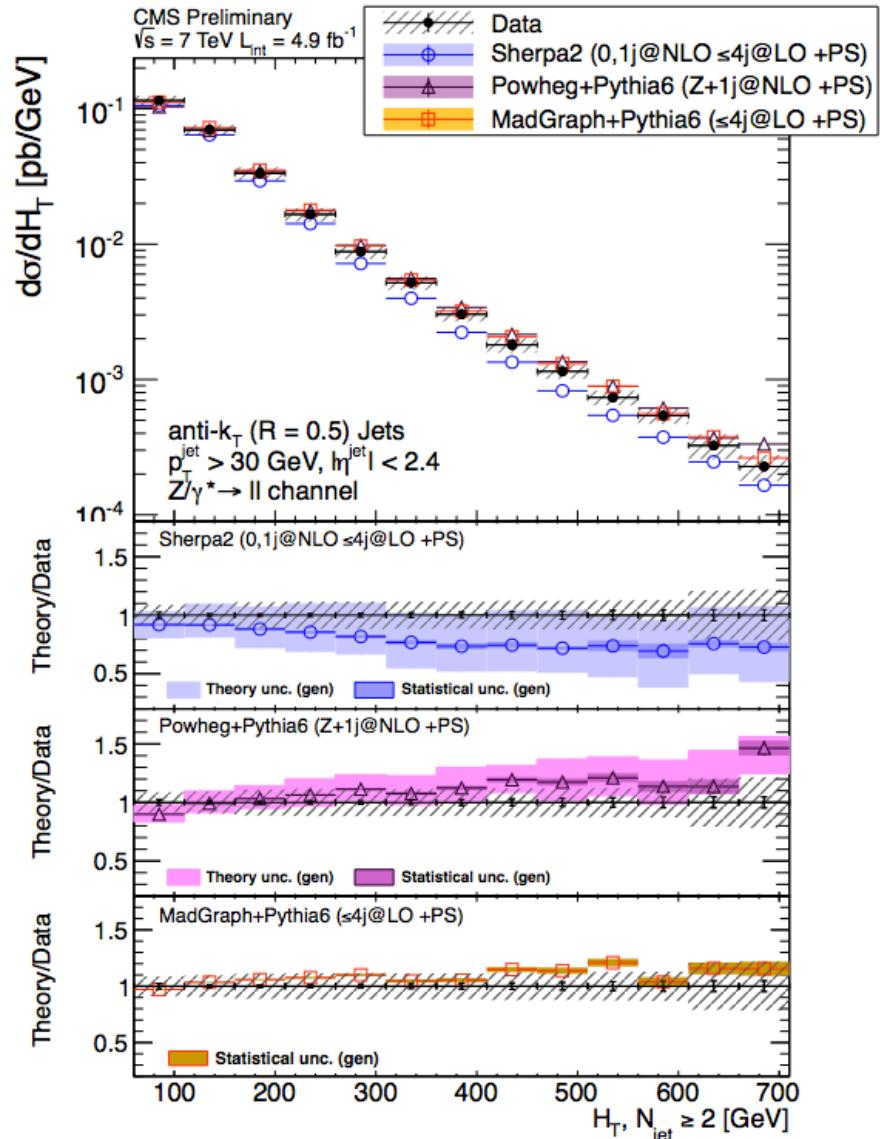
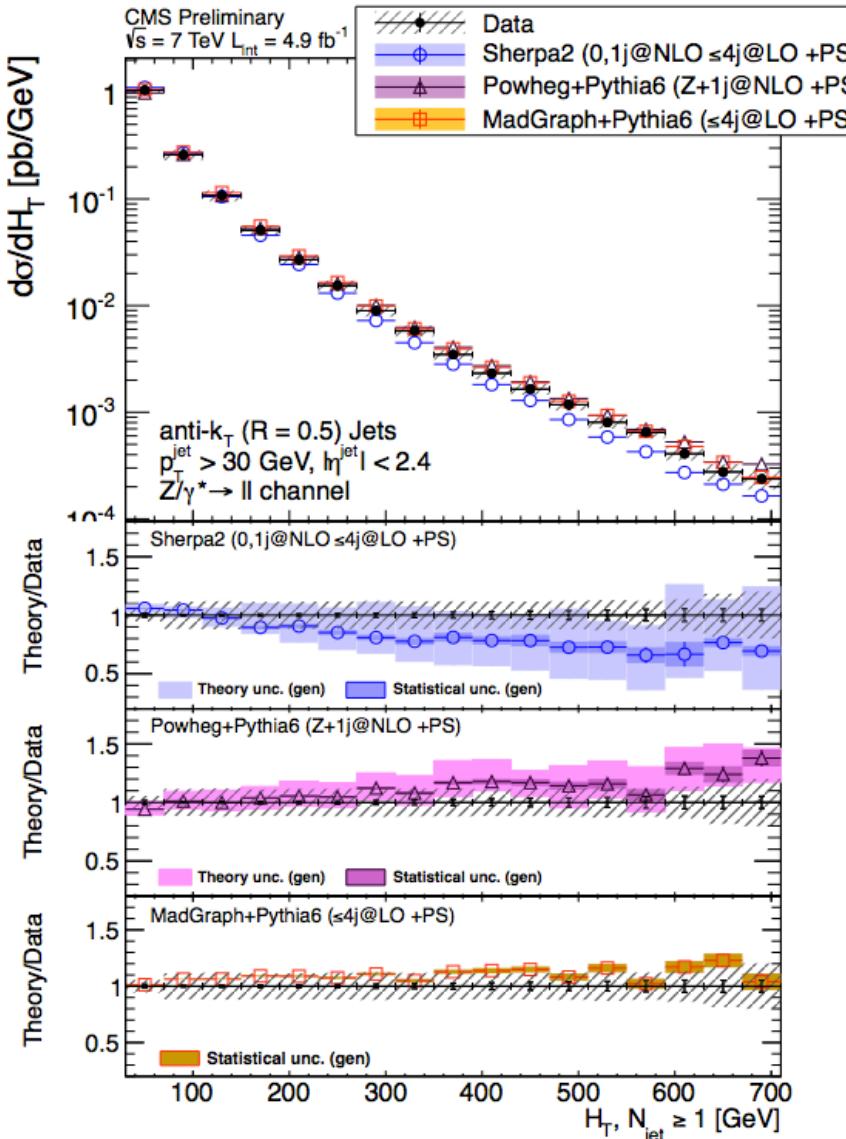
Phys. Rev. D85 (2012) 092002



Z+Jets Differential Cross Sections (CMS)



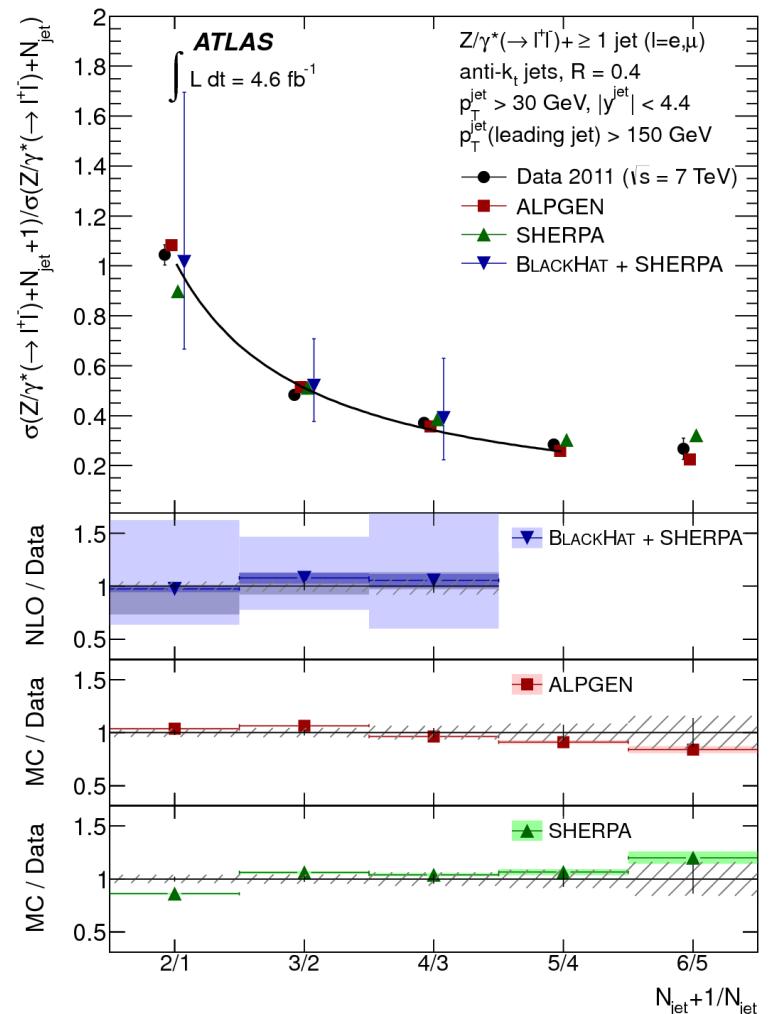
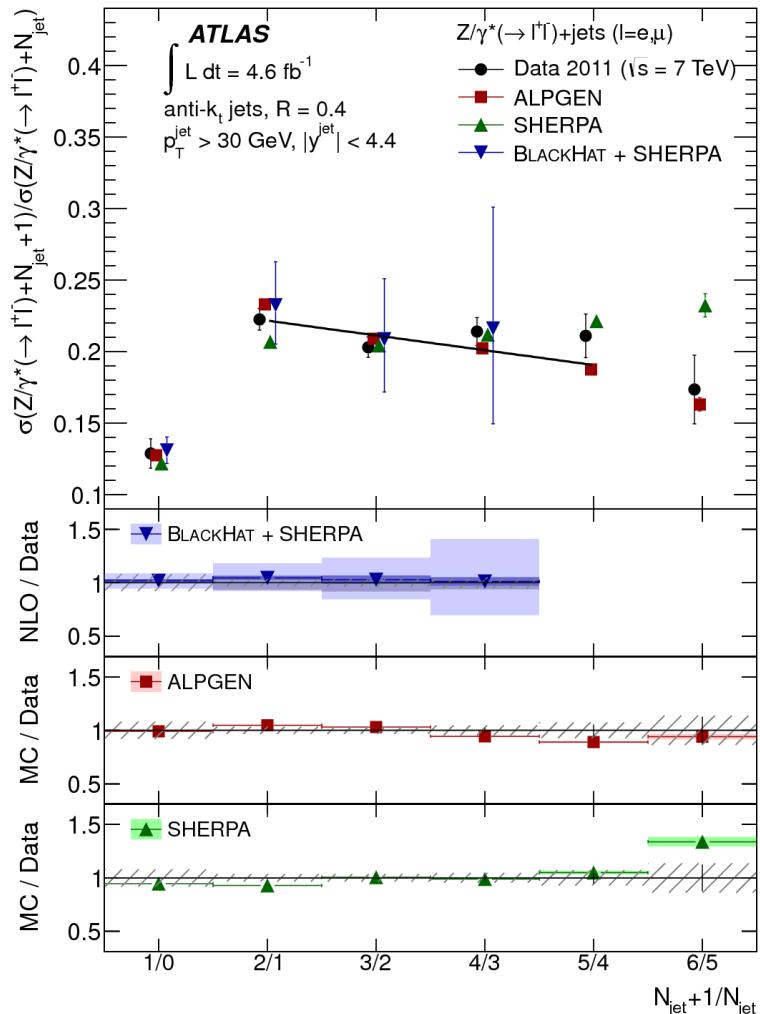
SMP-12-017



Z+Jets Differential Cross Sections (ATLAS)



arXiv:1304.7098v1

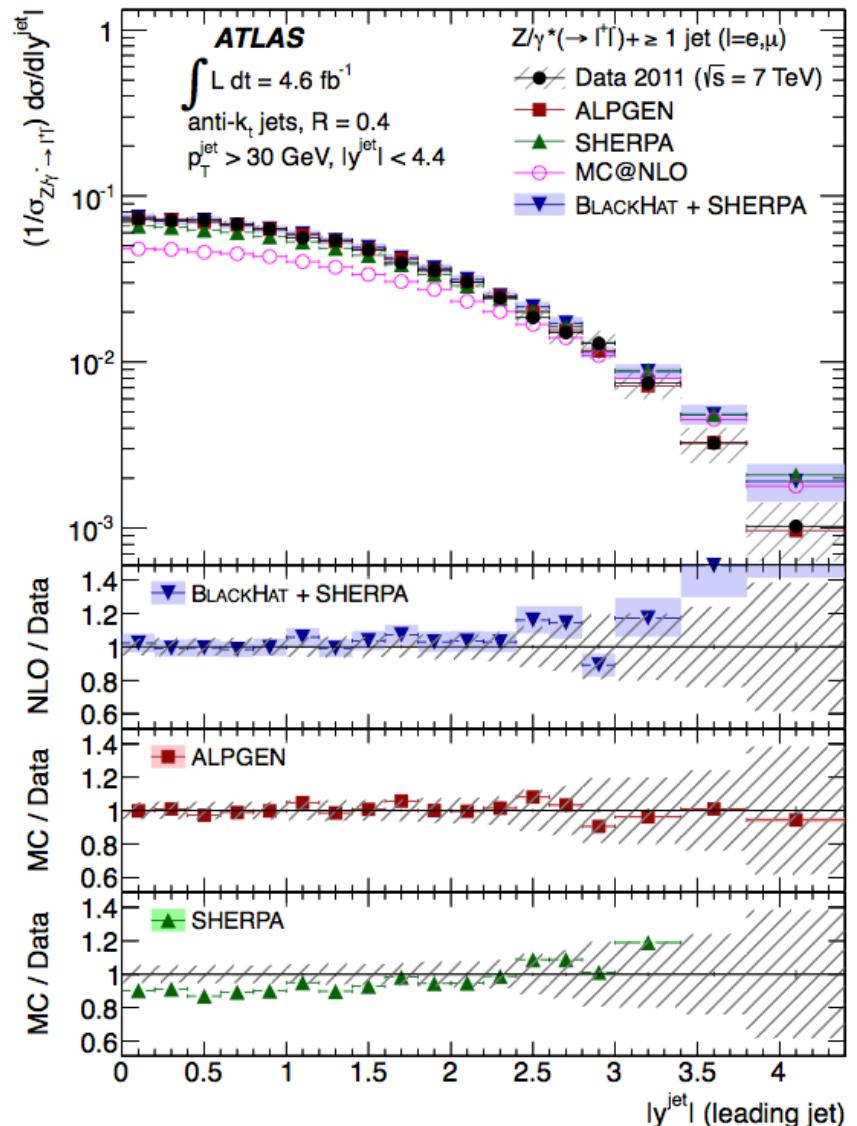
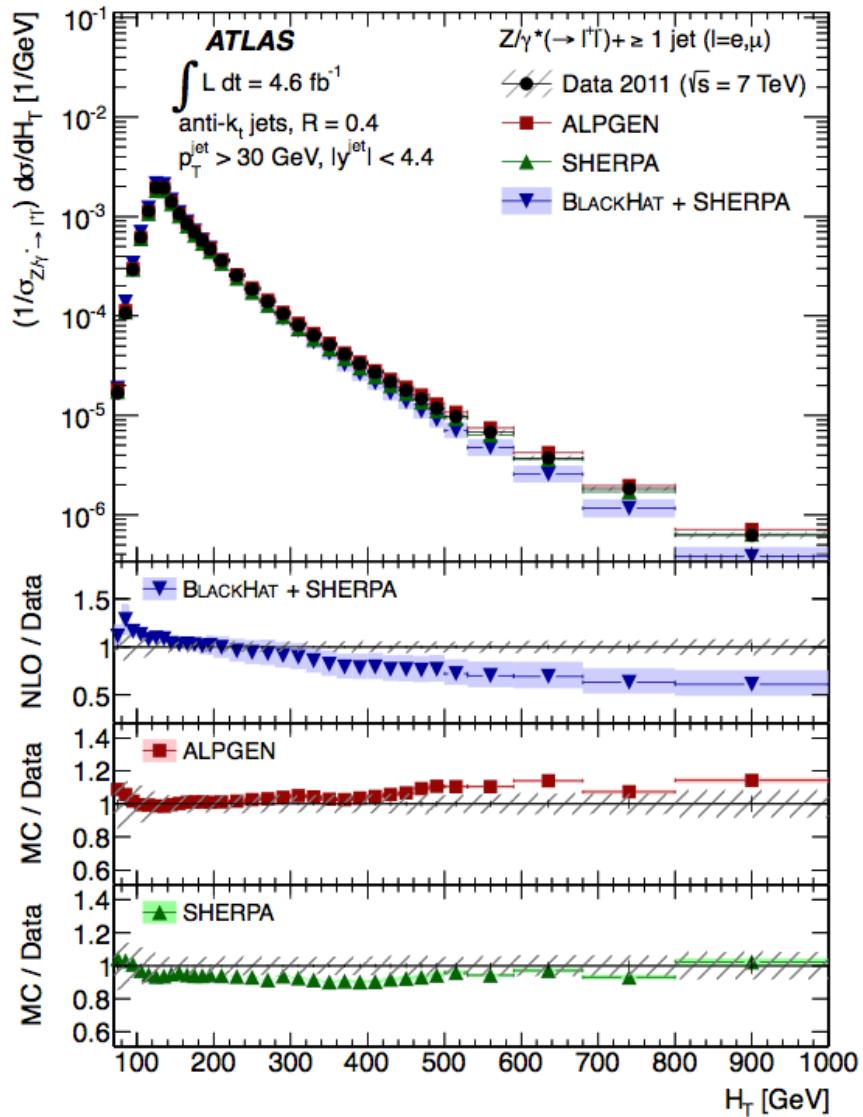


Transition from staircase (Berends) to Poisson scaling of the exclusive jet multiplicity ratio, expected from theory when large scale difference is introduced, is observed in the data.

Z+Jets Differential Cross Sections (ATLAS)

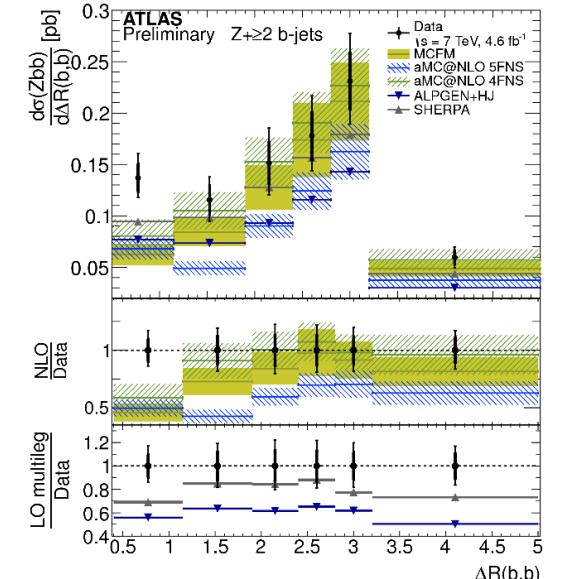
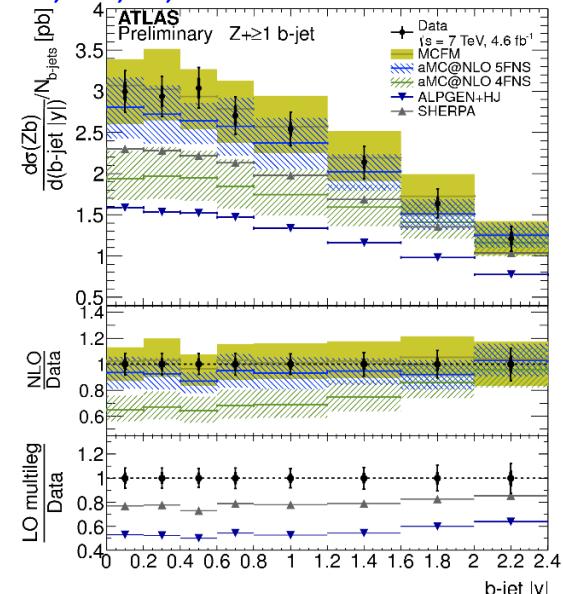
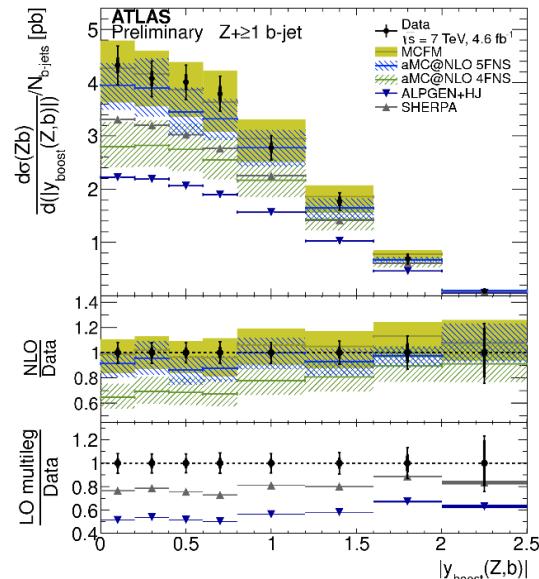
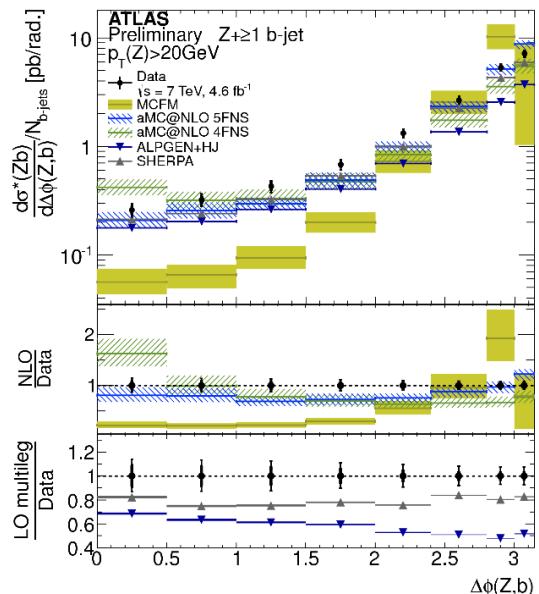


arXiv:1304.7098v1



Z+b(b) Production (ATLAS)

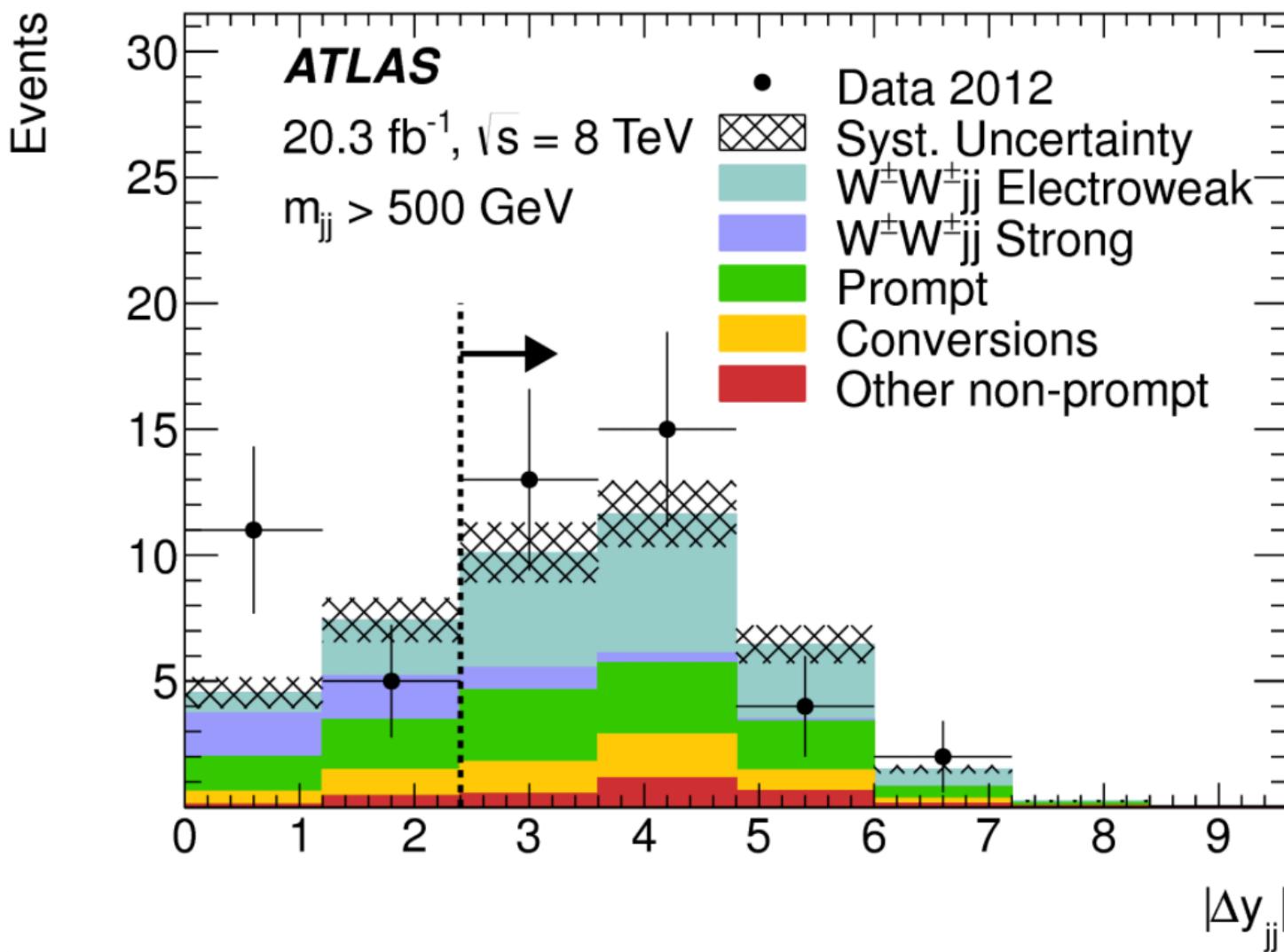
Ulla Blumenschein, LHCP, June, 2-7, 2014



Electroweak Production of $W^\pm W^\pm jj$ (ATLAS)



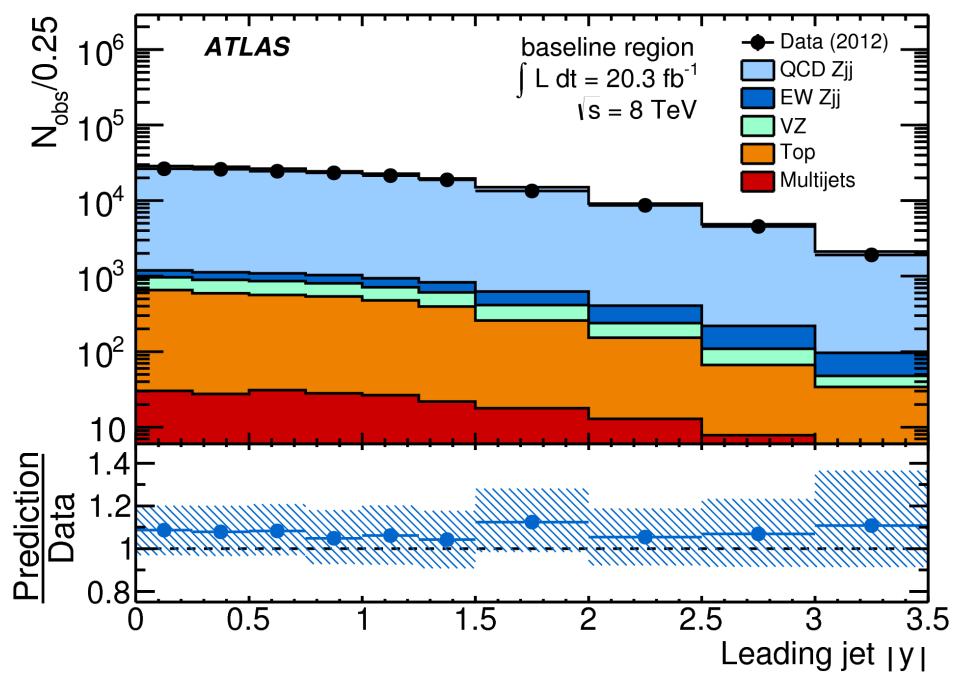
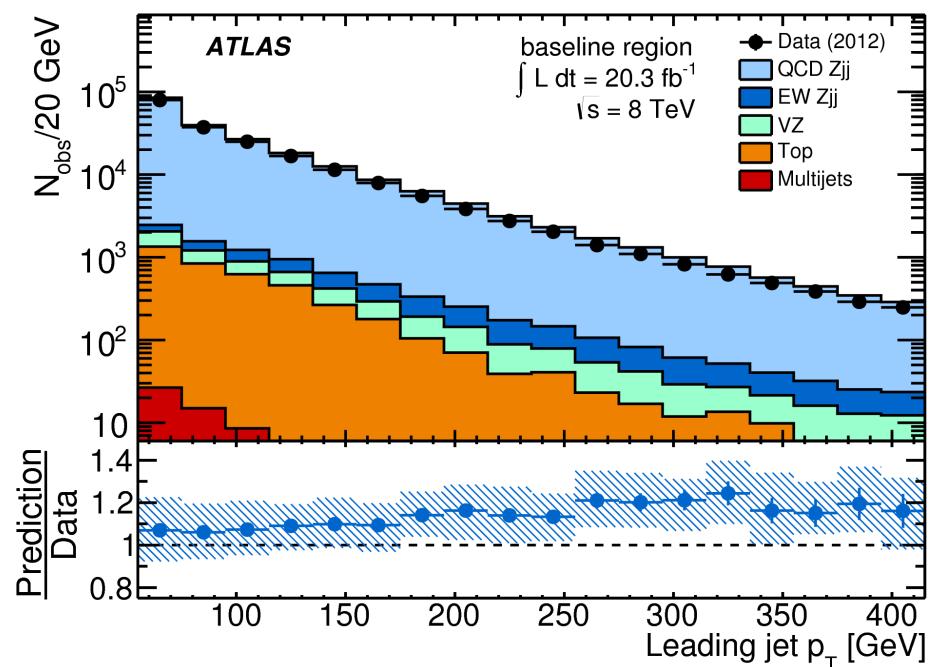
arXiv:1405.6241v1



Electroweak Zjj Production (ATLAS)



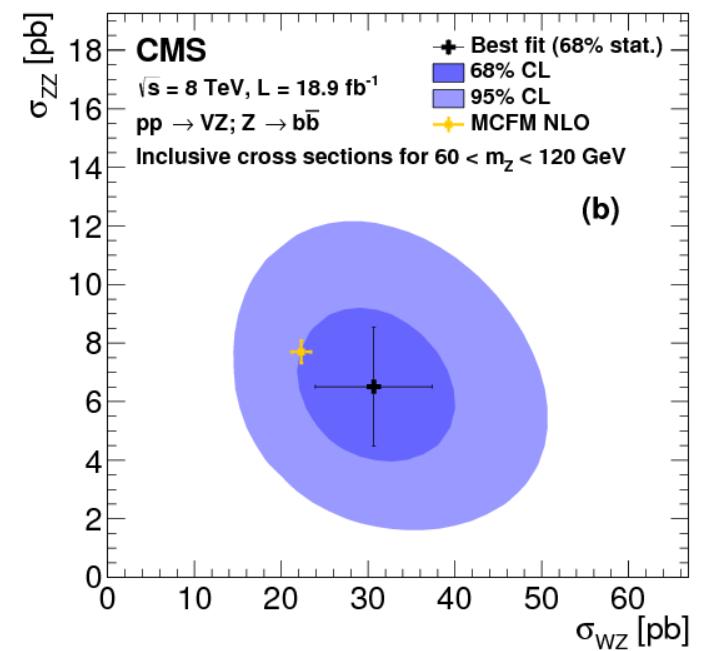
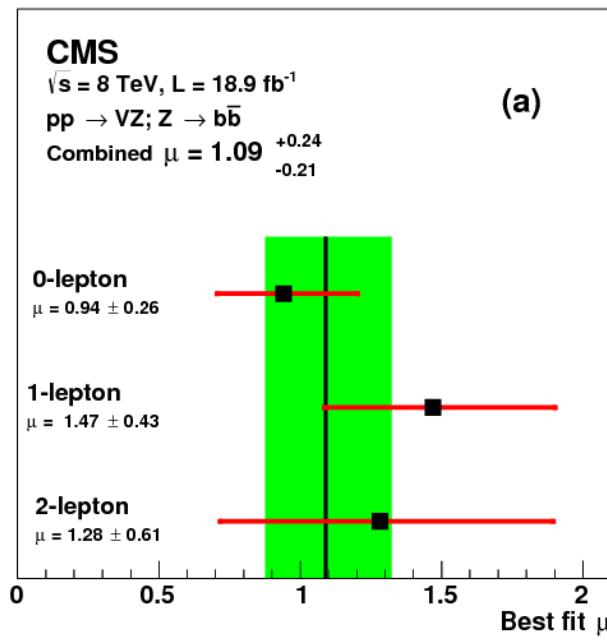
[arXiv:1401.7610v2](https://arxiv.org/abs/1401.7610v2)



WZ and ZZ Production using Z \rightarrow bb Decays (CMS)



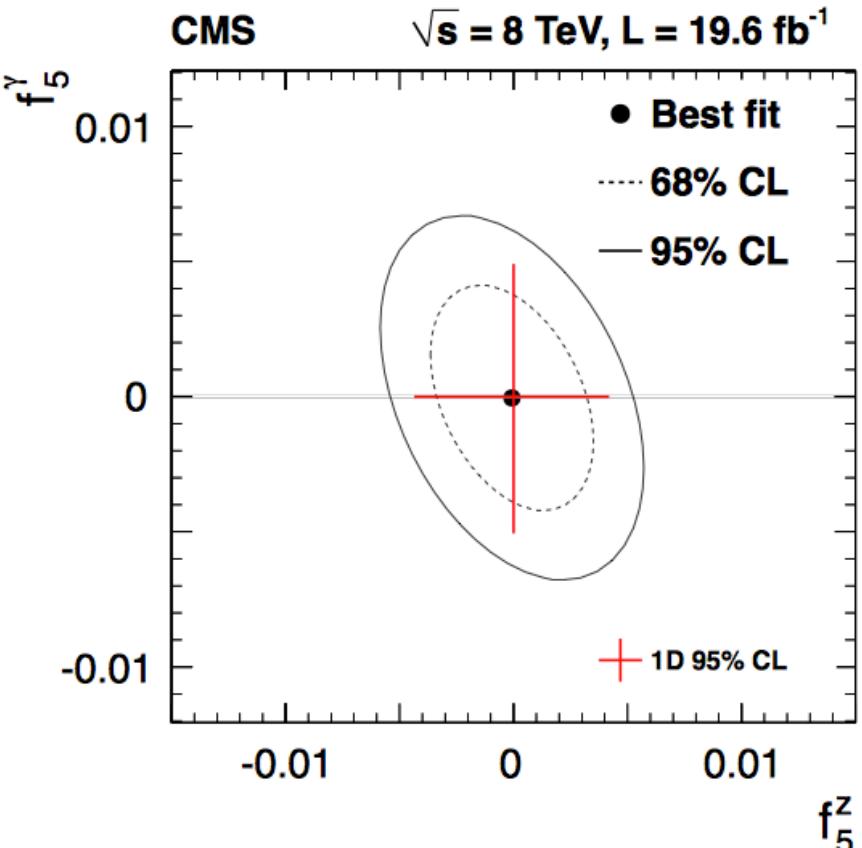
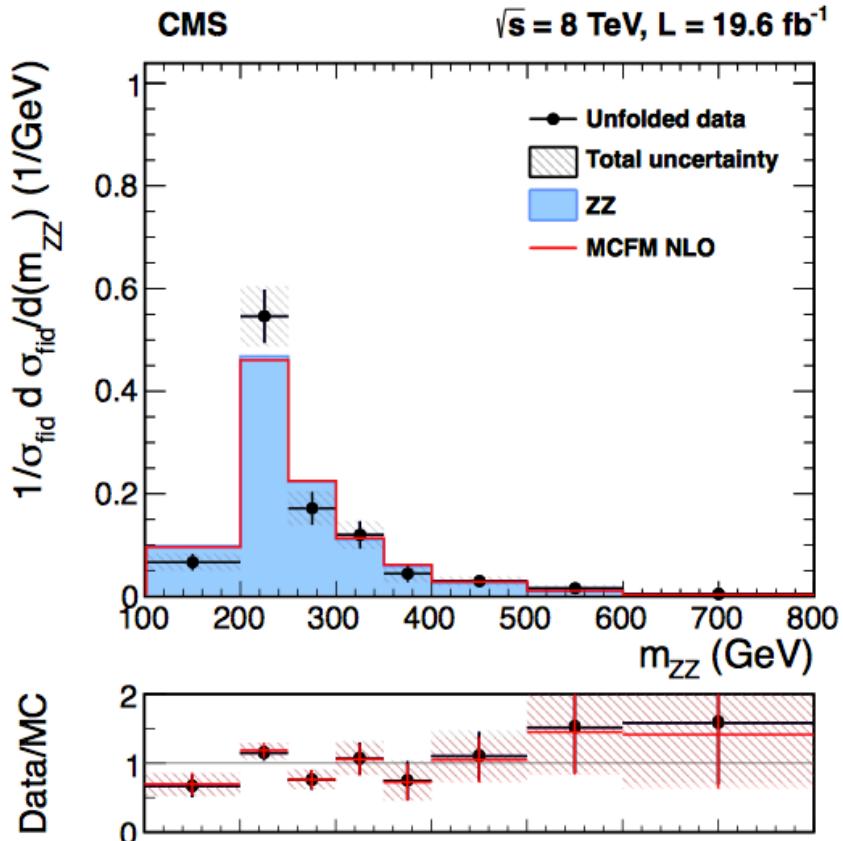
arXiv:1403.3047v1



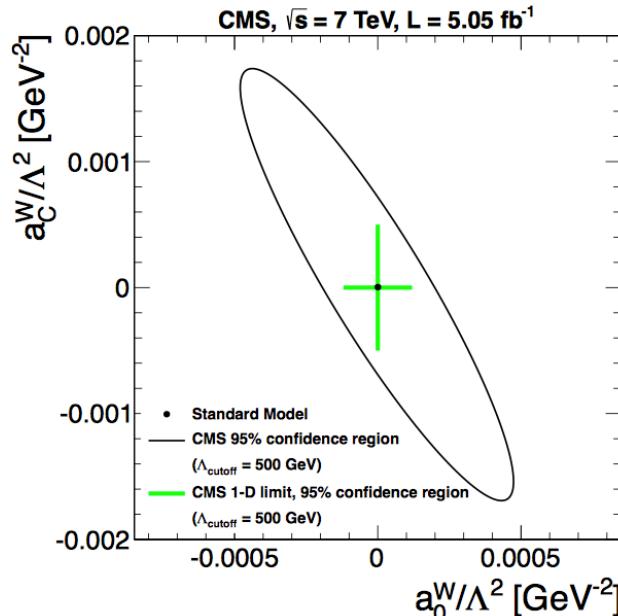
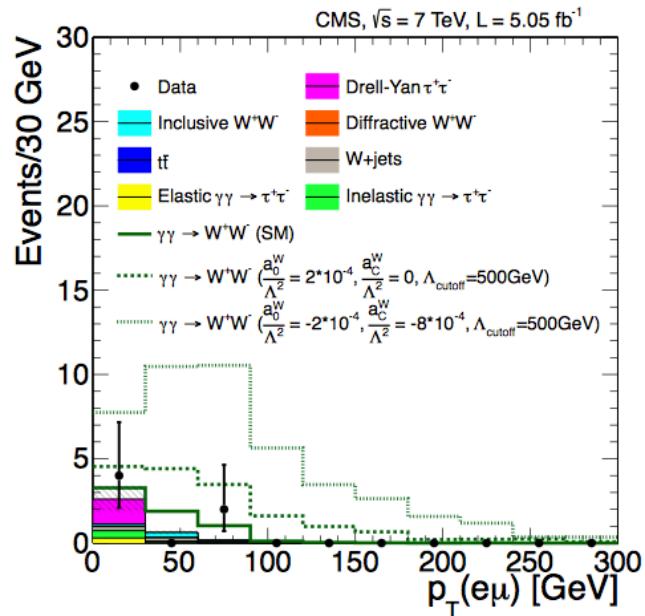
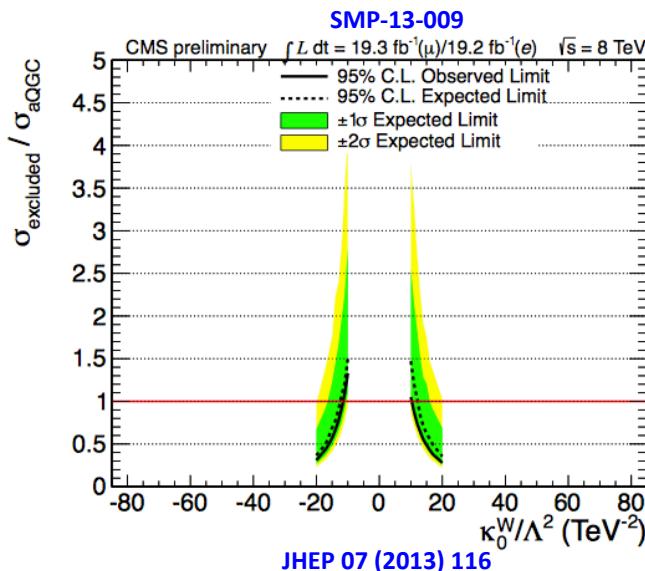
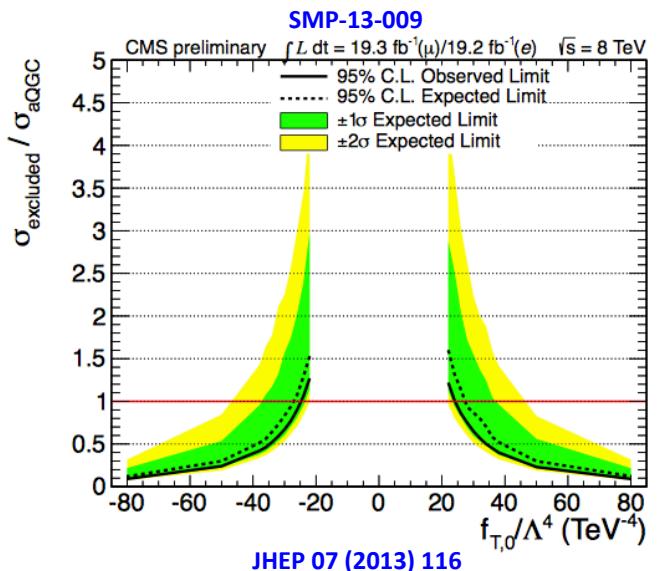
ZZ->4l Production (CMS)



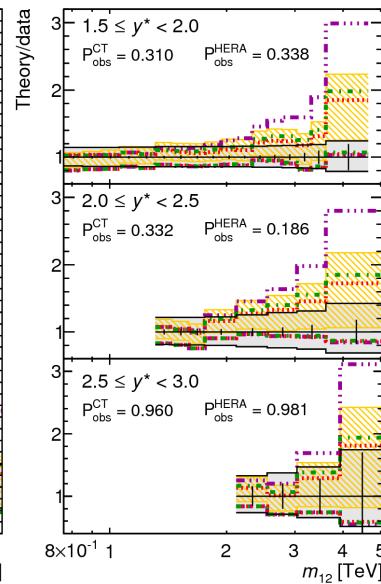
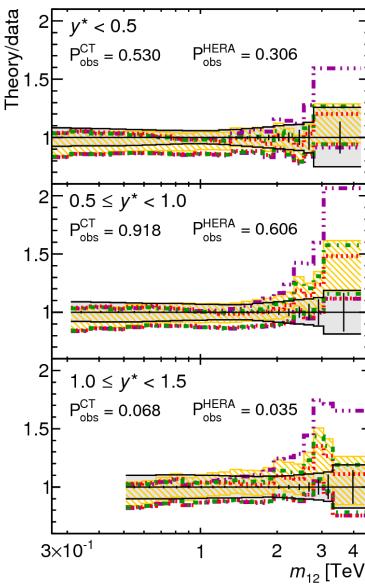
arXiv:1406.0113v1



Anomalous Quartic Gauge Couplings (CMS)



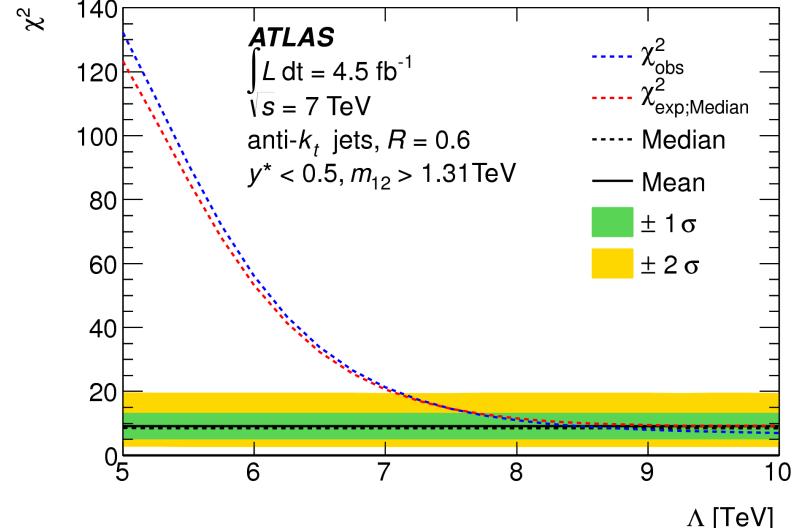
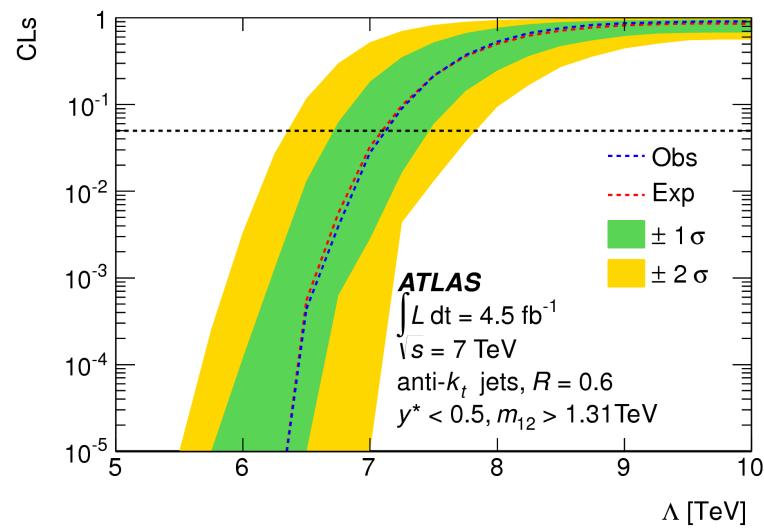
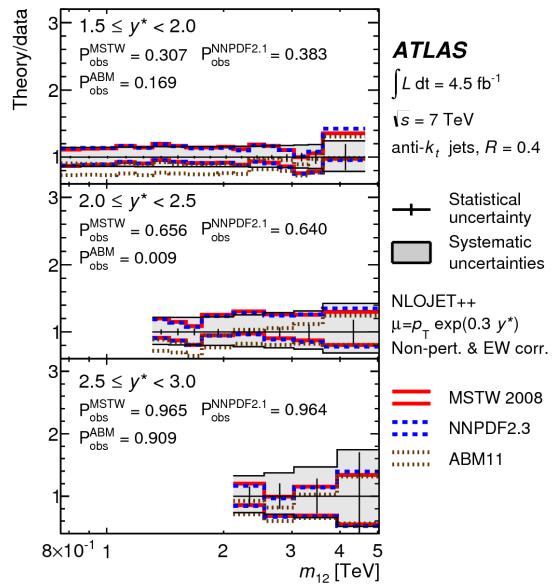
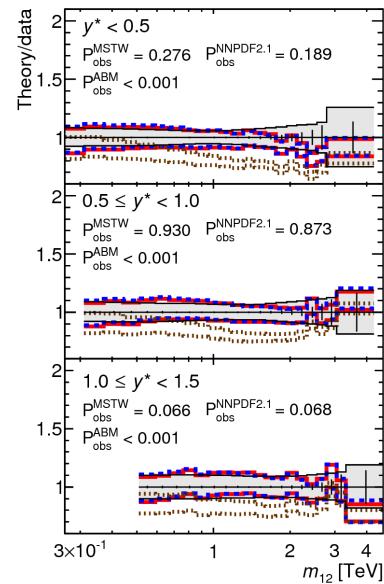
Measurement of Dijet Cross Sections (ATLAS)



[JHEP05\(2014\)059](#)

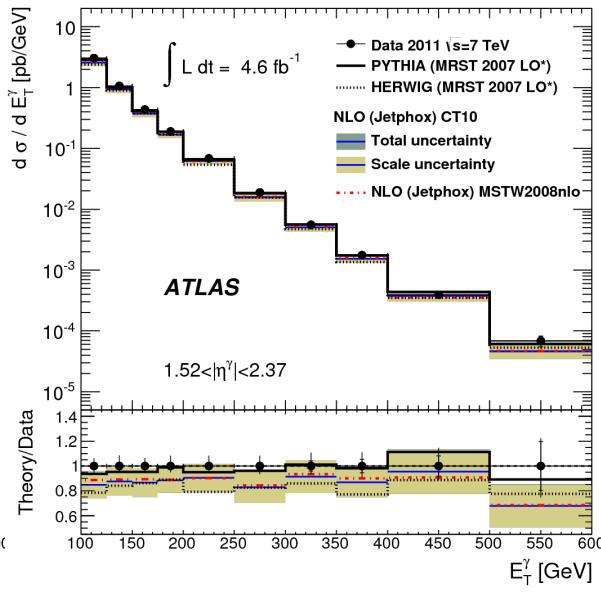
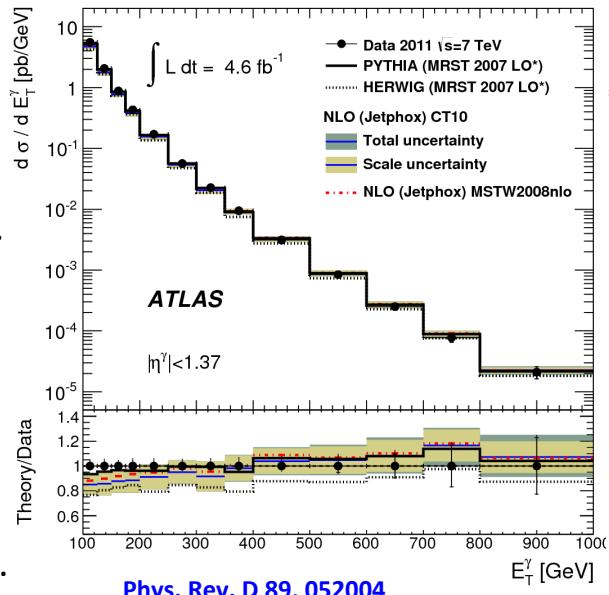
ATLAS
 $\int L dt = 4.5 \text{ fb}^{-1}$
 $\sqrt{s} = 7 \text{ TeV}$
anti- k_t jets, $R = 0.4$

- Statistical uncertainty
- Systematic uncertainties
- NLOJET++
 $\mu = p_T \exp(0.3 y^*)$
Non-pert. & EW corr.
- CT10
- HERAPDF1.5
- epATLJet13
- exp. only
- HERAPDF1.5
exp. only



Inclusive isolated prompt photon cross section (ATLAS)

- Prompt photon production test pQCD.
- Sensitivity to gluon content of proton.
- Gives possibility to constrain the PDFs.
- CS measured as a function of photon transverse energy and pseudorapidity.
- Large kinematic range, 100 GeV-1TeV.
- Comparison with PYTHIA and HERWIG.



The total inclusive cross section of direct photons calculated in the kinematic region $E_T^\gamma > 100$ GeV, $|\eta^\gamma| < 1.37$ and $E_T^{\text{iso}} \leq 7$ GeV is

$$\sigma(\gamma + X) = 236 \pm 2 \text{ (stat)}^{+13}_{-9} \text{ (syst)} \pm 4 \text{ (lumi)} \text{ pb.}$$

PYTHIA: 224 pb HERWIG: 187 pb

The total inclusive cross section for direct photons within the kinematic range $E_T^\gamma > 100$ GeV, $1.52 \leq |\eta^\gamma| < 2.37$ and $E_T^{\text{iso}} \leq 7$ GeV is

$$\sigma(\gamma + X) = 123 \pm 1 \text{ (stat)}^{+9}_{-7} \text{ (syst)} \pm 2 \text{ (lumi)} \text{ pb,}$$

PYTHIA: 118 pb HERWIG: 99 pb