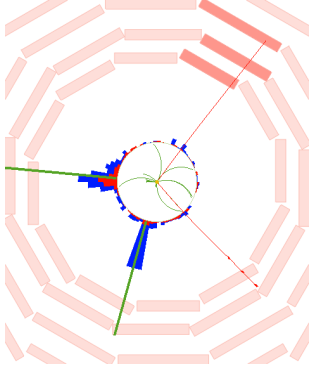
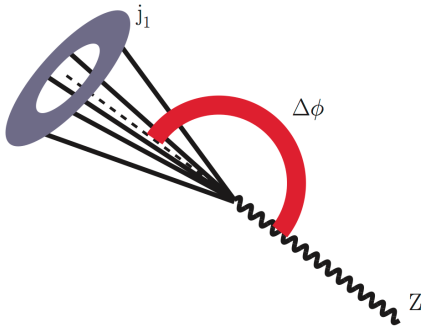
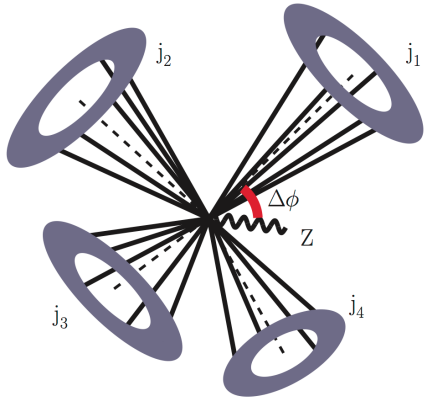


V+jets production at the CMS



Mehmet T. ZEYREK
METU Ankara, Turkey
on behalf of CMS Collaboration

IPMLHC 2013- Tehran, Iran
October 10, 2013



MOTIVATION

→Processes involving W & Z boson production are of the best understood processes at hadron colliders

→Test of perturbative QCD

→Precision measurements are sensitive to BSM effects.

→Leptons from Z and W events are used to understand the efficiencies.

→Provide constraints to PDFs

→Improve MC generators

→Backgrounds to New Physics & Higgs Searches

OUTLINE

@ 7TeV

→Z+jets, azimuthal correlations and event shape (*Phys. Lett. B 722 (2013) 238–261*)

→Photon+jets differential cross section (*CMS-PAS-QCD-11-005*)

→Z+1 jet and photon+1 jet rapidity distributions (*CMS-PAS-SMP-12-004*)

→W+2 jets, dijet mass spectrum (*Phys.Rev.Lett. 109 (2012) 251801*)

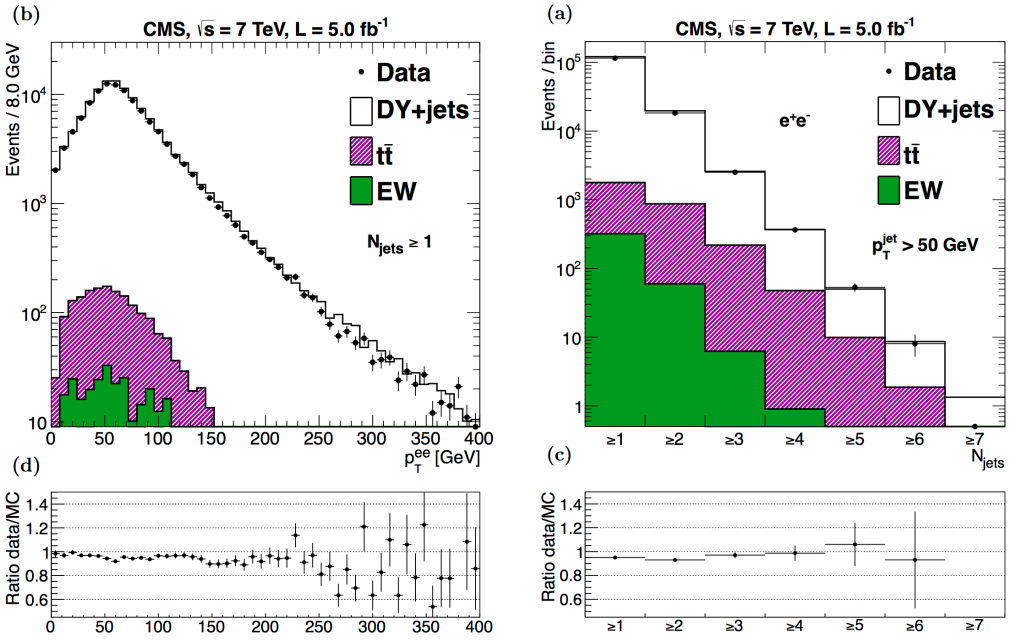
→Double parton scattering in W+jets (*PAS-FSQ-12-028*)

→Electroweak Z + forward-backward jets production(*arXiv:1305.7389*)

Z + Jets: Event-Shape Distributions

$\sqrt{s}$=7 TeV, 5 fb^{-1}

→Measurement of this process can be confronted with predictions of pQCD
→BG to many LHC processes →Improved understanging of Z+jets provide a tool extracting small signals



Z->ee + jets

→Two leptons with P_T>20 GeV and |η| <2.4 and 71 <MZ<111 GeV
→At least one jet with P_T>50 GeV and |η|<2.5
→Detector level, before background subtraction, after detector efficiency corrections.
→The MC (MadGraph) normalized to the data luminosity

Z + Jets: Angular Correlations

$\sqrt{s}$=7 TeV, 5 fb^{-1}

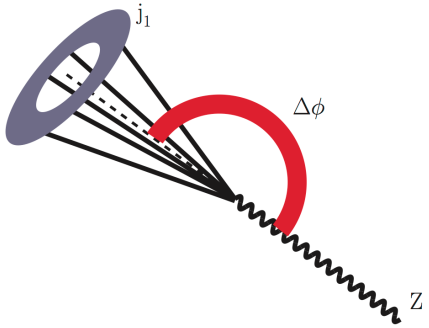
Measurements in two different regimes

$P_T(Z)>0$ GeV (Inclusive) & $P_T(Z)>150$ GeV (Boosted regime)

→Boosted regime is of particular interest: critical in BSM searches

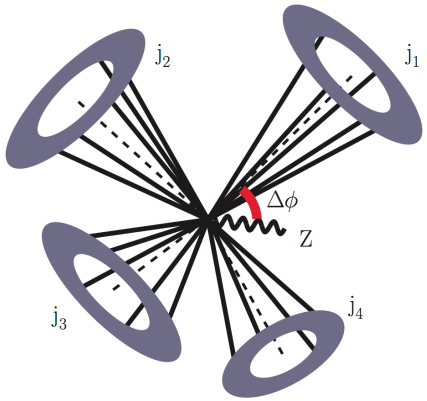
→Uncertainity of BG contribution is limited by the accuracy of MC models

→Accuracy of current MC models can be improved by studying correlations of Z & Jets



$\Delta\phi(Z,j_1)=\pi$

$\ln \tau_T \to -\infty$



$\Delta\phi(Z,j_1)<<\pi$

$\ln \tau_T \to 1$

Transverse Trust:kinematic topology

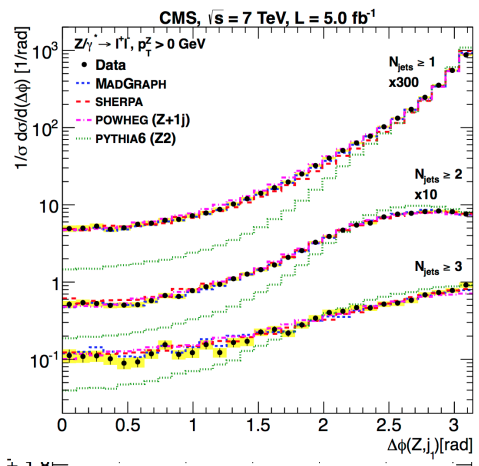
$$\tau_T \equiv 1 - \max_{\vec{n}_\tau} \frac{\sum_i |\vec{p}_{T,i} \cdot \vec{n}_\tau|}{\sum_i p_{T,i}}$$

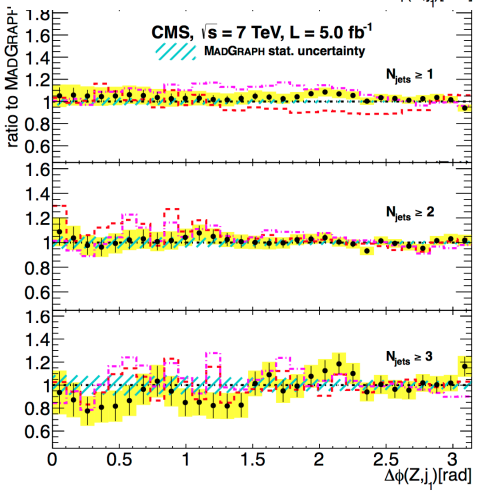
 Phys. Lett. B 722 (2013) 238–261

Z + Jets: Angular Correlations

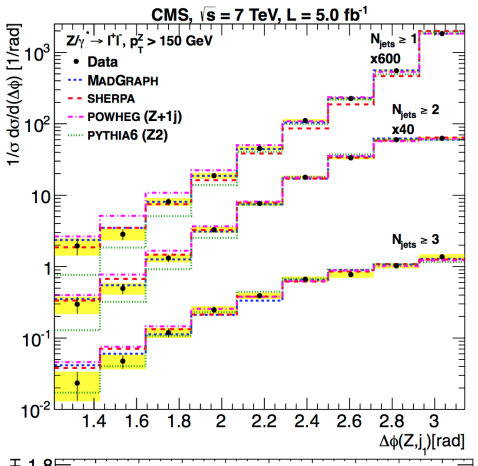
√s=7 TeV, 5 fb^{-1}

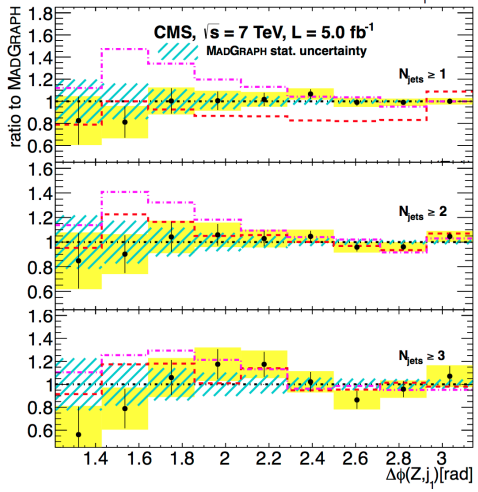
Inclusive





Boosted Regime





→Unfolding to correct for detector effects

→Direct comparison with theory

→MC simulations from Sherpa, Pythia6, Powheg and MadGraph.

→The error bars on data represent statistical uncertainty after unfolding

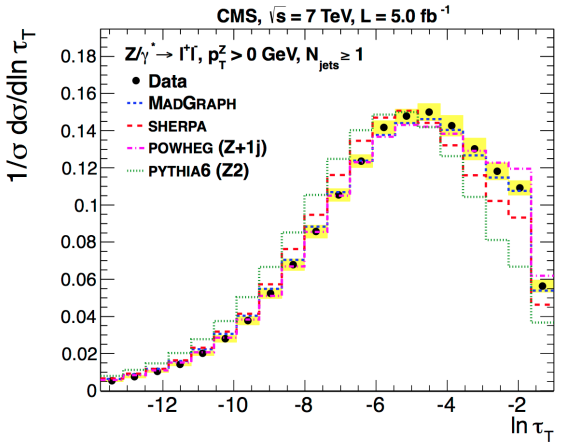
→The shaded (yellow) bands represent the sum of statistical and systematic errors.

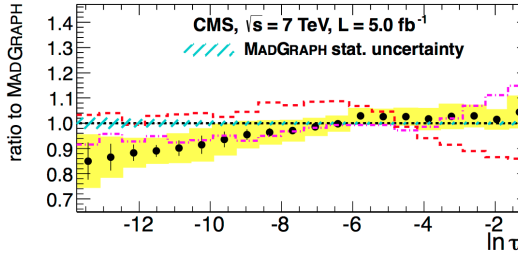
$\Delta\phi(Z,j_1)$

Z + Jets: Angular Correlations

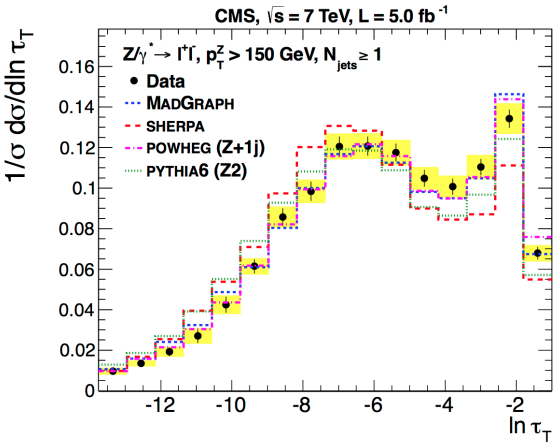
$\sqrt{s}$=7 TeV, 5 fb^{-1}

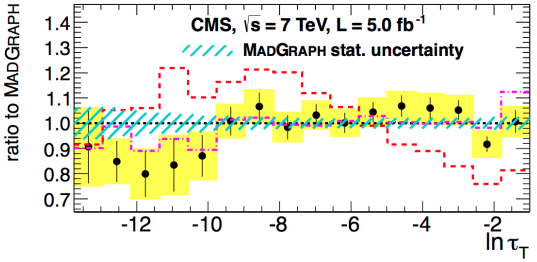
Inclusive





Boosted Regime





→MadGraph and Powheg reproduces data well

→Pythia6 (PS only) and Sherpa underestimate data

ln τ_T

Phys. Lett. B 722 (2013) 238–261

photon+jets differential cross section

$\sqrt{s}$=7 TeV, 2.14 fb^{-1}

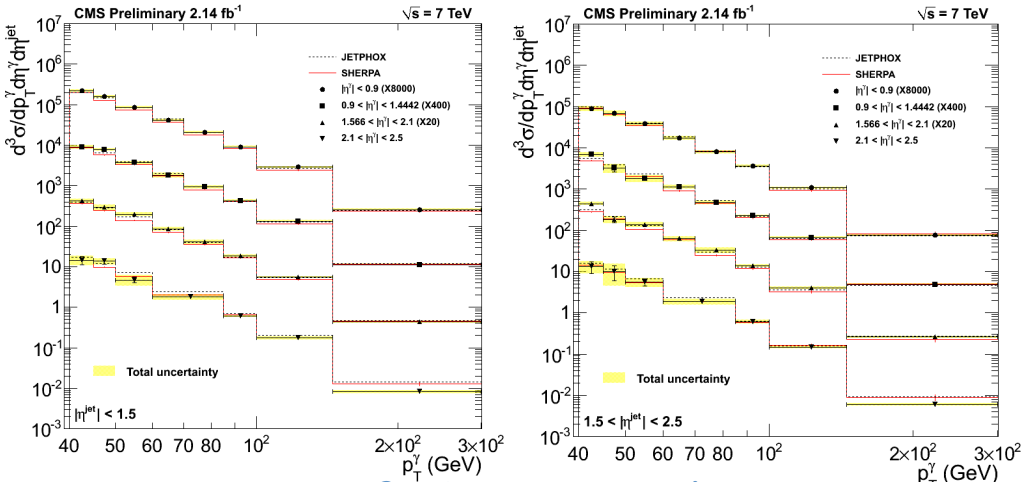
→Production of γ +jets directly sensitive to gluon PDF in proton

→BG for many processses, H->γγ, BSM searches

→Can be used for calibrating jet energies

→Photons and jets are reconstructed within |η|<2.5

→P^{j}_{T}>30 GeV 40 <P^{γ}_{T} < 300 GeV



$d^3\sigma/dP_T^{\gamma}d\eta^{\gamma}d\eta^{j}$

→Error bars are statistical uncertainties

→Yellow bands are the total uncertainties obtained by adding in quadrature statistical and systematic uncertainties.

→Comparison with :

→SHERPA tree-level Monte Carlo generator

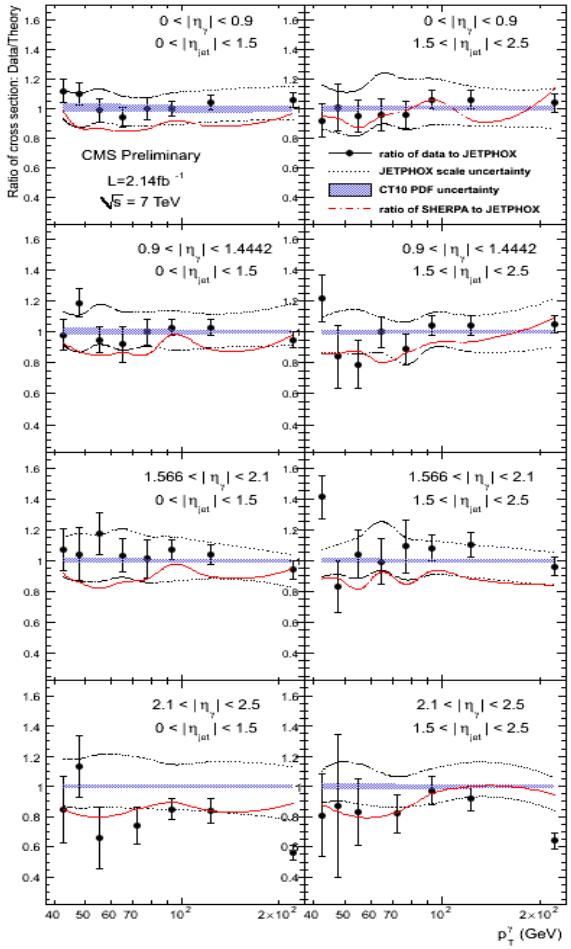
→NLO perturbative QCD calculation from JETPHOX

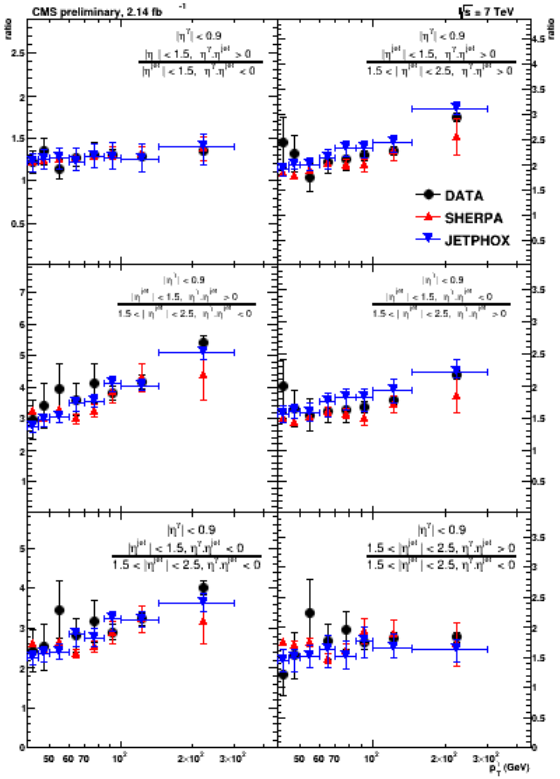
CMS-PAS-QCD-11-005

photon+jets differential cross section

Data/Theory

$\sqrt{s}$=7 TeV, 2.14 fb^{-1}





Ratios of cross section for various jet orientations wrt photon

→JETPHOX generally agrees with the data well

→SHERPA systematically underestimate the data

CMS-PAS-QCD-11-005

Z+1 jet rapidity distributions

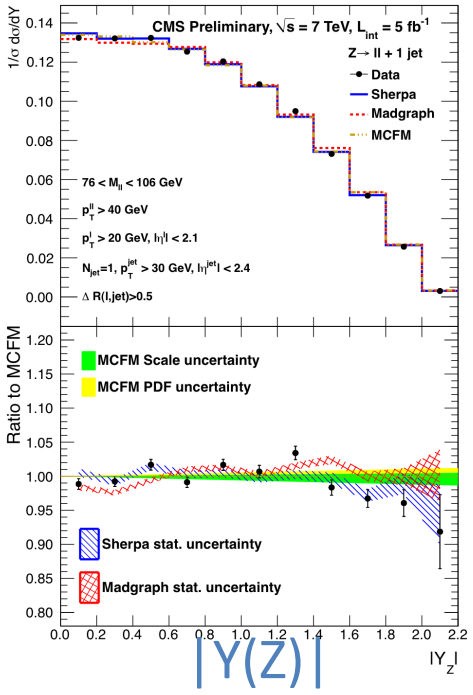
$\sqrt{s}$=7 TeV, 5 fb^{-1}

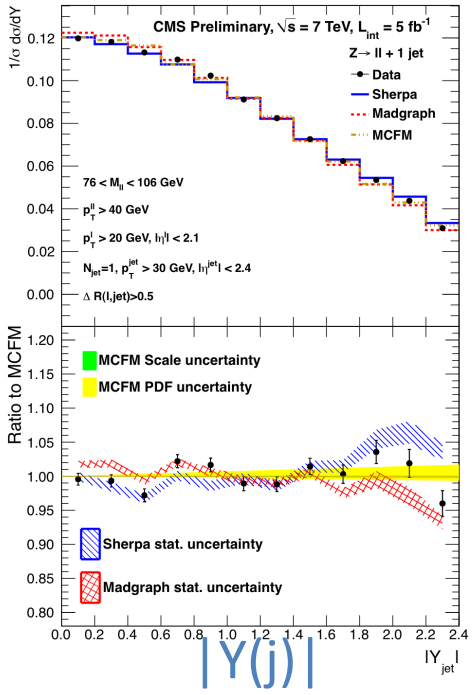
→Angular distributions is crucial in understanding structure & interactions of matter since Rutherford

→Measurement of Y in Z+jet events provides modeling of H properties in theory calc.

→Presence of EWK vertex makes the perturbative calc. more stable

→NLO pQCD calc. exist for Z+ up to 4 jets & γ+jet





→The rapidity distributions for events with a Z boson + one jet

→Z->l^+l^- + 1 j, l= e,μ

→P_T (l)>20. GeV

→|η(l)|<2.1

→76 GeV<MZ<106 GeV

→ P_T(ll)>40 GeV

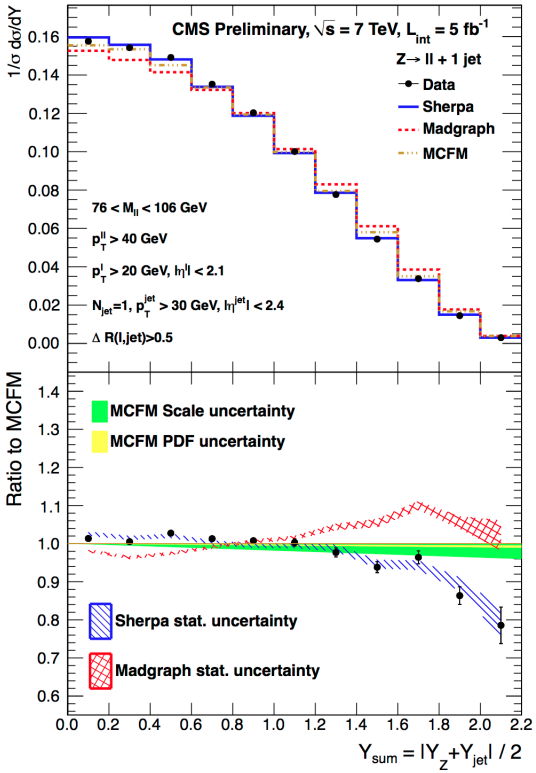
→P_T (j)>30. GeV

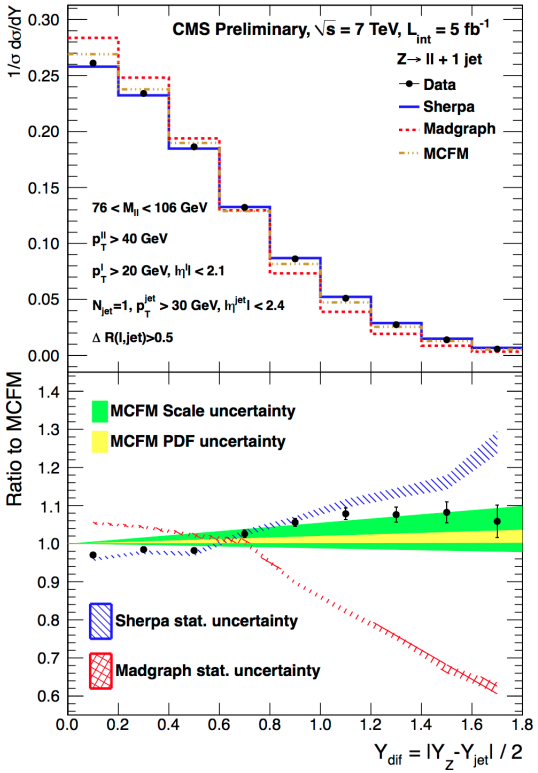
→|η(j)|<2.4

Z+1 jet rapidity distributions

√s=7 TeV, 5 fb^{-1}

→The rapidity distributions for events with a Z boson + one jet





→Comparison with Sherpa, Madgraph MCFM.

→Sherpa agrees better.

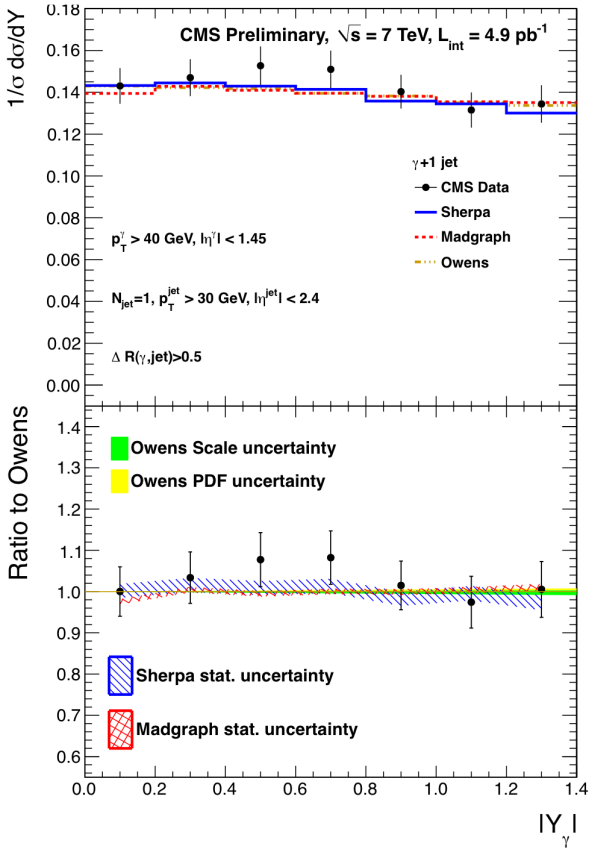
Ysum= (|Y(Z) + Y(j)|)/2

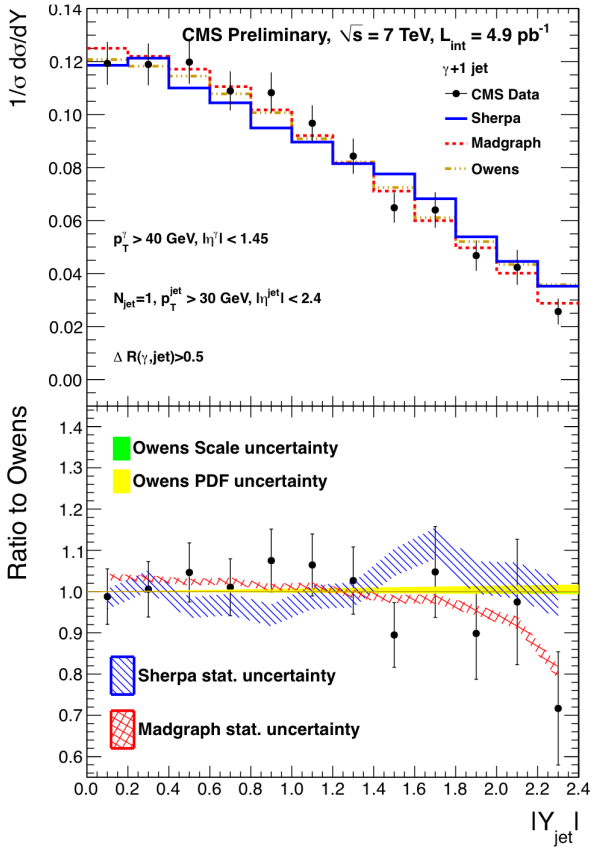
Ydiff= (|Y(Z) - Y(j)|)/2

photon+1 jet rapidity distributions

√s=7 TeV, 5 fb^{-1}

→The rapidity distributions for events with a real photon + one jet





→$p_T(\gamma)$ >30 GeV

→$|\eta(\gamma)|$<1.4

→$P_T(j)$> 30 GeV

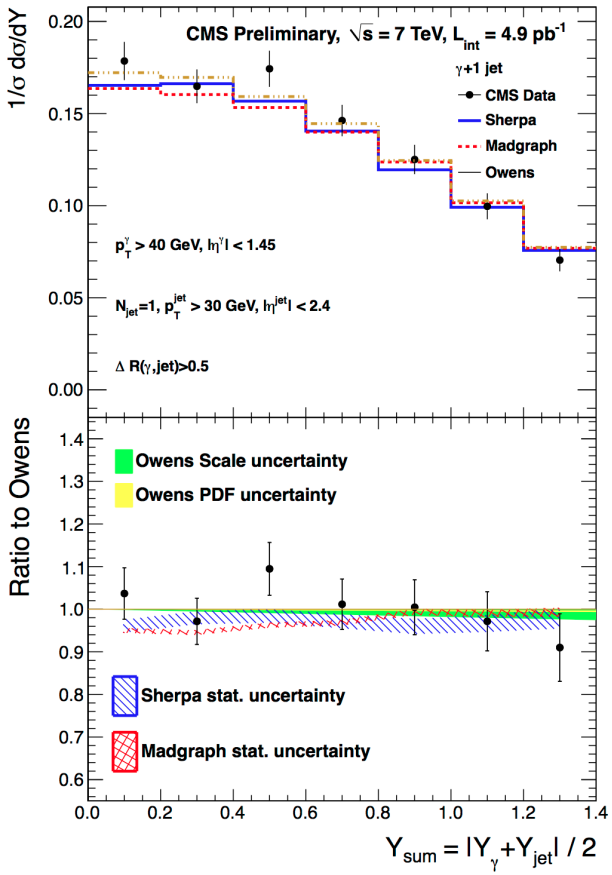
→$|\eta(j)|$<2.4

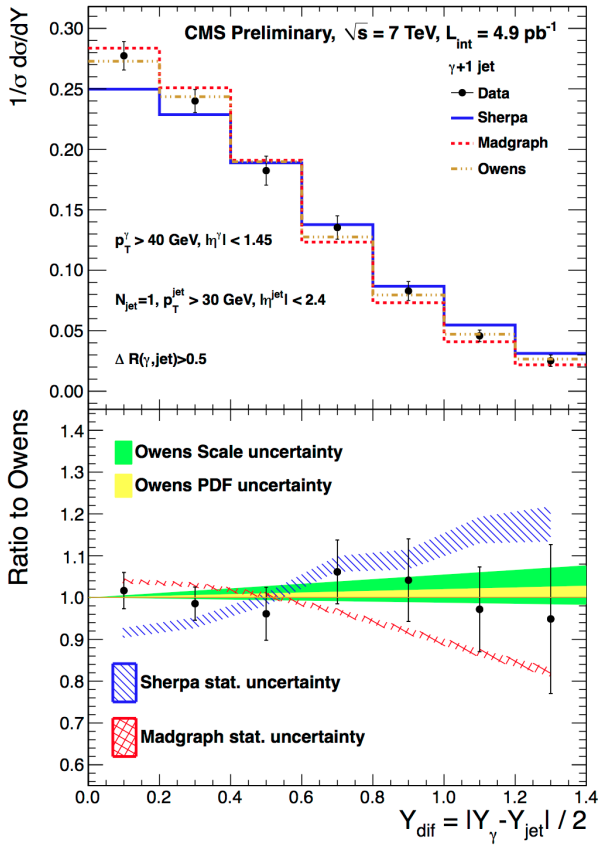
$|Y(\gamma)|$ $|Y(j)|$

photon+1 jet rapidity distributions

$\sqrt{s}$=7 TeV, 5 fb^{-1}

→The rapidity distributions for events with a real photon + one jet





→Comparison with Owens, Sherpa & Madgraph

Ysum= (|Y(γ) + Y(j)|)/2 Ydiff= (|Y(γ) - Y(j)|)/2

W+2 jets, dijet mass spectrum

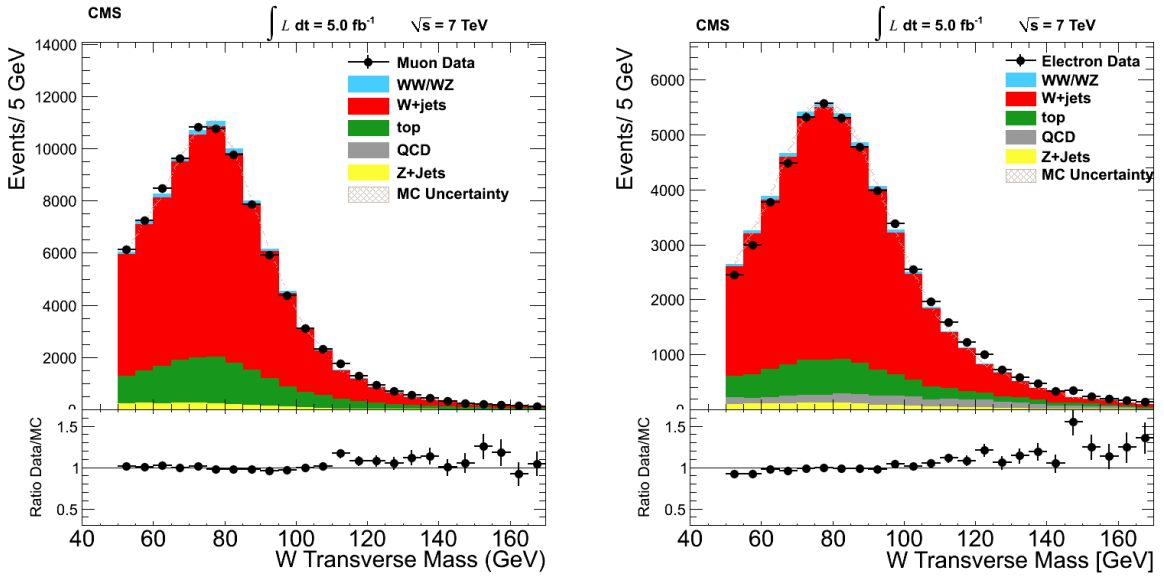
√s=7 TeV, 5 fb^{-1}

→Search for a former CDF bump in invariant mass spectrum of the two jets with highest transverse momentum in pp→ W+2-jet and W+3-jet events

$W \to \ell\nu$ selection	Jet selection
Single-lepton trigger	$p_T^{j1} > 40\,\text{GeV}$
Lepton identification and isolation	$p_T^{j2}, p_T^{j3} > 30\,\text{GeV}$
$p_T^{\mu(e)} > 25\ (35)\,\text{GeV}$	$\|\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2}\| > 45\,\text{GeV}$
$\not{E}_T^{\mu(e)} > 25\ (30)\,\text{GeV}$	$\|\Delta\eta(j1, j2)\| < 1.2$
$M_T > 50\,\text{GeV}$	$\Delta\phi(\not{E}_T, j1) > 0.4$
Exclude events with > 1 lepton	$0.3 < p_T^{j2}/m_{jj} < 0.7$

→pp→W(→lν)+jj final states

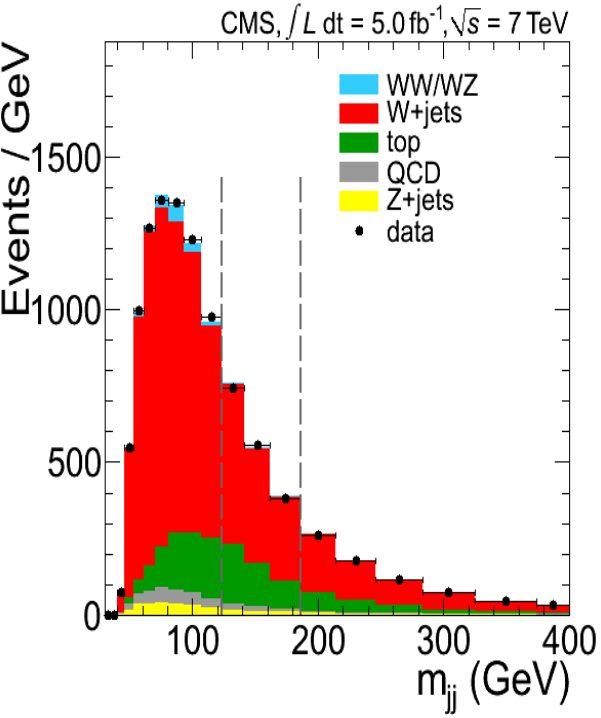
Control plot:W transverse mass (MT) →

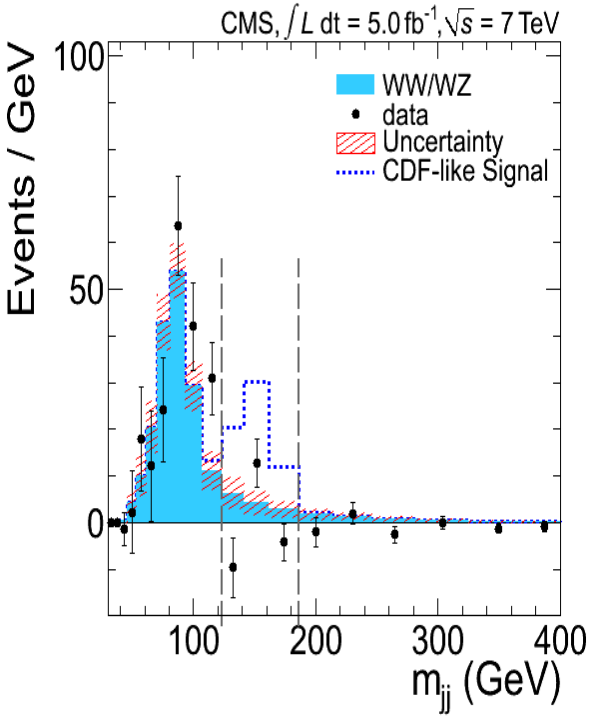


W+2 jets, dijet mass spectrum

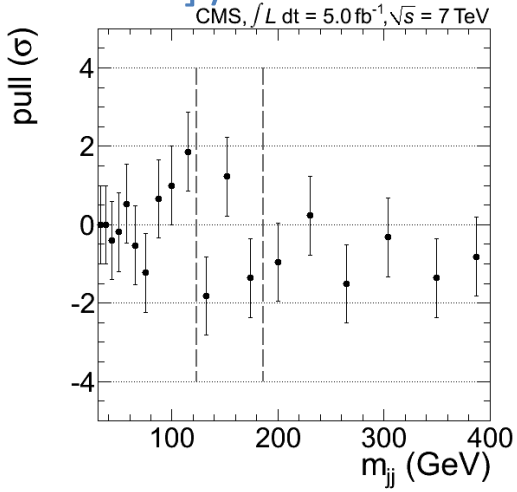
$\sqrt{s}$=7 TeV, 5 fb^{-1}

M(j1j2) data (μ+ 2 j, μ+ 3 j, e+2 j, and e+ 3 j comdined) before BG subtraction (left) and after BG subtraction except WW/WZ (right)





Pull distribution
[data - fit] / fit uncertainty



→No excess is observed

→An upper limit of 5.0 pb @ 95 % confidence level on the production cross section for a generic Gaussian signal with mass near 150 GeV.

 Phys.Rev.Lett. 109 (2012) 251801

Double parton scattering in W+jets

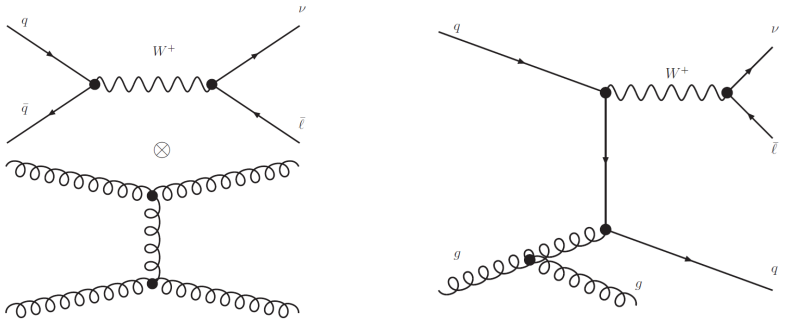
$\sqrt{s}$=7 TeV, 5 fb^{-1}

→p-p collisions @LHC energies probe small x values carried by partons

→The large parton densities at small x increase probability of 2 parton-parton scattering producing 2 identifiable hard scattering in p-p interaction

→DPS studies provide info on spatial structure of hadrons

→Constitute as BG to new physics searches @LHC



Feynman Diagrams for W+ 2j production from DPS (left) and single parton scattering (right).

W → μν selection	Jet selection
Single muon trigger	anti-kT PF jet with R = 0.5
Muon ID and isolation	$p_T > 20\,\text{GeV}/c$, $\|\eta\| < 2.0$
Exactly one muon $p_T > 35\,\text{GeV}/c$, $\|\eta\| < 2.1$	$\beta > 0.4$
$\not{E}_T > 30\,\text{GeV}/c$	$\Delta R(jet - \mu) > 0.5$
W transverse mass $> 50\,\text{GeV}/c^2$	

→Double parton scattering (DPS) is investigated in W->μν + 2j final states

→Exclusive W+2 jets events

→Inclusive W+2 jets events

PAS-FSQ-12-028

Double parton scattering in W+jets

√s=7 TeV, 5 fb^{-1}

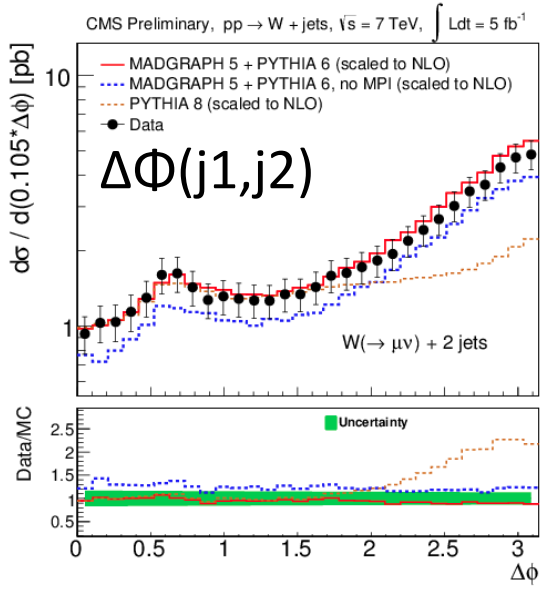
→Unfolded ΔΦ(j1,j2), Δrel pT, and ΔS distributions for W+2j exclusive sample

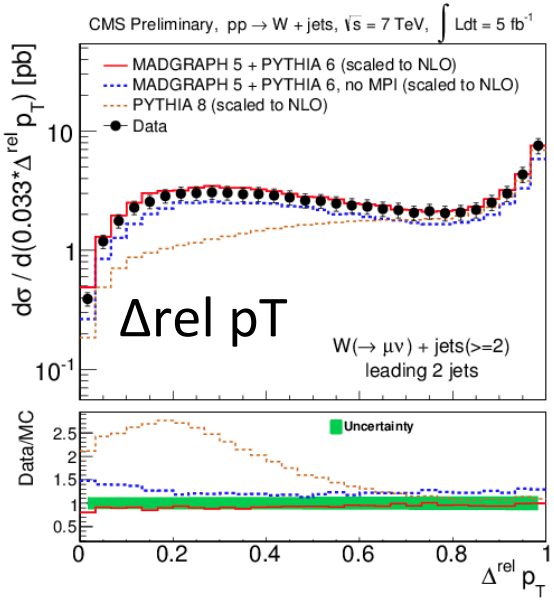
→MC predictions of MADGRAPH nicely describe the measurements

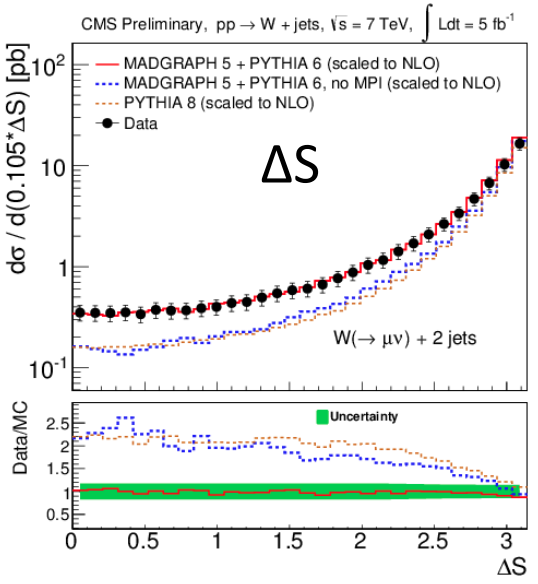
→The MC prediction without MPI & Pythia fails to describe the differential x-sec as well as the shape

→First step towards the upcoming extraction of the underlying DPS fraction@ LHC energies.

$$\Delta S = arccos\left(\frac{\vec{P}_T(\mu,\not{E}_T).\vec{P}_T(j1,j2)}{|\vec{P}_T(\mu,\not{E}_T)|.|\vec{P}_T(j1,j2)|}\right) \quad \Delta^{\text{rel}}\,\text{p}_\text{T} = \frac{|\vec{p}_T(j1)+\vec{p}_T(j2)|}{|\vec{p}_T(j1)|+|\vec{p}_T(j2)|}$$







Electroweak Z + forward-backward jets production

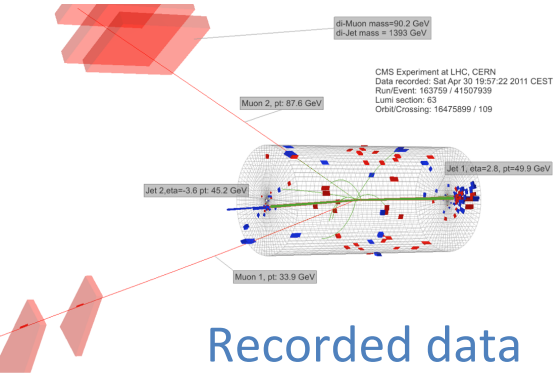
$\sqrt{s}$=7 TeV, 5 fb^{-1}

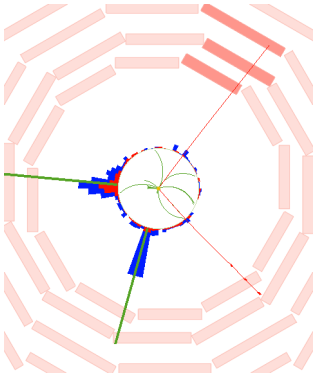
→EW production of W,Z + 2 well separated jets is quite sizeable @LHC

→Study of these processes are important for

- →VBF studies
- →Higgs boson searches
- →Measurements of EWK gauge couplings & Vector Boson scattering

→EWK cross sections of the Z boson with two forward-backward jets

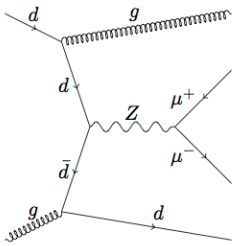




Recorded data

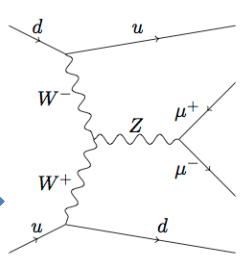
M(μμ)=90.2 GeV M(jj)=1.4 TeV.

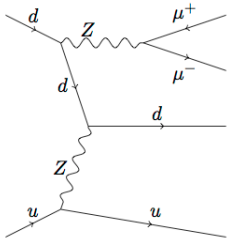
-> Main background: DY + 2j

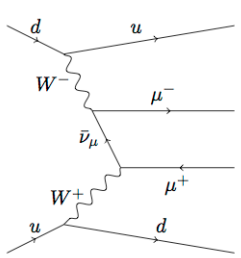


← DY + 2j

EW lljj production (for l=μ): VBF (left), bremsstrahlung (middle), and multiperipheral → (right).







Electroweak Z + forward-backward jets production

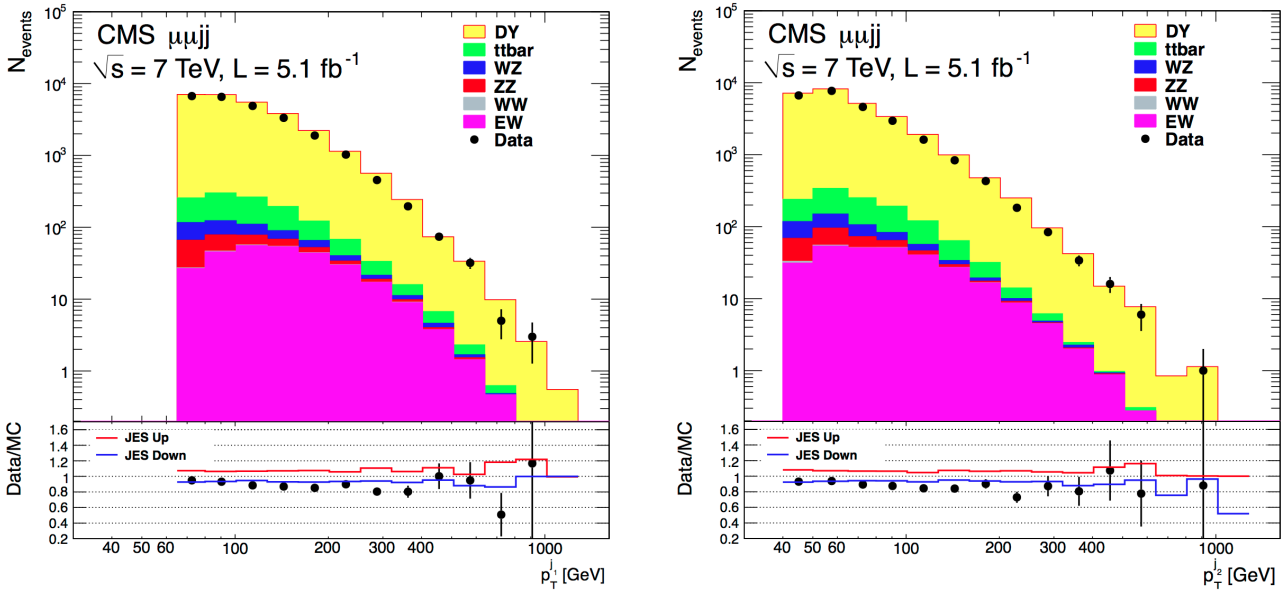
√s=7 TeV, 5 fb^{-1}

→Unfolded to parton level selections: mℓℓ>50 GeV, ptj>25 GeV, |ηj|<4.0, mjj>120 GeV

σ_{meas}=154±24(stat)±46(exp.syst)±27(th.syst)±3(lumi) fb

σ_{th}= 166 fb @NLO

pTj1 (left) and pTj2 (right) distributions after applying the Zμμ selection and the tagging jet requirement TJ1



Electroweak Z + forward-backward jets production

$\sqrt{s}$=8 TeV, 19.7 fb^{-1}

@8TeV

→ two methods of signal extraction to confirm & cross-check the presence of the signal.

→ MVA analysis as in 7 TeV

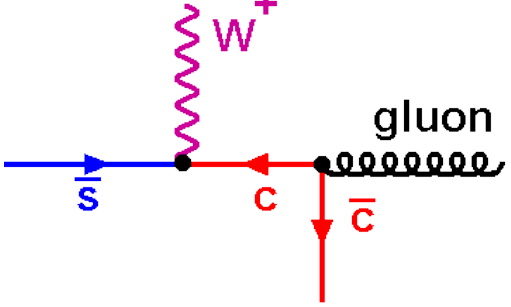
→ New method using data to model the main background

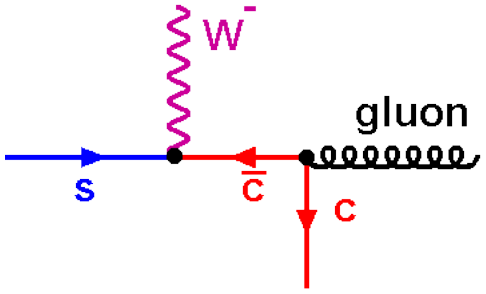
→Unfolded to parton level selections: mℓℓ>50 GeV, ptj>25 GeV, |ηj|<5.0, mjj>120 GeV

σ_{meas} = 226 ± 26(stat) ± 35(syst) fb

σ_{th}= 239 fb @NLO

V+HF



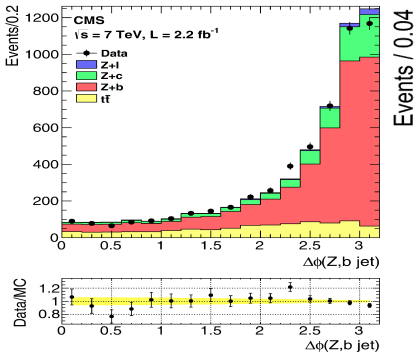


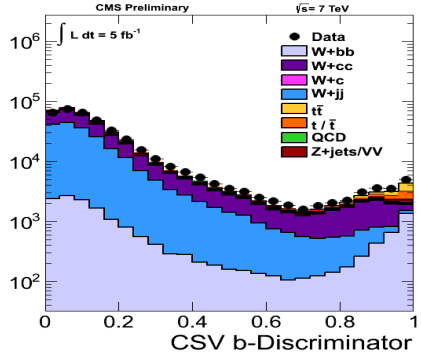
→**Z+b, bb jet cross sections at 7 TeV** (*JHEP 06 (2012) 126, CMS-PAS SMP-13-004*)

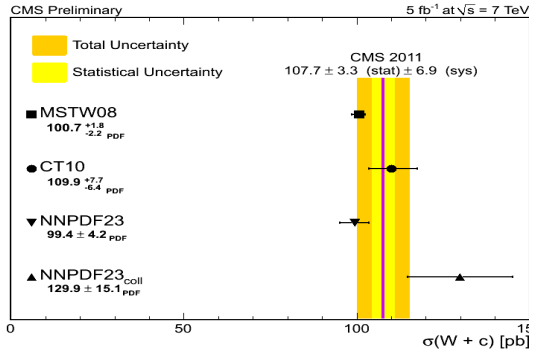
→**W+bb cross section at 7 TeV** (*CMS-PAS-SMP-12-026*)

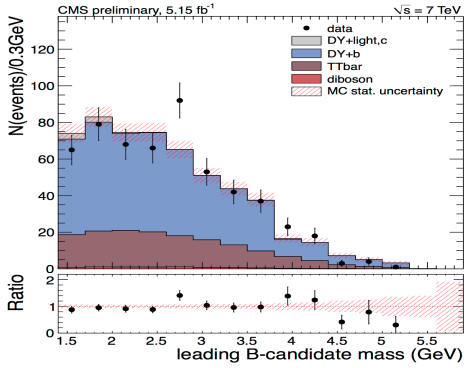
→**W+c differential cross section at 7 TeV** (*CMS-PAS-SMP-12-002*) arXiv:1310:1138

→**Z+bb jets, b hadron angular correlations at 7 TeV** (*CMS EWK-11-015*)arXiv:1310.1349









→Enough sensitivity to constrain the strange-quark PDF with the W+c measurements

→Generally good agreement with data, in shapes for MC ME+PS, and in overall normalisation for NLO calculations, in W/Z+bb measurements

SUMMARY

→The measurements provide a detailed description of V+jets production topological structure

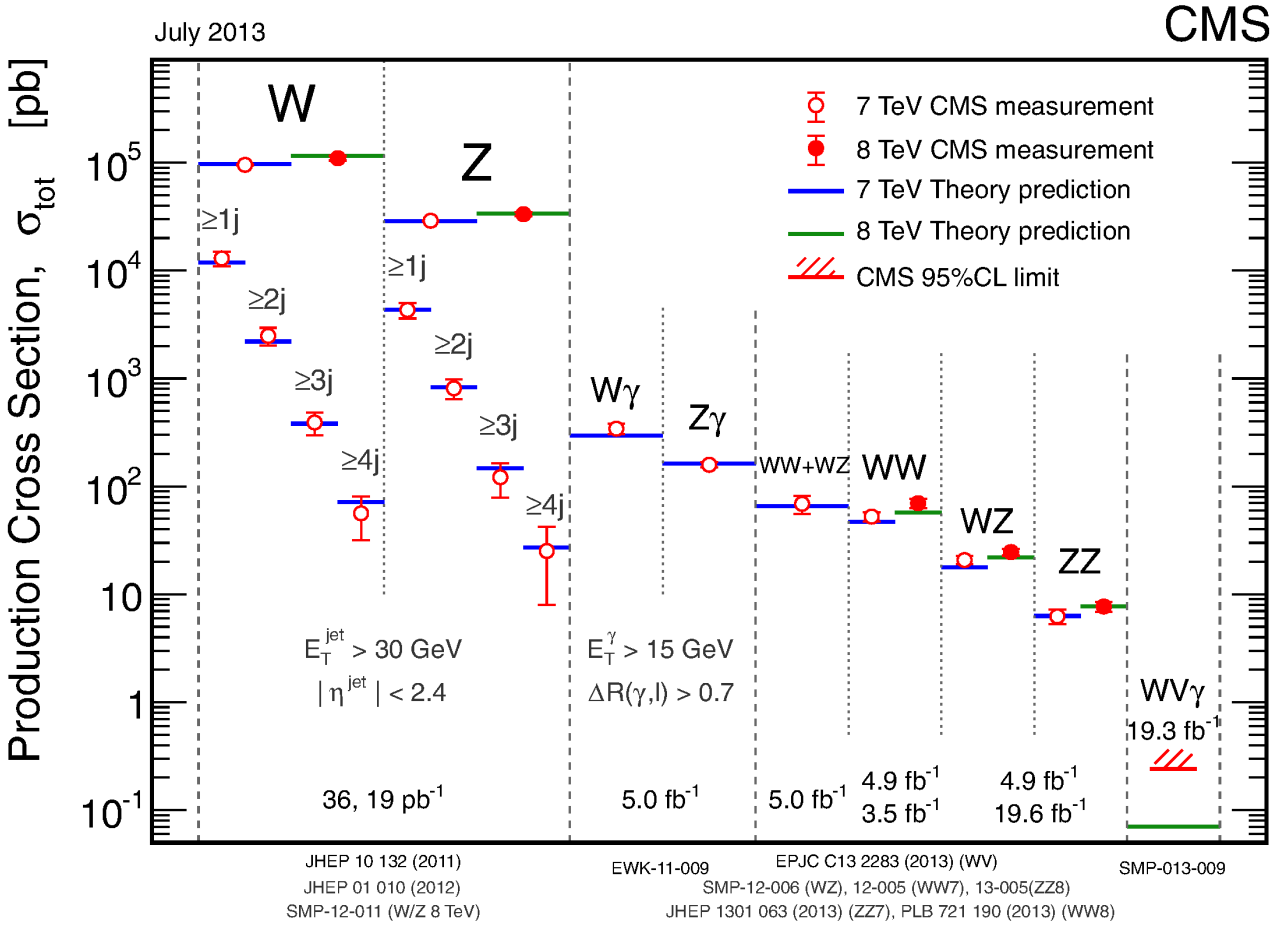
→Testing the validity of QCD
→Providing confidence in existing MC models for;
→Describing SM
→Determining BG in BSM searches

→Overall scale good agreement between Data and SM Monte Carlo predictions

→Only 7 TeV V+jet results; more precise results to come with full 20 fb^{-1} data @8 TeV

→ All CMS SMP public results can be found under the following link:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP

SUMMARY


July 2013
CMS
Production Cross Section, σ_{tot} [pb]
W
Z
≥1j
≥2j
≥3j
≥4j
≥1j
≥2j
≥3j
≥4j
Wγ
Zγ
WW+WZ
WW
WZ
ZZ
WVγ
19.3 fb^{-1}
7 TeV CMS measurement
8 TeV CMS measurement
7 TeV Theory prediction
8 TeV Theory prediction
CMS 95%CL limit
E_T^{jet} > 30 GeV
$|\eta^{jet}|$ < 2.4
36, 19 pb^{-1}
E_T^{γ} > 15 GeV
ΔR(γ,l) > 0.7
5.0 fb^{-1}
5.0 fb^{-1}
4.9 fb^{-1}
3.5 fb^{-1}
4.9 fb^{-1}
19.6 fb^{-1}
JHEP 10 132 (2011)
JHEP 01 010 (2012)
SMP-12-011 (W/Z 8 TeV)
EWK-11-009
EPJC C13 2283 (2013) (WV)
SMP-12-006 (WZ), 12-005 (WW7), 13-005(ZZ8)
JHEP 1301 063 (2013) (ZZ7), PLB 721 190 (2013) (WW8)
SMP-013-009

THANK YOU!