Vector Boson + Jets and Multiboson Results from ATLAS and CMS

Lindsey Gray

FermiLab

XLIXth Rencontres de Moriond, Electroweak Session

on behalf of the ATLAS and CMS Collaborations

Outline

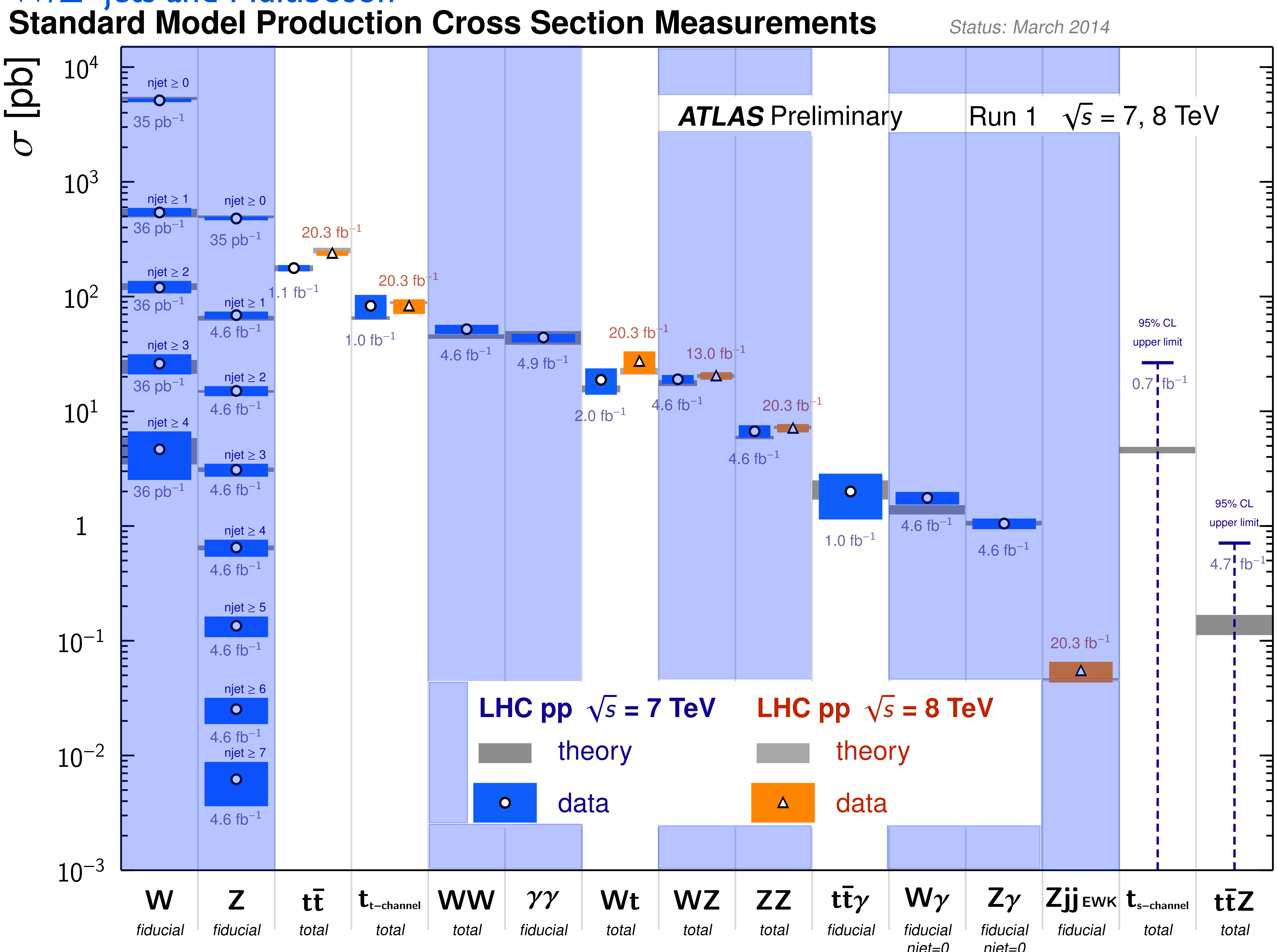
- W/Z+Jets Production at the LHC
  - Feb. 2014 → W+Jets differential measurements and MC comparisons
  - W+Charm, Strange PDF constraints
  - Z+Jets differential measurements
  - Z+Beauty production
  - Jan. 2014 → Electroweak Production of Z + 2 jets (VBF mode)
- Diboson and Triboson Production + Searches
  - Nov. 2013 → VZ, Z→bb Production at 8 TeV
  - ZZ→2l2ν & Neutral Anomalous Triple Gauge Couplings
  - Triple and Quartic Anomalous Gauge Couplings

New ATLAS
New CMS
Both New

Dec. 2013

Standard Model Measurements at ATLAS

W/Z+jets and Multiboson



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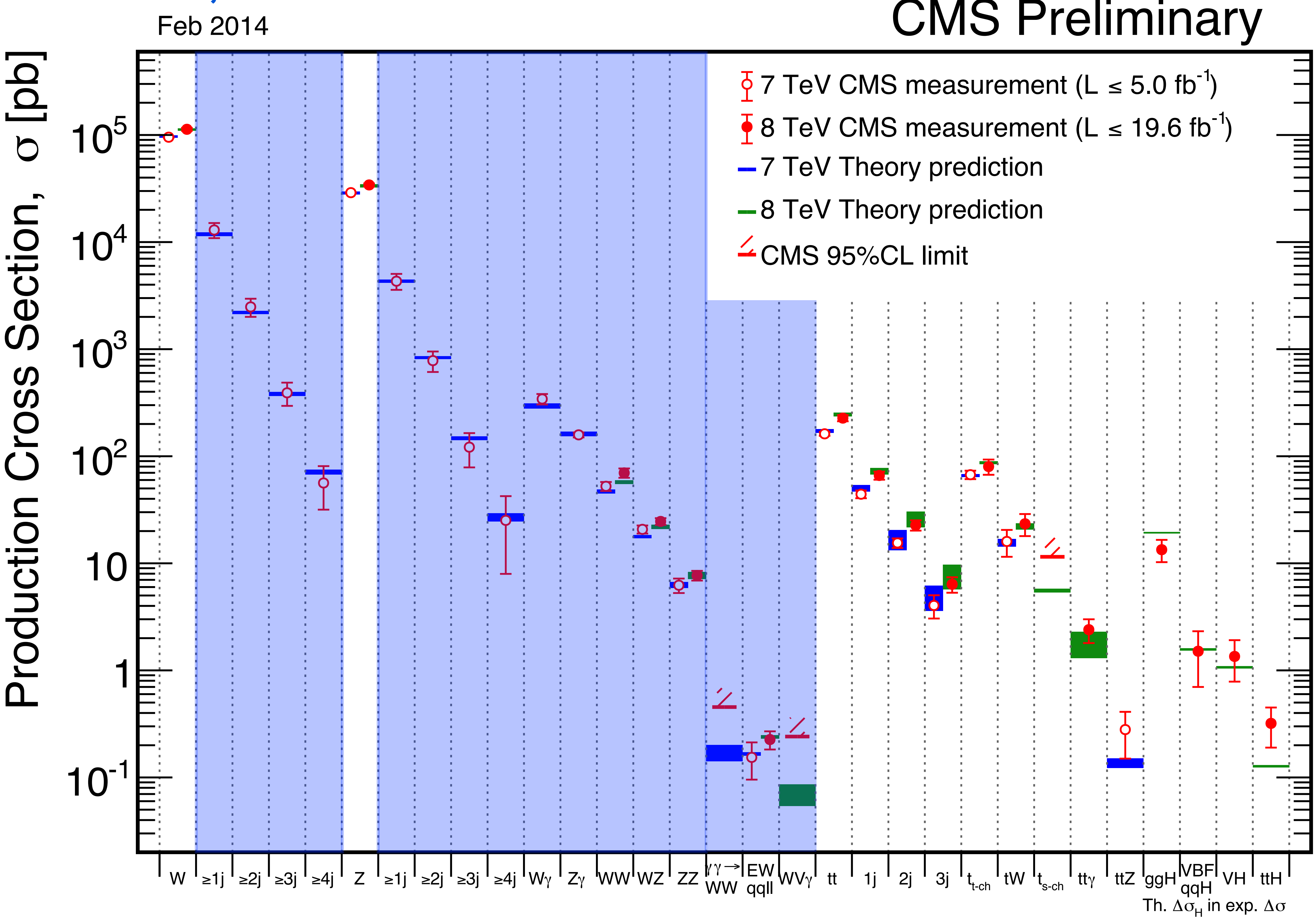
Standard Model Measurements at CMS

W/Z+jets and Multiboson



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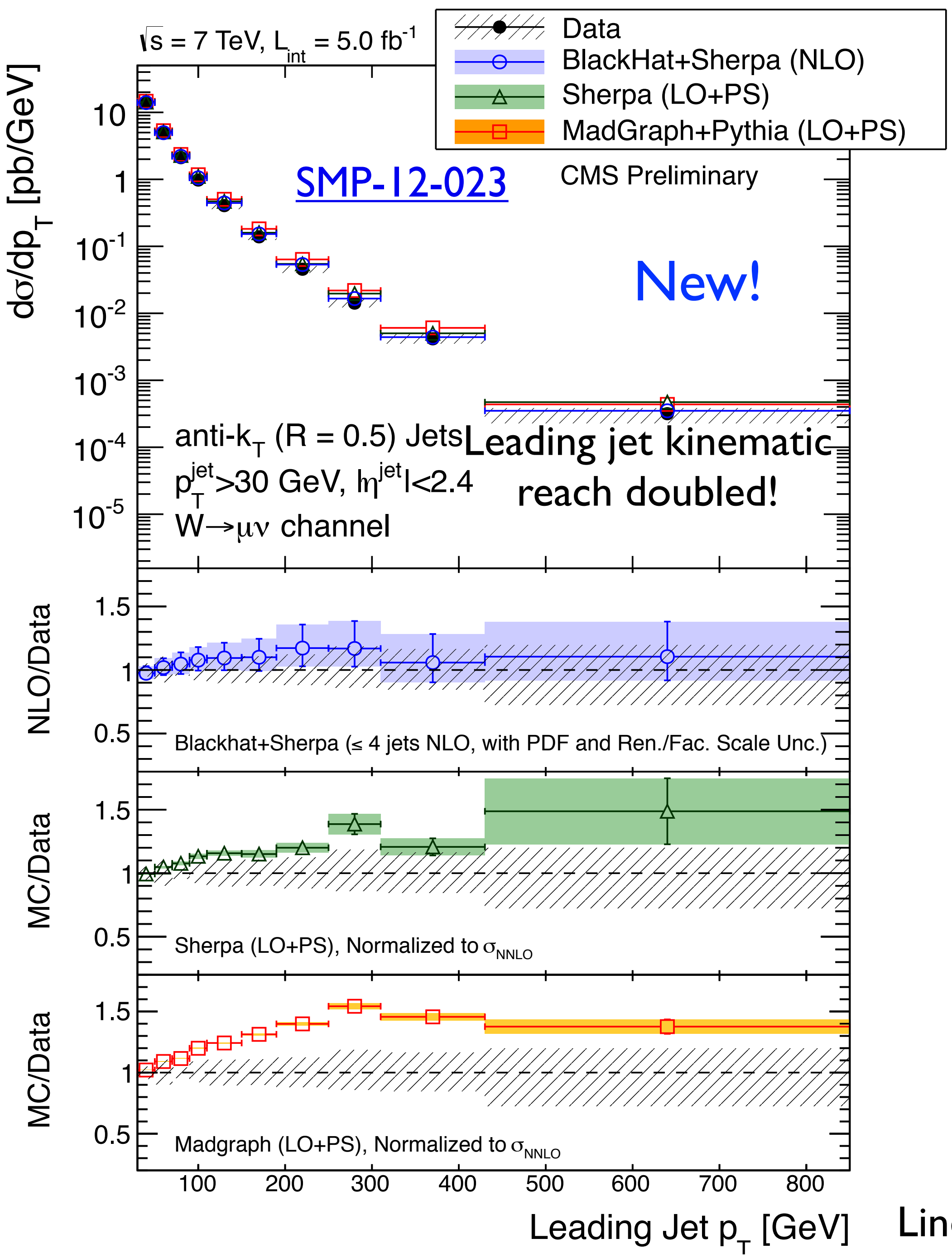
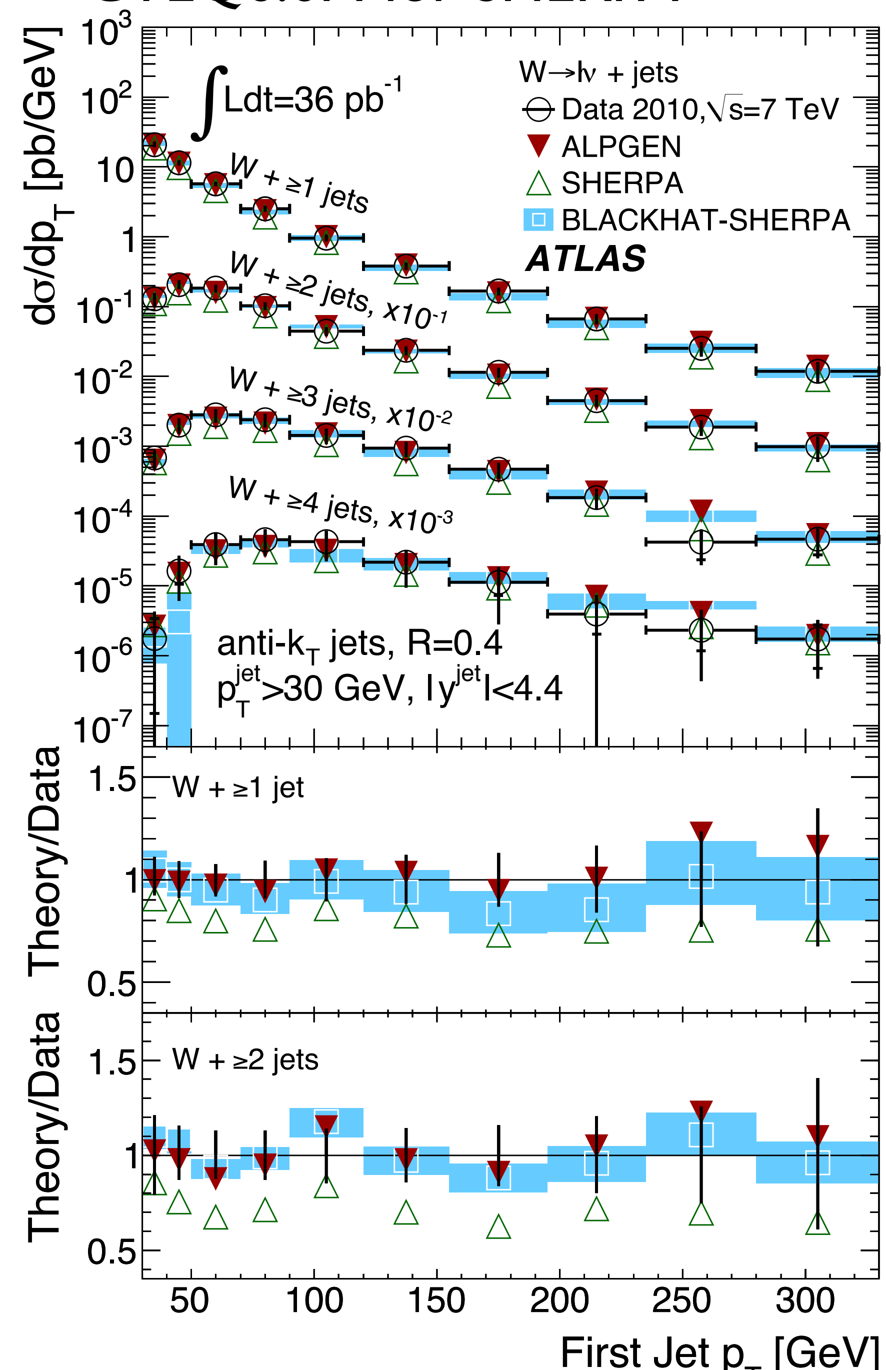
W+Jets Differential Cross Sections at the LHC

- CMS (5 fb^{-1} : 7 TeV)
  - Compare with SHERPA1.4 (+ BlackHat), MadGraph5 (normalized to FEWZ)
  - CT10 for SHERPA

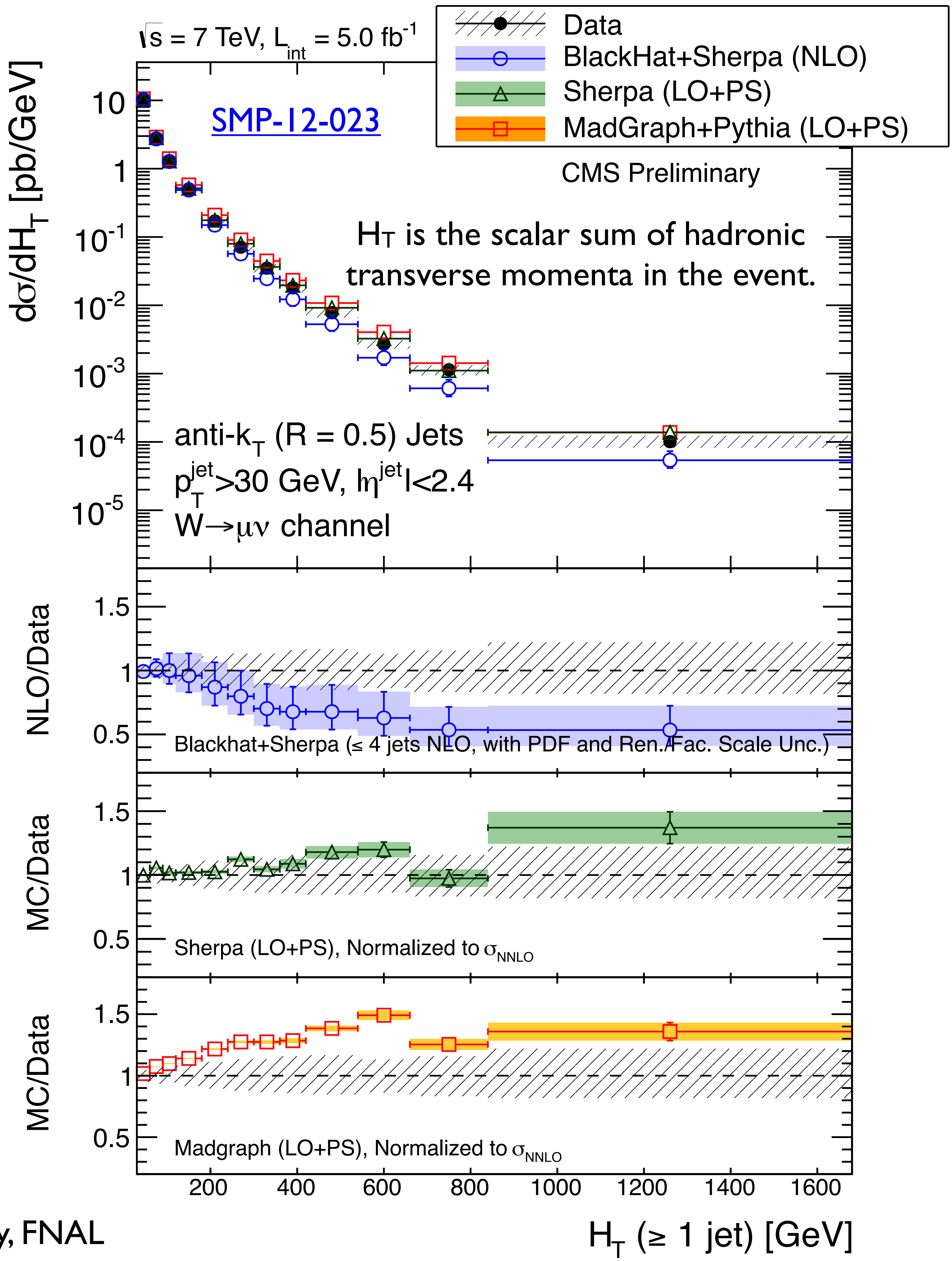


- ATLAS (36 pb^{-1} : 7 TeV)
  - Comparison with SHERPA1.3 (+ BlackHat), ALPGEN
  - CTEQ6.6M for SHERPA



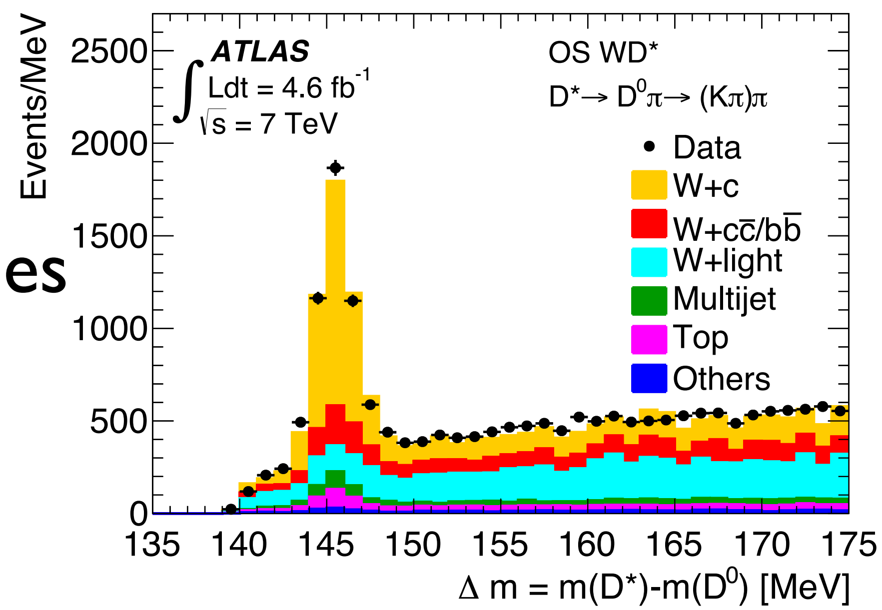
W+Jets Differential Cross Sections at the LHC

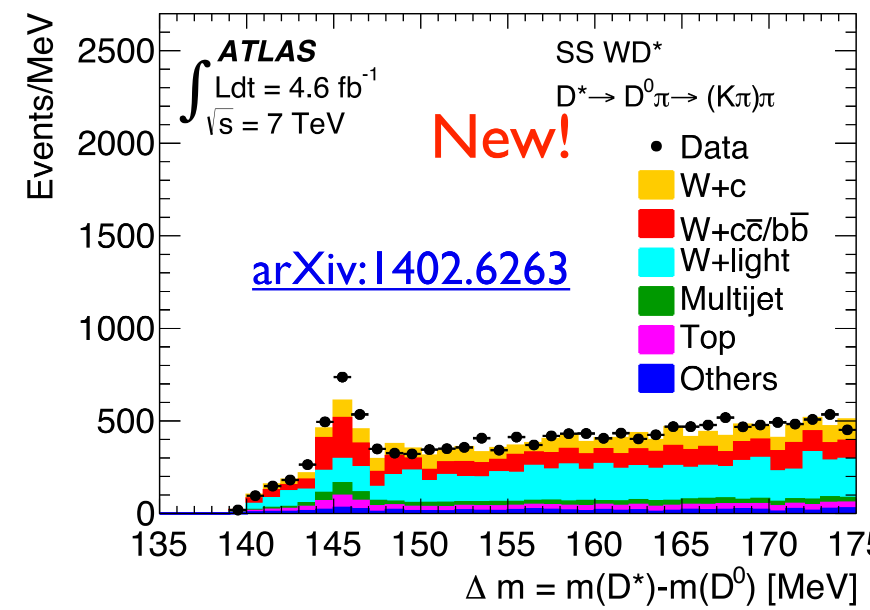
- CMS ($5\ fb^{-1}$: 7 TeV)
  - Compare with SHERPA1.4 (+ BlackHat), MadGraph5 (normalized to FEWZ)
  - CT10 for SHERPA
- ATLAS ($36\ pb^{-1}$: 7 TeV)
  - Comparison with SHERPA1.3 (+ BlackHat), ALPGEN
  - CTEQ6.6M for SHERPA
- Many distributions described well with the exception of H_T distribution, 1st incl. jet bin
  - Opposite trends observed for CMS/ATLAS for SHERPA stand alone (see backup)
    - H_T sensitive to calculation order at high parton multiplicity



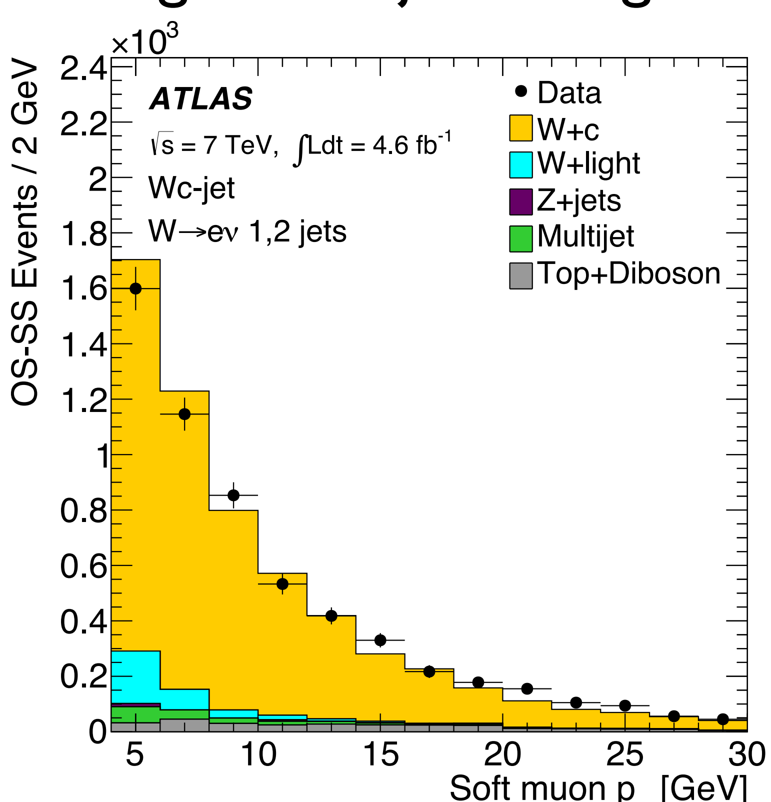
ATLAS : W+D/D*/Charm-jet Production

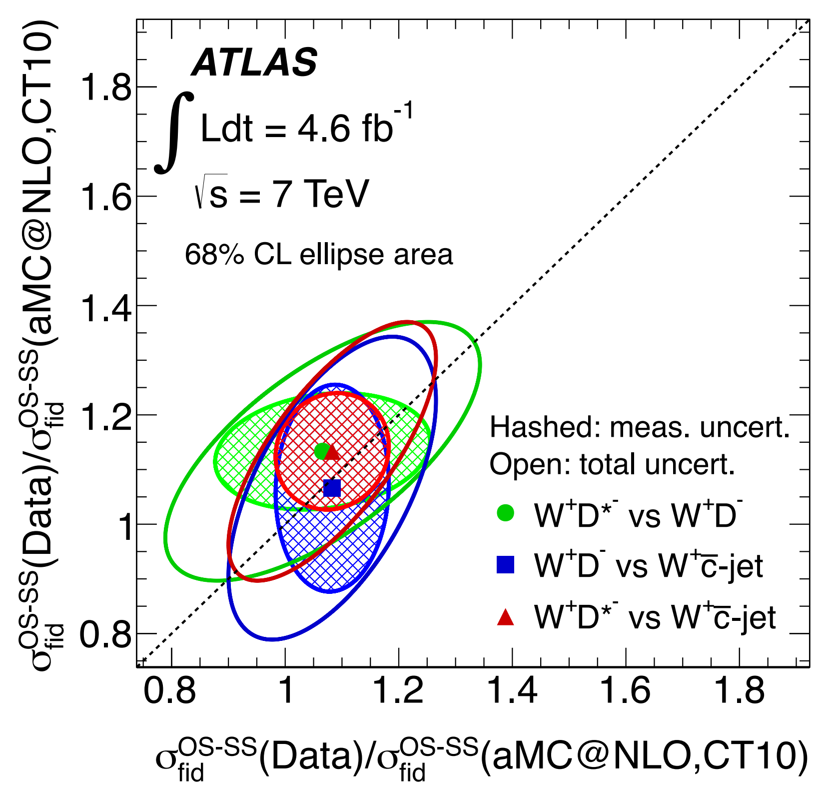
- Exploit $W^{(+)-}$ to probe the (anti-)strange PDF
- Two measurement strategies
  - Reconstruct exclusive charm decays
    - $\Delta m = m(D^*) - m(D^0)$ used as discriminant, no vertex requirement
  - Tag charm jets using muons

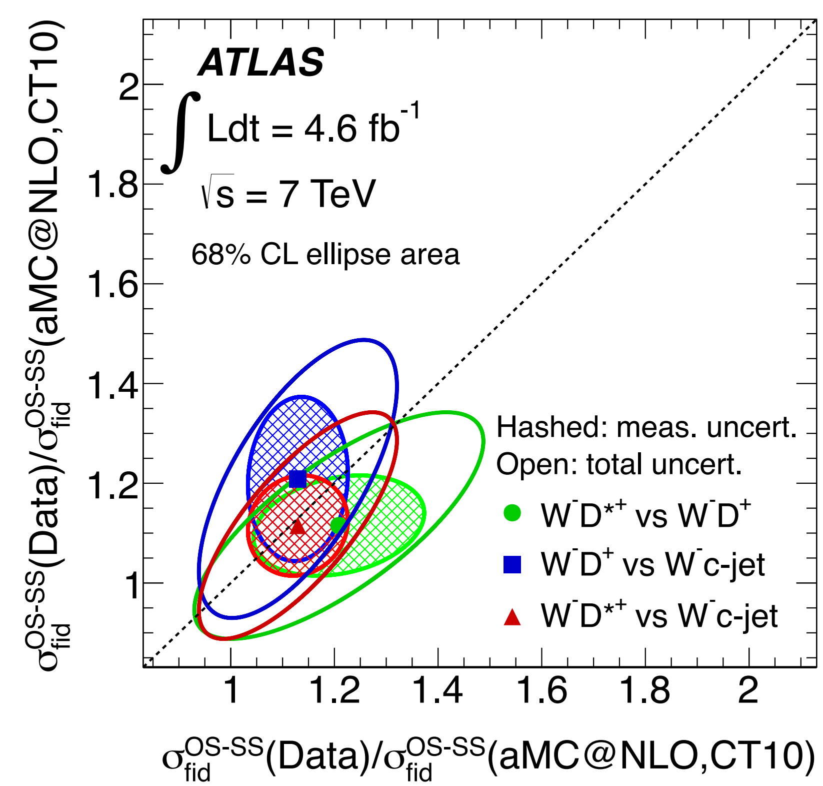




W + cc/bb subtracted using same-sign control region, exploiting flavor symmetry.



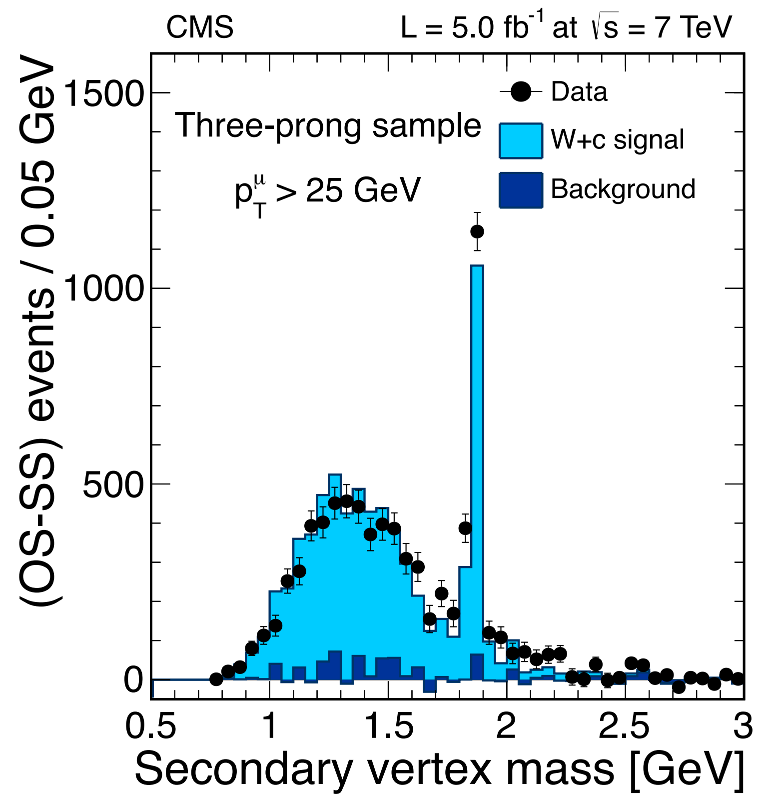


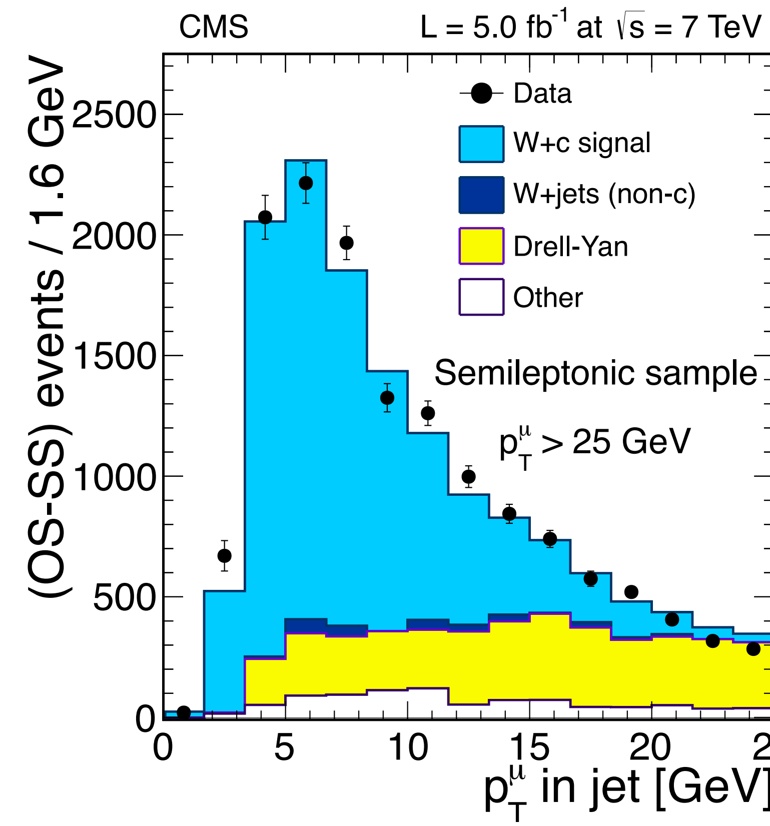


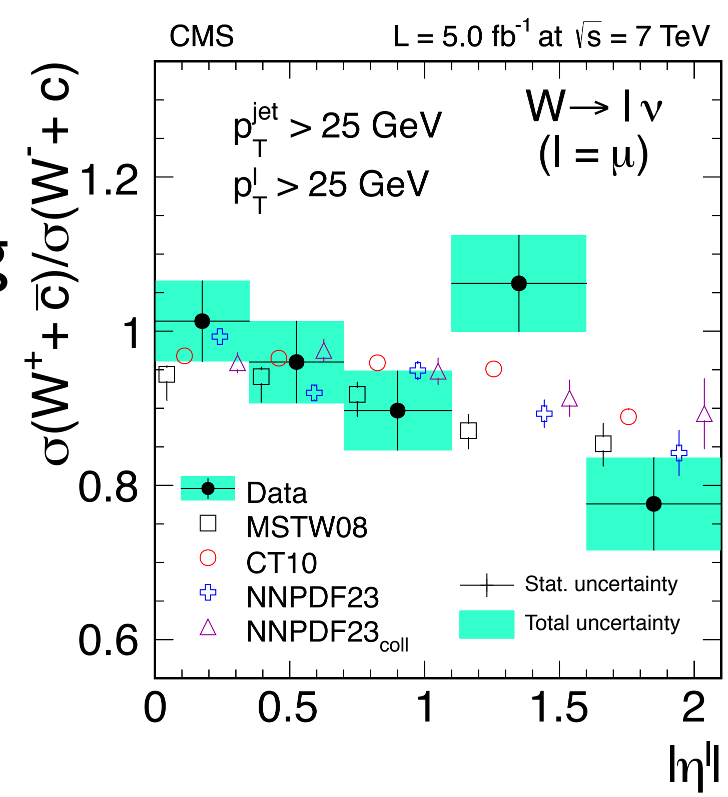
Simulation agrees well with charm/anti-charm correlations in data.

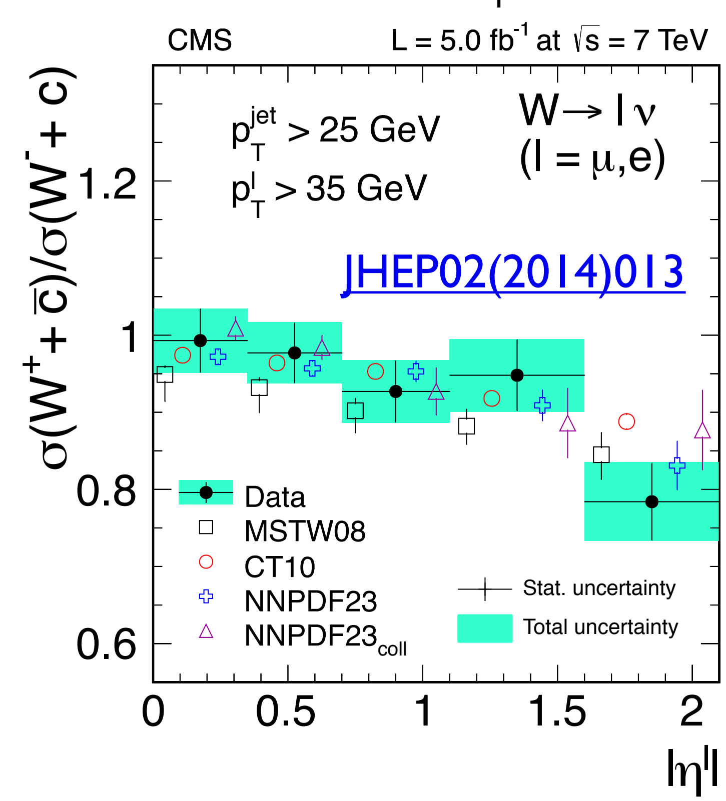
CMS :W+D/D*/Charm-jet Production

- Exclusive decay search
  - Exploit secondary vertex finding to suppress non-HF background
  - Search additionally for non-resonant c-decays by relaxing secondary vertex mass requirements
  - Search for 2/3 pronged vertices to tag $D^{0/+-}$
- Semi-leptonic decays tagged using soft muons in jets
- Extracted differential cross section ratios well predicted by simulation



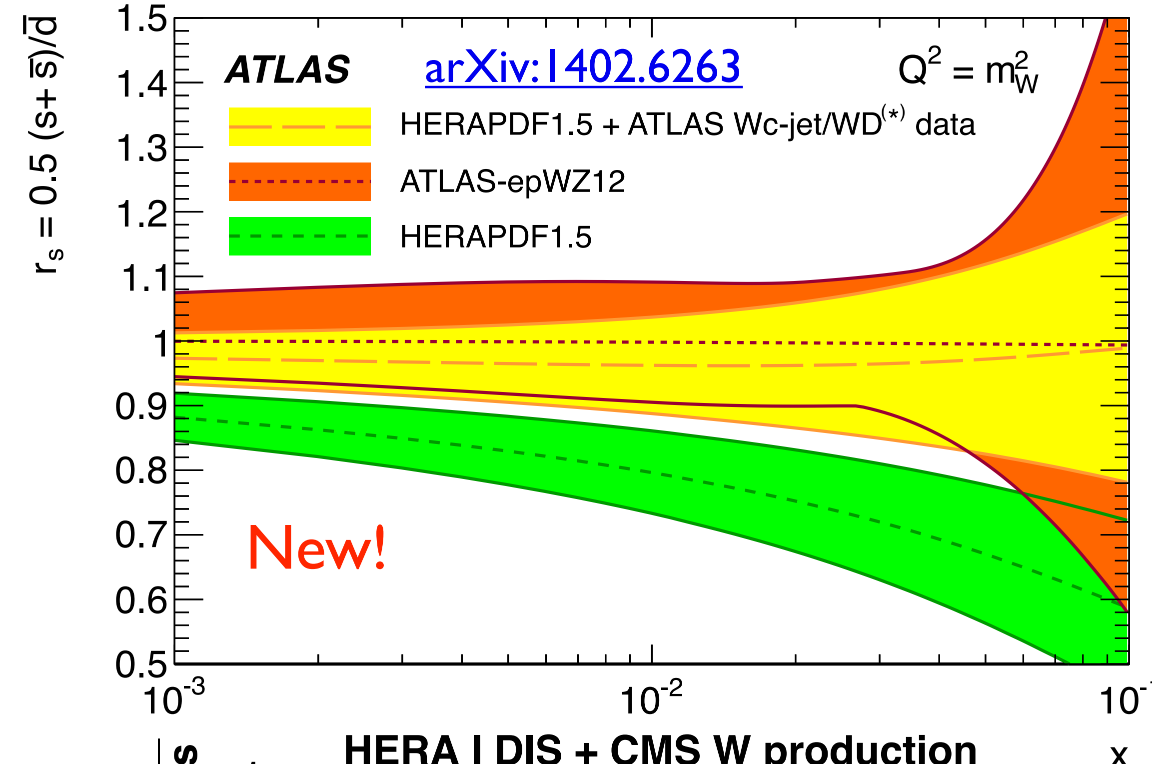


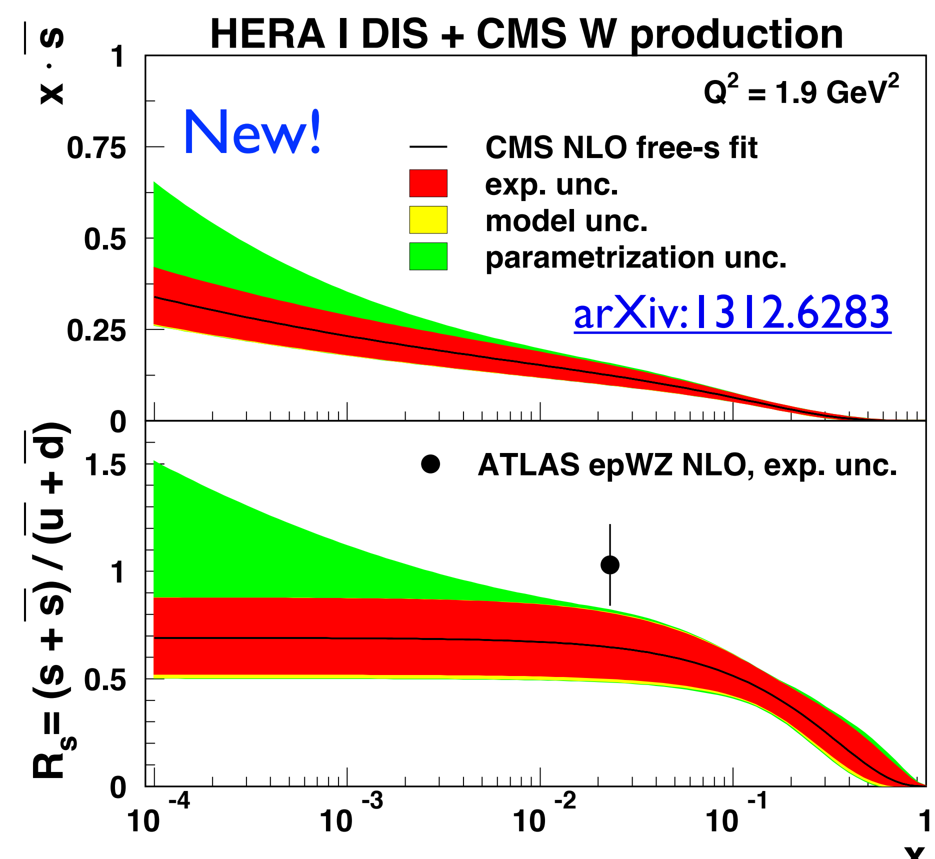




Constraints on the Strange Quark PDF

- ATLAS
  - Use W+c, $W^{+/-}$ asymmetry, Z rapidity
  - Use HERA DIS (v1.5) as baseline
    - Strange PDF parameterized by one variable
- CMS
  - Use W+c & $5fb^{-1}$ $W^{+/-}$ asymmetry
  - Use HERA DIS (v1.0) as baseline
    - Allow strange PDF shape and normalization to vary independently
- Similar CMS and ATLAS measurements using different methodologies!
  - Small tension over strange-suppression between ATLAS & CMS results

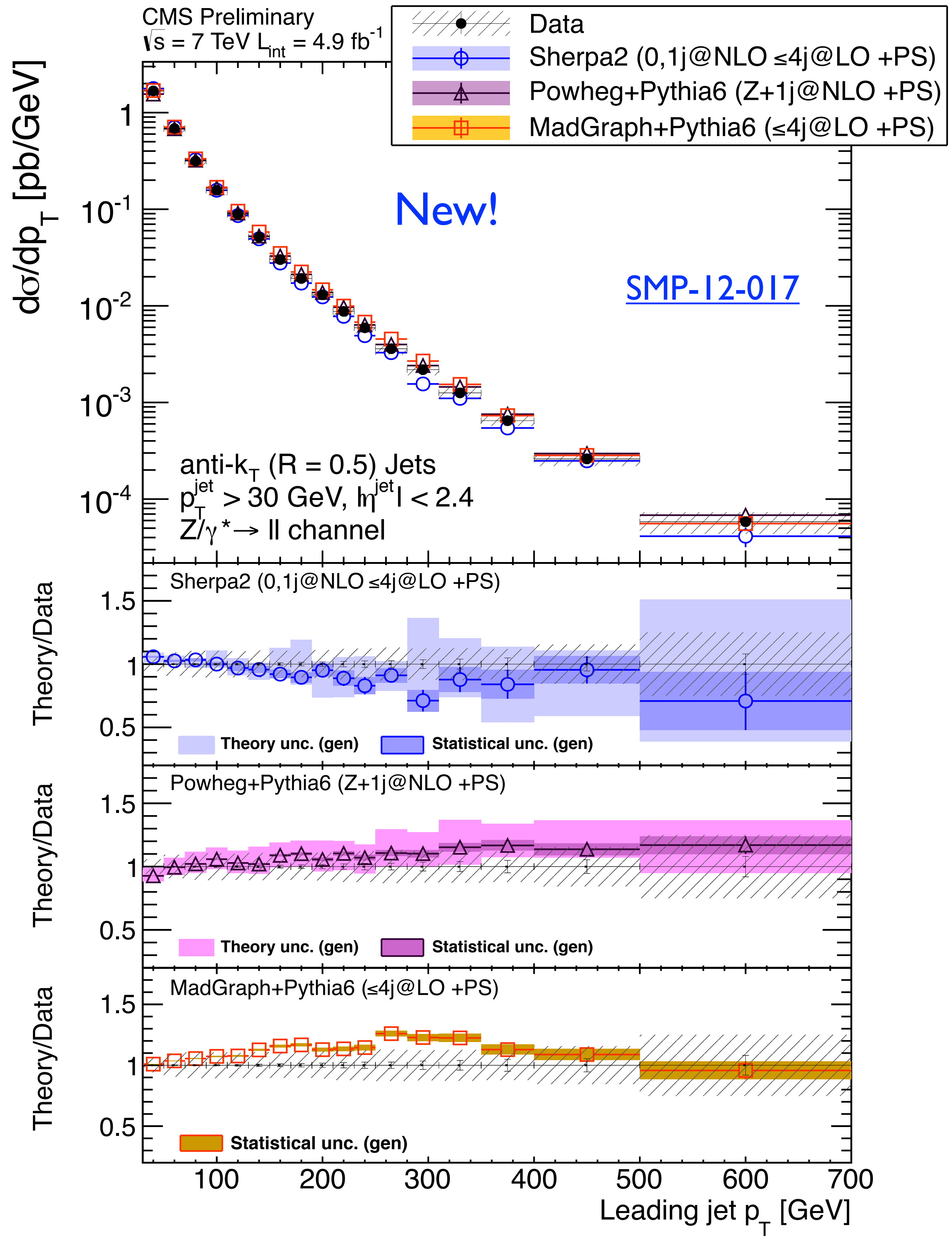




Further discussion in Mark Sutton's talk, afternoon session!

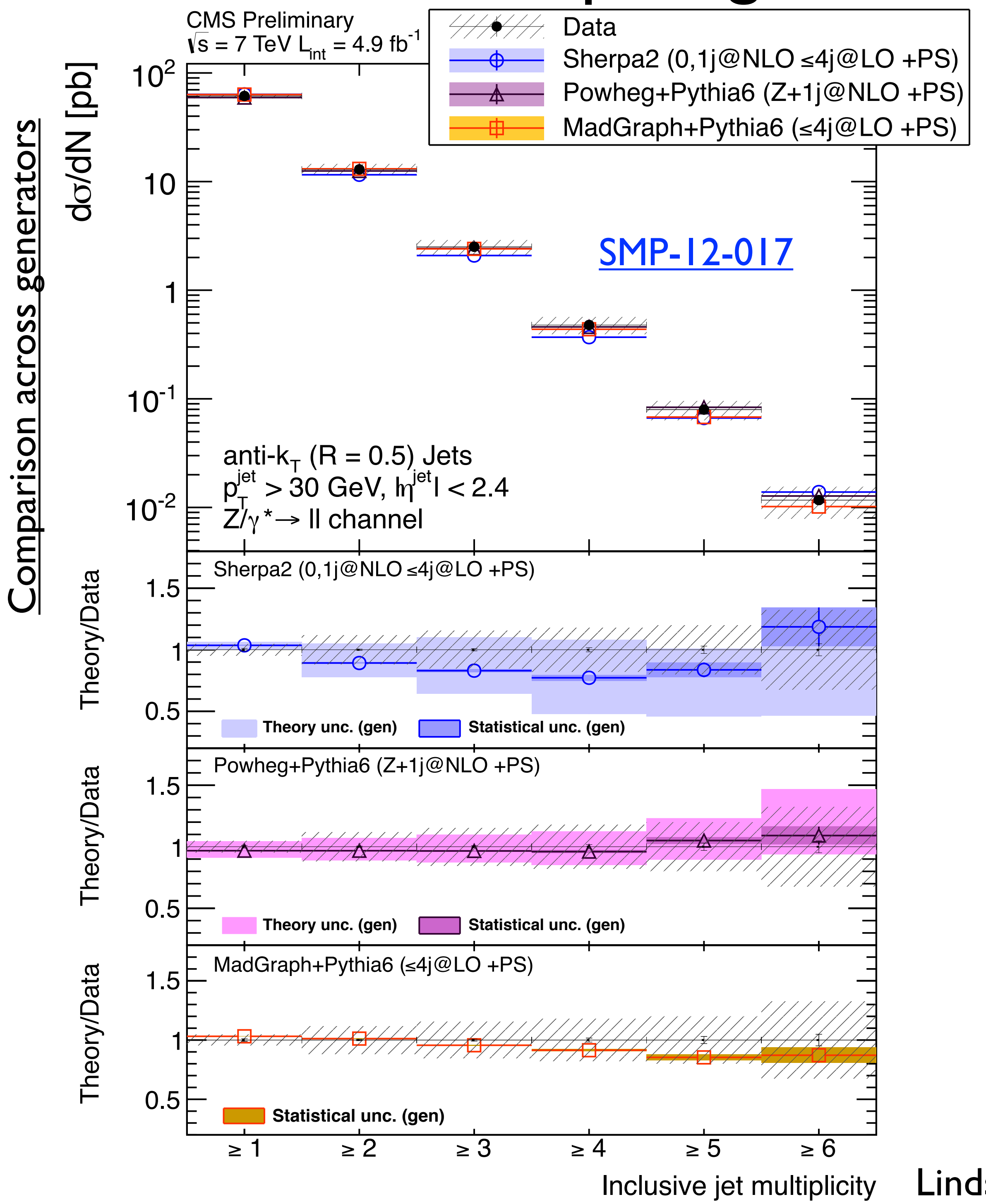
Z+Jets Differential Cross Sections at the LHC

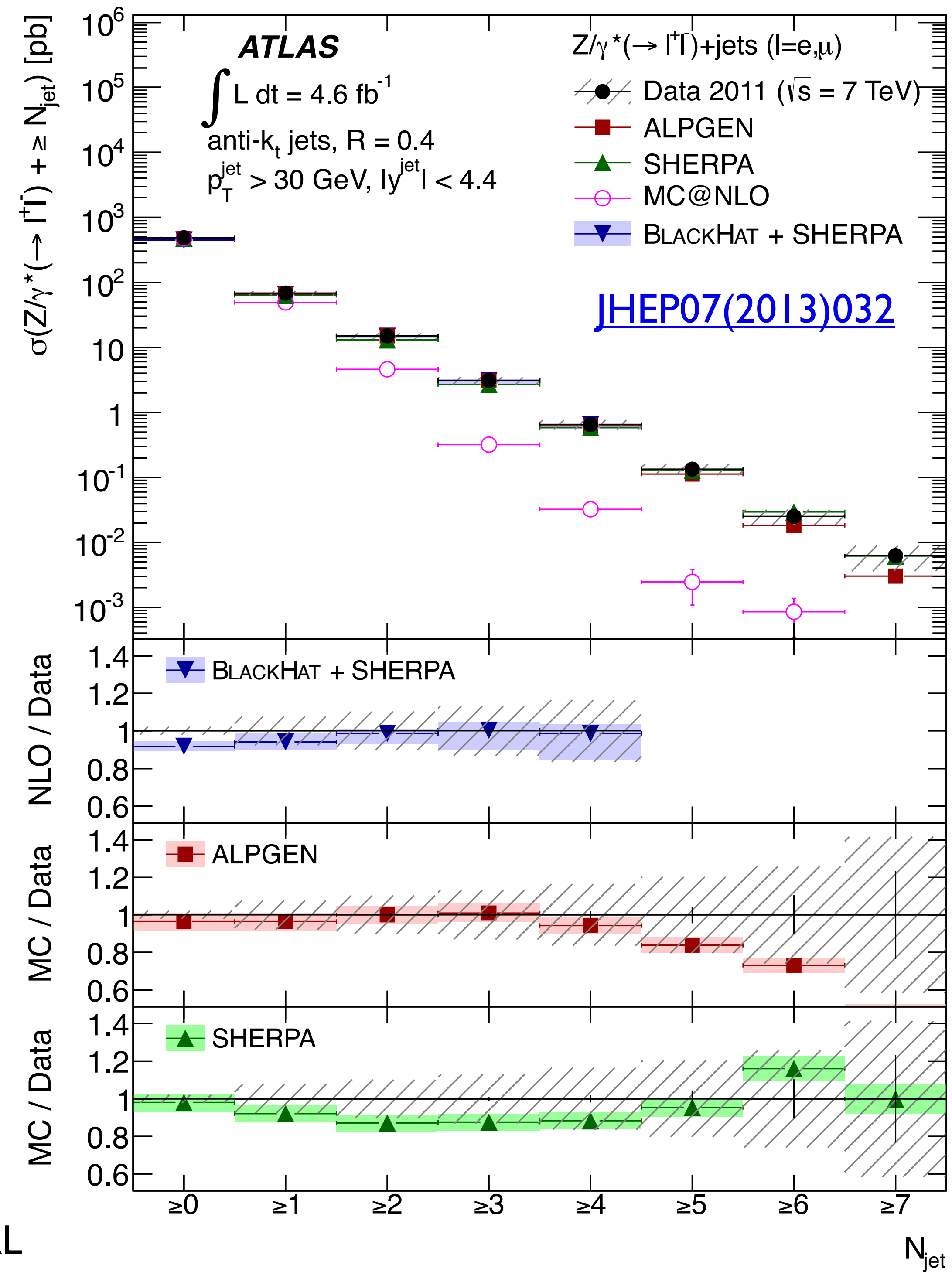
- ATLAS (5 fb^{-1} : 7 TeV)
- CMS (5 fb^{-1} : 7 TeV)
- Study same variables as in W+Jets cross sections
- CMS result compares to:
  - SHERPA2 + 0,1 jets matched @NLO
    - Up to 4 jets in matrix element @LO
    - First time SHERPA2 is compared to V+Jets sector!
  - POWHEG + 0,1 jets matched @NLO
  - MadGraph5, normalized to FEWZ



Z+Jets Differential Cross Sections at the LHC

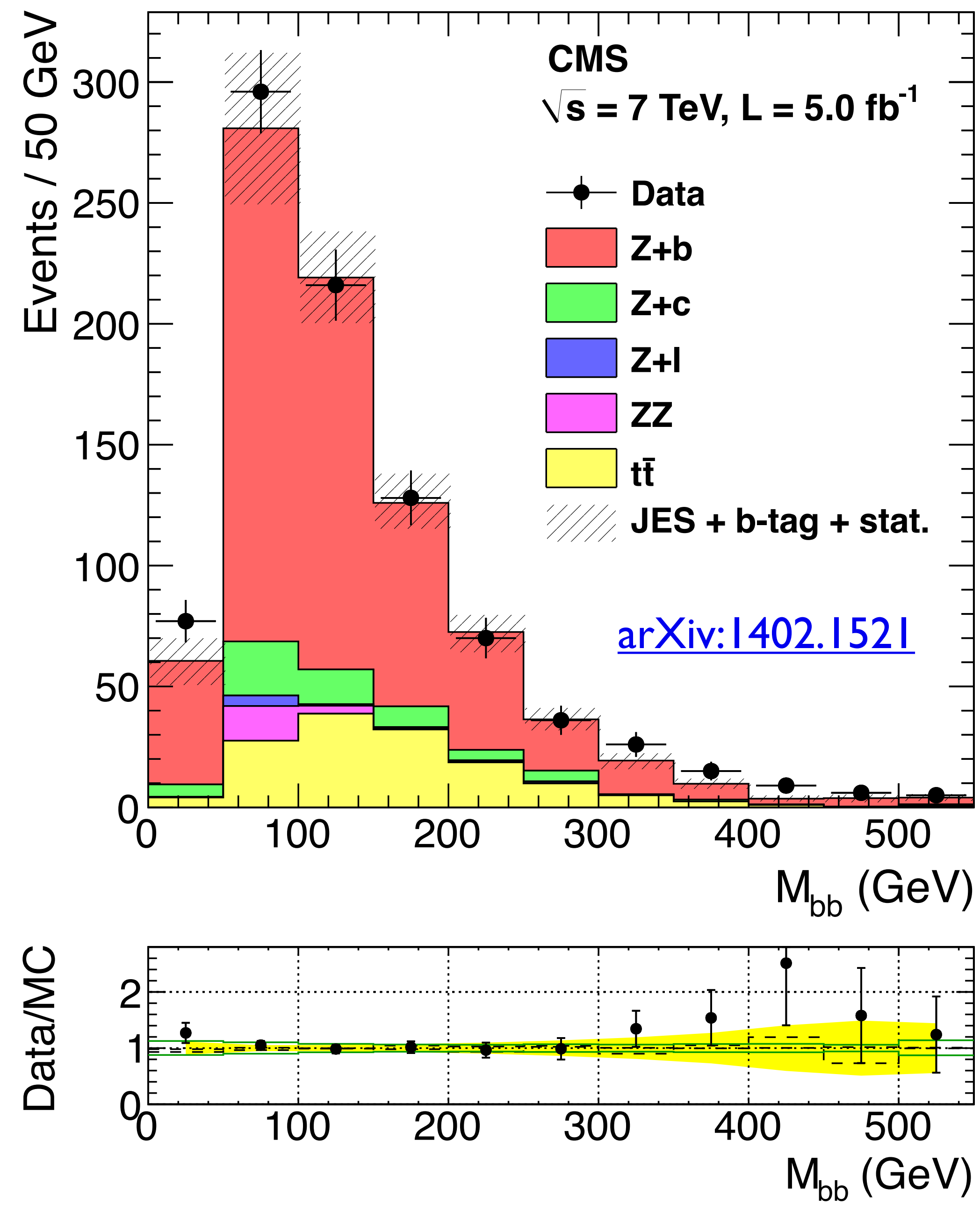
- Discrepancies in basic jet distributions observed in CMS result when comparing SHERPA2
- Tension with data is less marked in ATLAS result due to higher order calculation in SHERPA+BlackHat





Z+b(b) Production at CMS

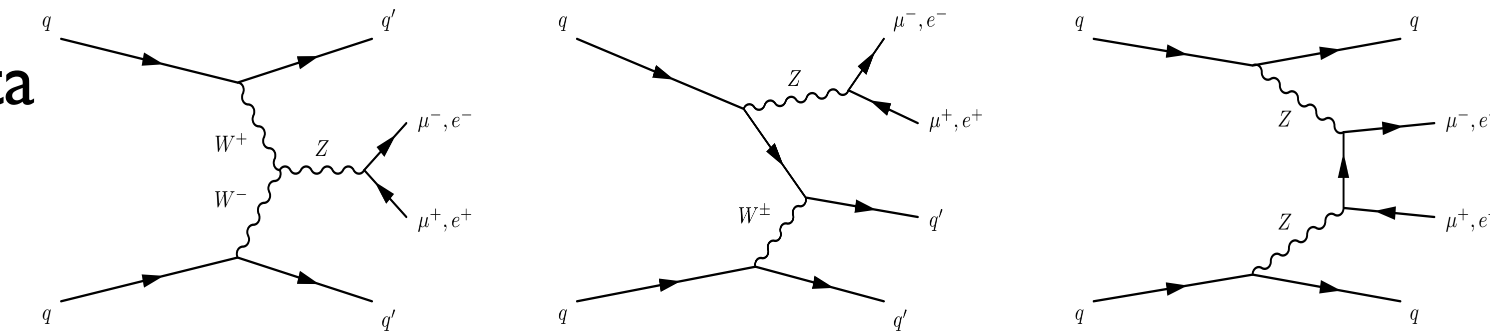
- Measure Z+b(b) production exploiting secondary vertex ID
  - Employ discriminant using secondary vertex decay length
    - Residual lighter flavor contribution determined using template fit
  - 2 b-jet final state recently added
    - Good agreement seen with MC prediction
- Significant improvement of agreement with MC in the 5 active flavor scenario

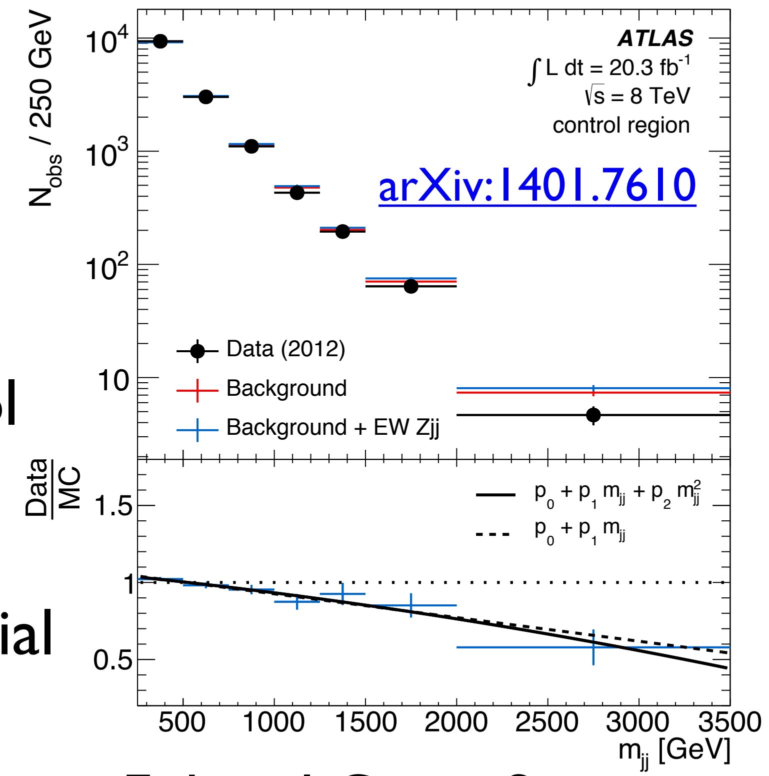


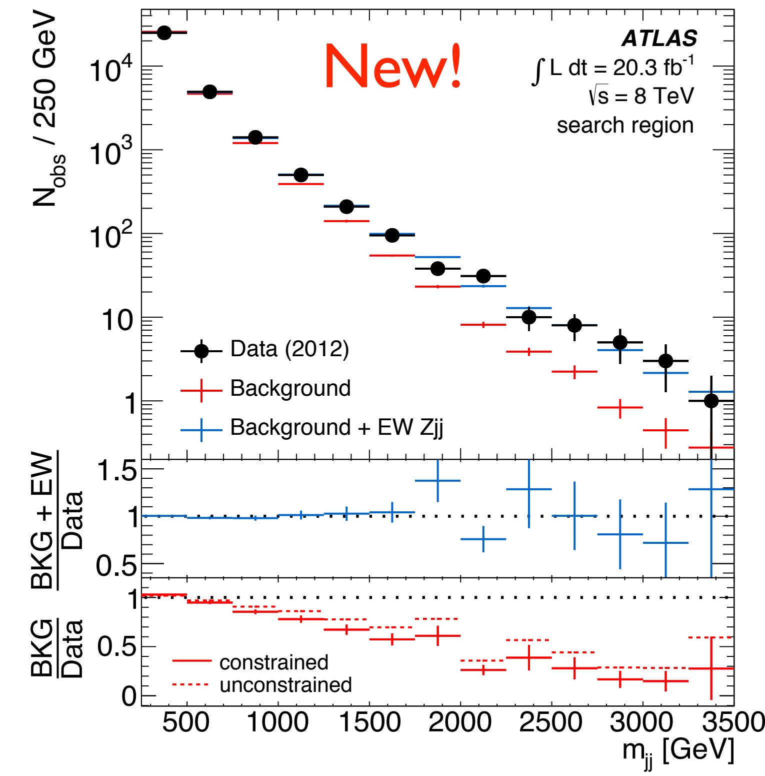
Cross section	Measured	MADGRAPH (5F)	aMC@NLO (5F)	MCFM (parton level)	MADGRAPH (4F)	aMC@NLO (4F)
σ_{Z+1b} (pb)	$3.52 \pm 0.02 \pm 0.20$	3.66 ± 0.22	$3.70^{+0.23}_{-0.26}$	$3.03^{+0.30}_{-0.36}$	$3.11^{+0.47}_{-0.81}$	$2.36^{+0.47}_{-0.37}$
σ_{Z+2b} (pb)	$0.36 \pm 0.01 \pm 0.07$	0.37 ± 0.07	$0.29^{+0.04}_{-0.04}$	$0.29^{+0.04}_{-0.04}$	$0.38^{+0.06}_{-0.10}$	$0.35^{+0.08}_{-0.06}$
σ_{Z+b} (pb)	$3.88 \pm 0.02 \pm 0.22$	4.03 ± 0.24	$3.99^{+0.25}_{-0.29}$	$3.23^{+0.34}_{-0.40}$	$3.49^{+0.52}_{-0.91}$	$2.71^{+0.52}_{-0.41}$
$\sigma_{Z+b/Z+j}$ (%)	$5.15 \pm 0.03 \pm 0.25$	5.35 ± 0.11	$5.38^{+0.34}_{-0.39}$	$4.75^{+0.24}_{-0.27}$	$4.63^{+0.69}_{-1.21}$	$3.65^{+0.70}_{-0.55}$

ATLAS : Electroweak Zjj Production

- > 5σ observation based on 8 TeV data
  - Also limits on anomalous gauge couplings
- Use SHERPA used to create signal and background templates
  - Bkg. template shape scaled and constrained using central-jet control region
  - Measurement performed in 4 fiducial regions
  - Leading systematics from jet energy scale, control region statistics, lepton corrections to particle level
- Good agreement with SM







Fiducial Cross Section:

$$\sigma_{\mathrm{EW}} = 54.7 \pm 4.6\,(\mathrm{stat})\ ^{+9.8}_{-10.4}\,(\mathrm{syst})\ \pm 1.5\,(\mathrm{lumi})\ \mathrm{fb}.$$

Cross Section Prediction (POWHEG):

$$46.1 \pm 0.2\,(\mathrm{stat})\ ^{+0.3}_{-0.2}\,(\mathrm{scale})\ \pm 0.8\,(\mathrm{PDF})\ \pm 0.5\,(\mathrm{model})\ \mathrm{fb}$$

Further discussion in Andy Pilkington's talk, later this session!

CMS : Electroweak Zjj Production

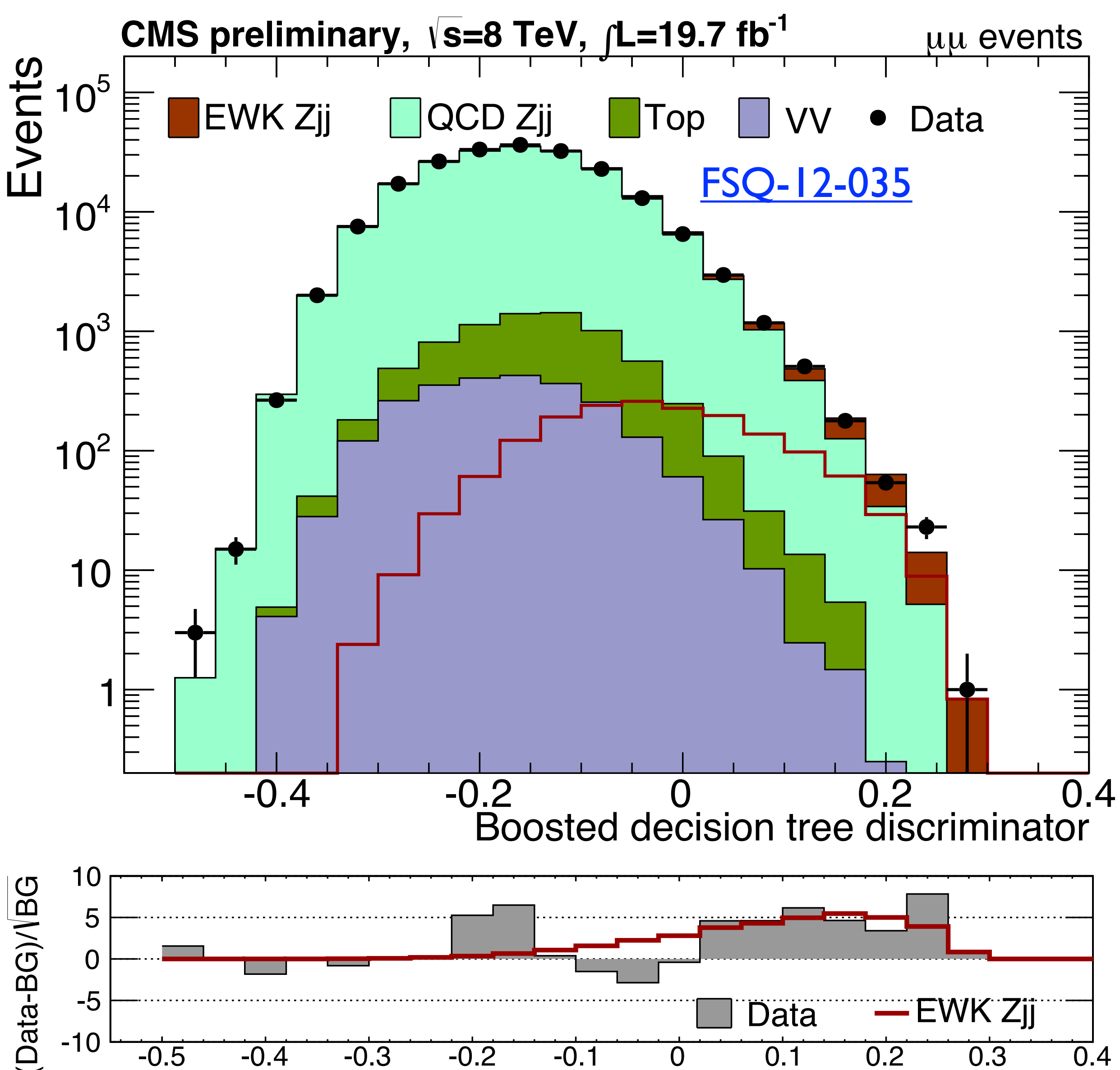
- Employ two methods and combine results to measure cross section

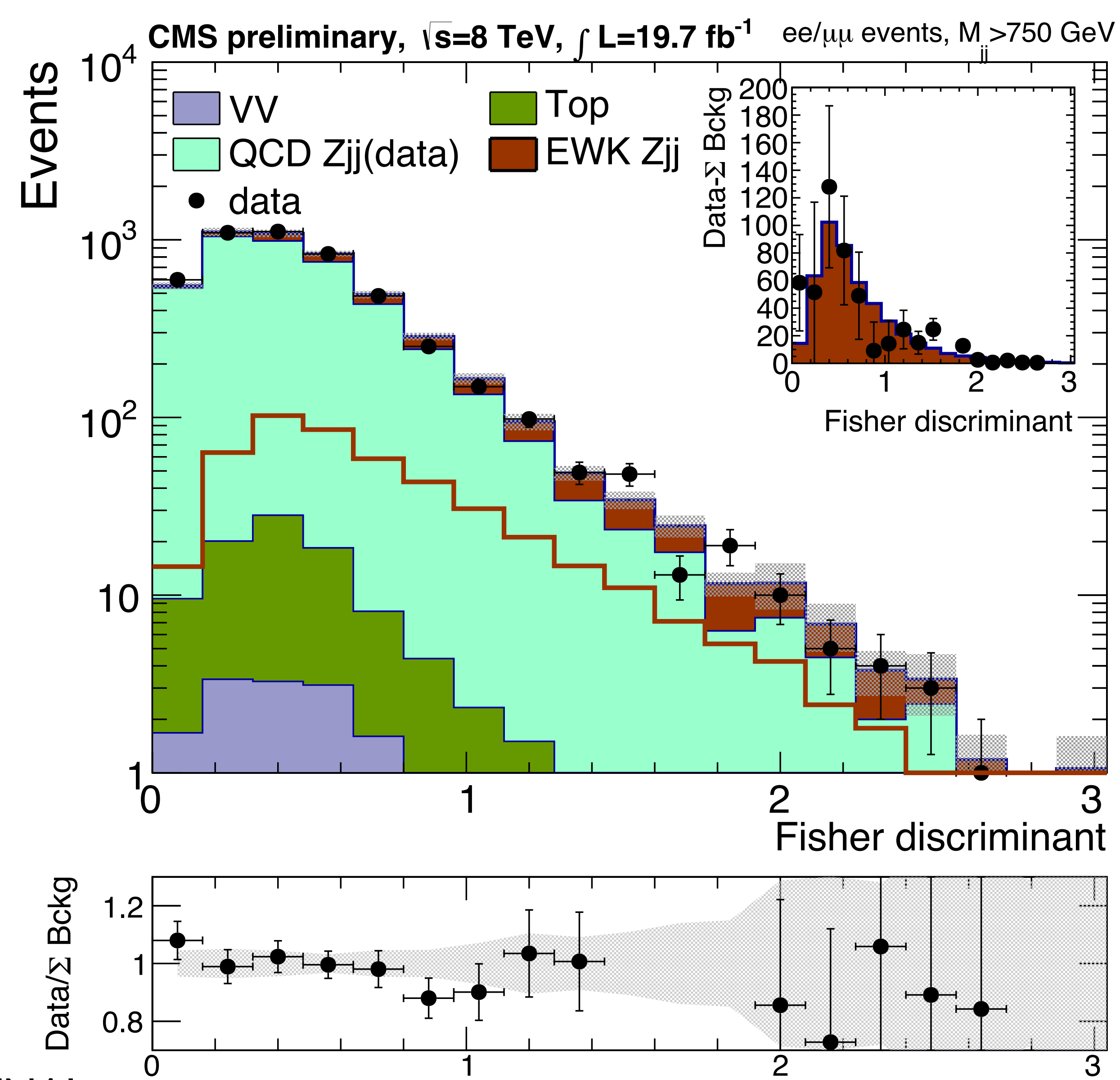
$$\sigma(\text{EWK } \ell\ell\text{jj}) = 226 \pm 26_{\text{stat}} \pm 35_{\text{syst}} \text{ fb.}$$

- BDT analysis, μ channel only

NLO Prediction : 239 fb

- Data-driven template for QCD from γ+2 jets





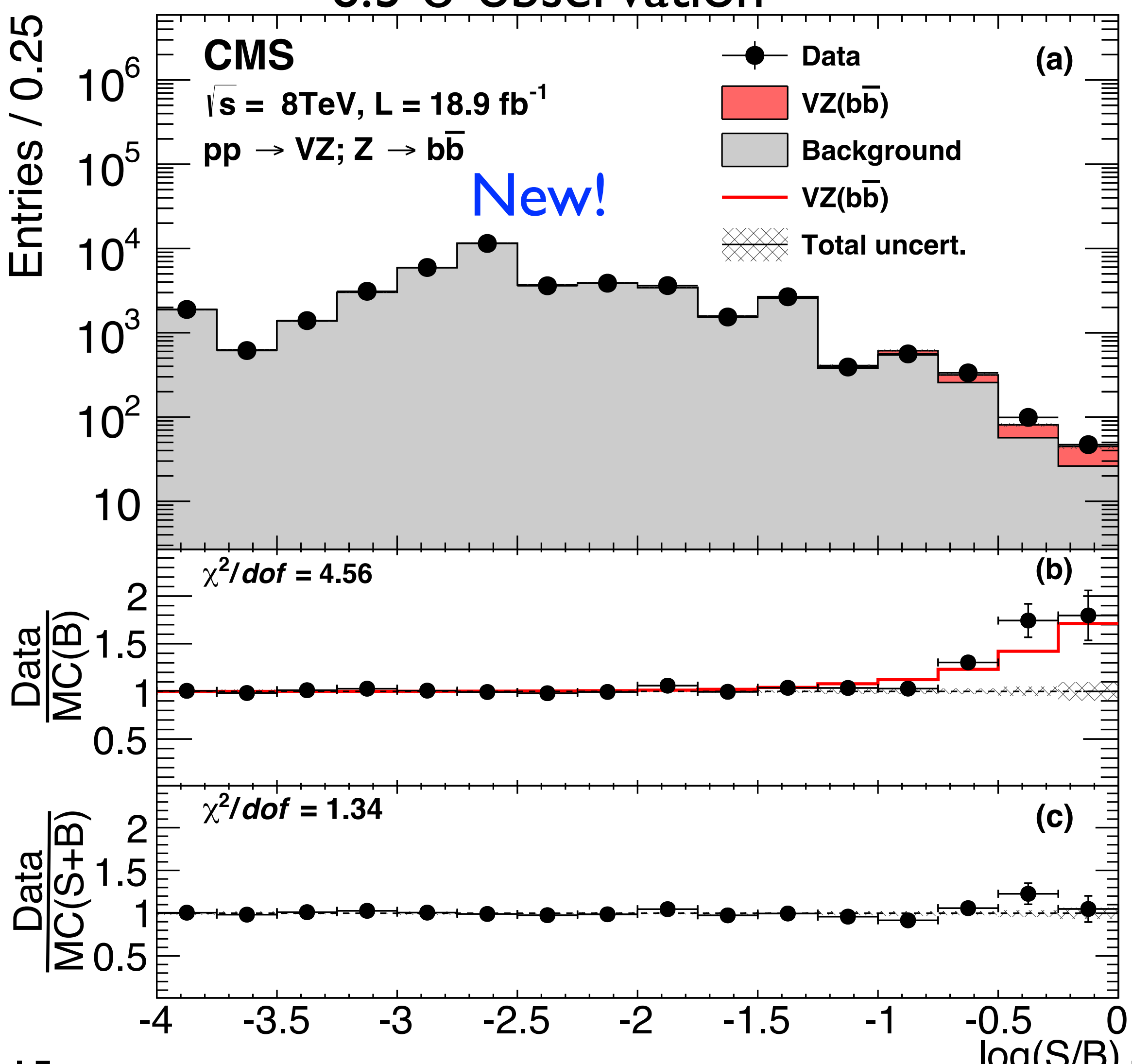
WZ and ZZ using Z→ bb Decays

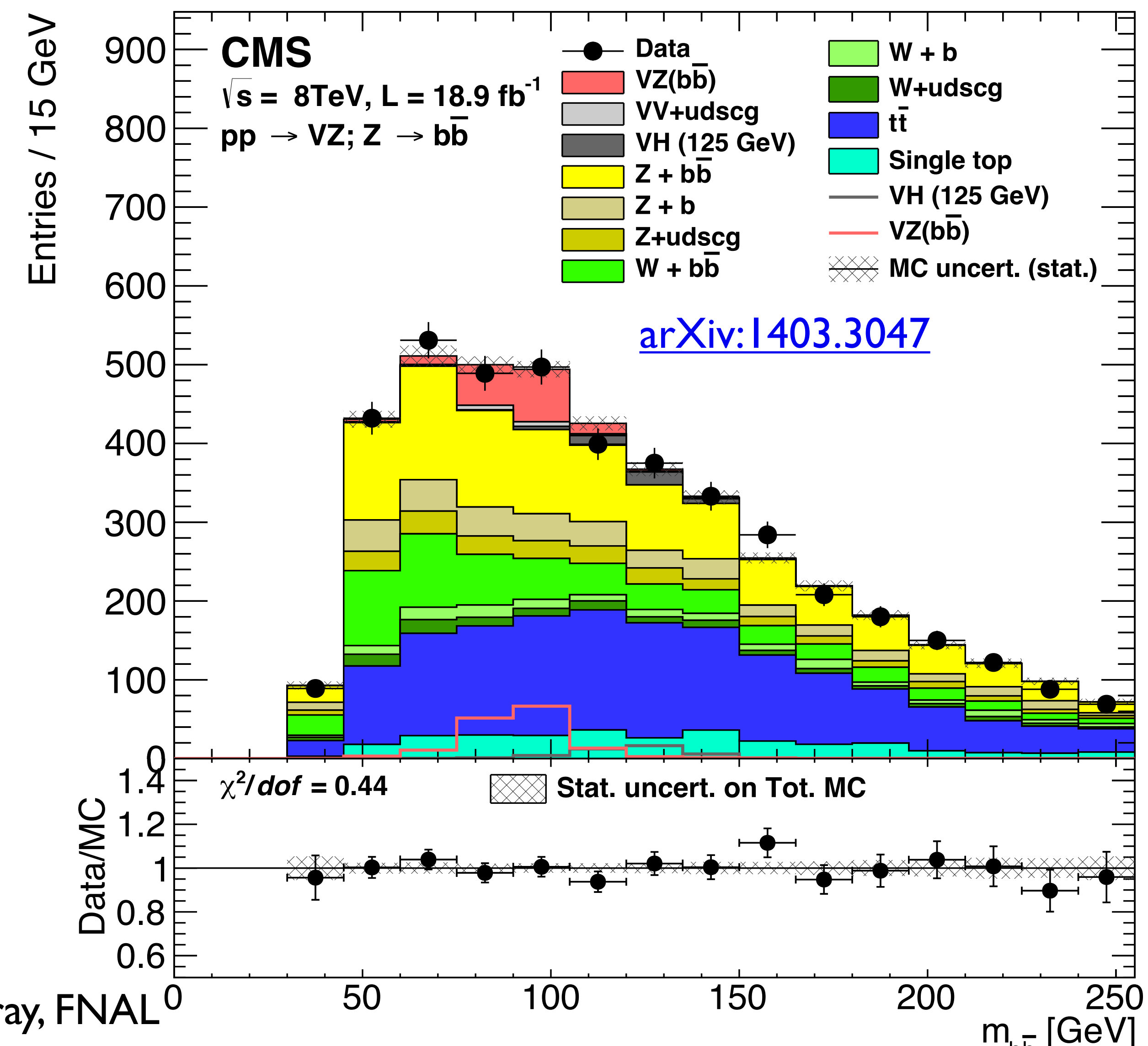
See Caterina Vernieri's talk in YSF4 for further details!

◉ Spin-off of CMS H>bb analysis

- Scalar boson considered as background
- BDT analysis based on classification in V p_T, events sorted by expected S/B
  - 6.3 σ observation

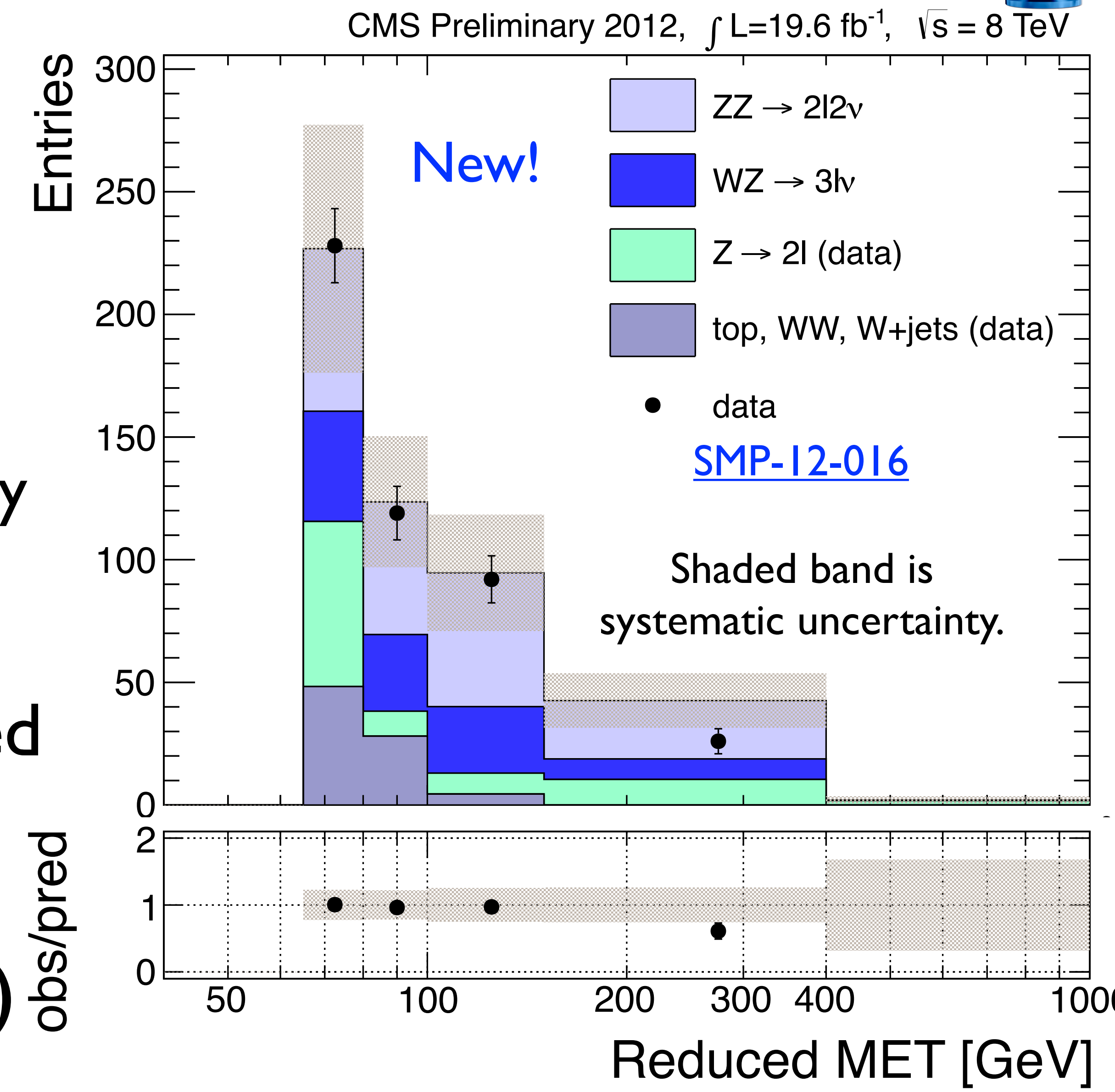
- Corresponding category based analysis using similar event selection
  - 4.3 σ observation





ZZ→2l2ν Cross Section Measurement

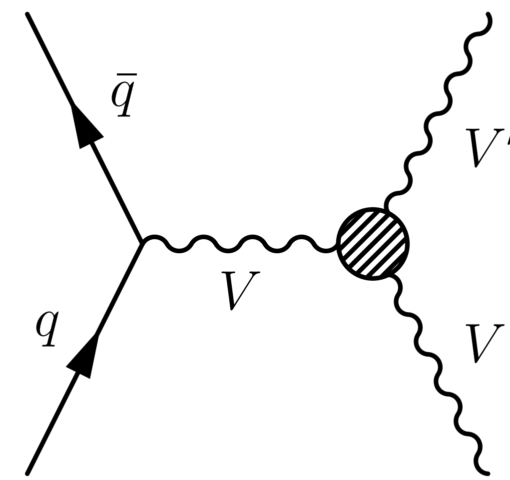
- Measure production cross section using a template fit
  - Use “Reduced” MET
    - Use minimum MET requiring that energy be jet-clustered or not
  - Better rejection of Drell-Yan compared to raw MET
- Updated ATGC Limits (in later slide)



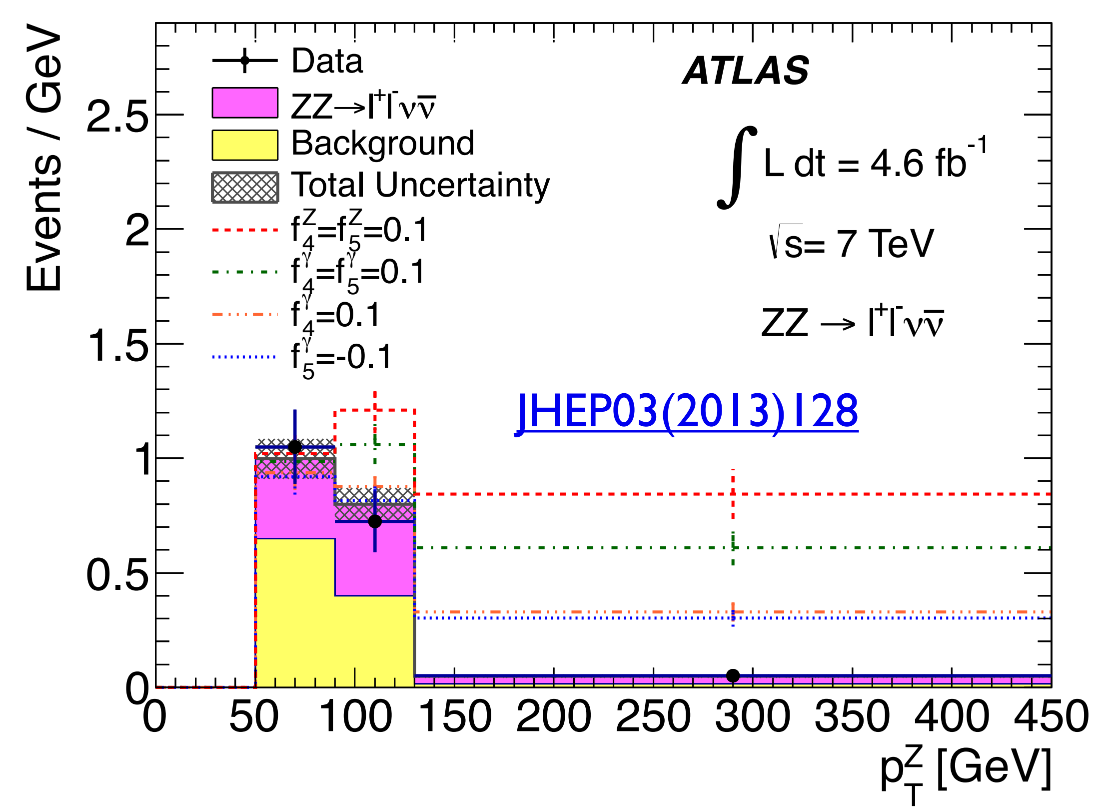
Channel	σ [fb] 7 TeV theory σ $249^{+4.6\%}_{-3.3\%}$ fb	8 TeV theory σ $305^{+4.5\%}_{-3.0\%}$ fb
ee	284^{+101}_{-90} (stat) $^{+75}_{-64}$ (syst) ± 10 (lumi)	224^{+48}_{-45} (stat) $^{+71}_{-50}$ (syst) ± 9 (lumi)
$\mu\mu$	135^{+69}_{-62} (stat) $^{+56}_{-57}$ (syst) ± 5 (lumi)	305^{+43}_{-41} (stat) $^{+88}_{-66}$ (syst) ± 13 (lumi)
Combined	192^{+57}_{-52} (stat) $^{+51}_{-40}$ (syst) ± 7 (lumi)	261^{+32}_{-31} (stat) $^{+71}_{-52}$ (syst) ± 11 (lumi)

Anomalous Gauge Coupling Searches

- Search for effects of higher order operators involving SM fields
  - Dimension 6
    - Effects of new particles in loops
  - Dimension 8
    - Skipping dim. 6 operators motivated by massive propagator in 4 boson vertex
- Operators generate new couplings that become strong as the boson momenta increase
- Substantial improvement in limits from increasing center of mass energy

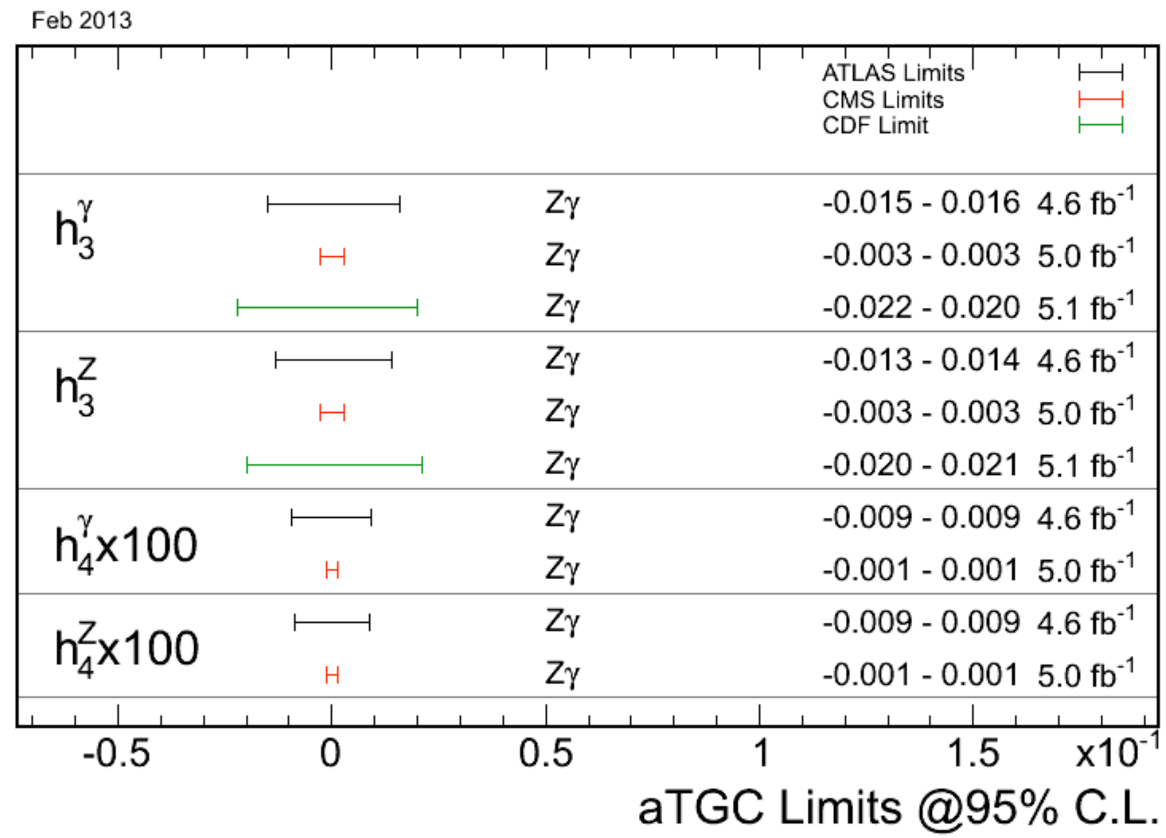


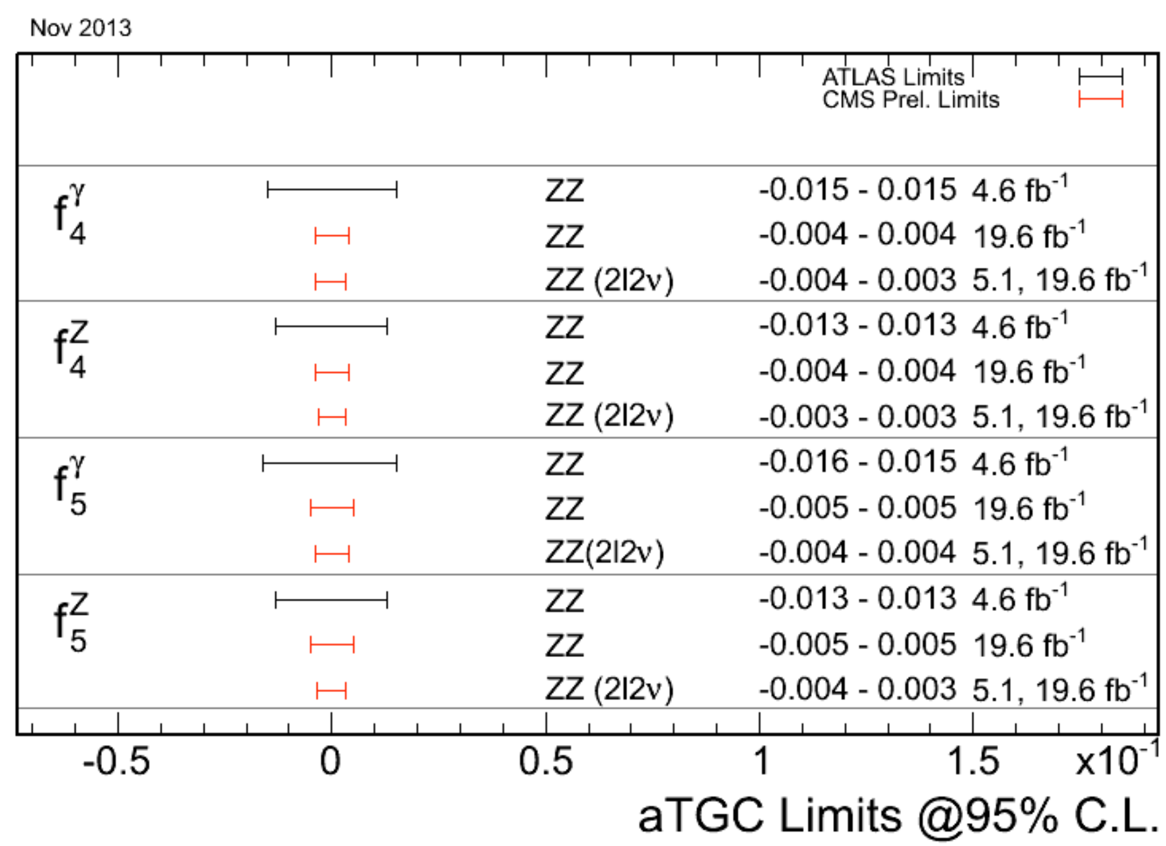
Example ATGC effect in ZZ:



Anomalous Triple Gauge Coupling Searches

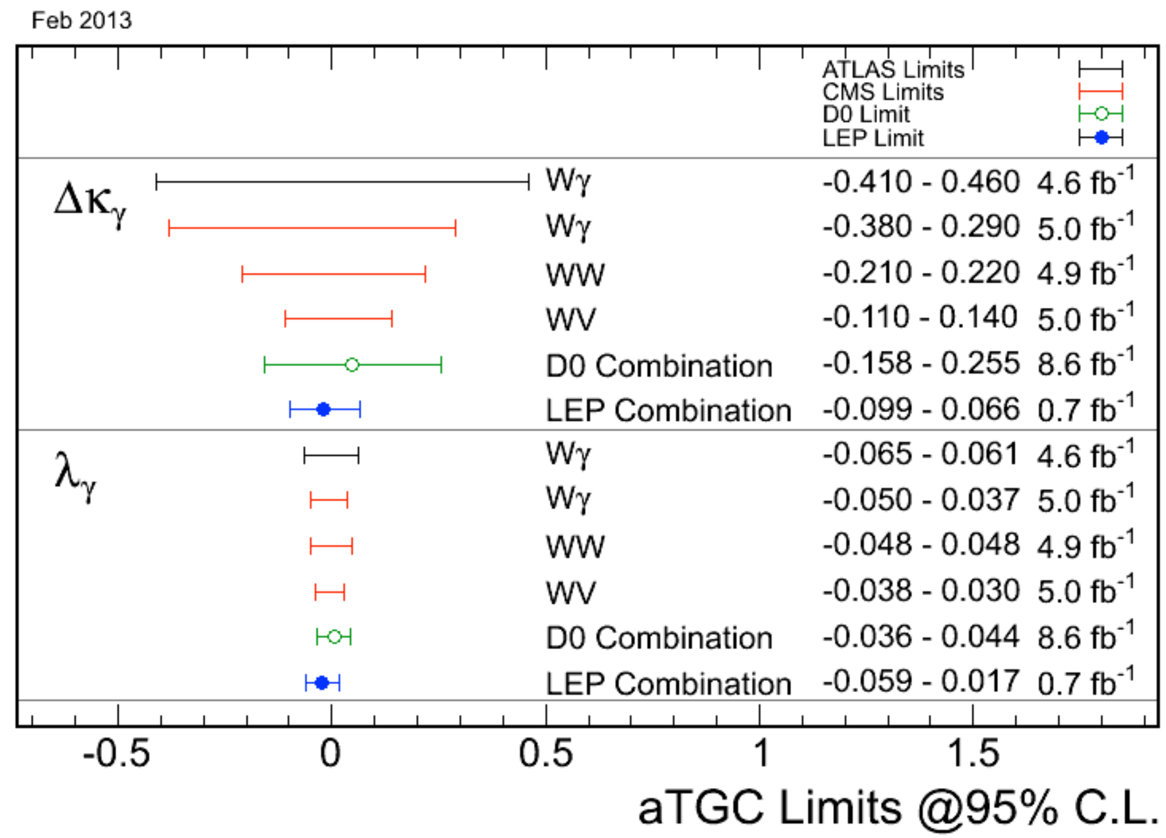
- Neutral anomalous triple gauge coupling limits updated
  - CMS 2l2ν data
  - Improvement in limits due to higher branching fraction
- Further exploitation of data can be achieved through combination of channels
  - Already done in Zγ channels for ννγ + llγ

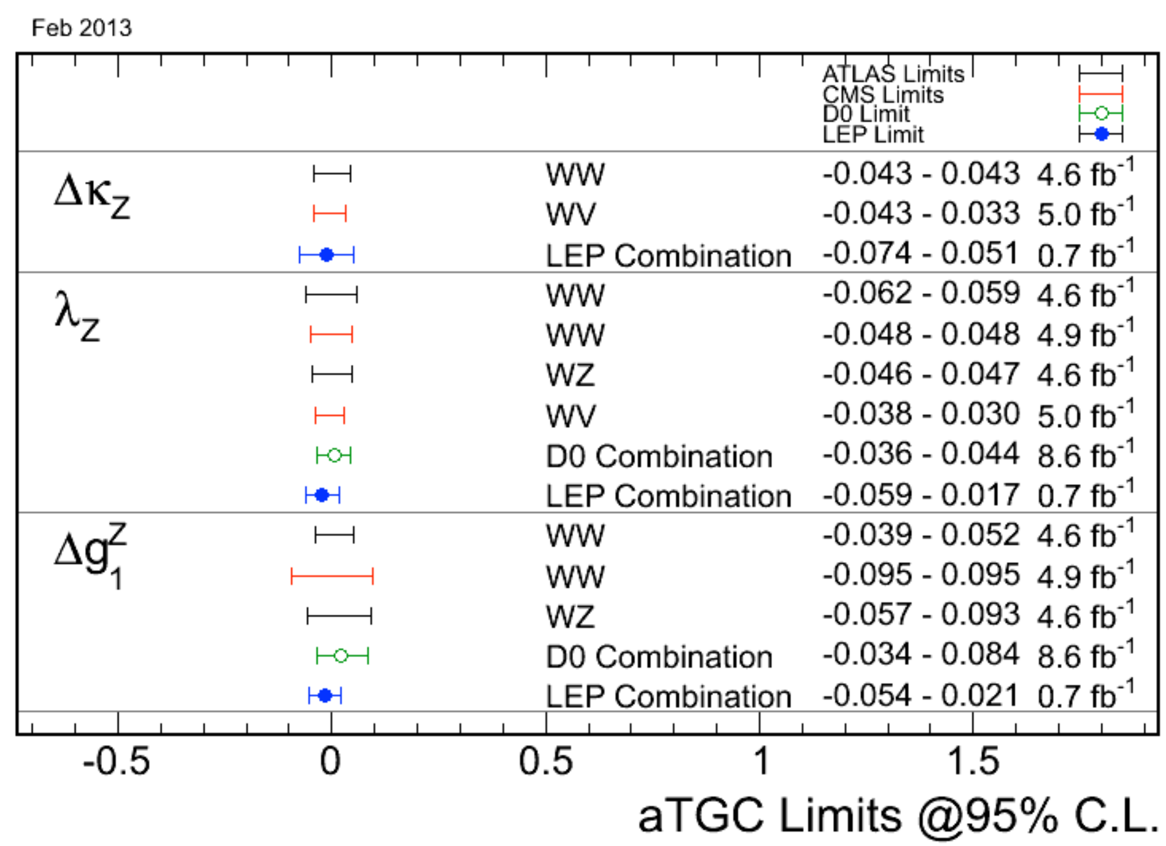




Anomalous Triple Gauge Coupling Searches

- Charged anomalous triple gauge coupling limits
  - LHC uniformly approaching LEP sensitivity
    - Surpassing LEP in some cases!
- Advances made exploiting new final states
  - Merged-jet topologies in WV, V→dijet
- Many 8 TeV analyses still to come
  - Significant improvements in sensitivity per channel expected





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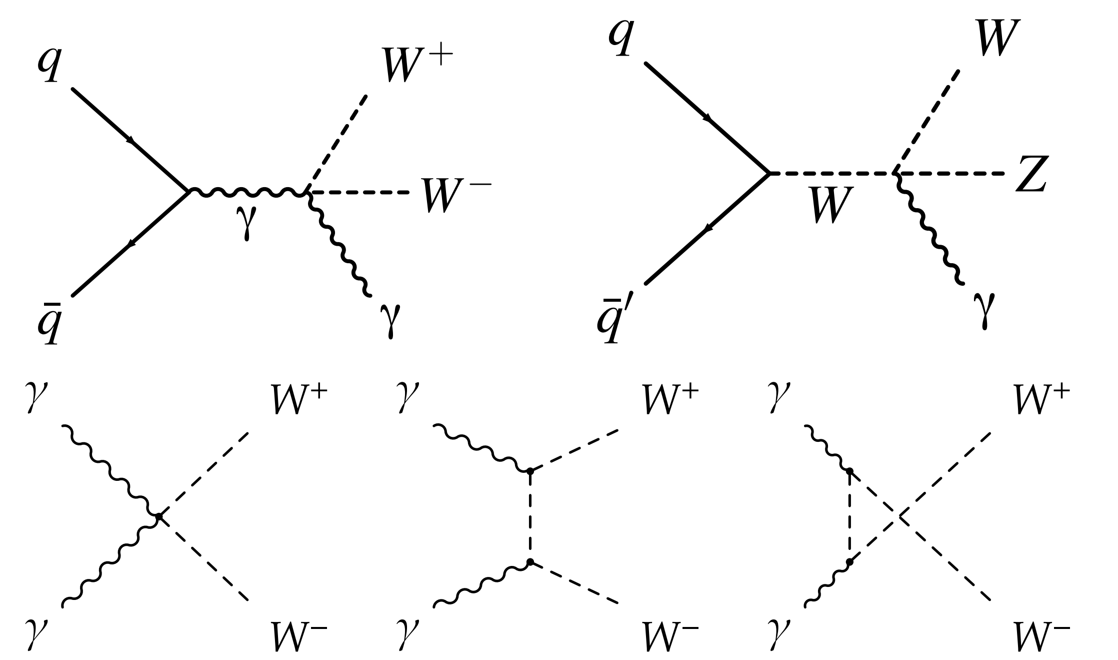
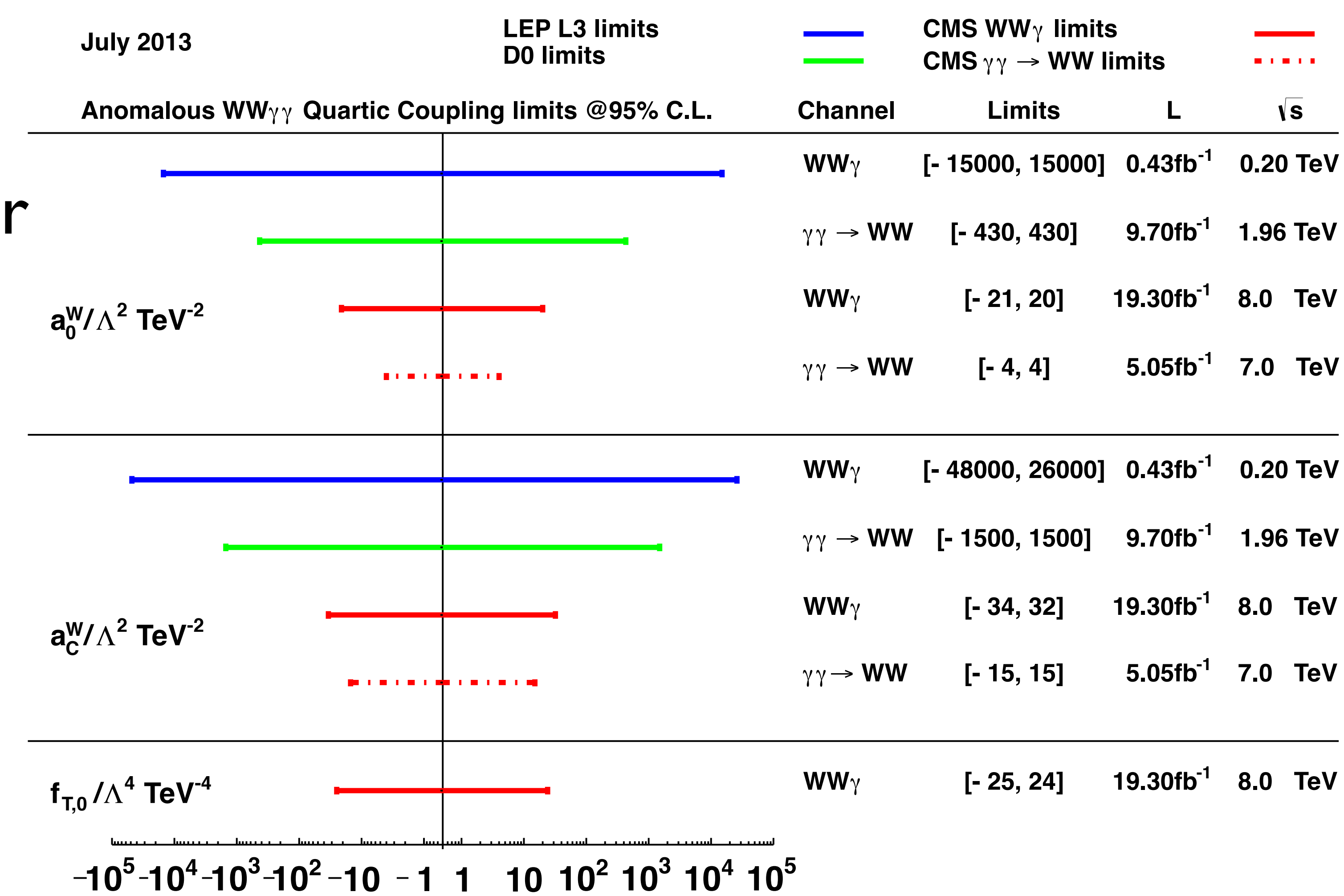
Anomalous Quartic Gauge Coupling Searches

- Exploit unique final states to access pure quartic contributions
  - Exclusive WW production
  - WWγ and WZγ, with one massive boson decay into jets
- New measurements in last year
  - Probing charged quartic gauge couplings
    - WWγγ, WWZγ
- Significant improvement over D0 and LEP





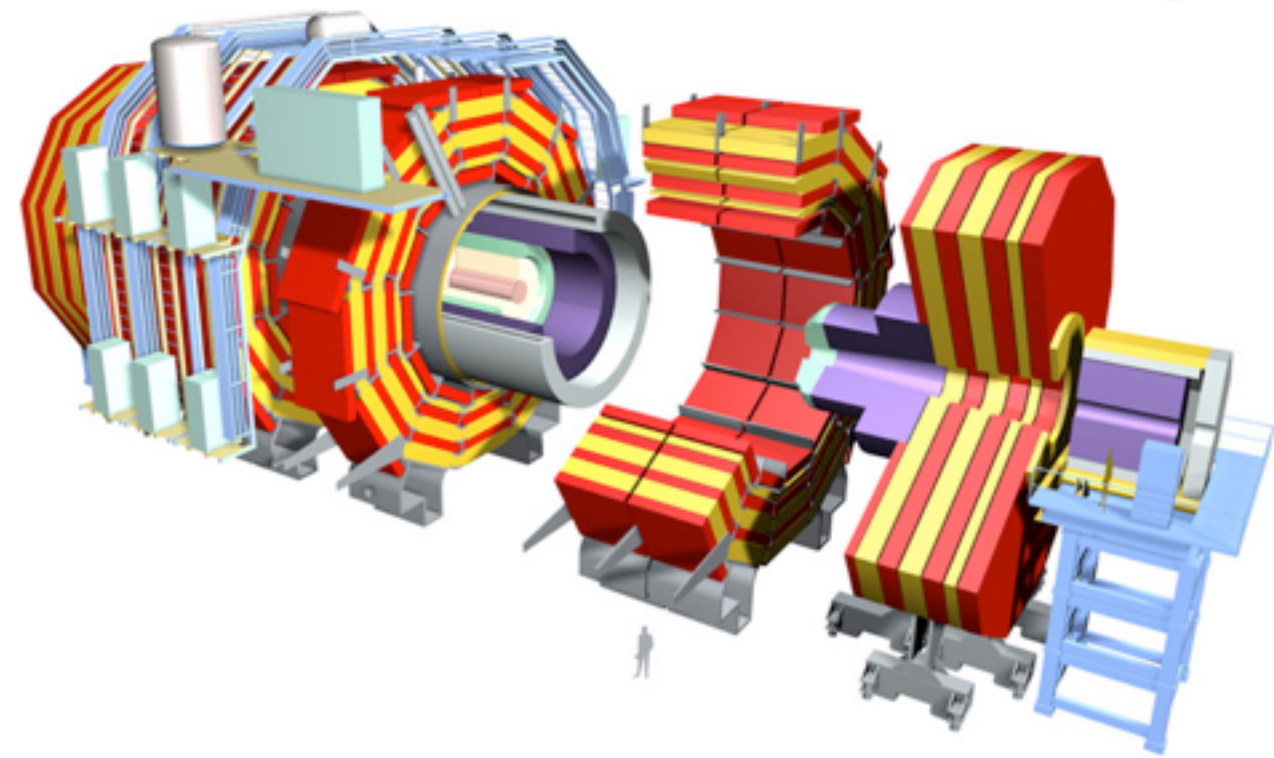
Conclusions

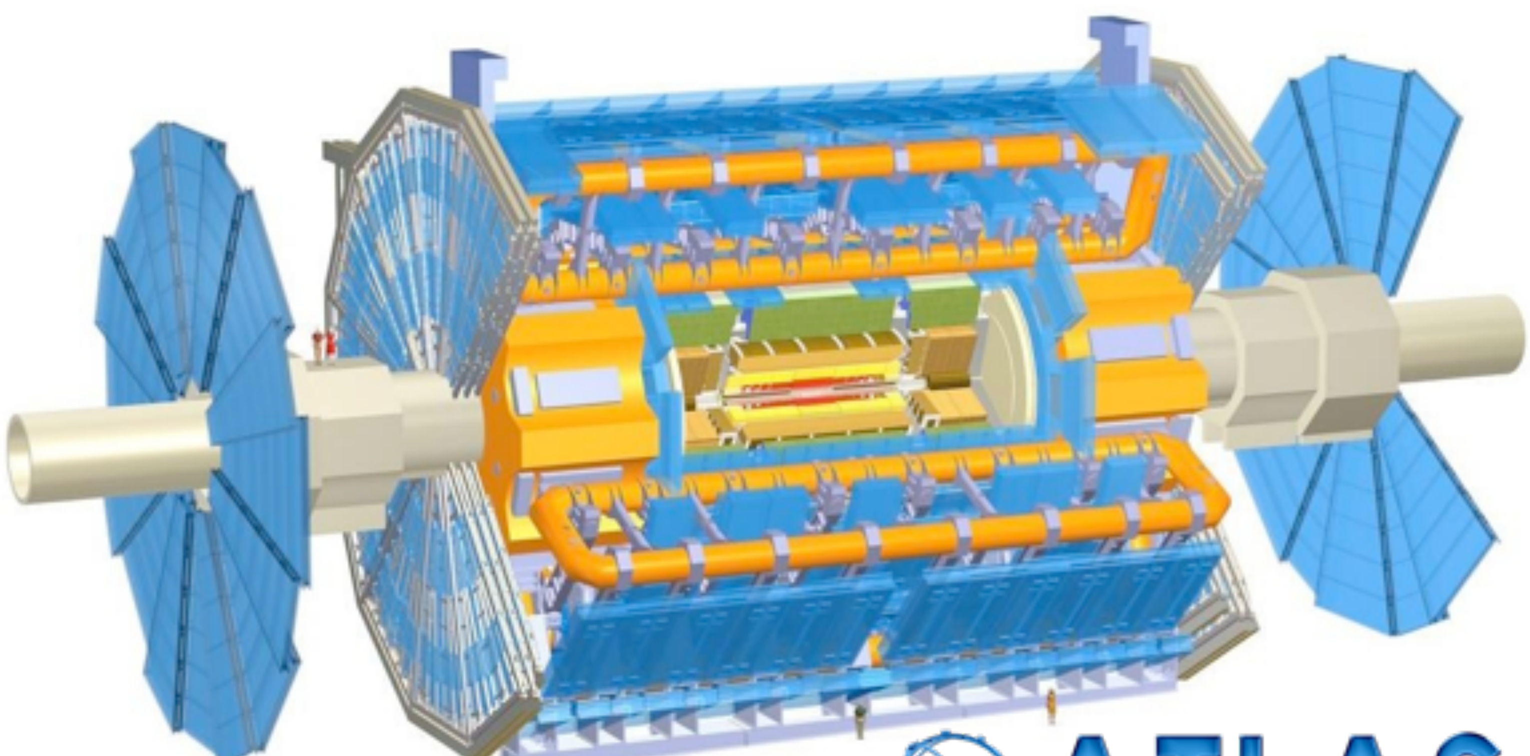
- Standard Model V+Jets measurements from the first LHC run are improving and testing the limits of our predictive capabilities
  - Matching at NLO and high parton multiplicity generators being put to the test by both ATLAS and CMS
  - New PDF constraints improve predictions and help better prepare us for the 13 TeV run
  - Electroweak production of jets now well measured and confirmed by both collaborations
- Multiboson measurements and limits rapidly improving in accuracy as 8 TeV data are analyzed
  - New diboson channels available
  - Statistical power of LHC data now rivals precision of LEP

BACKUP

ATLAS & CMS

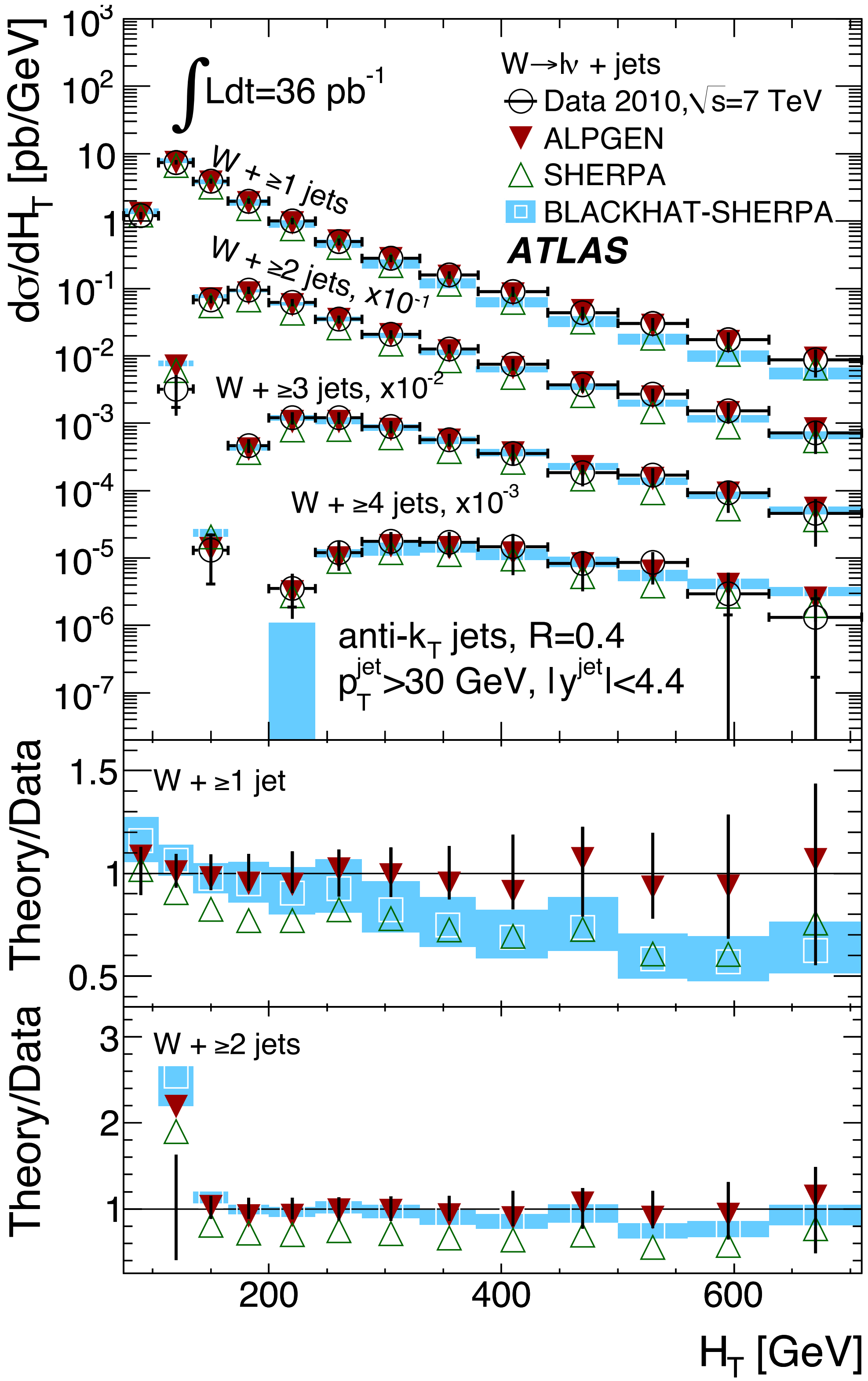
3.8 T Solenoid
Track p_T resolution ~ 1%
Fully Silicon Tracker
Lead Tungstate ECAL
Brass Sampling HCAL
Extensive Muon System in Return Field

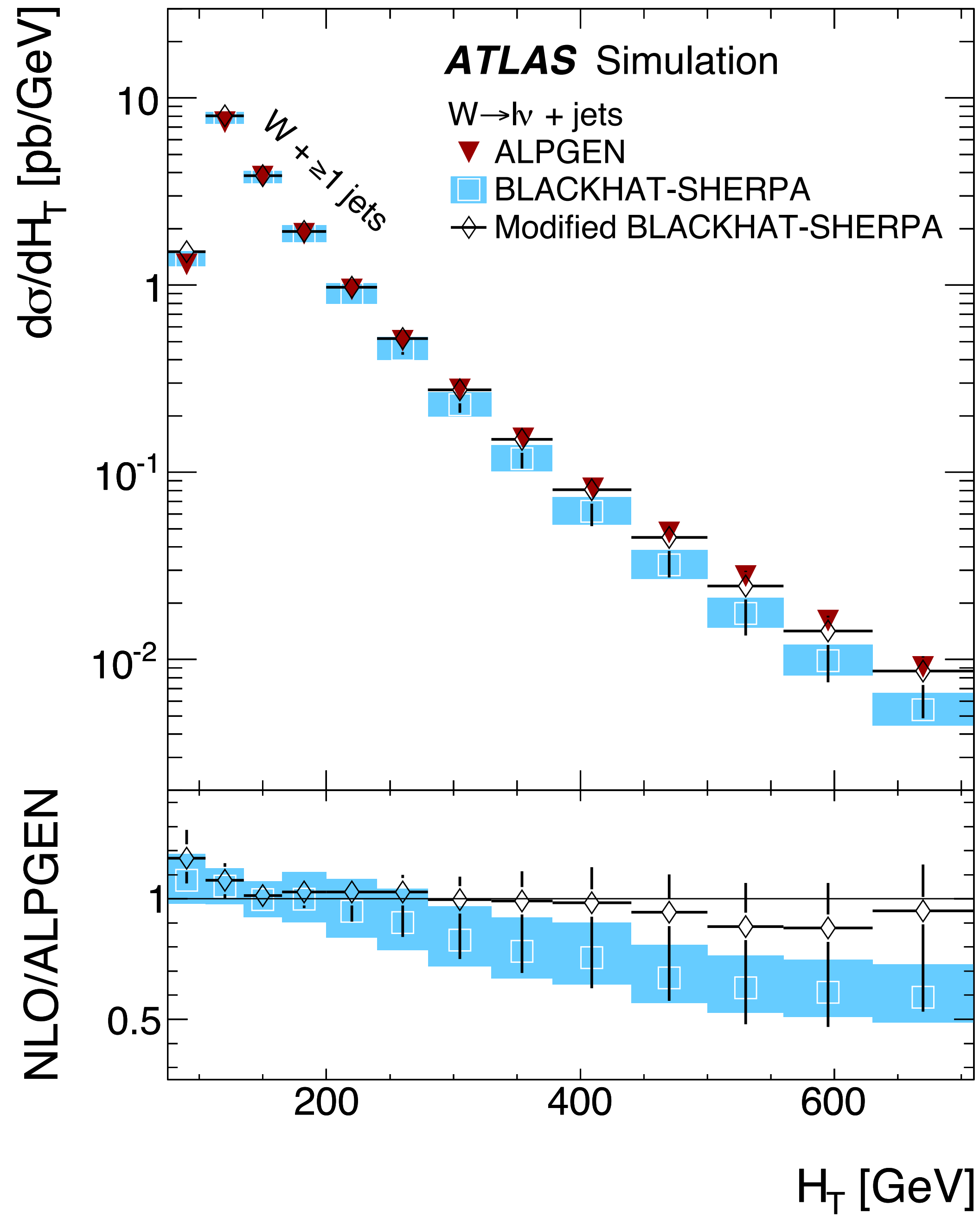




2 T Solenoid
Track p_T resolution ~ 2.5%
Silicon Tracker ID + TRT
Liquid Argon ECAL
Steel HCAL with Scintillating Tiles
Extensive Muon System in Toroidal Field

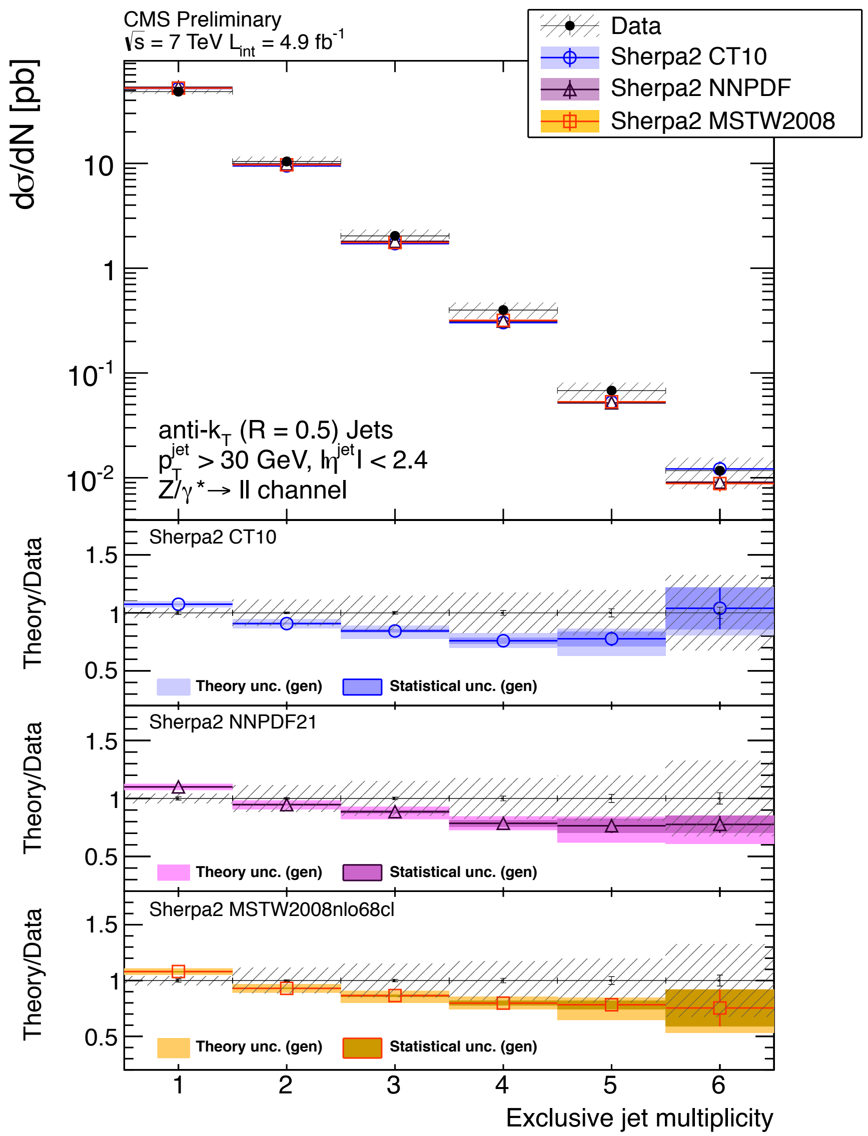
Further W+Jets Plots

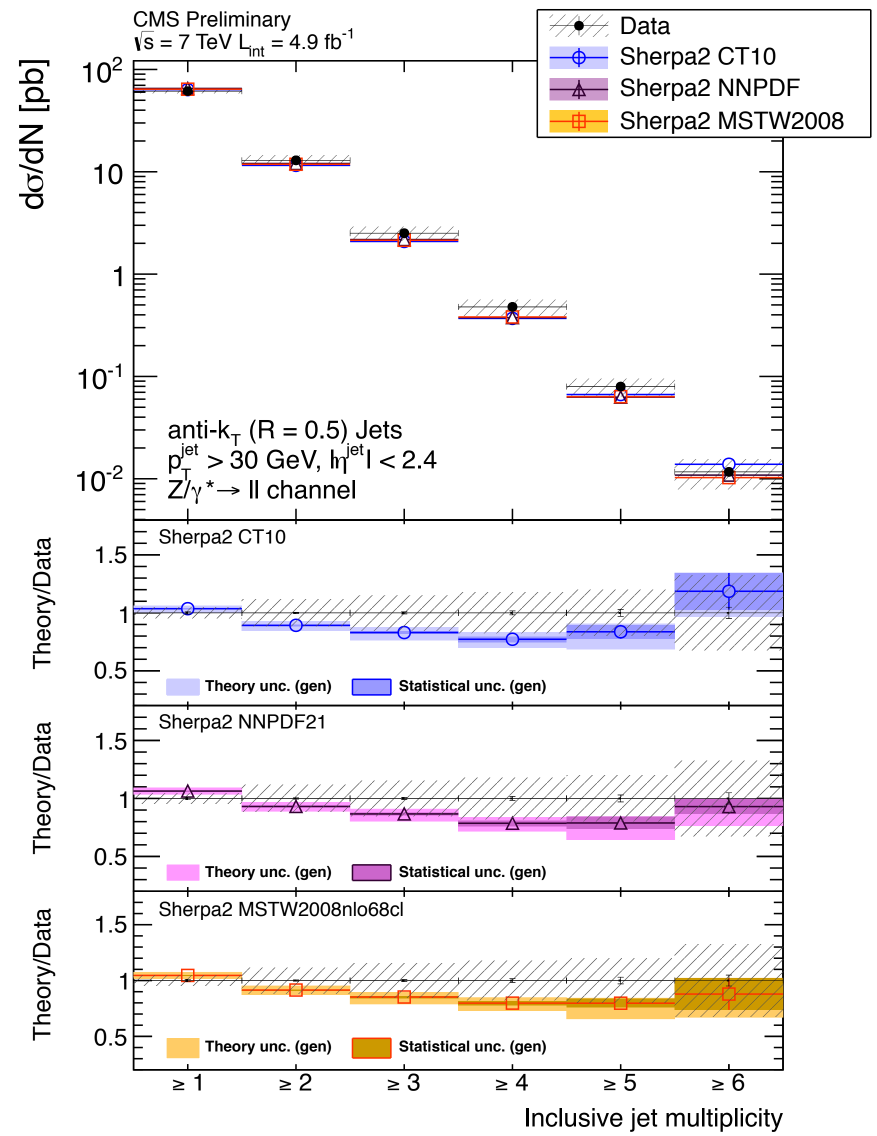


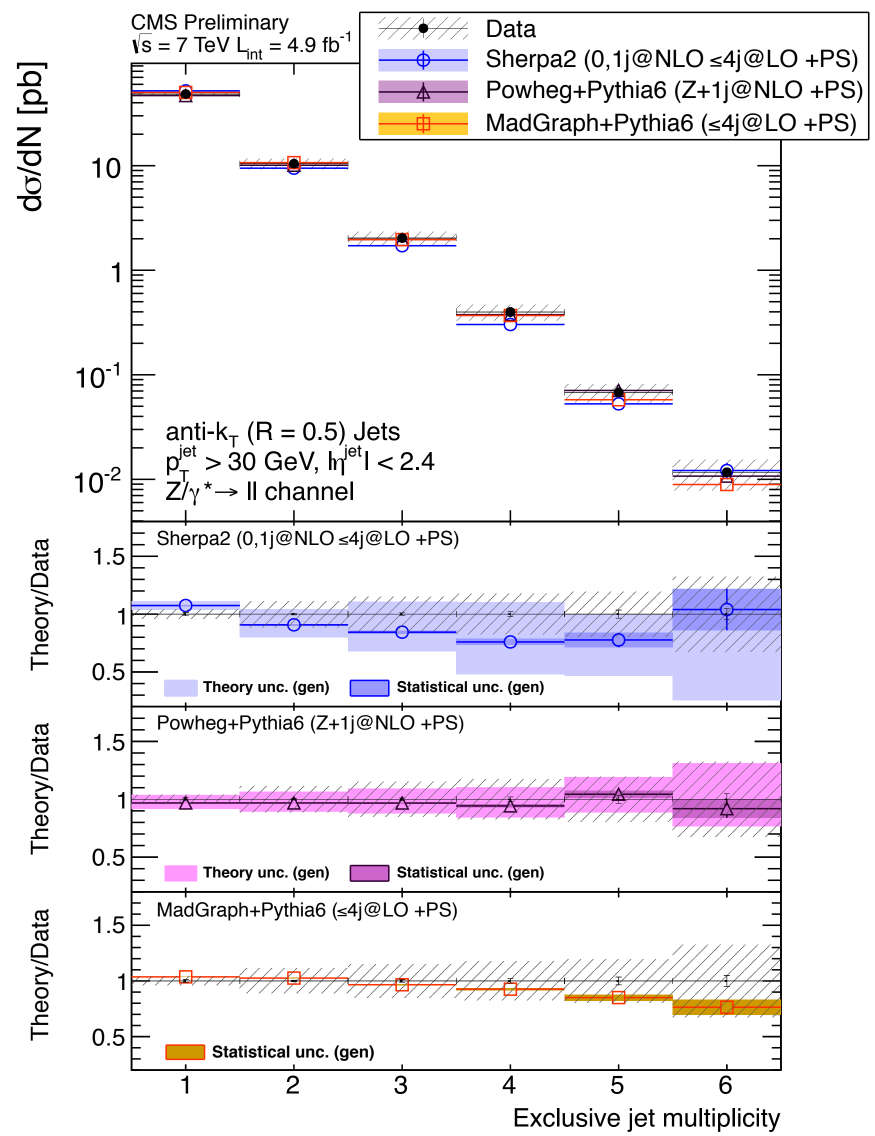


Further Z+Jets Plots

Comparison across PDFs







Further Z+Jets Plots