A (short) review of Standard Model studies in CMS

Simon de Visscher (CERN)
on behalf of the CMS collaboration

Kruger 2014, Dec 2nd

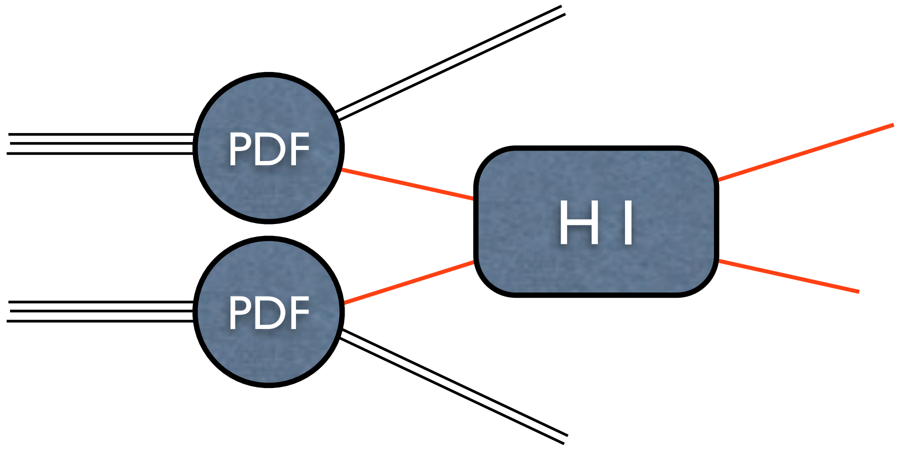
Disclaimer

- This talk does **not** do a full review of Standard Model (group) CMS results
  - more than 60 public notes and papers since 2011.
- Selection: only recent and/or representative studies are discussed here
- For more informations, check out any SMP CMS public results
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP
    - plots
    - notes, papers
    - link to HepData, to Rivet analysis details

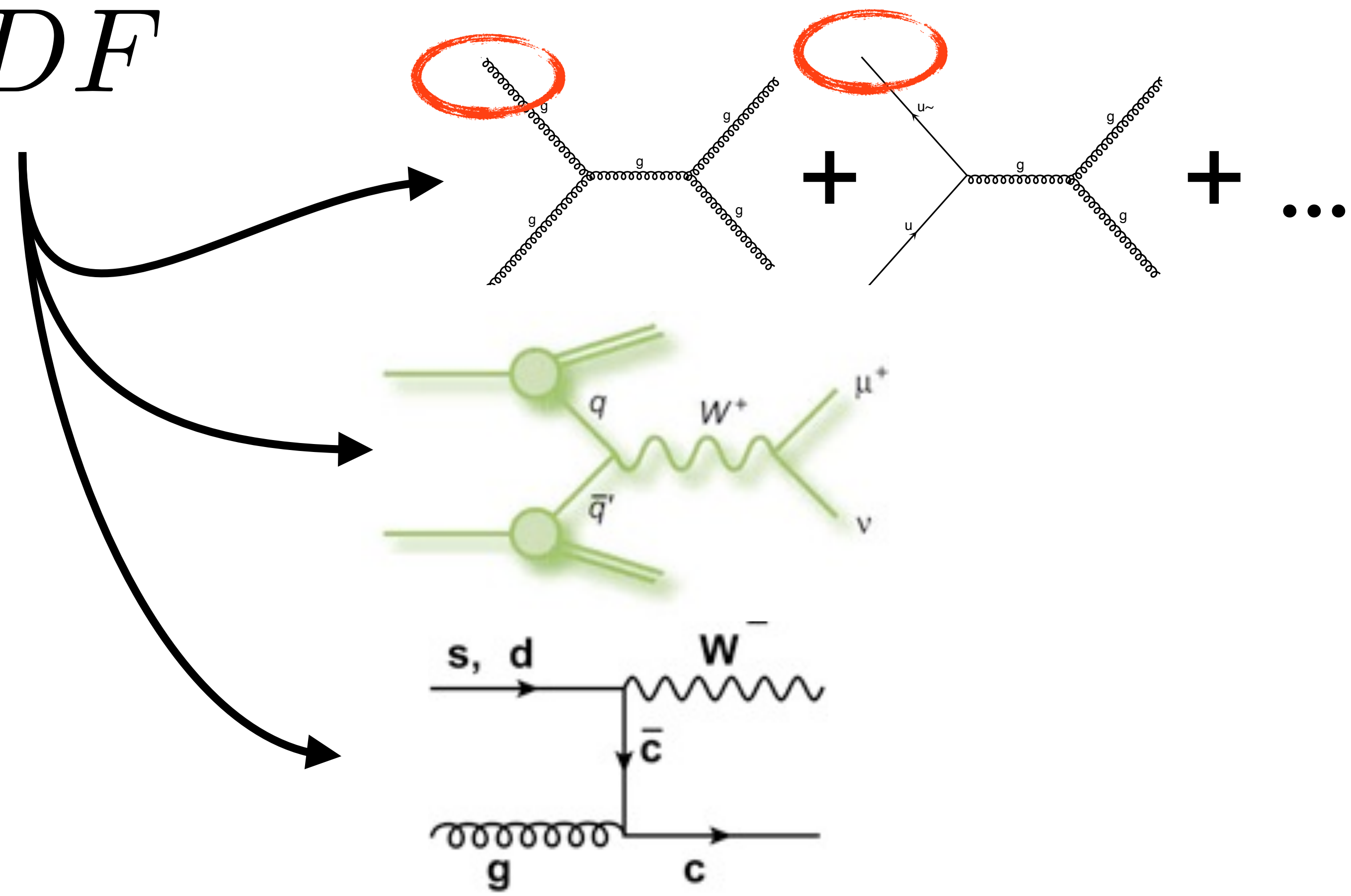
Outline

- PDF, α_s
- W, Z boson production in association or not with jets
- diboson production: aTGC and aQGC

PDF, α_s



$$\sigma \sim \sigma_{HI} \times PDF$$

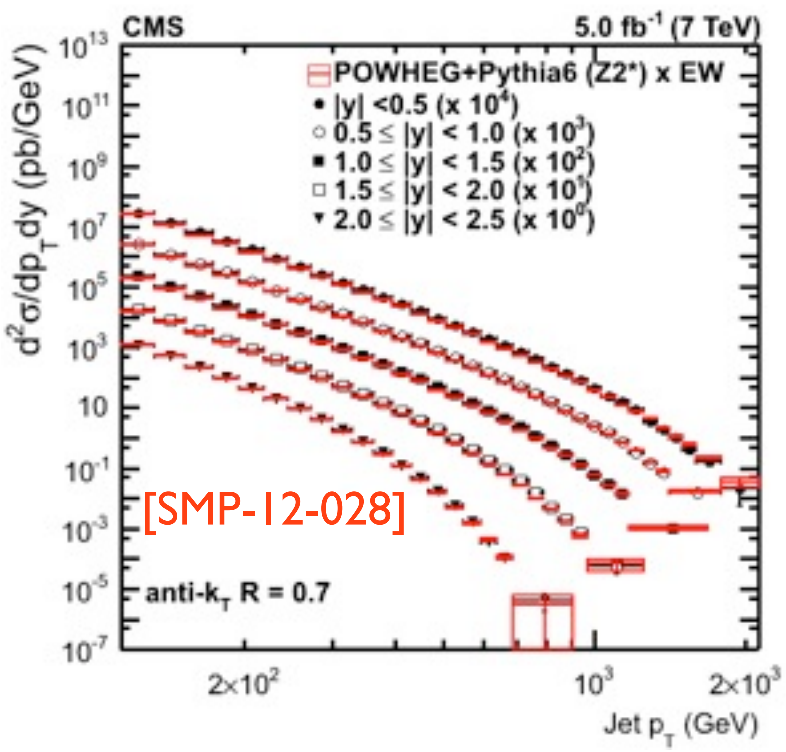


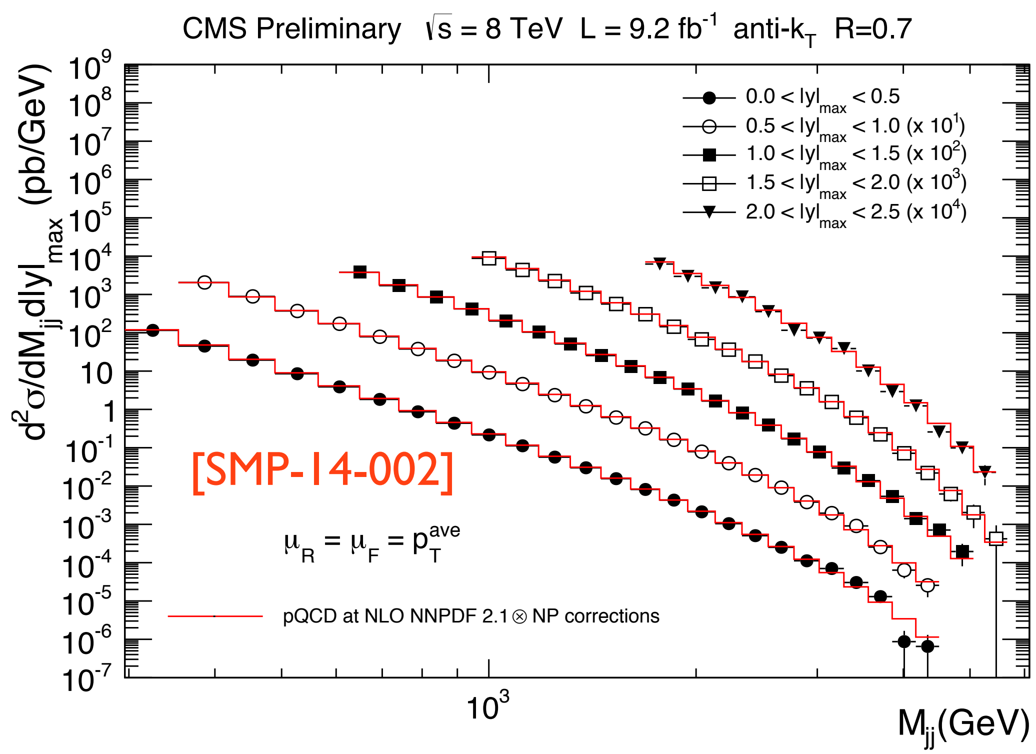
g,q-PDF

u,d-PDF

s-PDF

PDF from n-jet cross-section



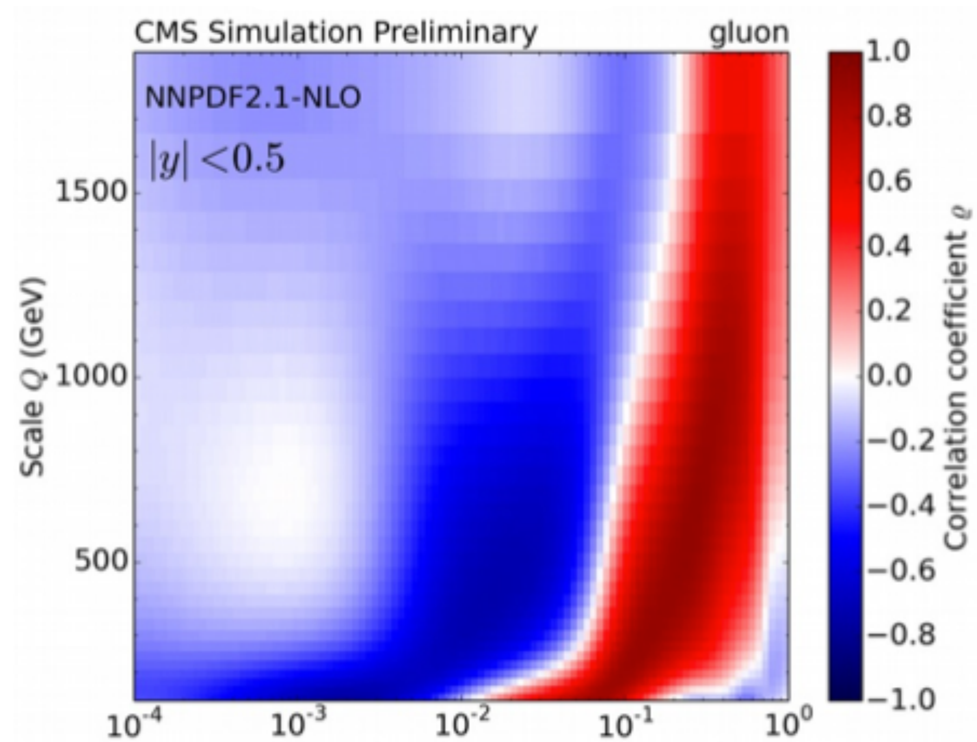


Good agreement between unfolded data and NLO prediction on order(s) of magnitude in Pt, M_{jj} !!

Small differences resulting on PDF choice
⇒ allows to constrains PDF

q-PDF? g-PDF? depends on their correlation with variable

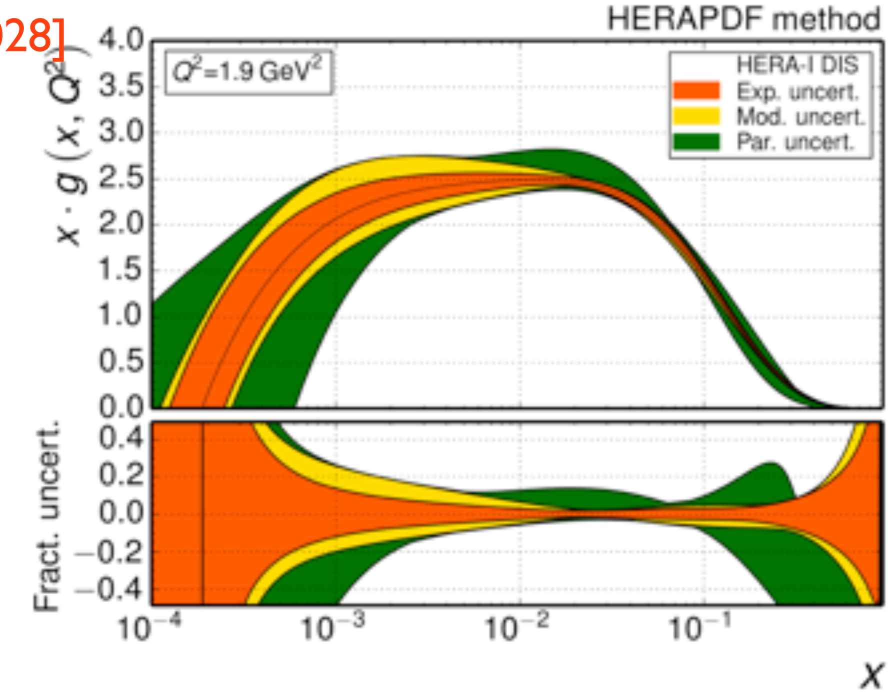
In general g-PDF is better constrained by QCD events



Kruger 2014, Dec 2nd

PDF from n-jet cross-section

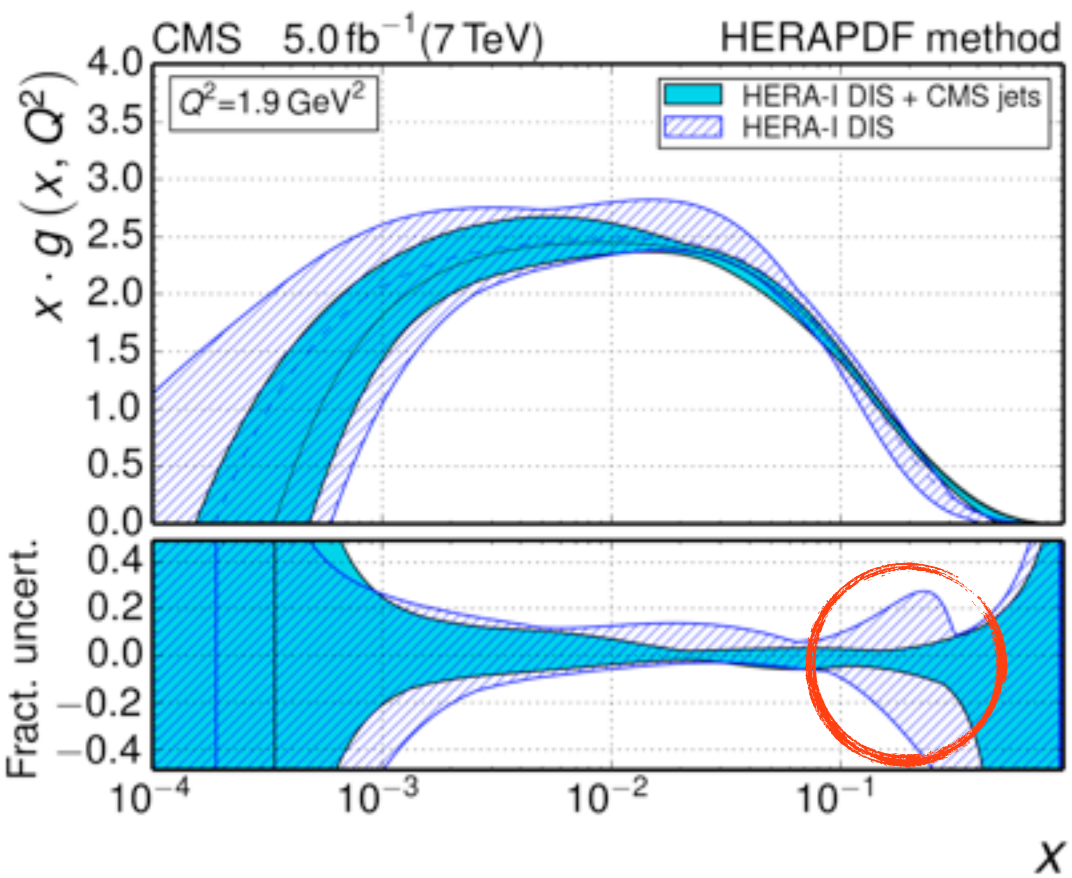
[SMP-12-028]

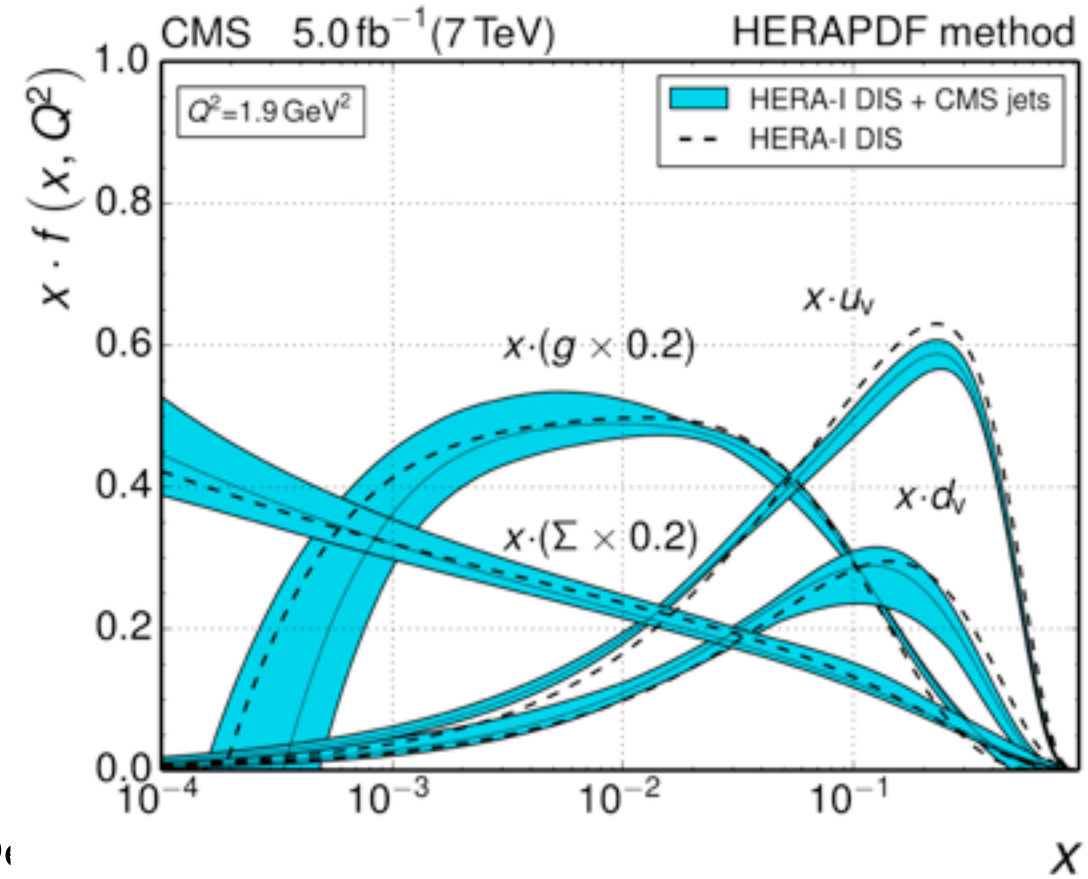


HeraFitter package used to constraint the PDFs
- CMS Jet Pt data: input
- input compared with prediction from theory (NLOJet)
- PDF parameters chosen to fit the theory to the data

Reduction of uncertainties, especially for g-PDF

Impact on all PDF's is present, here at Q^2=1.9 GeV^2

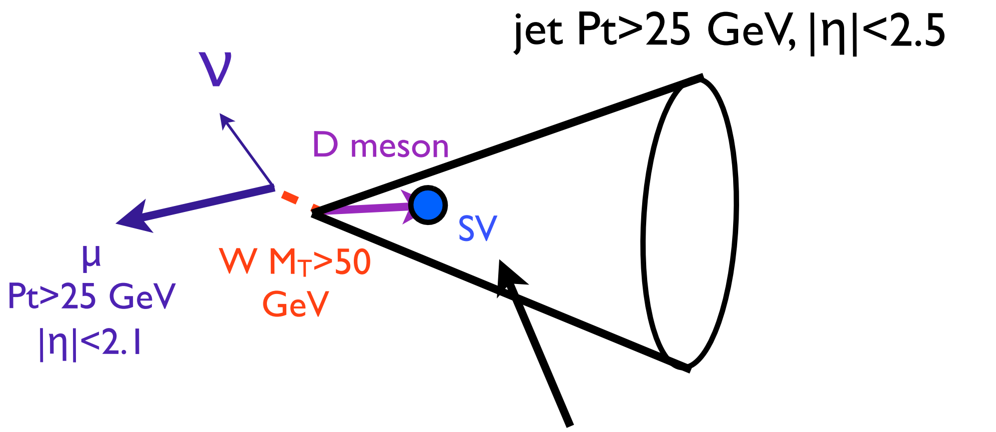




q-PDF from W+c and A_W

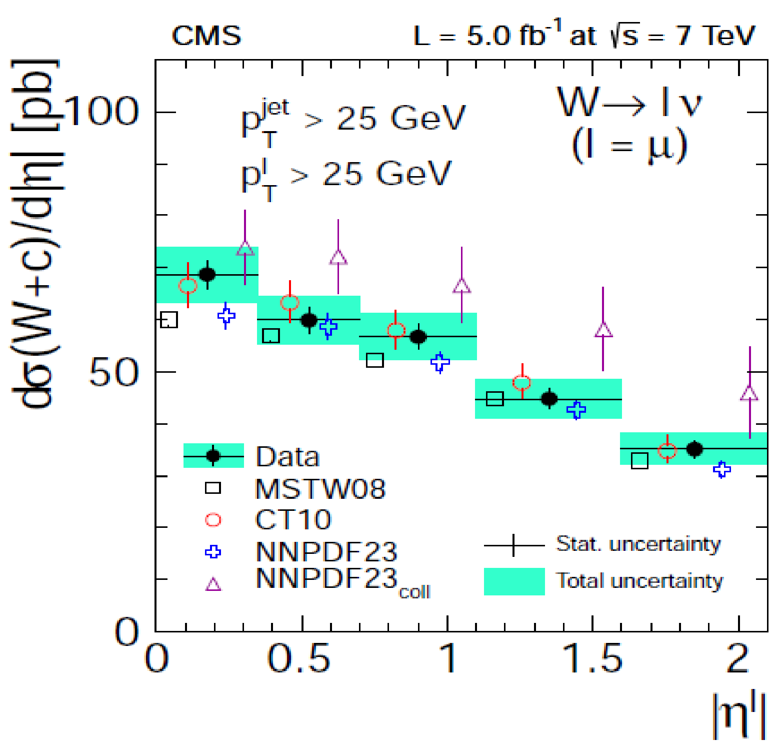
[JHEP 02 (2014) 013]

W+c: probe s-quark PDF



$$D^{\pm} \to K\pi\pi, D^0 \to K\pi, D^{*\pm} \to D^0\pi \to K\pi\pi$$

Strategy: OS-SS to remove tt, single-top, Wcc, Wbb, ...

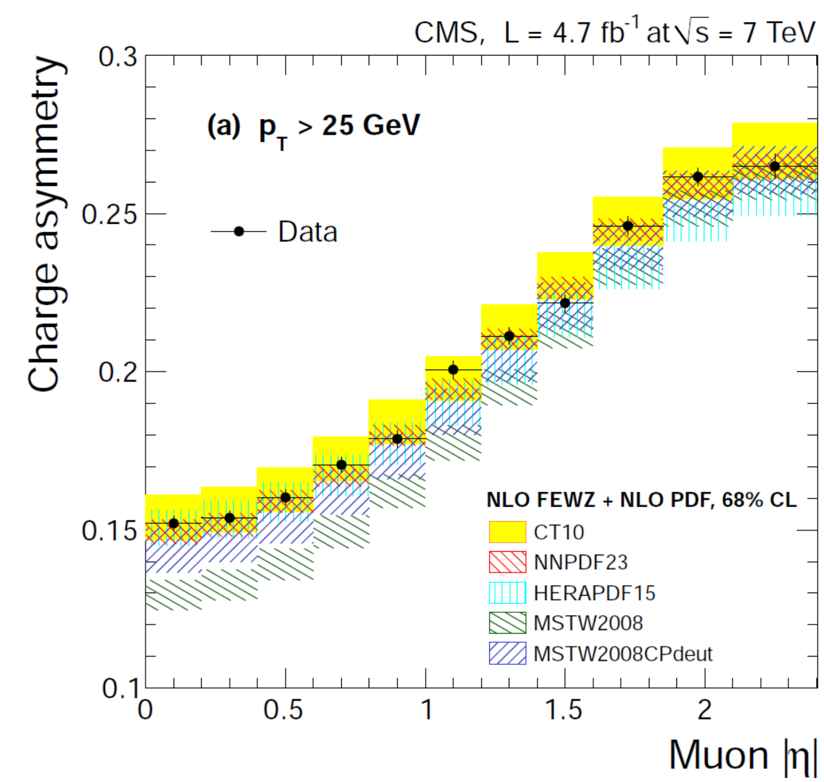


[PRD 90 (2014) 032004]

A_W measurement: u, d quarks PDF

$$A_W = \frac{W^+ - W^-}{W^+ + W^-} \sim \frac{u_v - d_v}{u_v + d_v + 2u_{sea}}$$

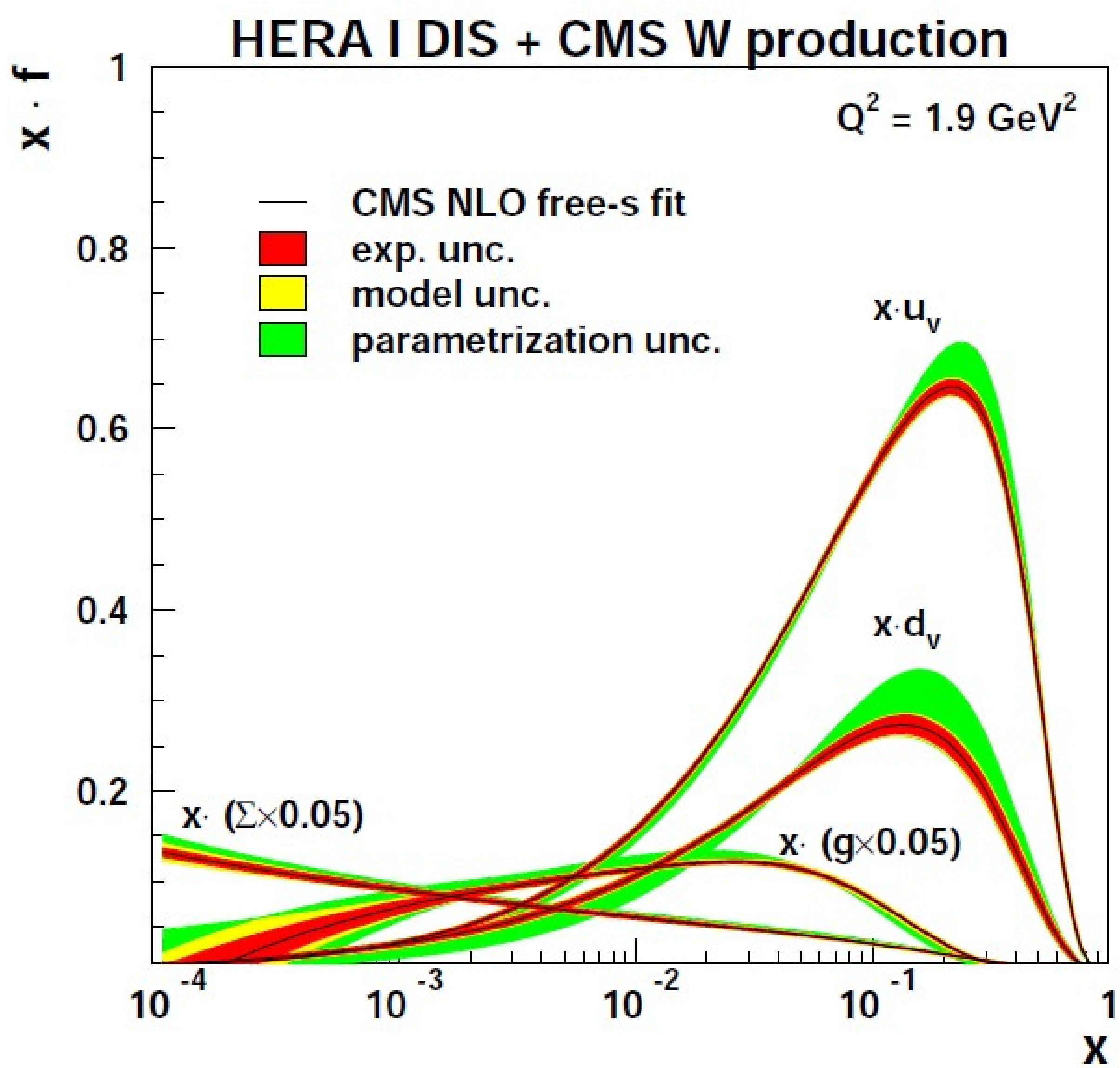
Excess of W^+ over W^- and rapidity

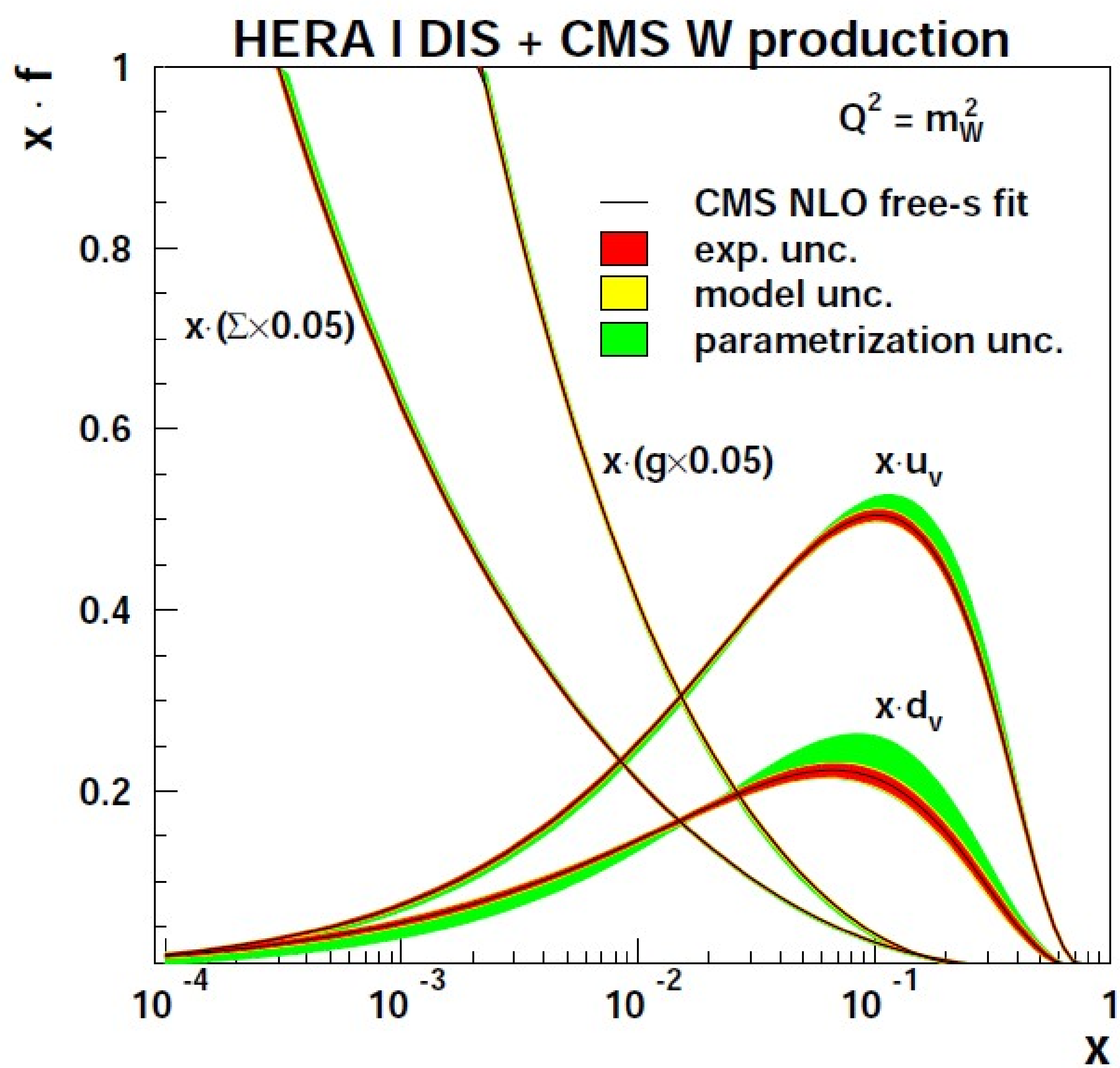


PDF from W+c and A_W

[PRD 90 (2014) 032004]

HeraFitter package used for the analysis
Data: Hera I DIS
NLO predictions available (MCFM)

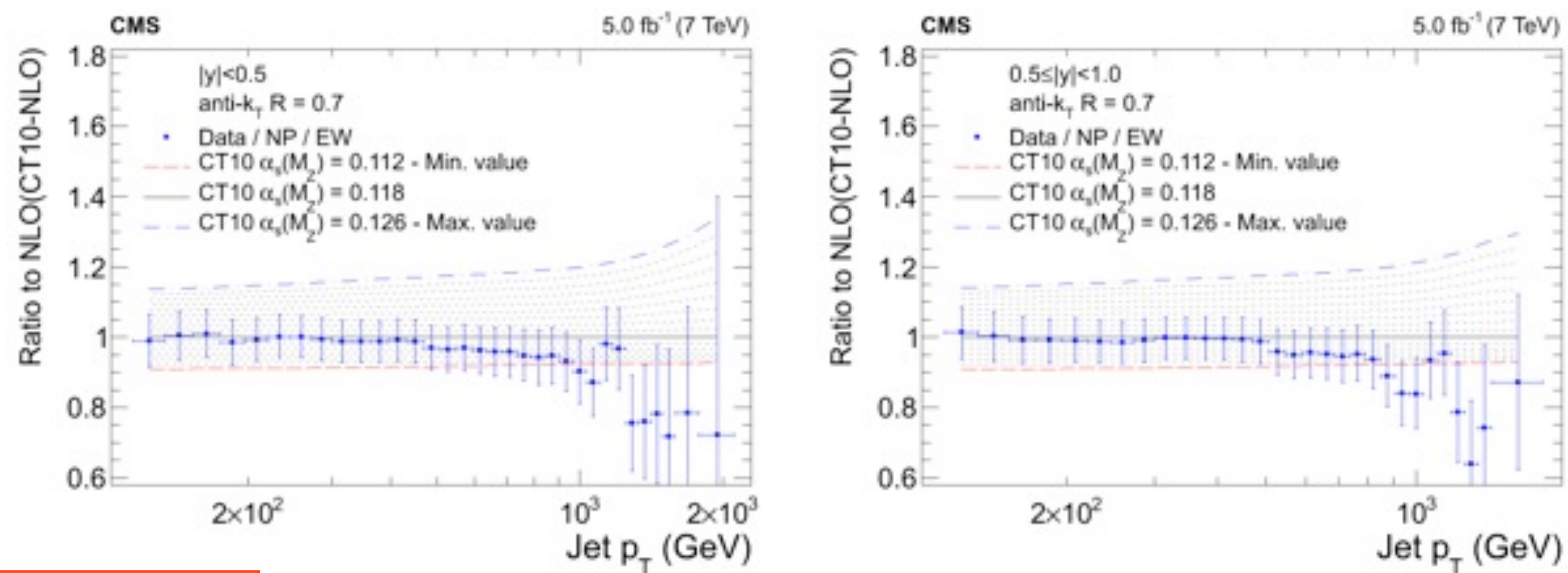




α_s from n-jet cross-section

[SMP-12-028]

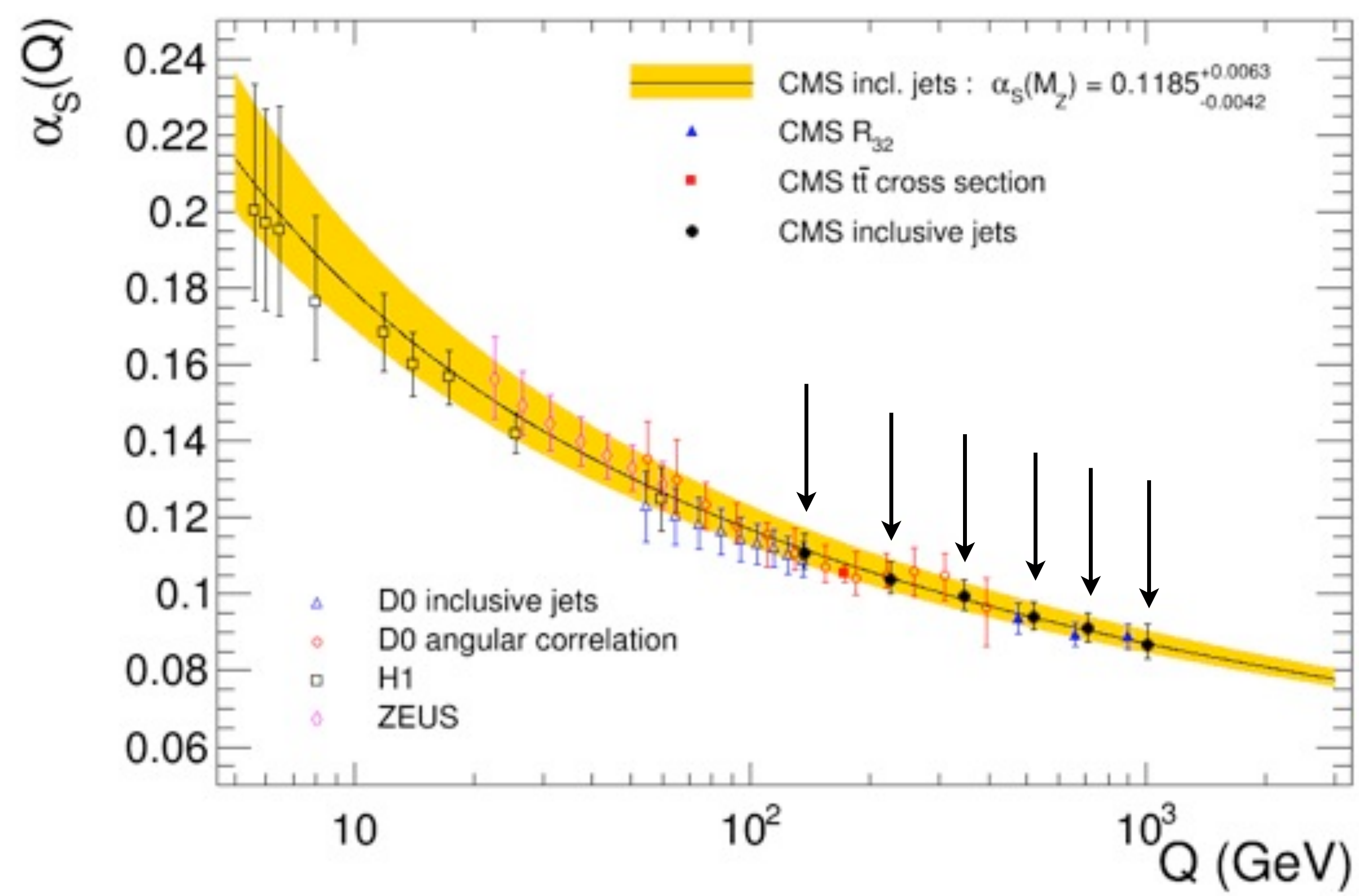
Use jet Pt to extract $\alpha_s(Q)$
*(NP+MPI)-corrections applied to NLOJet prediction



1) Fit on all eta ranges to extract $\alpha_s(M_Z)$

$$\alpha_S(M_Z) = 0.1185 \pm 0.0019\,(\text{exp}) \pm 0.0028\,(\text{PDF}) \pm 0.0004\,(\text{NP})^{+0.0053}_{-0.0024}\,(\text{scale})$$

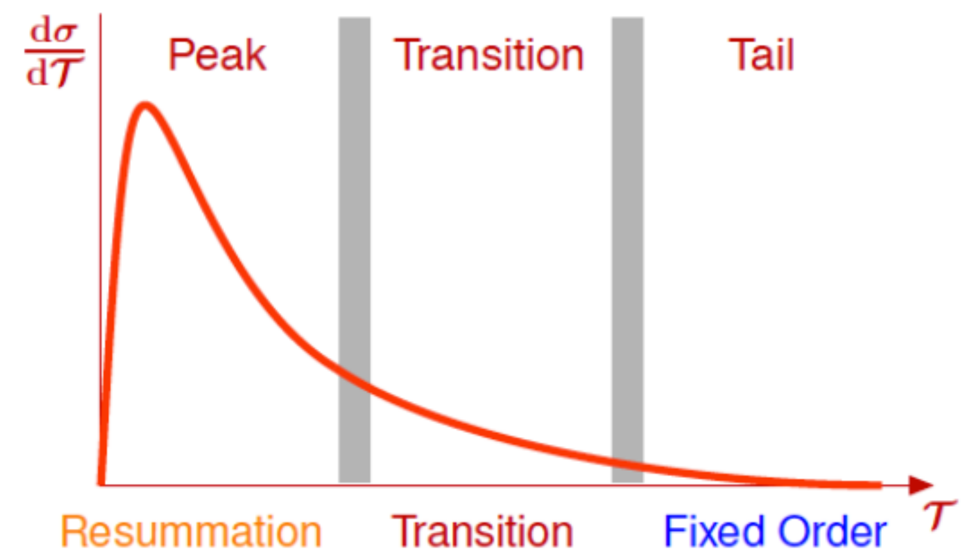
2) Bin in Jet Pt, evaluate $\alpha_s(M_Z)$ and extrapolate using a 2-loop solution (HOPPET-RGE)



Vector boson, jets

V, V+jets

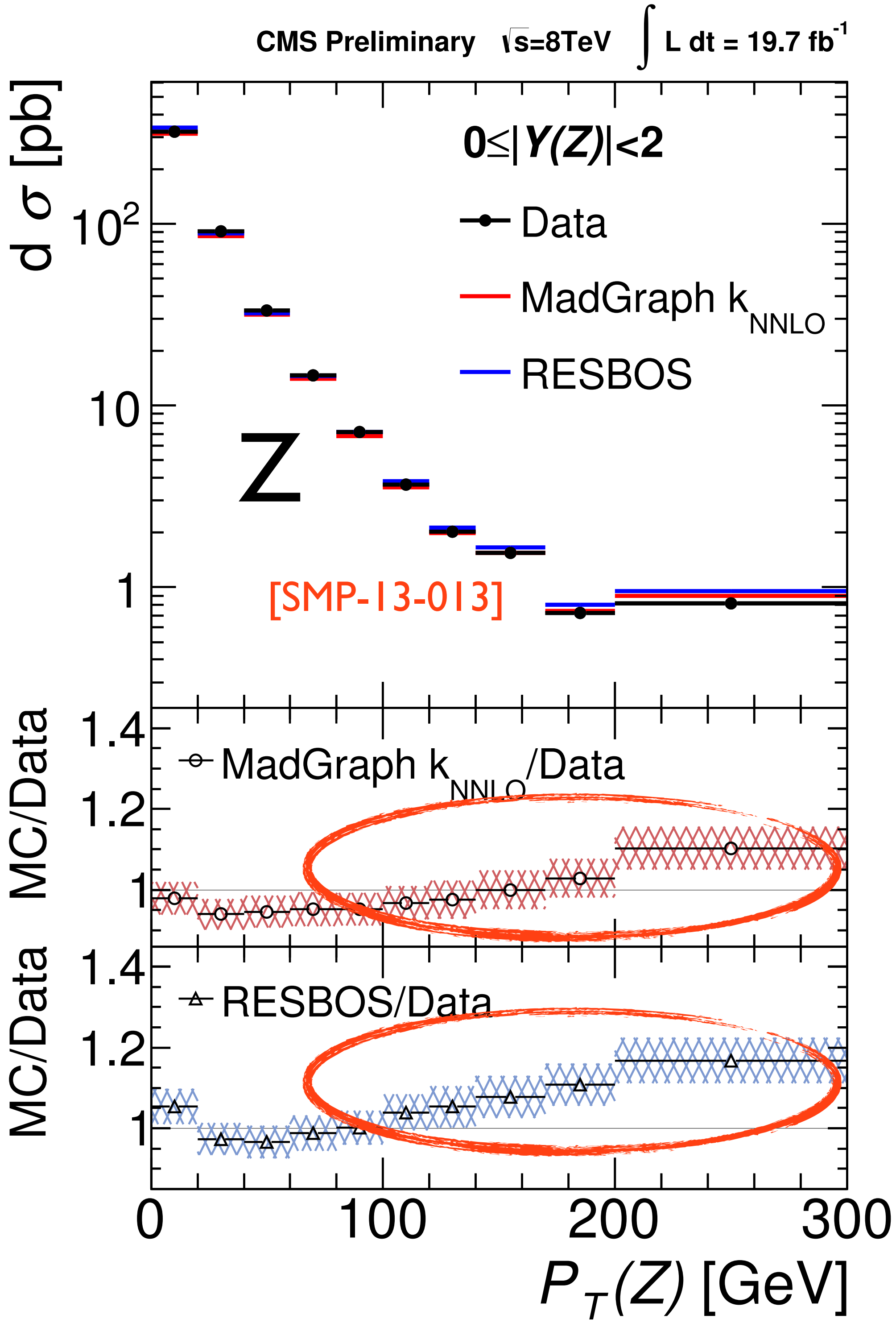
- Why study the emission of a vector boson, with or without associated jets ?
  - Background for searches
  - Sensitivity to
    - soft physics description
    - merging techniques in soft/mid-scales
    - QCD/QED corrections at harder scales



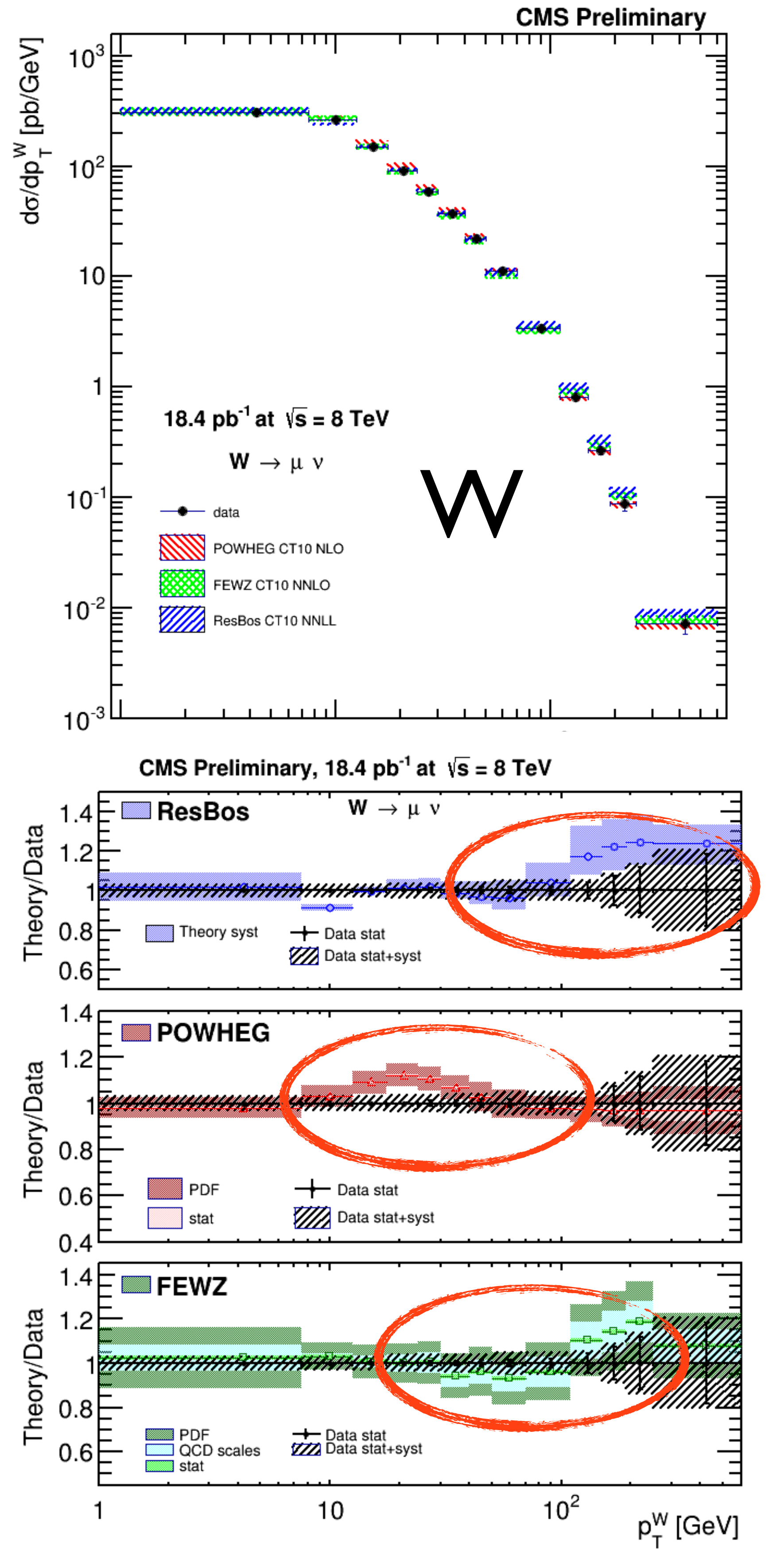
- stress test of event generators/calculations
  - tree-level vs NLO vs NNLO
    - Madgraph_aMC@NLO, Powheg, Sherpa, BlackHat,...
  - Parton shower algos (+Tunes)
    - Pythia6 vs Pythia8 vs Herwig vs... ...
  - Merging schemes (scale dependencies,...)
    - KtMLM vs ShowerKt vs CKKW-L vs FxFx vs UMEPS vs UNLOPS vs...

Dynamics of W, Z bosons: $d\sigma/dp_T$

[SMP-13-006]

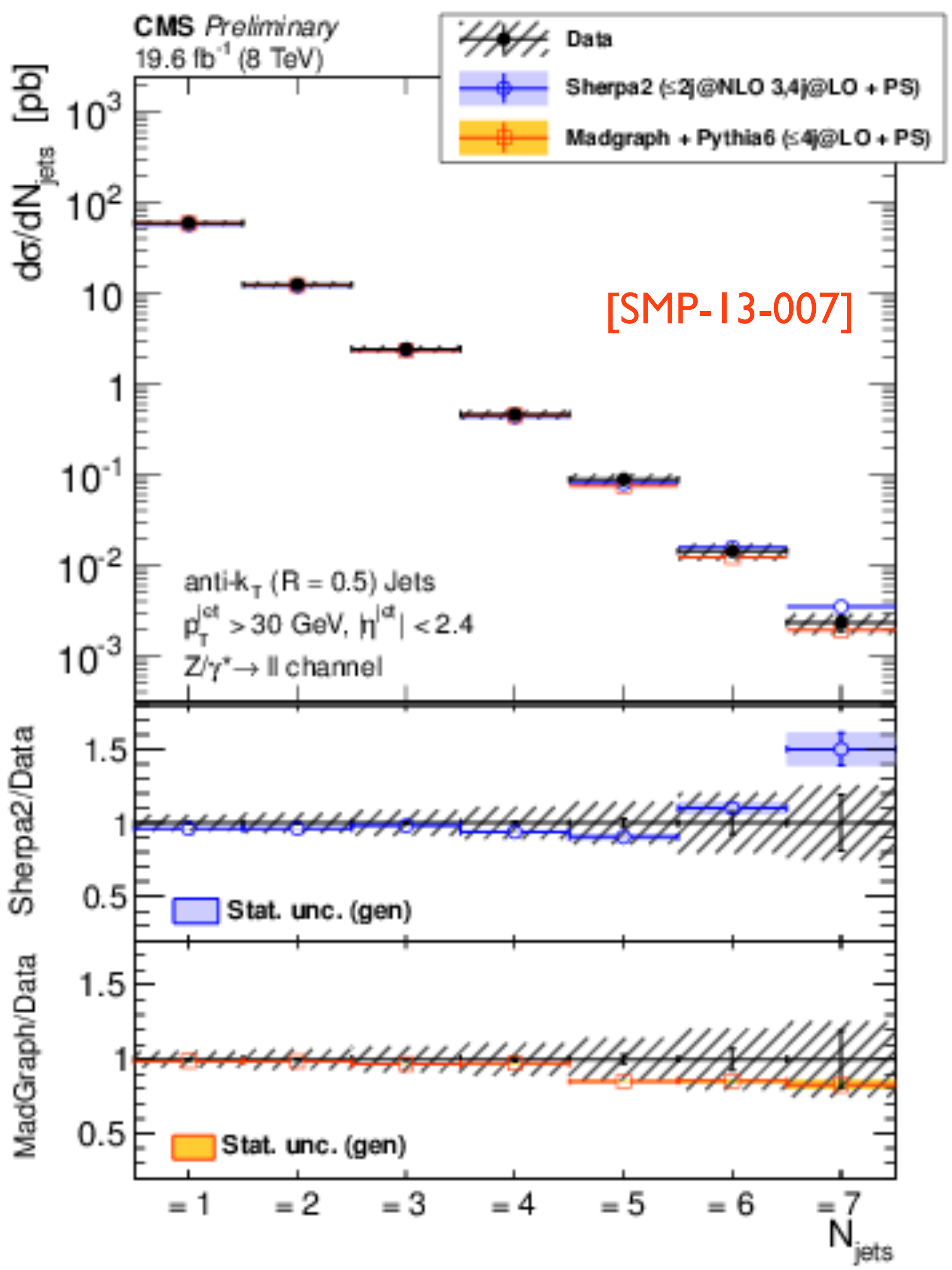


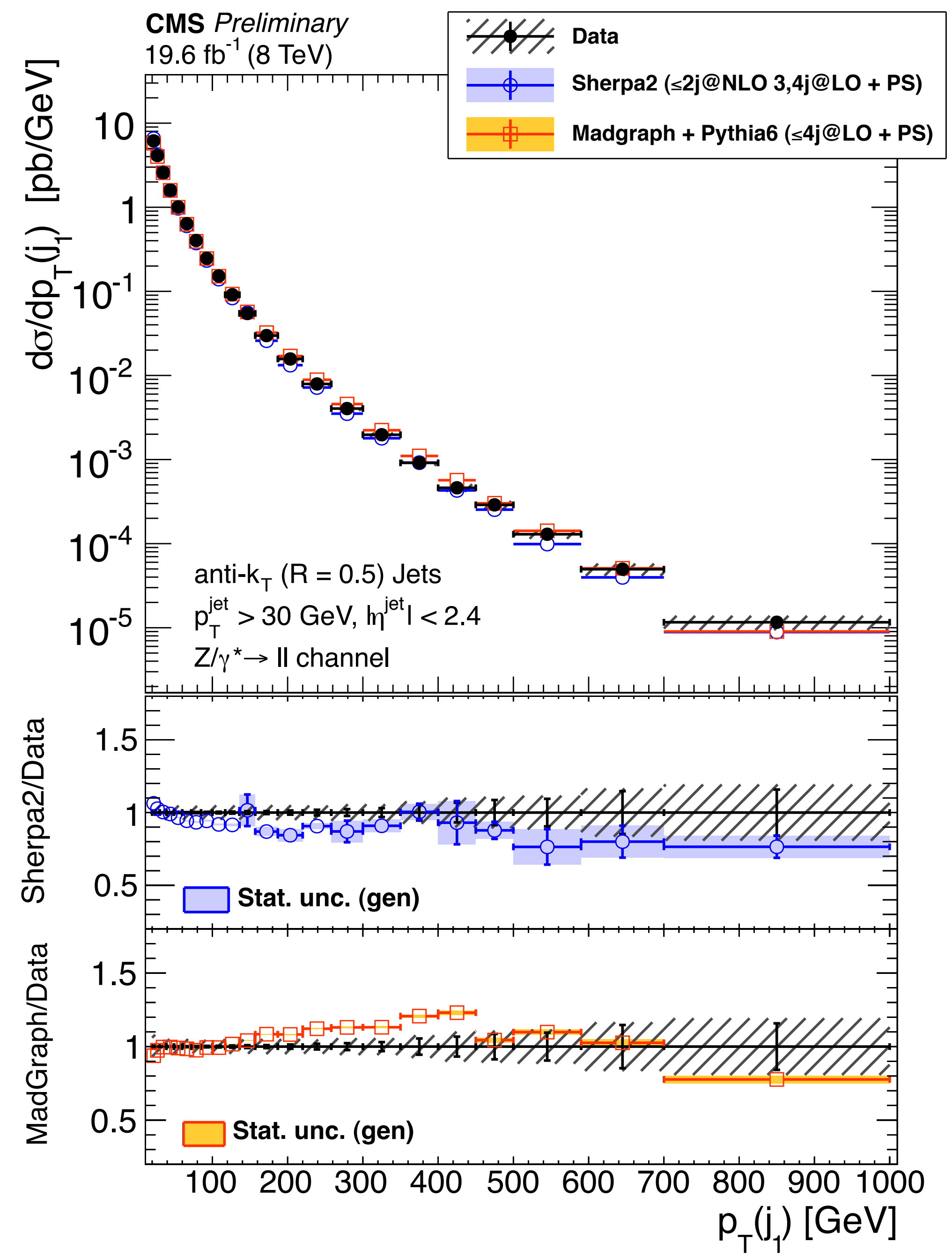
- Very simple final state
  - 1 or 2 leptons
- Large statistics
  - ~% level uncertainty



No prediction matches the data, LO or NLO

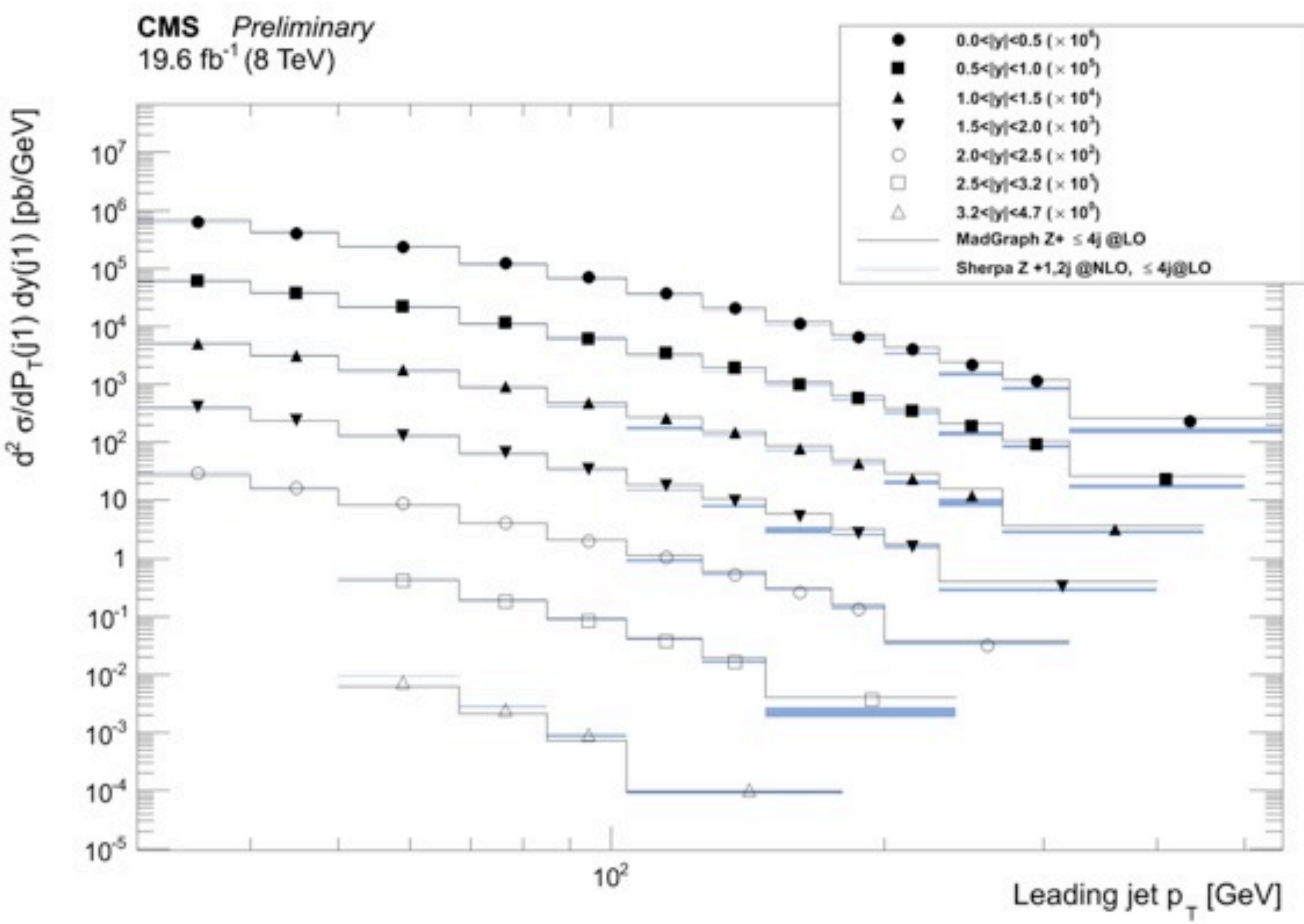
Z+jets





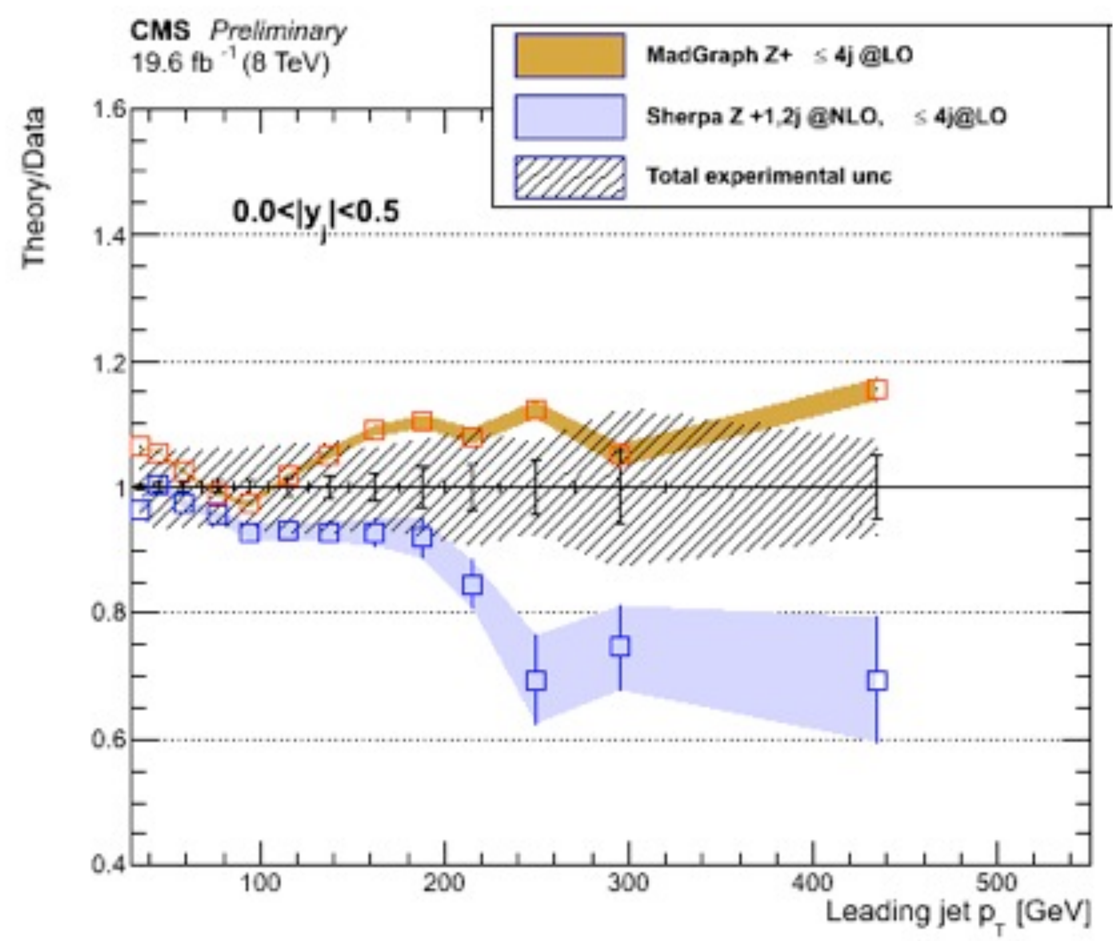
Trend observed for both Sherpa@NLO and MG prediction
Slighly better job by Sherpa@NLO for Pt(Jet)

Z+jets: 2D



[SMP-14-009]

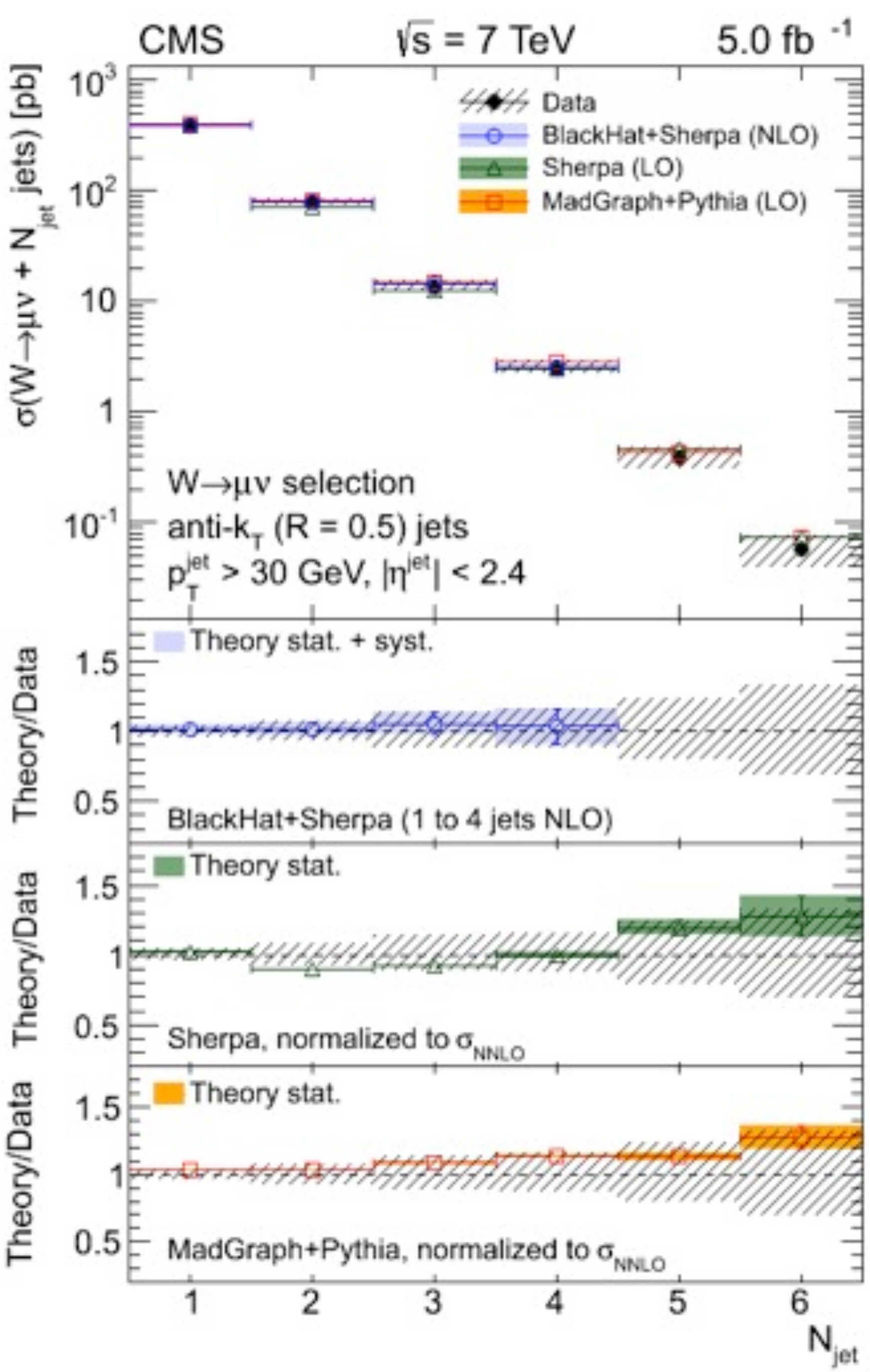
Double differential measurement of jet kinematics.
Eta coverage extended to 4.7

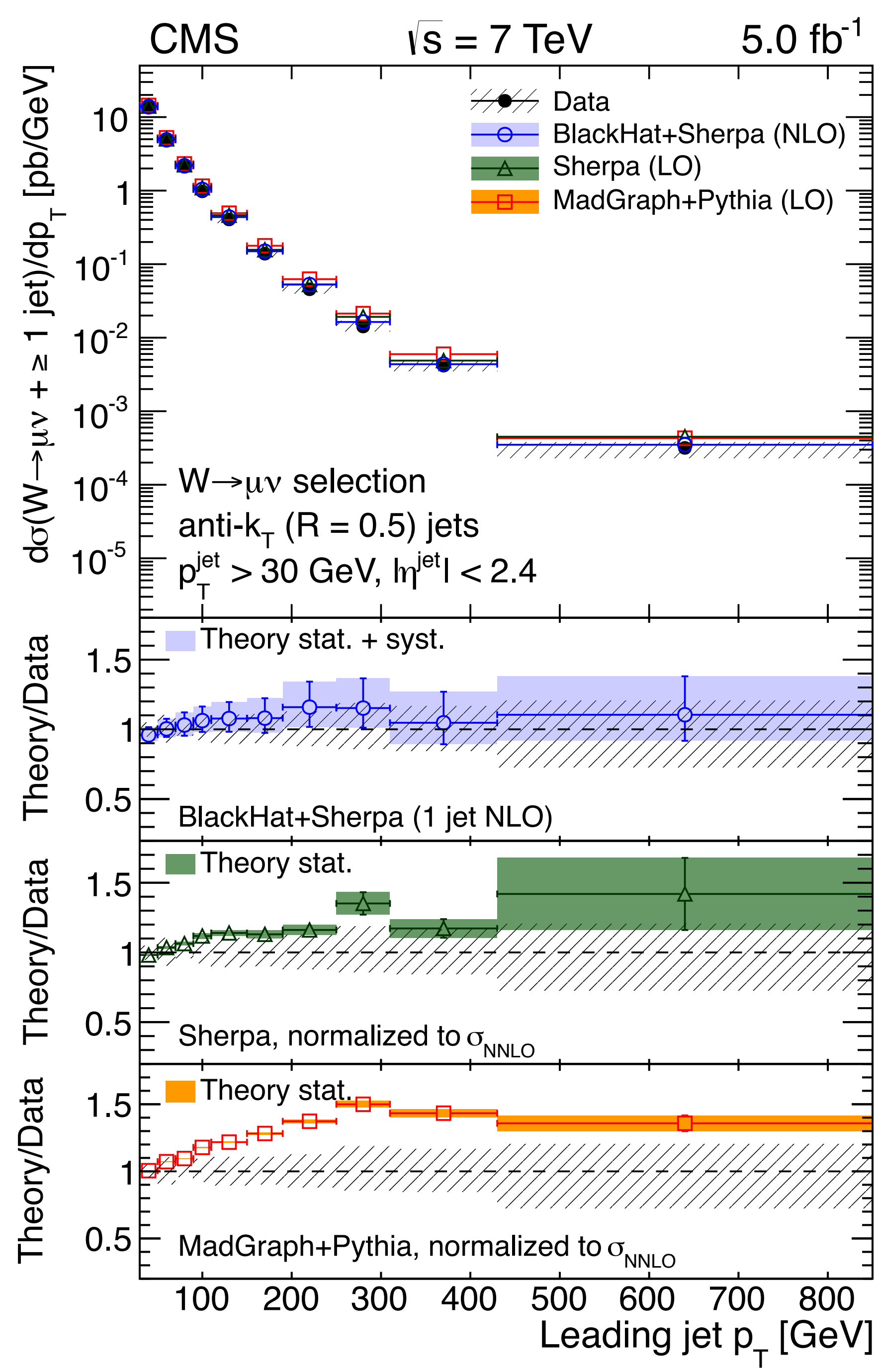


Severe trend for Sherpa
More reasonable for MG
Could be also considered to constraint PDFs

W+jets

[SMP-12-023]





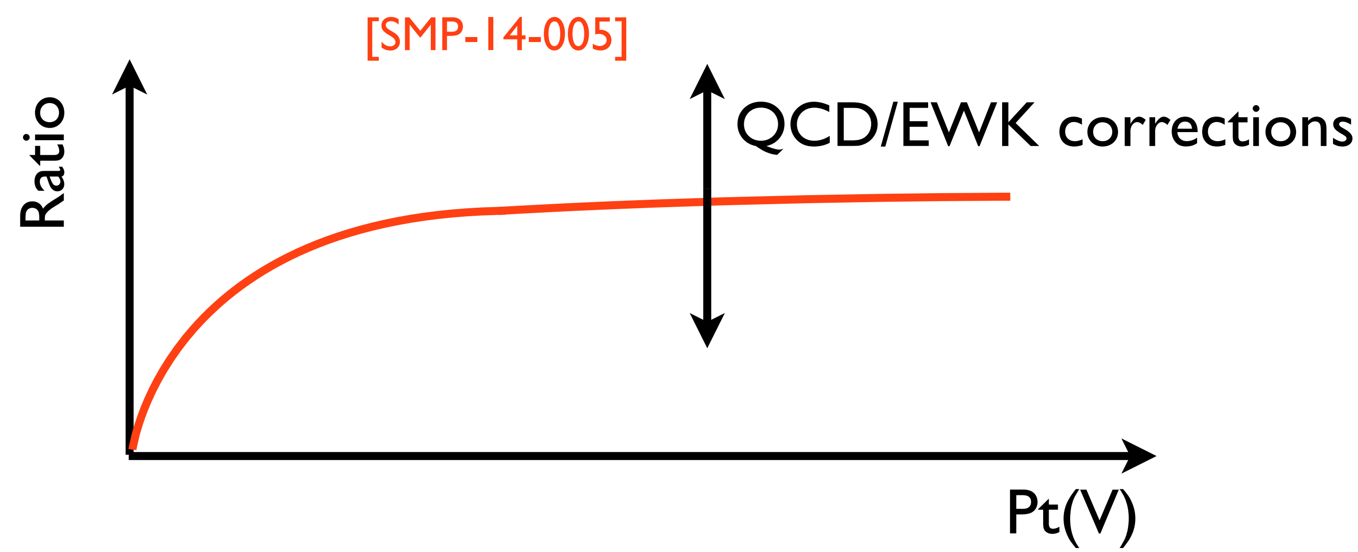
NLO: agreement is reasonable

LO:

- NJet prediction is generally ok (within uncertainties)
- Jet pt spectrum is overestimated

Z/γ+jets ratio

- Why Z/γ?
  - In high Pt

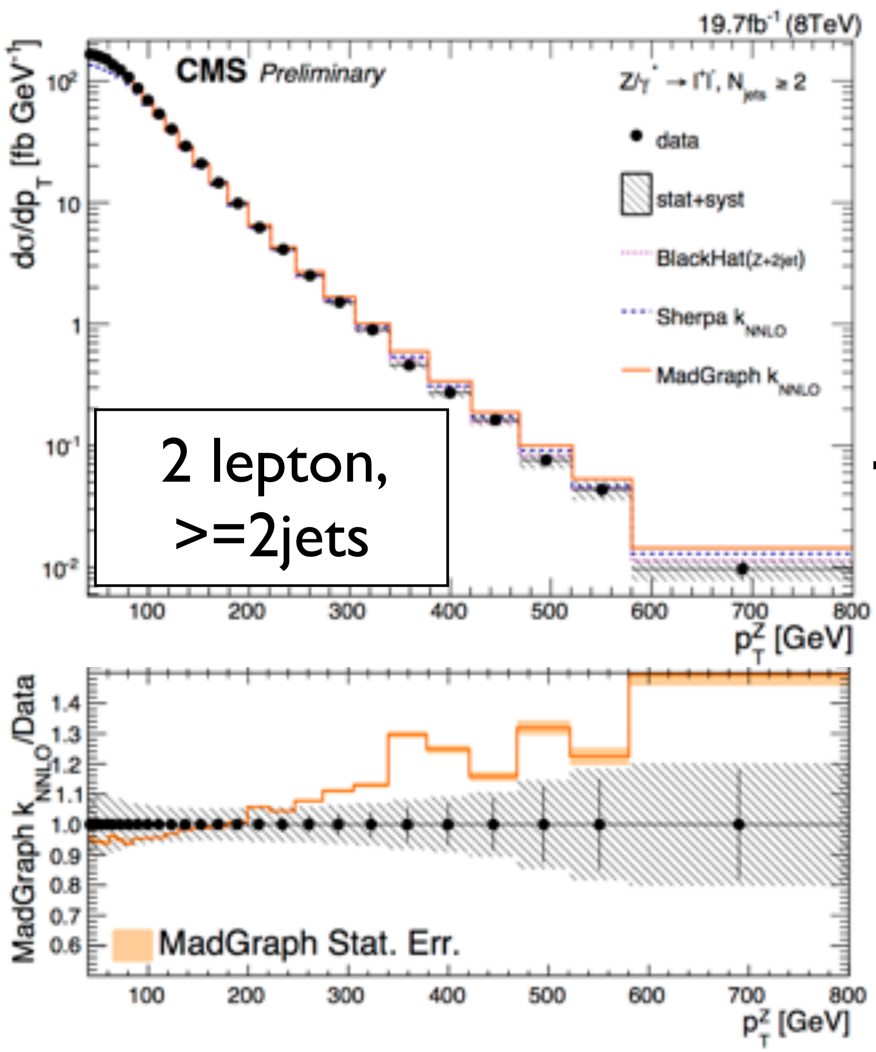


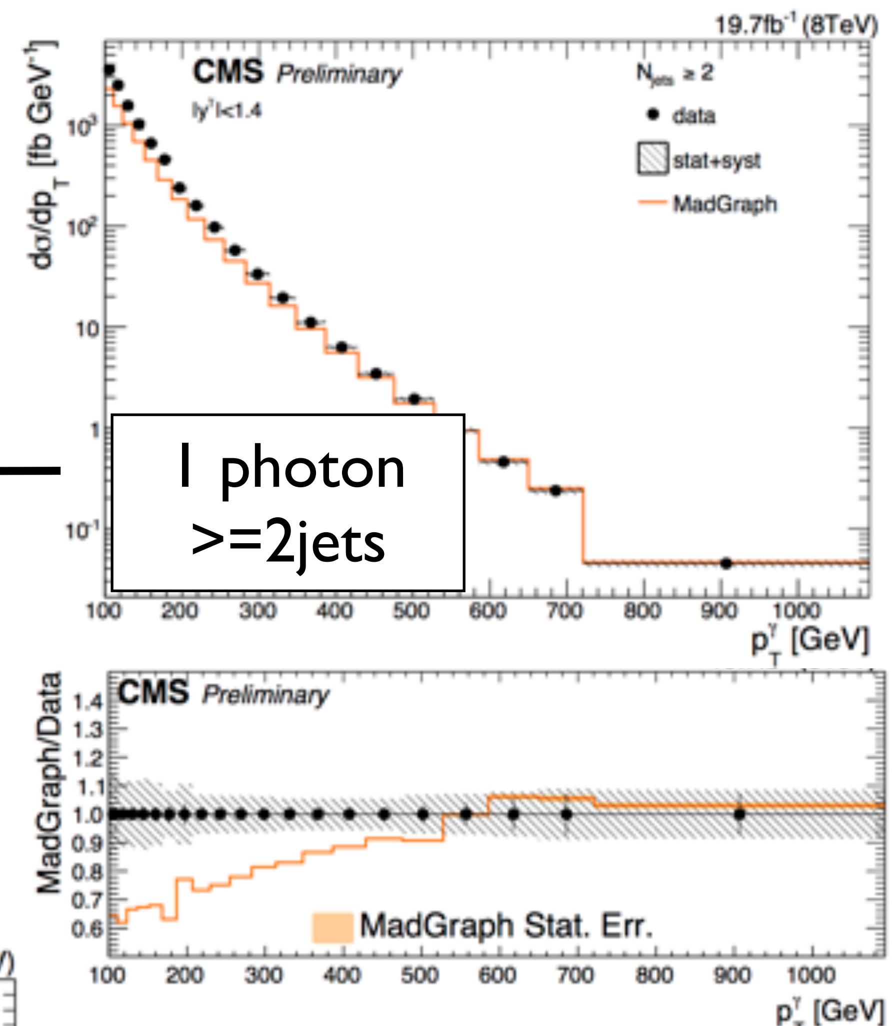
  - Both Z and γ+jets are large background processes for many searches
    - Particularly relevant for the modeling of Z→νν+jets (SUSY) in MET+jets final state

- Exp. final state:
  - 2 lept + >=1 jet, Pt>20 GeV, |η|<2.4, trigger match, M(ll)∈[81,101] GeV
  - γ + >=1 jet, Pt>100 GeV, $|\eta_{\gamma}|$<1.4
  - >= 1 jets: pt>30 GeV, |η|<2.4
  - DeltaR(photon, γ OR lepton)>0.5

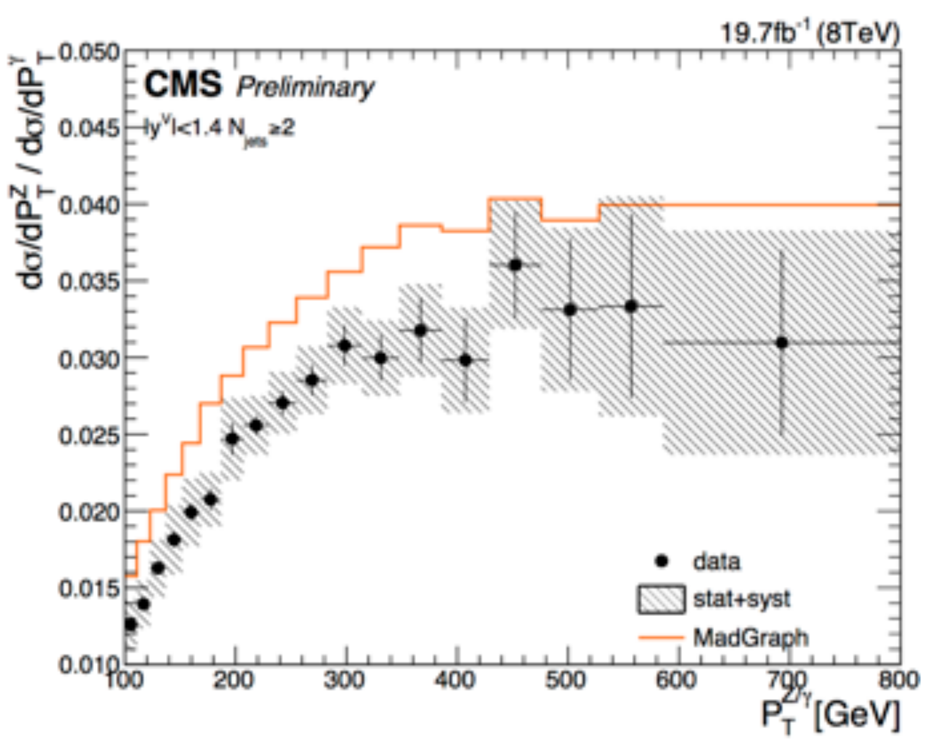
Z/γ+jets ratio

[SMP-14-005]



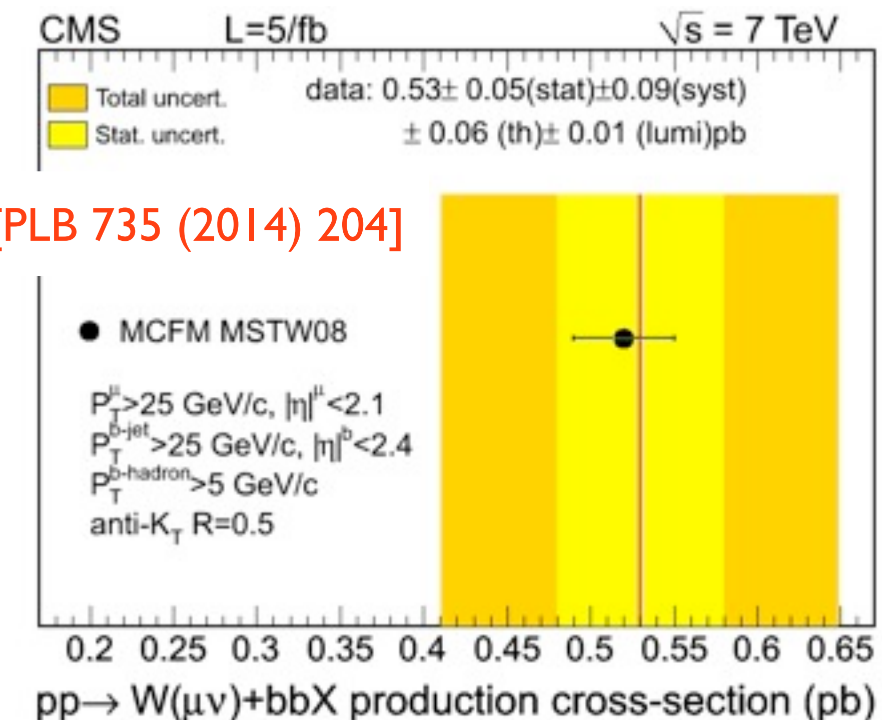


Ratio of unfolded Z and photon quantities



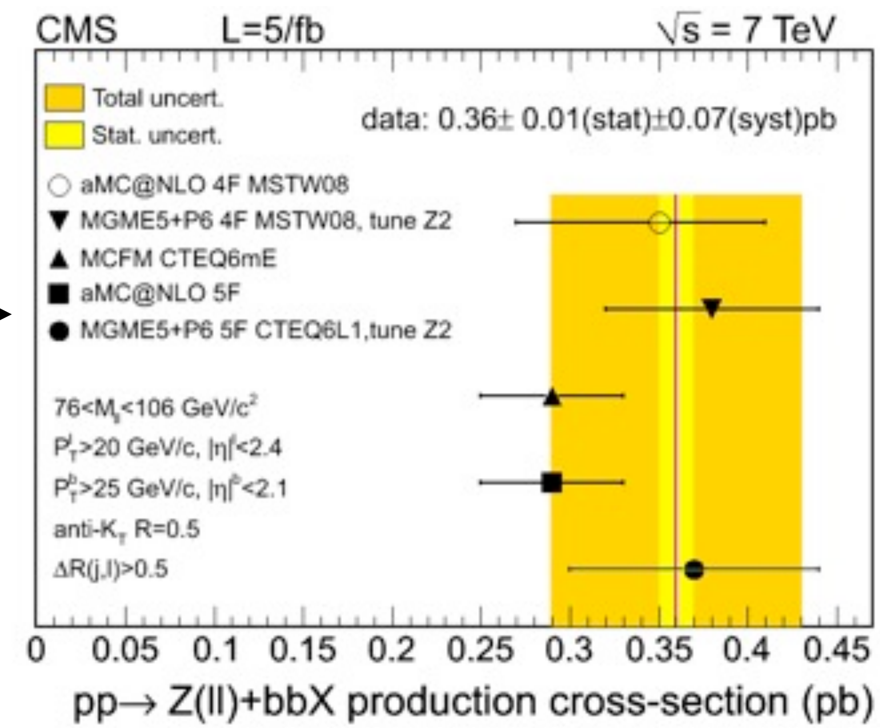
MG predicts good shape, but wrong ratio.
BlackHat will be added soon

W+b-jets, Z+b-jets, Z+ b-hadron

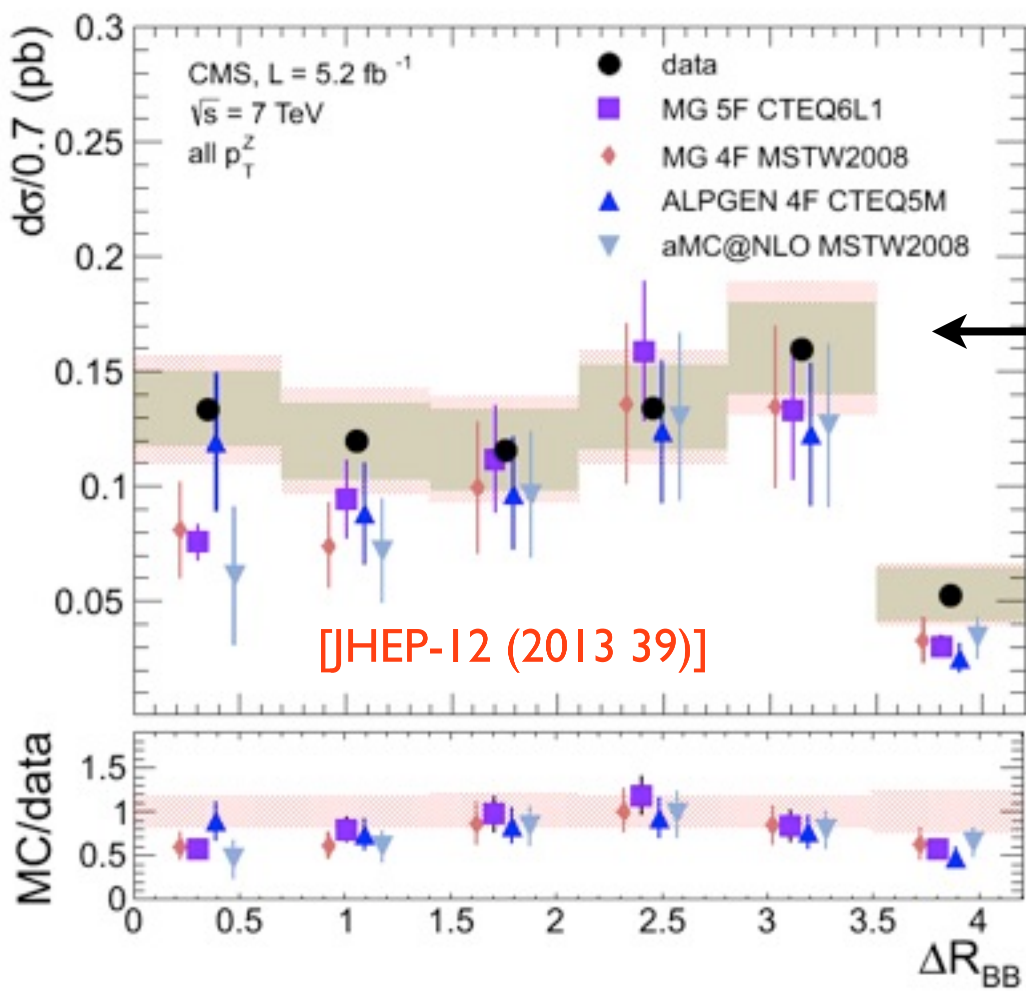


[PLB 735 (2014) 204]

b-jets



[JHEP 1406 (2014) 120]



[JHEP-12 (2013 39)]

b-hadrons

In general:

*V+2b-jets is well predicted

*Collinear BB production is not well predicted

*4F seems: better job in V+2b-jets

*5F seems: better job in V(=Z)+1b-jet

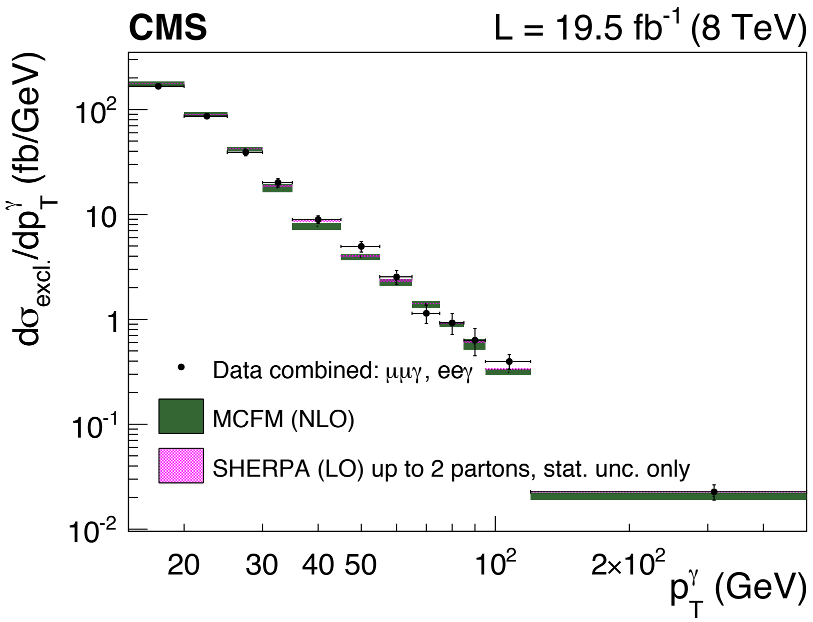
diboson: aT/Q GC

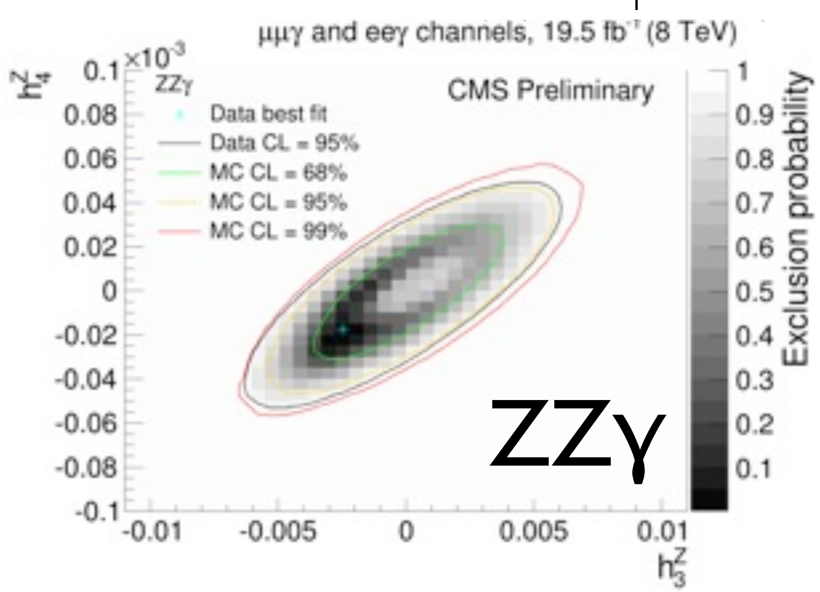
diboson studies

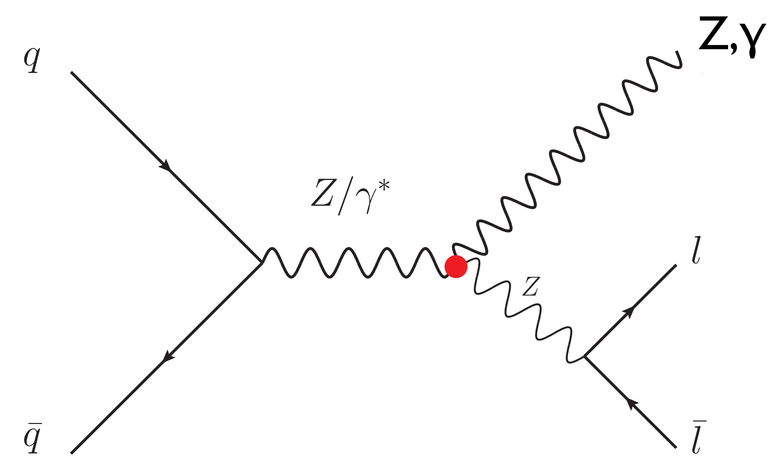
- Why?
  - Background for searches
    - ZZ, WW, γγ
  - Gate to explore «extended» Standard Model (see Fabio's talk)
    - moving to dim 6 or 8: adds new couplings without involving new particles
    - Trilinear anomalous gauge couplings
      - ZZγ, Zγγ, WWγ, ...
    - Quartic gauge couplings
      - WWWW, WWZZ,..
  - diboson process xsec are well predicted by theory (NLO, NNLO)
    - Any significant deviation could be a sign of anomalous gauge coupling

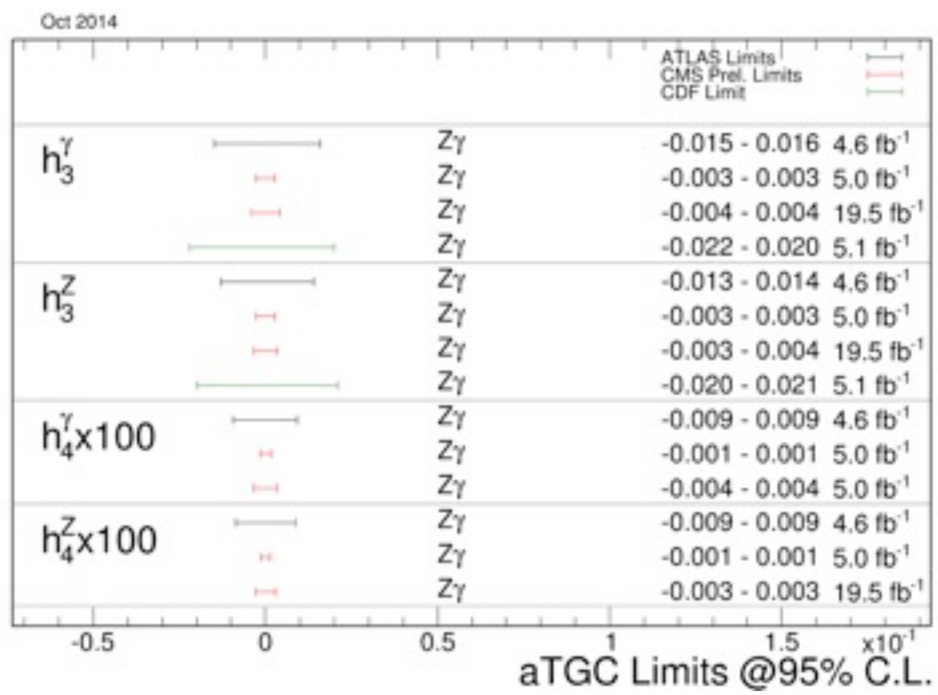
Neutral ZZγ and Zγγ aTGC: Zγ and ZZ

Zγ (llγ)

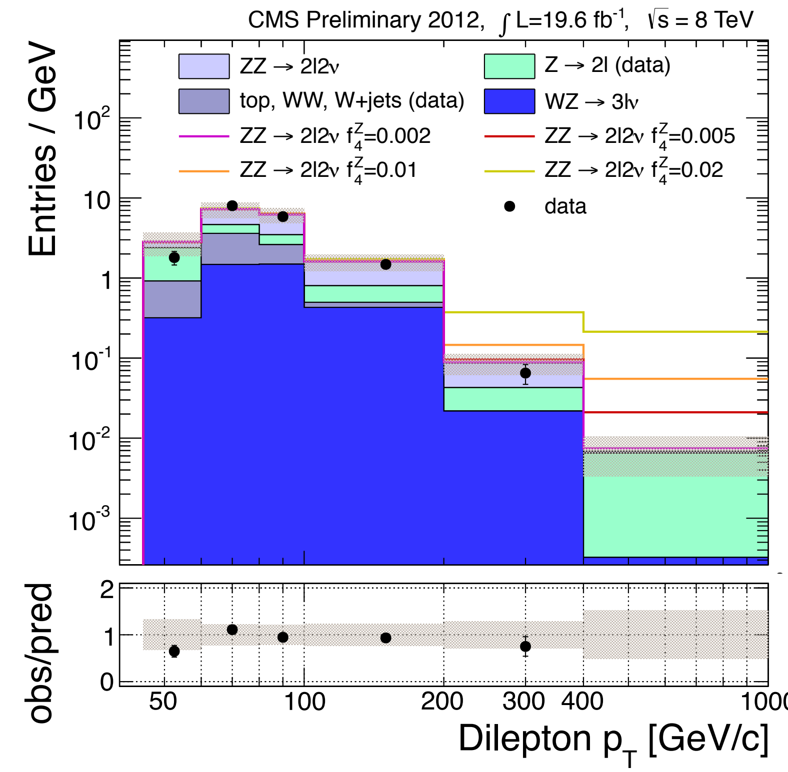


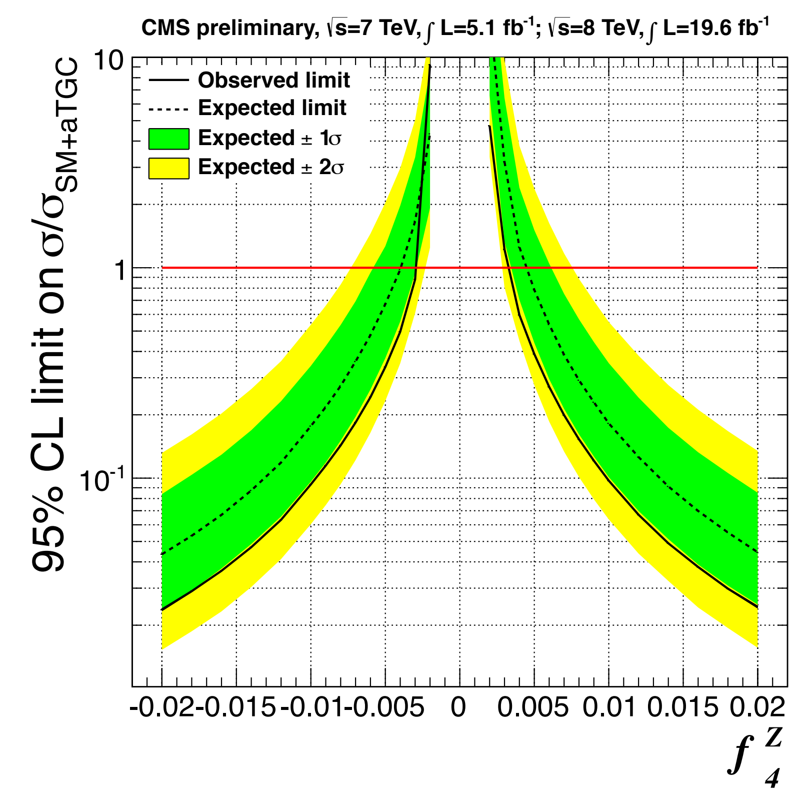






ZZ (2l2ν)

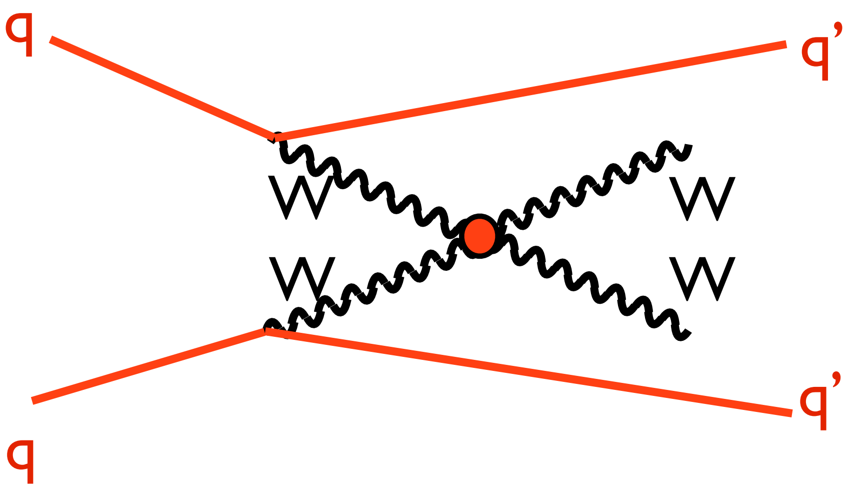




So far, no evidence for aTGC: new couplings compatible with 0

Same conclusion for studies with other FS

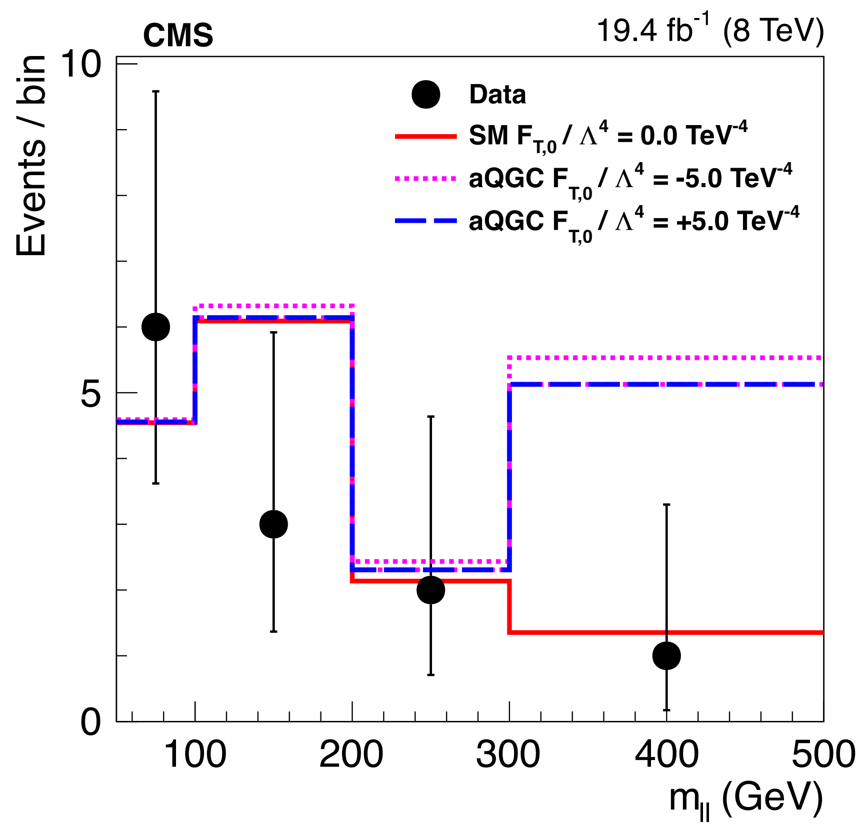
aQGC using same sign WW+2 jets



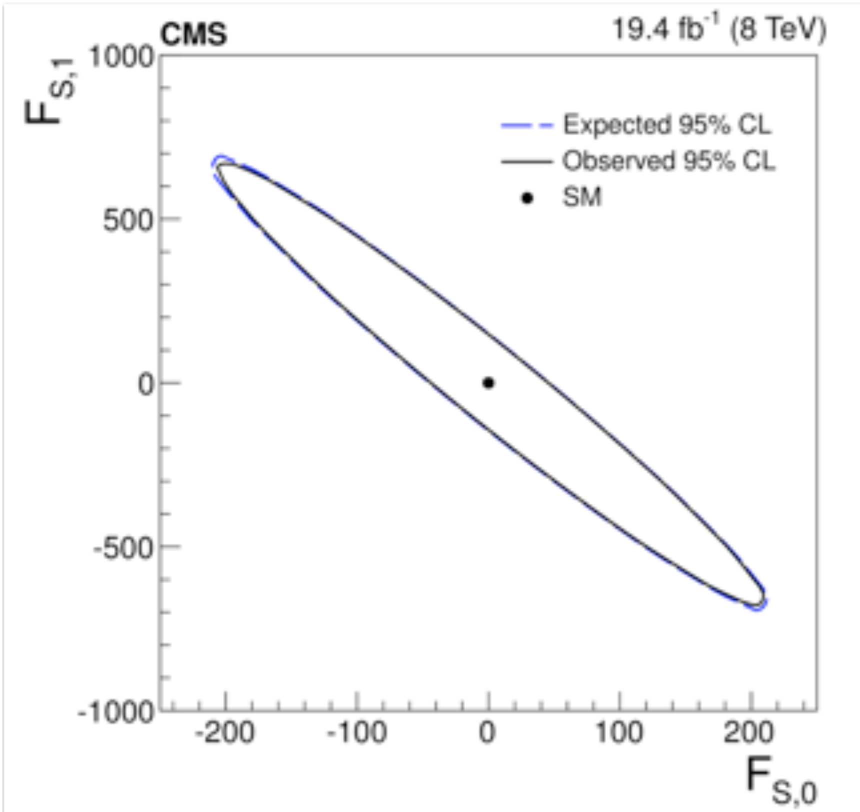
[SMP-13-015]

Same sign W bosons: suppresses QCD background

VBS⇒Large rapidity + high mass between forward jets



data vs 2 aQGC scenarios



Limits (here on 2 couplings only)

So far, no evidence for aQGC: new couplings (Phys. Rev. D 74 (2006) 073005) compatible with 0

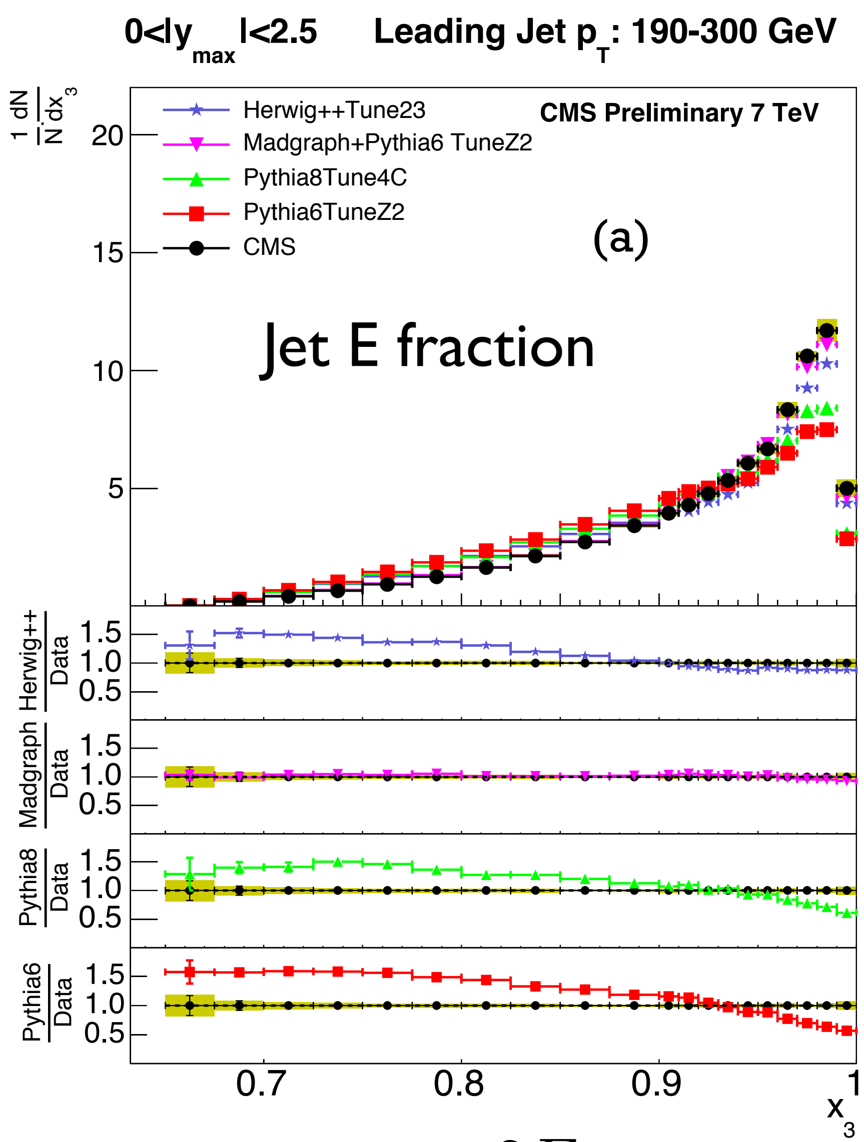
Conclusion

- Standard model processes are studied in CMS
  - more than 60 papers or public notes since ~2010
  - spans various kind of final states
  - QCD, W+c, W asymmetry: impact on PDF, α_s
  - V, V+jets: stress test for tree-level, NLO, NNLO, 4F vs 5F, merging schemes
  - VV: «extended» version of the Standard Model probed with aTGC and aQGC.
- One important message from Run I
  - Prediction from theory existing/used in Run I are not yet providing a «universal» solution for background predictions. A new era has started with the advent of merged ME+PS @ NLO event generators: one of the first Run II todo is test them as accurately as possible, and provide a quick feedback to the theory side

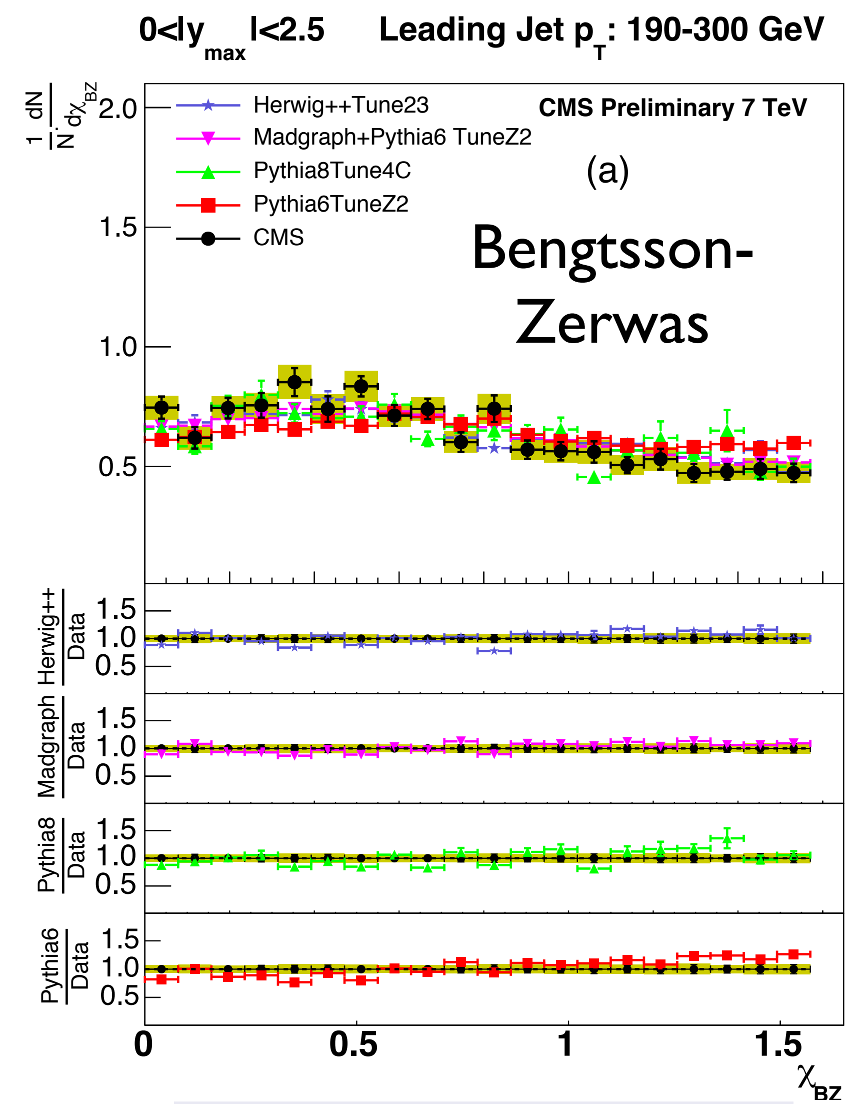
Backup slides

Testing (ME+)PS predictions on 3 and 4-jet cross-section

[QCD-11-006]



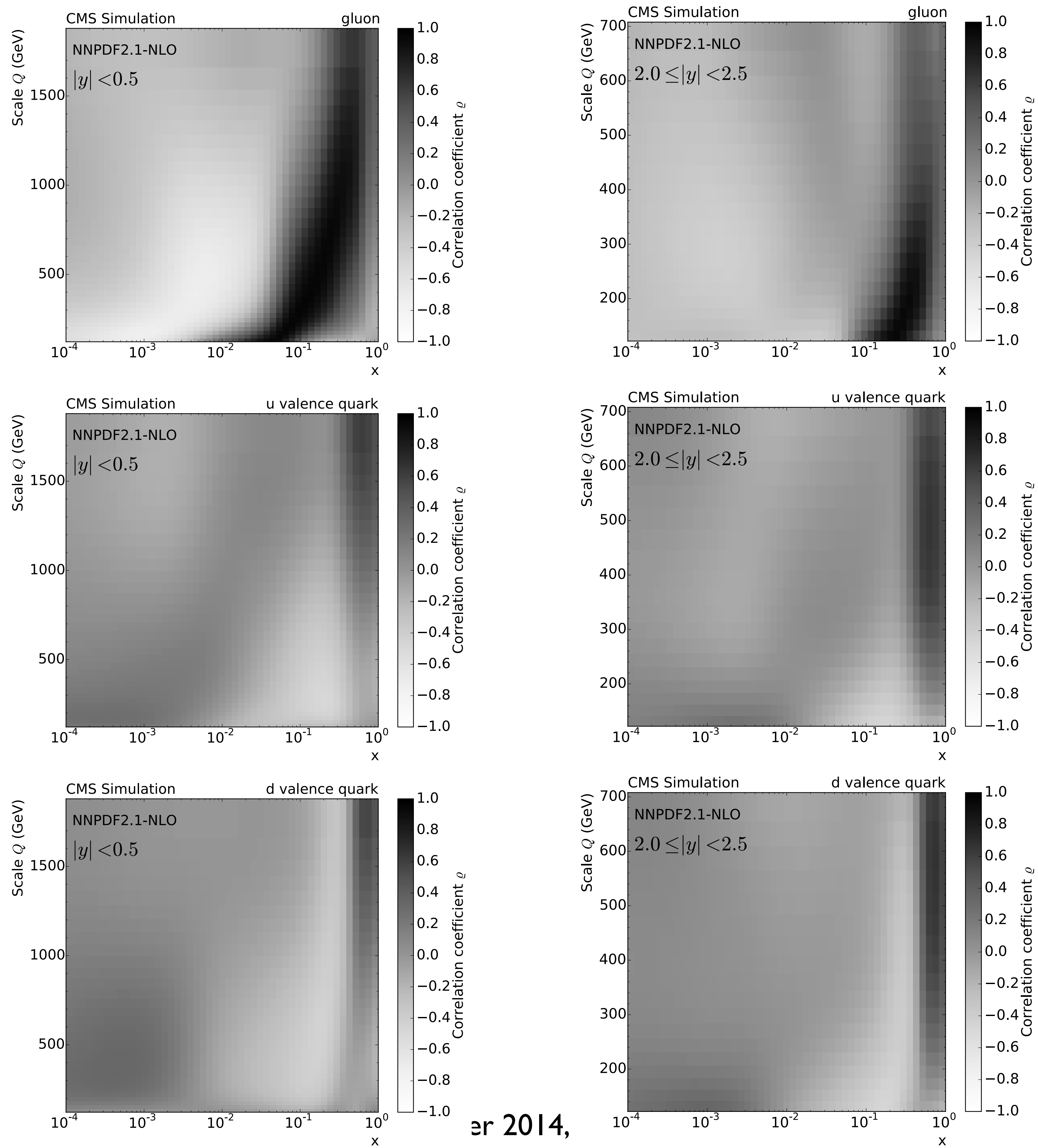
$$x_i = \frac{2E_i}{\sqrt{\hat{s}_{234}}}$$



$$\chi_{BZ} = \frac{(\mathbf{p}_1 \wedge \mathbf{p}_2)\cdot(\mathbf{p}_3 \wedge \mathbf{p}_4)}{|\mathbf{p}_1||\mathbf{p}_2||\mathbf{p}_3||\mathbf{p}_4|}$$

MG5+P6: most consistent with data (multi-partonic TL prediction)
Depending on variable, P6 and H++ can do as good as MG

scale-x correlation



er 2014,

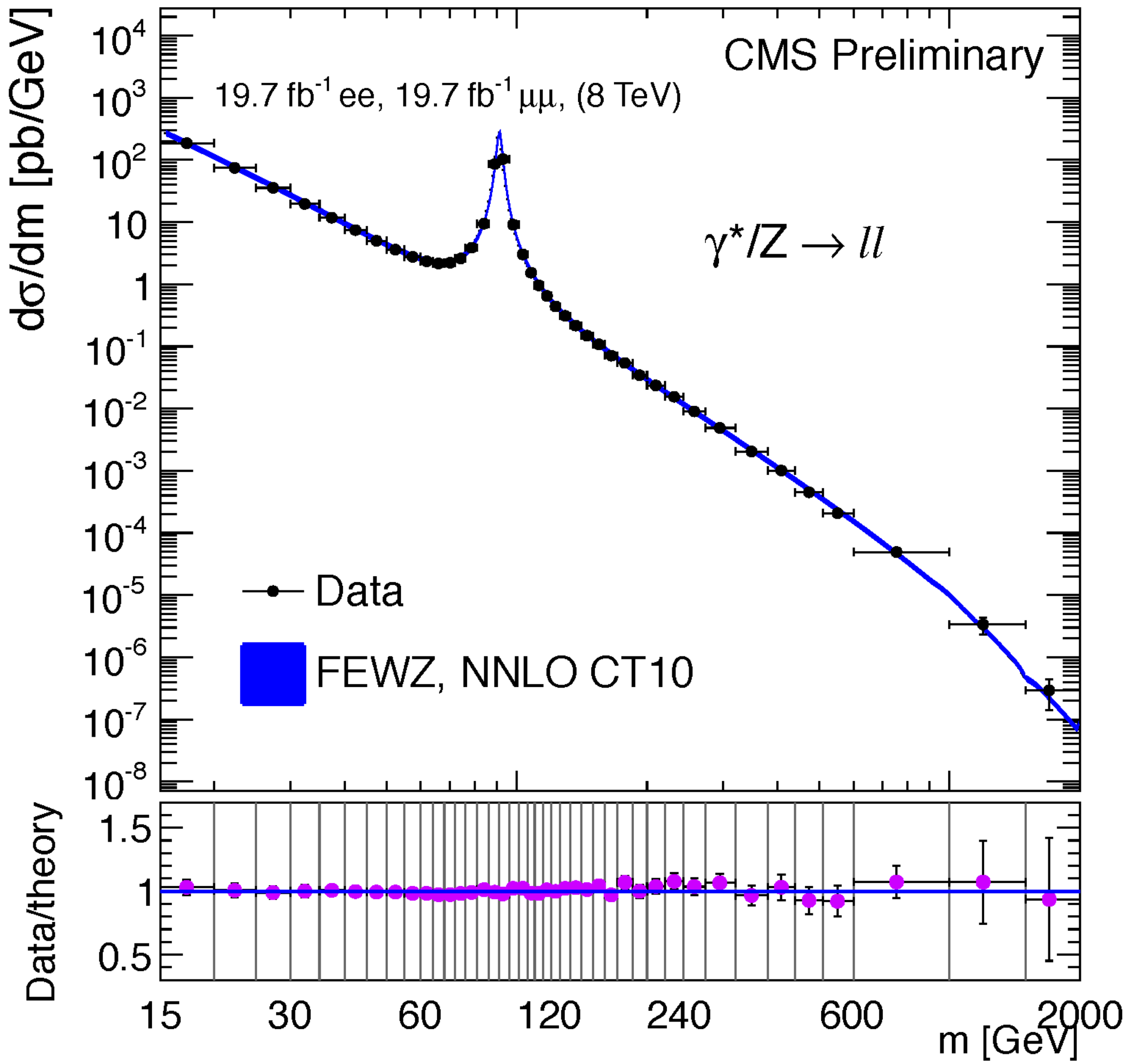
SMP-12-028 uncertainties

Systematic source		Shift in standard deviations
JEC0	absolute jet energy scale	0.01
JEC1	MC extrapolation	−0.26
JEC2a	single-particle response barrel	1.03
JEC2b	single-particle response endcap	−1.64
JEC2c	single-particle decorrelation $\|y\| < 0.5$	−0.11
JEC2d	single-particle decorrelation $0.5 \leq \|y\| < 1.0$	0.08
JEC2e	single-particle decorrelation $1.0 \leq \|y\| < 1.5$	0.85
JEC3	jet flavor correction	0.05
JEC4	time-dependent detector effects	−0.21
JEC5	jet p_T resolution in endcap 1	0.68
JEC6	jet p_T resolution in endcap 2	−0.38
JEC7	jet p_T resolution in HF	0.00
JEC8	correction for final-state radiation	−0.01
JEC9	statistical uncertainty of η-dependent correction for endcap	−0.38
JEC10	statistical uncertainty of η-dependent correction for HF	0.00
JEC11	data-MC difference in η-dependent pileup correction	0.89
JEC12	residual out-of-time pileup correction for prescaled triggers	−0.13
JEC13	offset dependence in pileup correction	0.10
JEC14	MC pileup bias correction	0.29
JEC15	jet rate dependent pileup correction	0.43
Unfolding		−0.31
Luminosity		0.10
NP correction		0.62

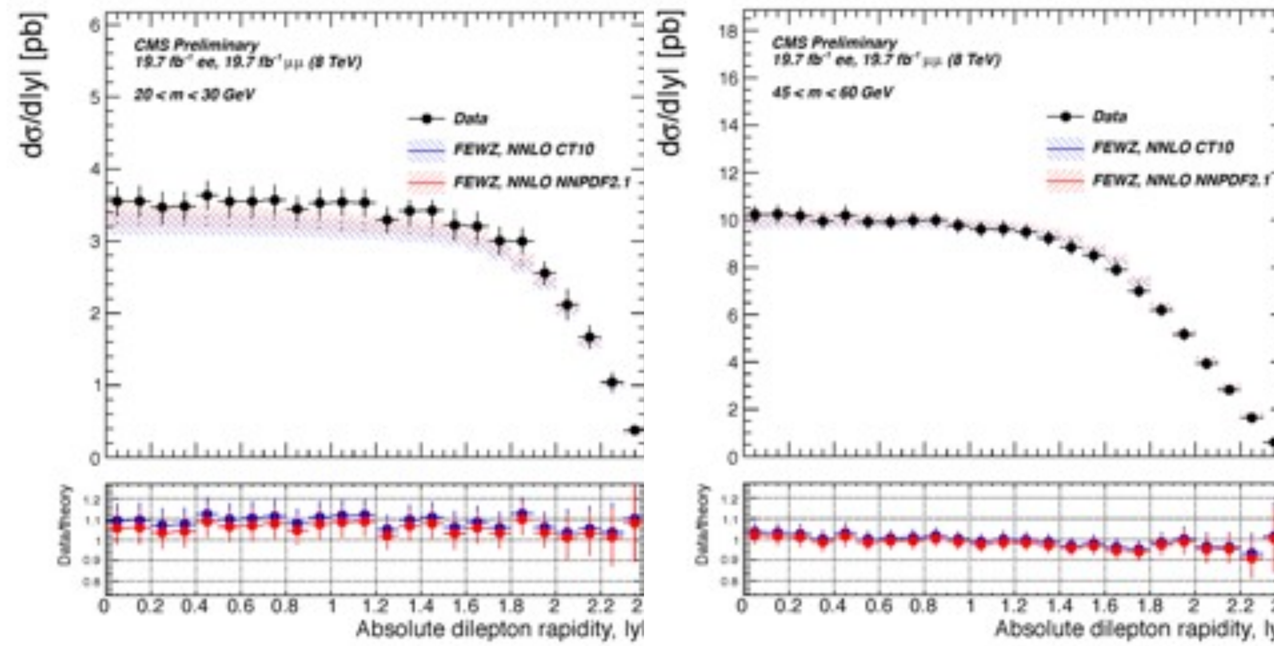
PDF from Drell-Yan: $d^2\sigma/dmdy$

[SMP-14-003]

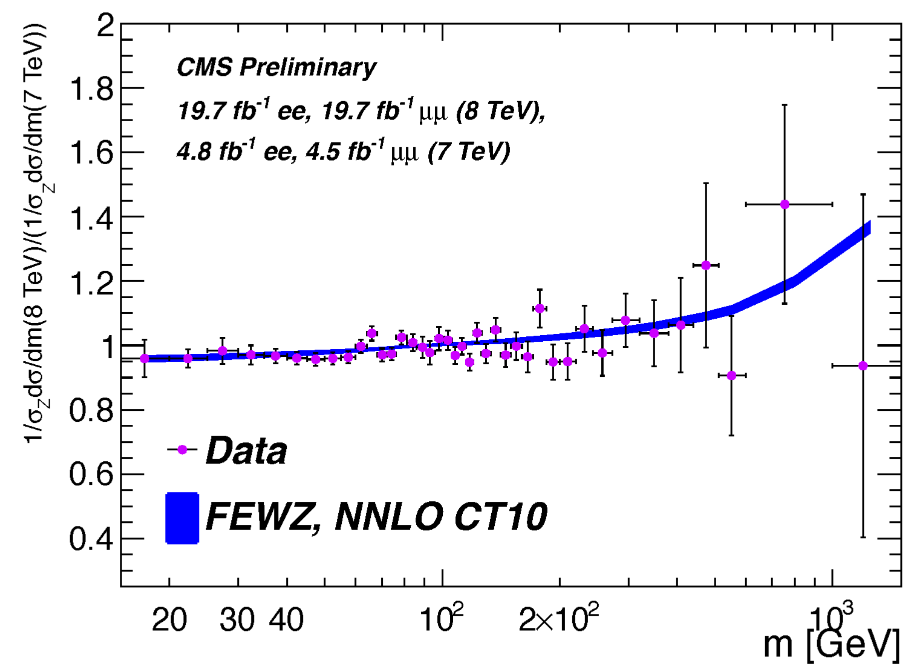
Classical channel to test QCD calculations and PDF



Description of M(ll) over 10 orders of magnitude!



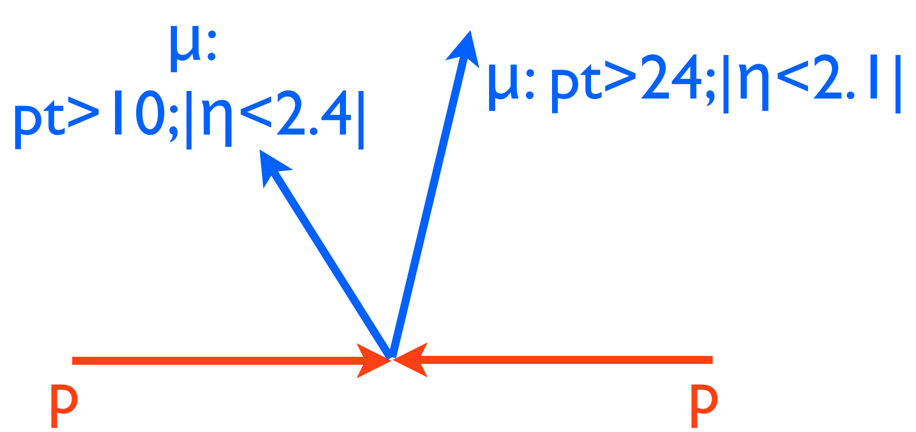
Data/MC agreement depends on PDF and M(ll) range



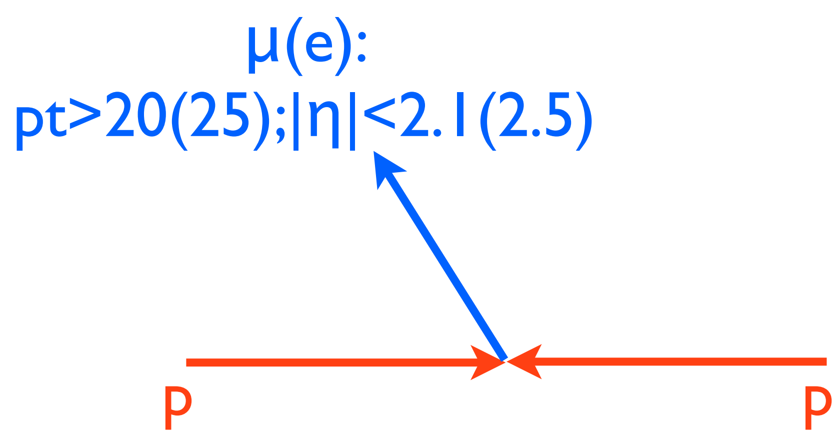
pre-FSR DY 8/7 TeV ratio: entirely depending on sqrt(s) and x!

V+X

- Drell-Yan



- W

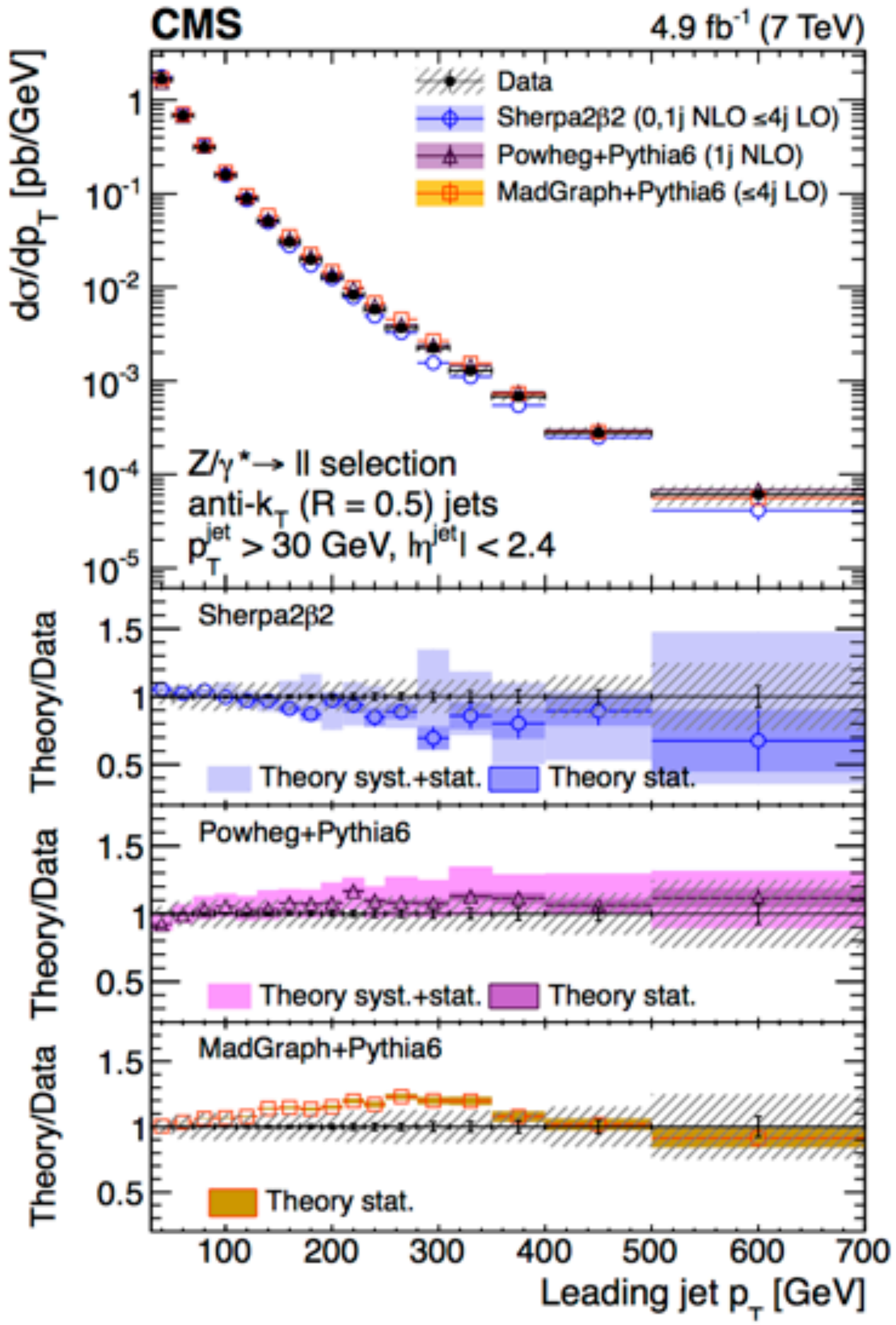


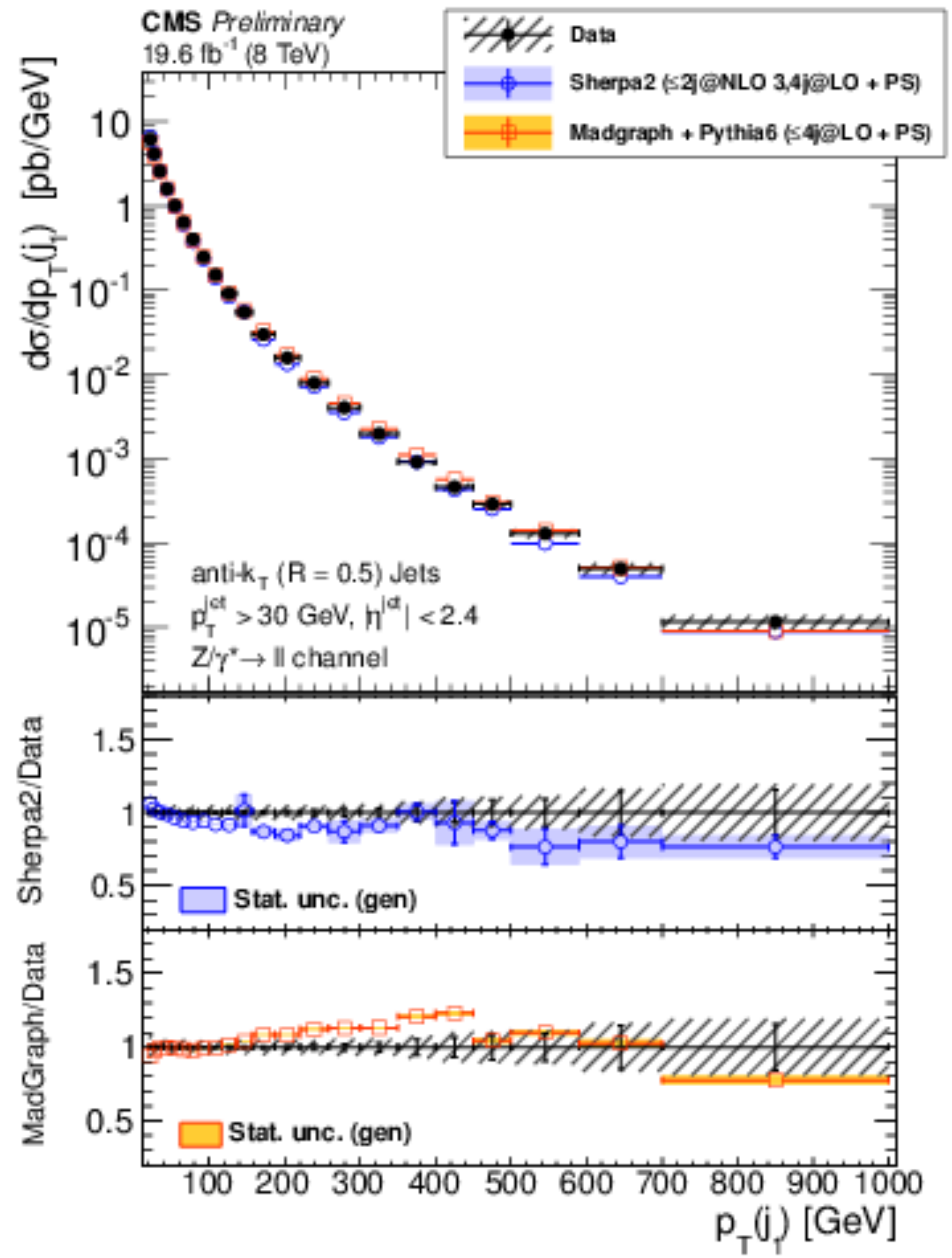
- Unfolded to:
  - M(μμ)∈[81,101]
  - Pt(μ)>25(10), |η(μ)|<2.1(2.4)
- Unfolded to
  - Pt(e)>25, |η(e)|<2.4
  - Pt(μ)>20, |η(μ)|<2.1

data/MC comparisons

RESBOS: NNLL/NLO Q_T resummation in W, Z processes
FEWZ: NNLO prediction of W, Z spectra
MG5: tree-level prediction, interfaced with Pythia6
POWHEG: NLO event generator, interfaced with Pythia6

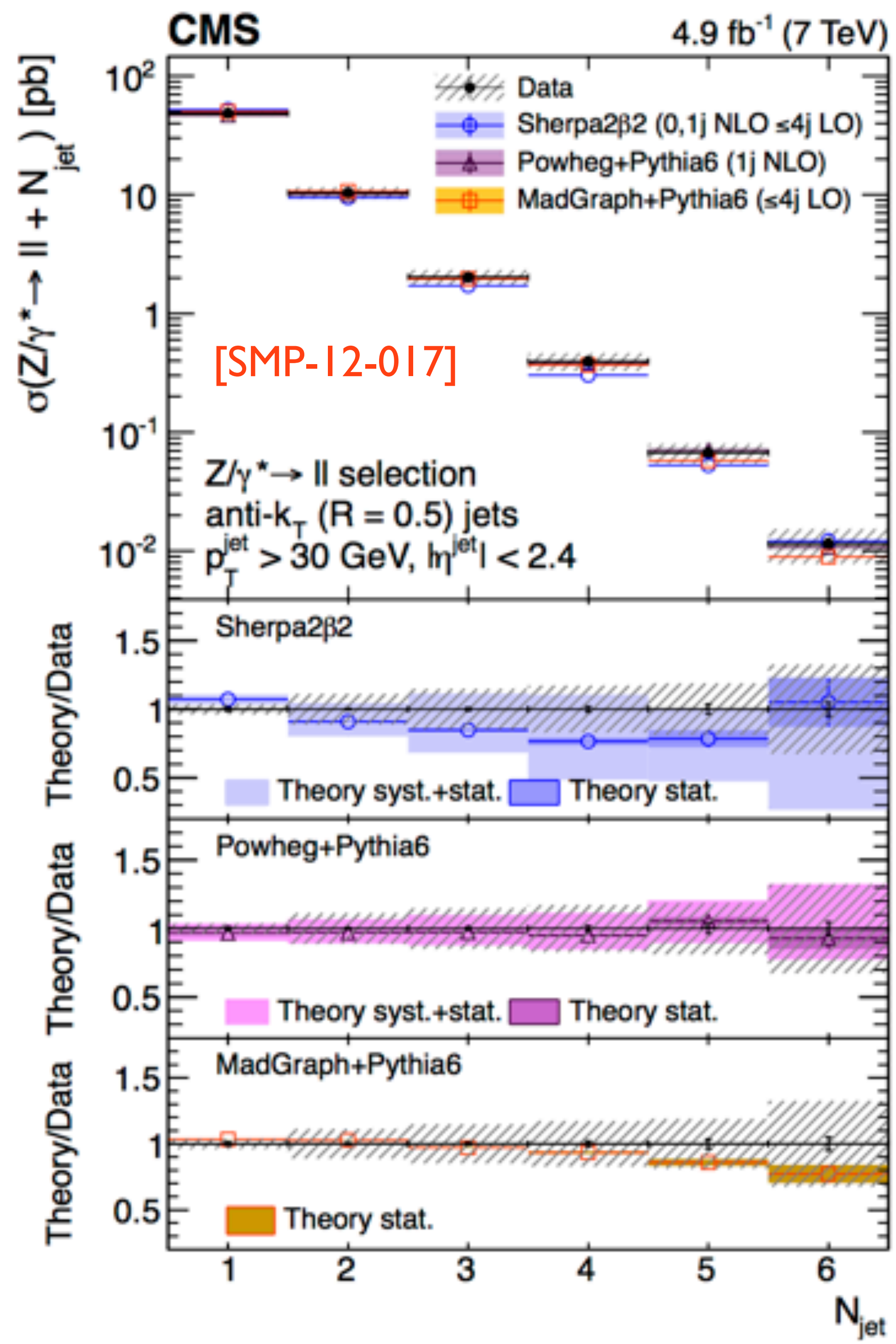
Z+jets: Jet Pt

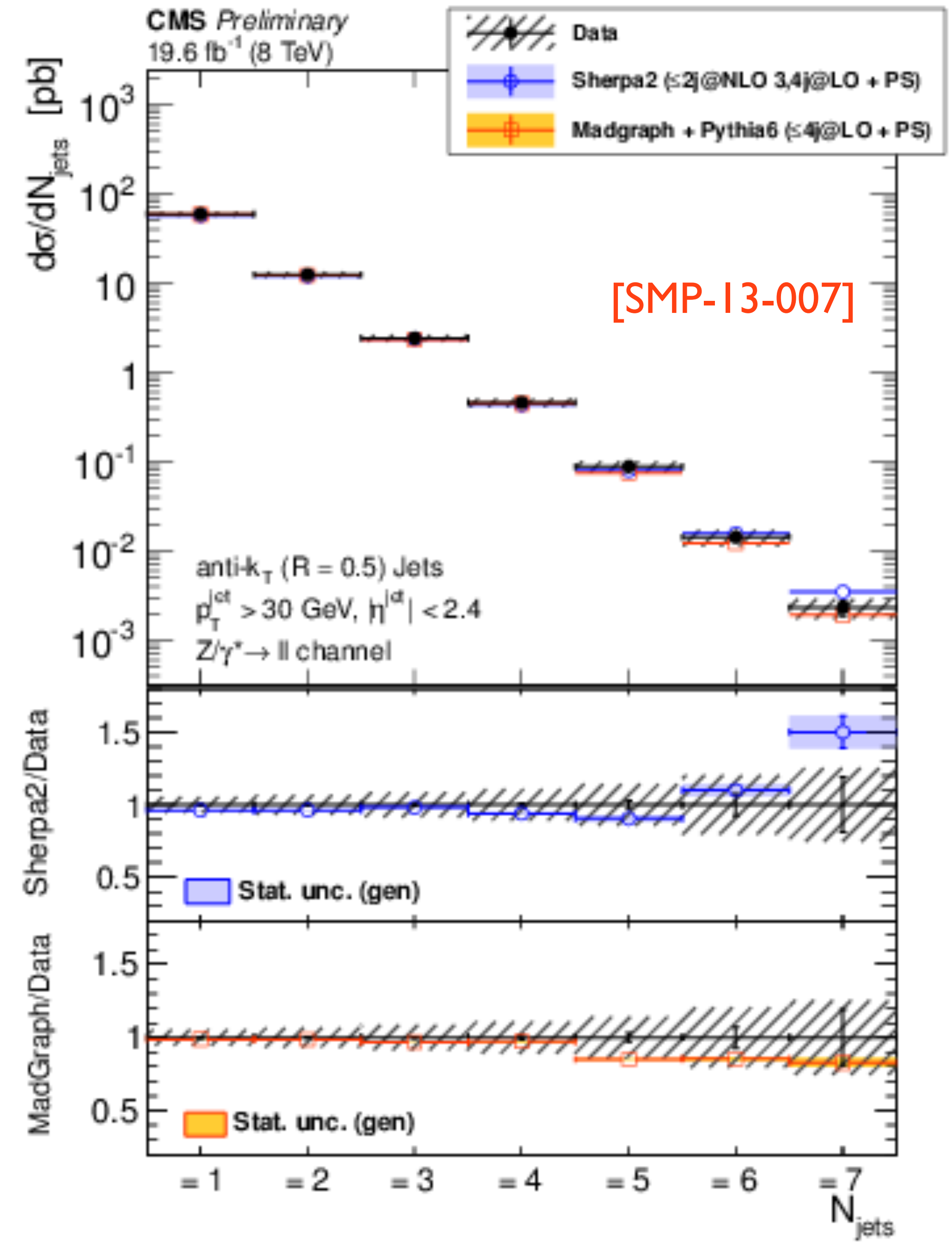




7 TeV: same trend for powheg+P6 and MG, inverted trend for Sherpa
8 TeV: idem for MG and Sherpa

Z+jets





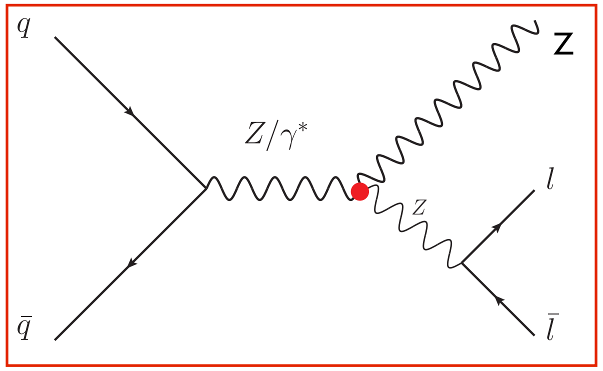
7 TeV: -powheg+P6 does the best job

-trends for MG and Sherpa (No theory uncertainties included)

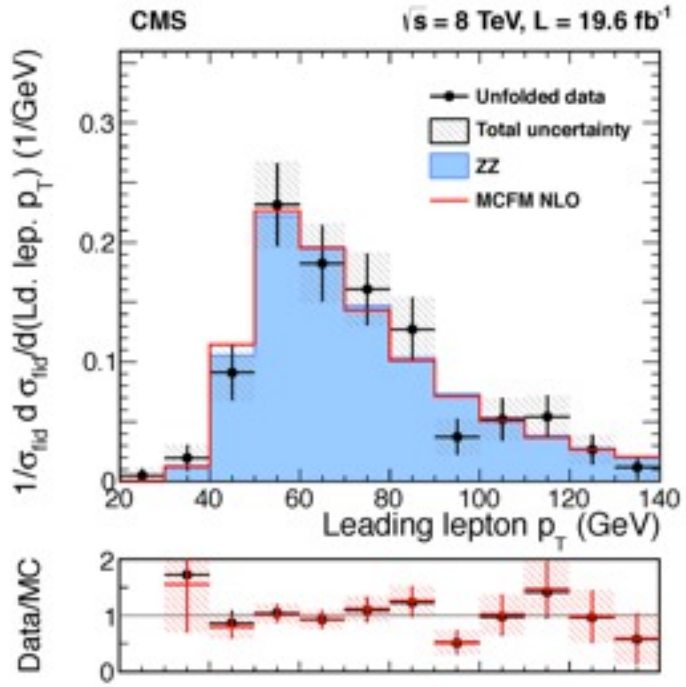
8 TeV: same for MG and Sherpa

Note: MG and Sherpa ME contains up to 4j in ME calculation

Neutral ZZγ and Zγγ aTGC: ZZ process



[SMP-13-005]



Scrutinize in 4 leptons final state

Also here, no evidence for ZZZ and ZZγ aTGC: new couplings compatible with 0