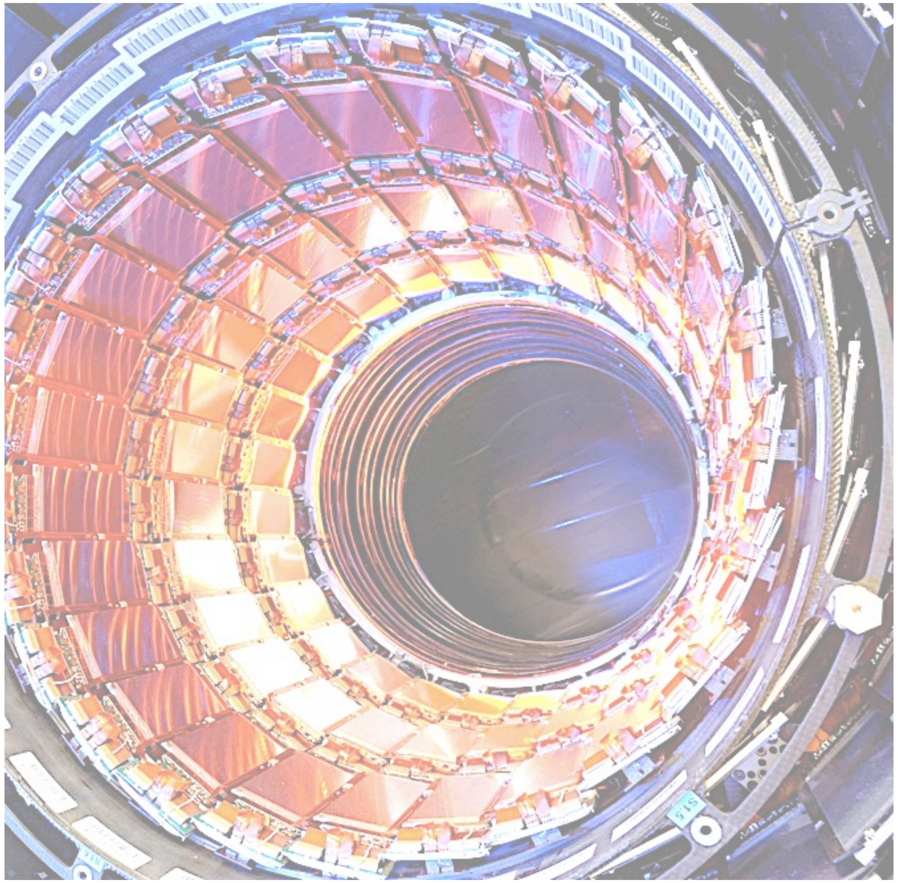
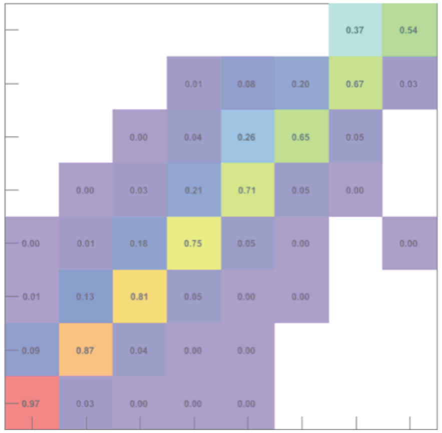
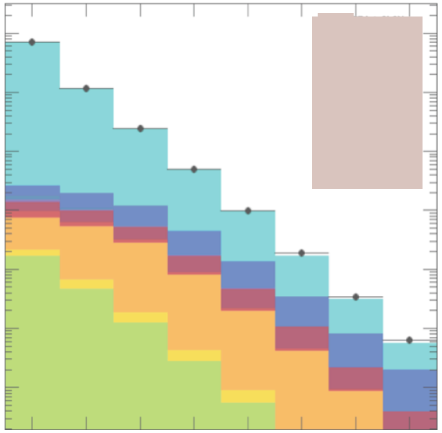






Rapidity distributions in exclusive Z + jet and photon + jet events in pp collisions at sqrt(s)=7 TeV

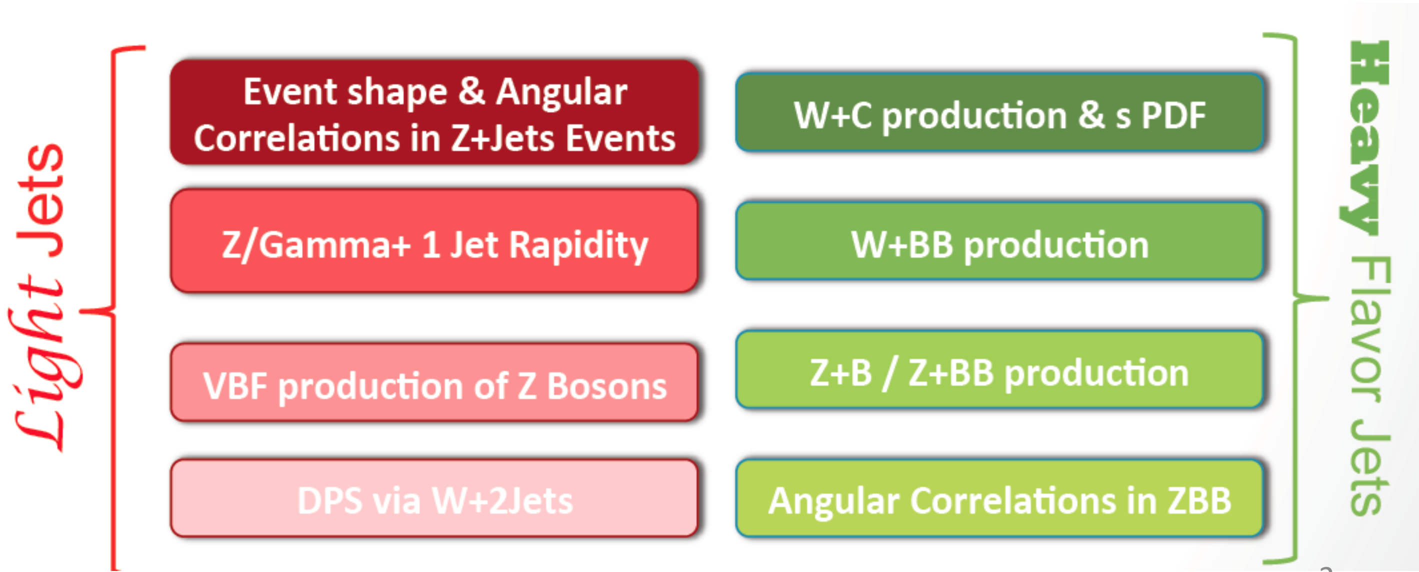
Tomislav Seva (on behalf of the CMS Collaboration)

IIHE – Universite Libre de Bruxelles

Boston Jets Physics Workshop 2014

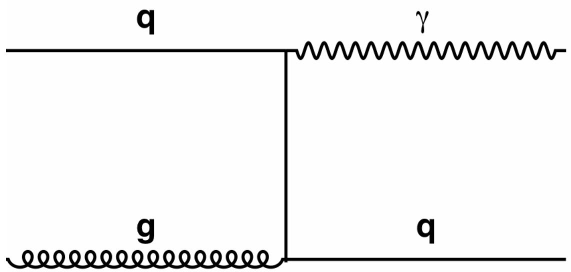
Vector Boson + Jets

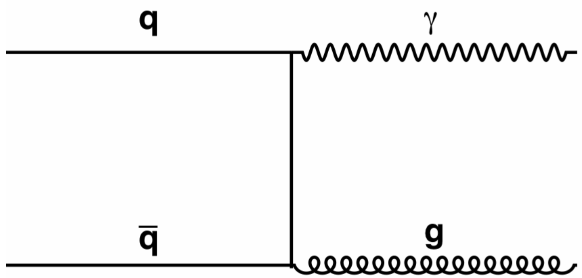
- The study of the production and kinematics of vector bosons associated with jets is a major testing ground of perturbative QCD predictions and Monte Carlo techniques associated to
  - Madgraph, Alpgen, Sherpa, MCFM, BlackHat-Sherpa, Powheg, aMC@NLO, etc.
- A background to SM measurements (tt, single top, VBF, WW-scattering) and new physics (Higgs, SUSY, etc)
- CMS V + Jets program



Introduction

Phys.Rev. D88 (2013) 112009





$$E\frac{d^3\sigma}{d\vec{p}} \rightarrow \frac{d^3\sigma}{d(p^*)^2\, dy_B\, d\cos\theta^*} \propto \frac{1}{S}\sum_{i,j}\frac{f_i(x_1)}{x_1}\frac{f_j(x_2)}{x_2}\frac{d\hat{\sigma}_{ij}}{d\cos\theta^*}$$

$Y_{sum} = (Y_{jet} + Y_\gamma)/2$

Boost to CoM

$Y_{dif} = (Y_{jet} - Y_\gamma)/2$

$\cos\theta^* = \tanh Y_{dif}$

We measure Yv,Yjet, Ysum, and Ydif , where V is either a photon or Z boson and a single exclusive jet

Z/Gamma + 1 Jet

Phys.Rev. D88 (2013) 112009

Focus on exclusive Z + 1 and **γ**+ 1 jet events

Distributions of interest

- Rapidity distribution of the vector boson: $|y_V|$
- Rapidity distribution of the leading jet: $|y_{jet}|$
- Rapidity difference: $y_{diff} = |y_V - y_{jet}|$

  - Related to the scattering angle at the center of momentum frame: $\tanh(y_{diff}) \sim \cos\vartheta^*$

- Rapidity average $y_{sum} = |y_V + y_{jet}|$

  - Rapidity boost from the lab frame to the center of momentum frame

Z/Gamma + 1 Jet

- **Select** events containing a vector boson and a jet that satisfy kinematic and ID selections. We use POG cuts and efficiencies when possible
- Estimate **background** contribution (photon only)
- Derive **efficiency** from MC and correct it with data-to-MC scale factors via tag and probe
- **Unfold** the distribution of Y_{jet} for Z + 1 jet
  - Other variables have unfolding correction consistent with zero
- **Combine** the electron and muon channels
  - Apply acceptance-correction for electrons
- Evaluate **Systematic** uncertainties
- **Compare** shapes with MCFM, Madgraph, and Sherpa
- **Evaluate** theory systematic uncertainty

Z/Gamma + 1 Jet: Events selection

2011 data at 7TeV with luminosity of 5 fb^{-1}

Photon

- $p_T > 40$ GeV
  for fully efficient trigger
- $|\eta| < 1.44$ calorimeter boundary
- Isolation – tracker, ECAL and HCAL

Z boson

- Oppositely charged leptons with isolation of 15%(20%) for muons and electrons
- Lepton selection: $p_T > 20$ GeV and $|\eta| < 2.1$
- 76 GeV < m_Z < 106 GeV, $p_T > 40$ GeV
- Z_{pt}>40 GeV

Jets

- Anti-kt with dR = 0.5
- $p_T > 30$ GeV , $|\eta| < 2.4$ (for good tracker acceptance)
- Energy correction for non-primary (pileup) interactions
- Removal of jets that are dR < 0.5 from photon (lepton)
- Require exactly 1 jet, veto any other event that has more jets

Z/Gamma + 1 Jet: Events selection

Muon ID
- Tracker and Global Muons
- SUM Isolation Pt < 3 GeV(ΔR=0.3)
- Beam spot position <2cm
- Pixel hits >=1
- Tracker hits>10
- Chi2<10
- Muon hits>1

Electron ID:
- Zero missing hits on track
- No conversions
- Shower width < 0.01(0.03)
- $\Delta\phi_{in}$ < 0.06(0.03)
- $\Delta\eta_{in}$< 0.004(0.007)
- H/E< 0.04(0.15)
- PF relative isolation <0.2 (ΔR=0.4)

Photon ID
- Ecal Iso < 4.2 +0.006*pT
- Hcal Iso < 2.2+0.0025*pT
- Track Iso < 2.0+0.001*pT
- H/E<0.05
- Veto pixel seed
- $\Delta R_{\gamma j}$>0.5

Jet ID
- Anti-kt, R=0.5
- Neutral hadron frac<0.99
- Neutral EM frac <0.99
- Number of Constituents>1
- Charged Multiplicity> 0
- Charged EM fraction<0.99

Z/Gamma + 1 Jet: Systematic uncertainties

Source	$\|y_V\|$ (%)	$\|y_{jet}\|$ (%)	y_{sum} (%)	y_{dif} (%)
Jet energy	0.4	0.6	0.3	0.4
Pileup reweight	0.5	0.1	0.3	0.1
Unfolding	—	5.0	—	—
e Statistical	7.1	2.2	8.0	5.7
e Efficiency	3.1	0.9	3.2	2.8
e Background	0.2	0.2	0.2	0.2
μ Statistical	6.3	1.9	6.1	4.6
μ Efficiency	1.5	0.4	1.2	1.2
μ Background	0.2	0.2	0.2	0.2
γ Statistical	6.6	19	8.6	15
γ Efficiency	0.4	0.6	0.4	1.0
γ Background	7.0	2.0	1.0	11

Jet energy scale is dominant correlated uncertainty

Pileup reweighing by vary the input minimum bias cross section by ±5%

Background subtraction:
Z+jets: dominant is ttbar, VV (1%)
γ+jets : decays of neutral hadrons (data driven matrix method)

Corrections for trigger, object selection and isolation efficiencies

Normalization of distributions

Dominant uncertainty comes from the limited size of data

Z/Gamma + 1 Jet: generator parameters

Measured distributions are compared to LO tools :

- Madgraph 5.1.1.0 with Pythia 6.4.24 for parton shower and hadronization
- Sherpa 1.3.1 + with APACIC++ parton shower

For both vector bosons + jets

Basic differences:

- factorization and normalization scales
- parton shower and hadronization
- matching between ME and PS

  CKKW for Sherpa and kt-MLM for Madgraph

NLO tools :

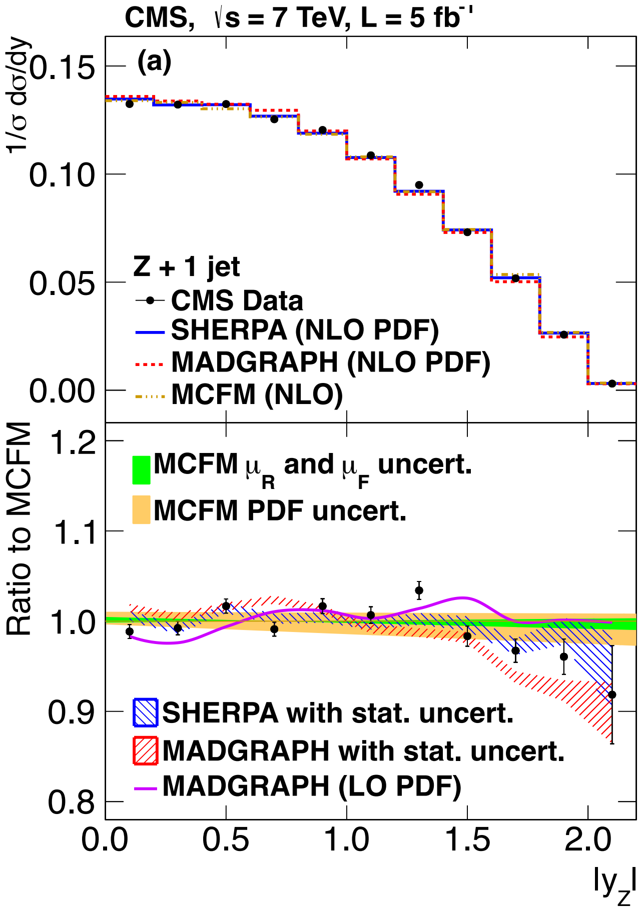
- MCFM for Z boson + jets
- Owens for Υ + jets

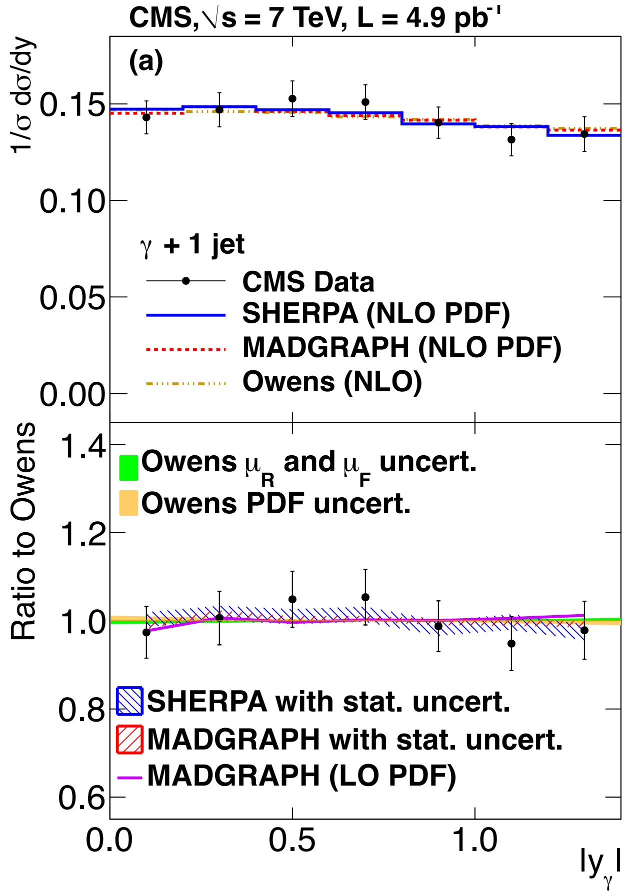
Uncertainties tested:

Scale up/down

PDF uncertainty -> PDF4LHC prescription

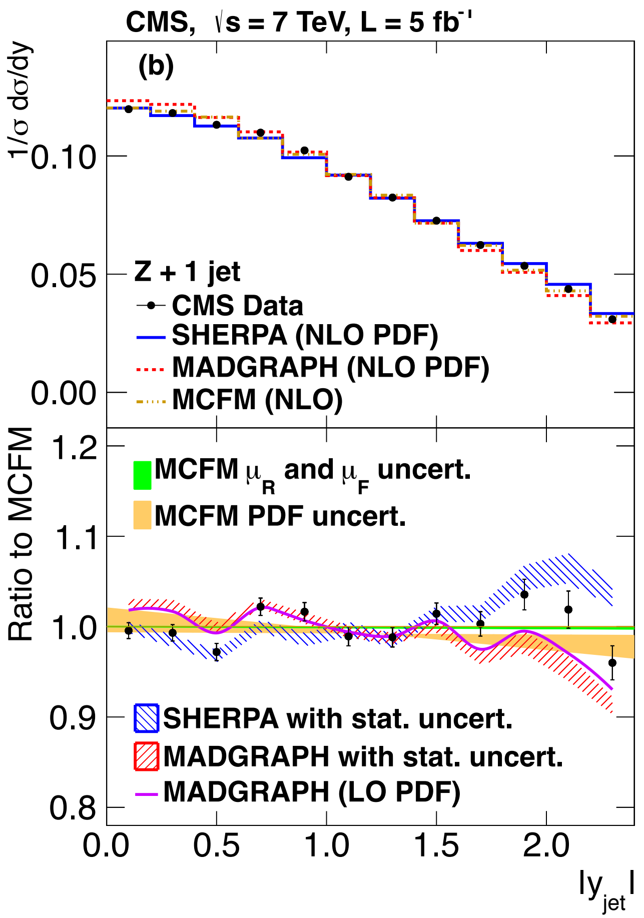
Results: Z/Gamma + 1 Jet: y_V

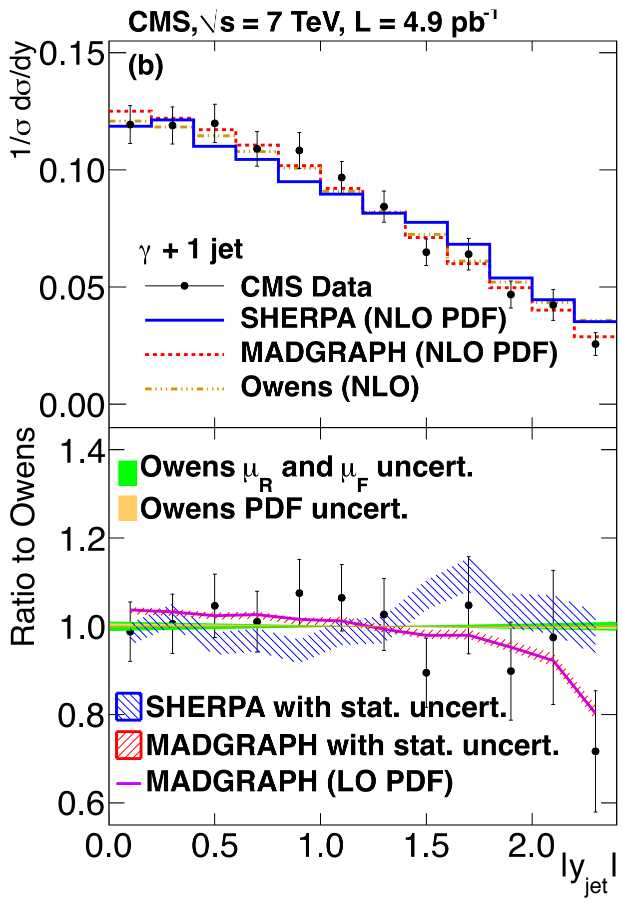




All predictions agree with data within 5 %

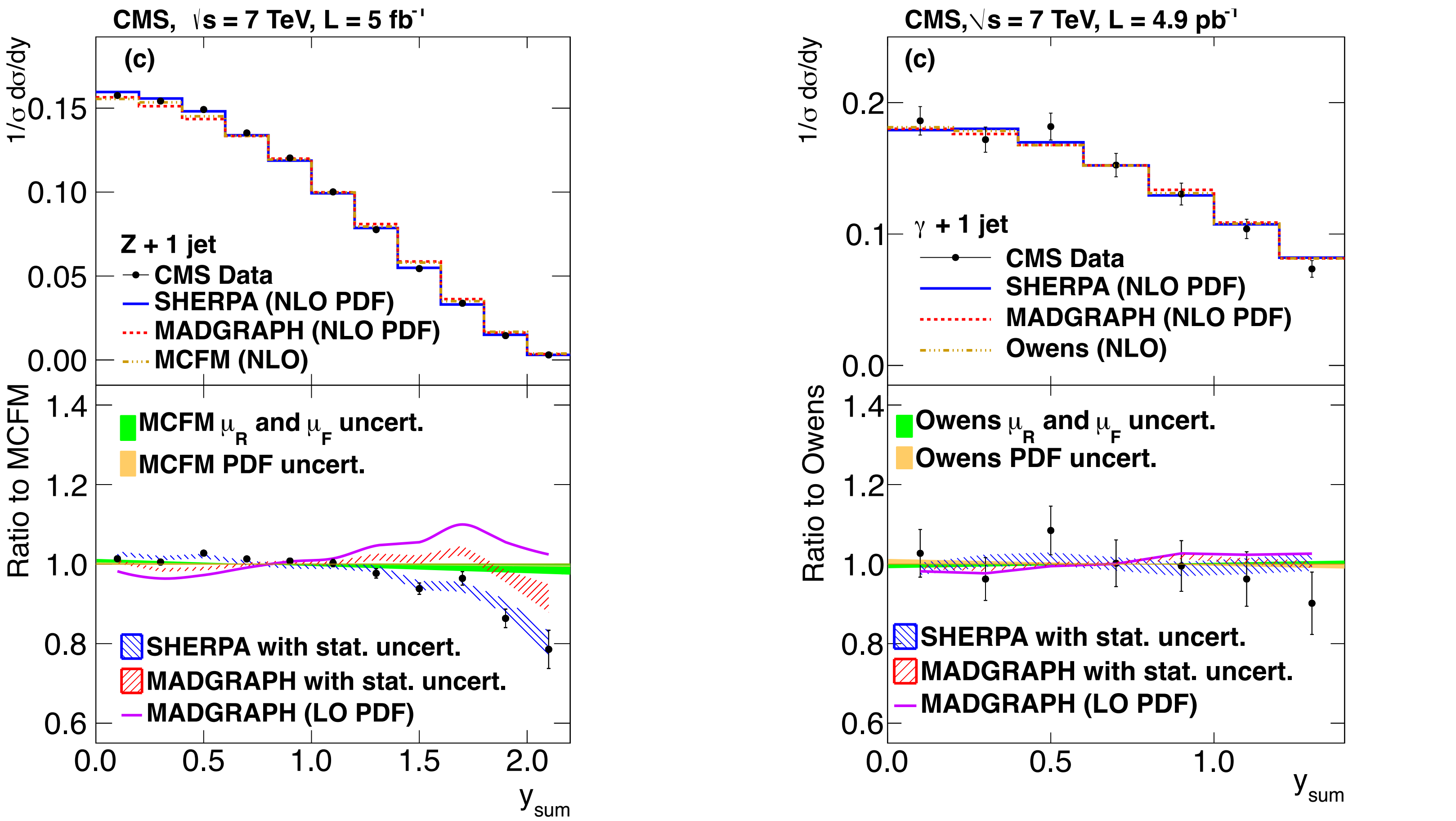
Results: Z/Gamma + 1 Jet: y_J





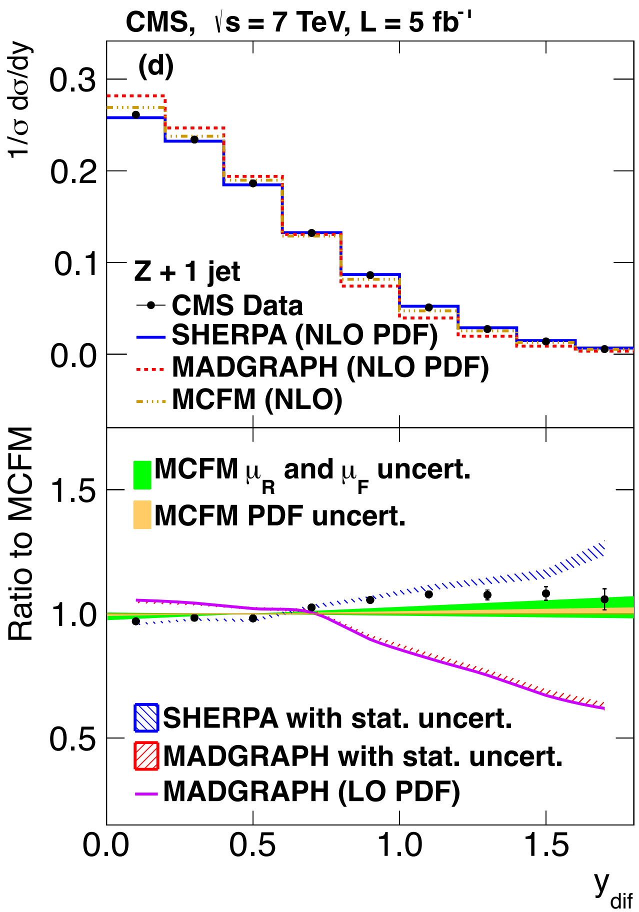
All predictions agree with data within 5 %

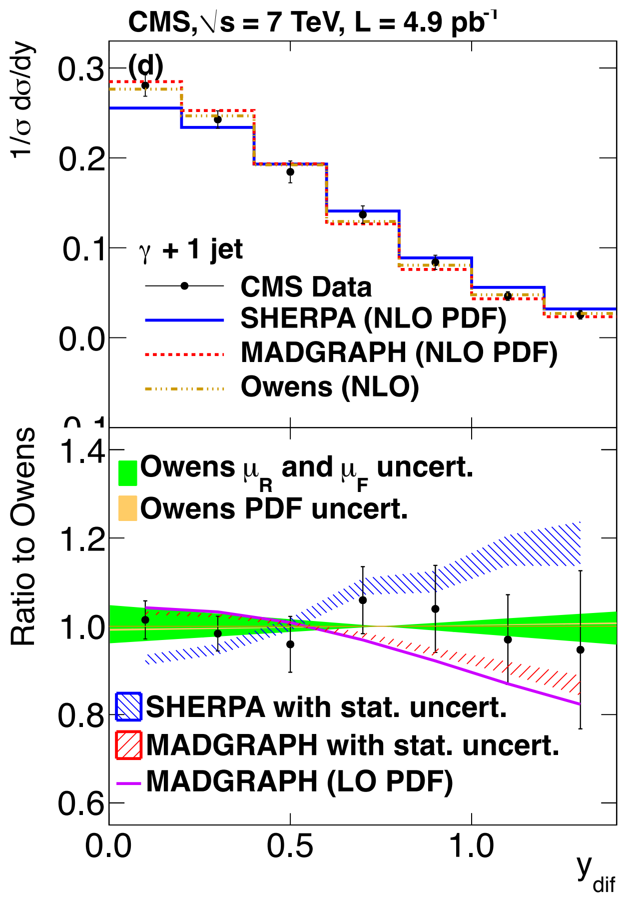
Results: Z/Gamma + 1 Jet: y_{sum}



Sherpa reproduces data for Z+1 jet over the complete range, MadGraph deviates between 5-20 % over the whole range, MCFM reproduces data for $Y_{sum} < 1.2$

Results: Z/Gamma + 1 Jet: y_{diff}





MCFM and Owens reproduce data, Sherpa reproduces data better than MadGraph especially for Z+1 Jet

Summary

Measurement of rapidity distributions in Z/Gamma + 1 jet has been presented

Rapidity distributions of $|y_V|$ and $|y_J|$ are well described by MCFM, Sherpa and Madgraph predictions within 5%

Distribution of y_{sum} is described by all prediction better than 5% for $y_{sum} < 1.0$

Distribution of y_{diff} is described by MCFM and Sherpa well in the $y_{diff} < 0.8$.
MCFM is better than 10% in whole range. Sherpa and Madgraph show increasing discrepancy in the the higher range.

For y_{diff} Sherpa reproduces data better than MadGraph
- Difference introduced in matching step of matrix elements and parton shower

Future plans: redo the analysis with 8TeV and ~20fb^{-1} (x4 from 7TeV)

BACKUP

Documentation

- Contact: Stephan L. Linn
- CADI: SMP-12-004 http://cms.cern.ch/iCMS/analysisadmin/cadi?ancode=SMP-12-004)
- Paper: SMP-12-004 (Paper draft V10)
- https://twiki.cern.ch/twiki/bin/viewauth/CMS/GammaJetAngular
- https://twiki.cern.ch/twiki/pub/CMS/GammaJetAngular/rivet_CMS_2013_1258128.tgz -->should be in the Rivet 1.84
- Theory prediction: AN-2012-230
- γ+1 jet: AN-2011-497
- Z+1jet
  - e: AN-2012-135
  - μ: AN-2012-037

Combination of Electron and Muon

- **B**est **L**inear **U**nbiased **E**stimator
  - Andrea Valassi, NIM, A500, 391
  - Louis Lyons, Duncan Gibaut, and

  Peter Clifford, NIM, A270, 110

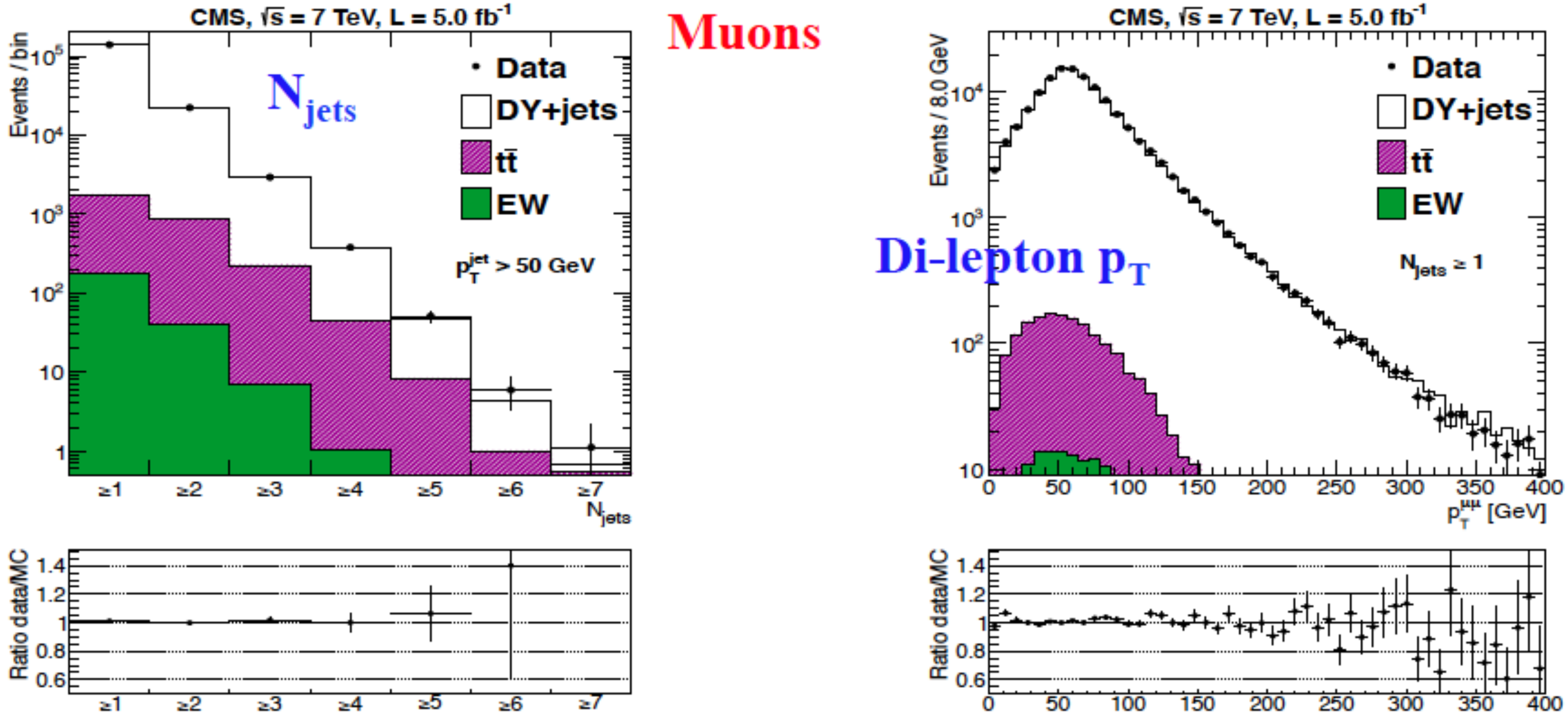
$$\begin{pmatrix} \sigma^2_{unc1} + \sigma^2_{corr1} & \sigma_{corr1}\sigma_{corr2} \\ \sigma_{corr1}\sigma_{corr2} & \sigma^2_{unc2} + \sigma^2_{corr2} \end{pmatrix}$$

- JES and PU uncertainties are 100% correlated between electron and muon channel
- The covariance matrix has 2N dimension
  - N is the number of bins with non-zero contents
  - For each channel of Yjet, the bin-to-bin correlation is obtained from the covariance matrix of RooUnfold after unfolding
- For every bin of the observable, the uncorrelated uncertainty is at least 3 times of the correlated uncertainty

	Sherpa	Madgraph/ MadEvent	MCFM	Owens
PDF	CTEQ6.6M	CTEQ6.1L	CTEQ6.6M	CTEQ6.6M
μ_F	m_z	$(M_Z^2+\Sigma p^2_{jet})^{0.5}$	m_z	P_T
μ_R	m_z		m_z	P_T
ME	Comix	Madgraph	Internal	Internal
PS	APACIC	Pythia	None	None
Matching Zed +jets	CKKW(20GeV)	Kt-MLM(20GeV)	None	None
Matching Gamma+jets	CKKW(10GeV)	Kt-MLM(9-12GeV)	None	None
Hadronization		Pythia	None	none

Z+jets

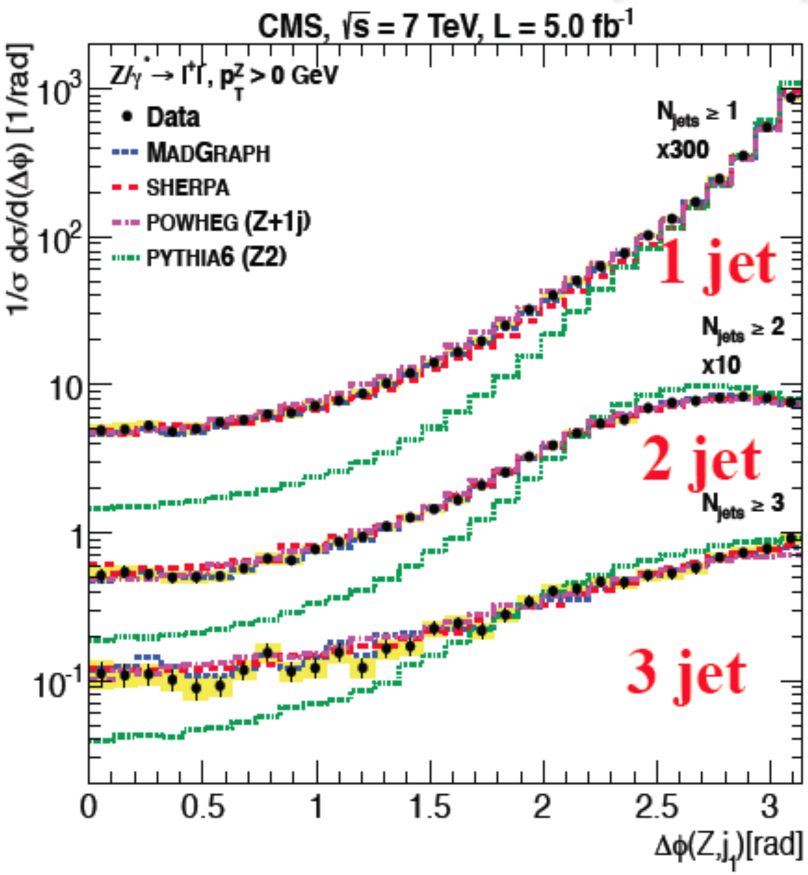
Data compared to CMS detector simulation of signal and background MC
- leptons p_T >20 GeV, $|\eta|<2.4$, jet p_T > 50 GeV, $|\eta|<2.5$

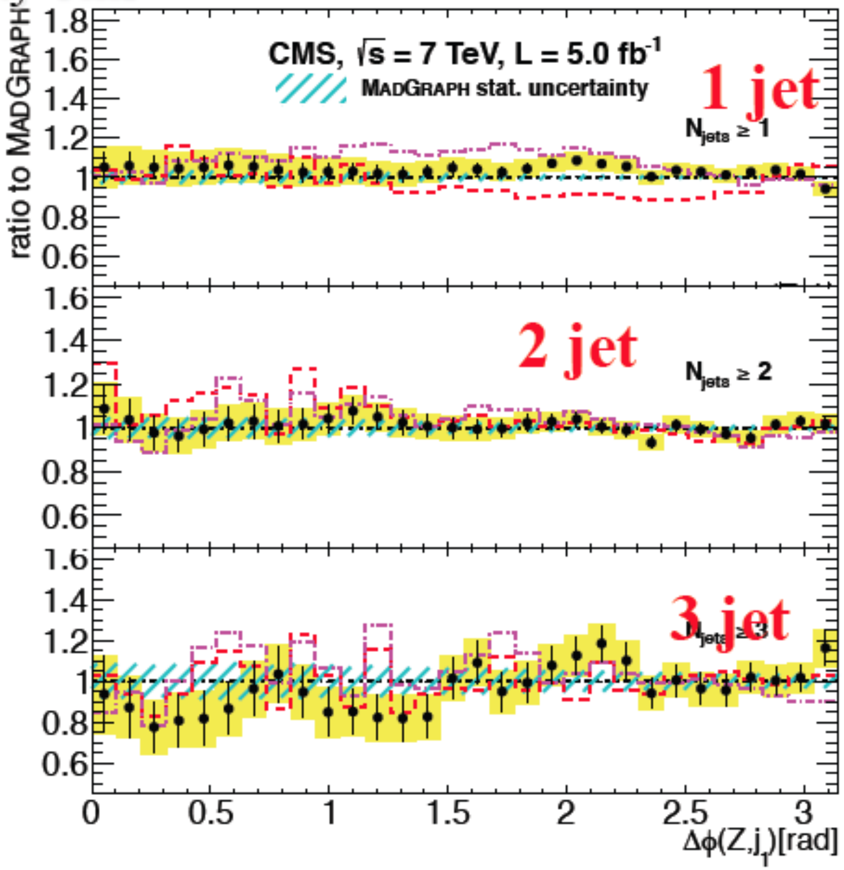


Very good agreement both in shape and absolute scale
(global NNLO k-factor applied)

Z+jets: $\Delta\Phi(Z, J_1)$

Plotted in 3 different inclusive jet multiplicity bins

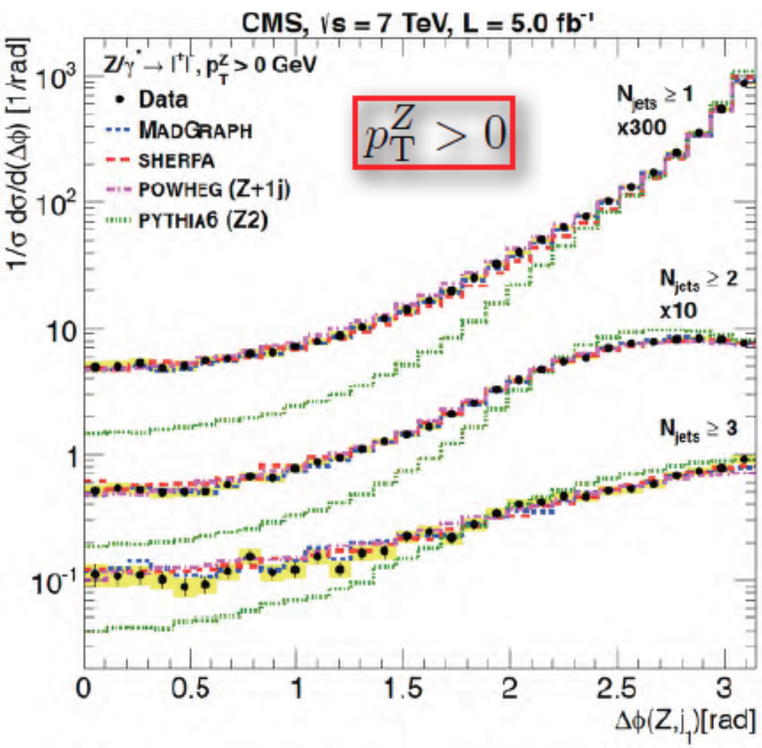


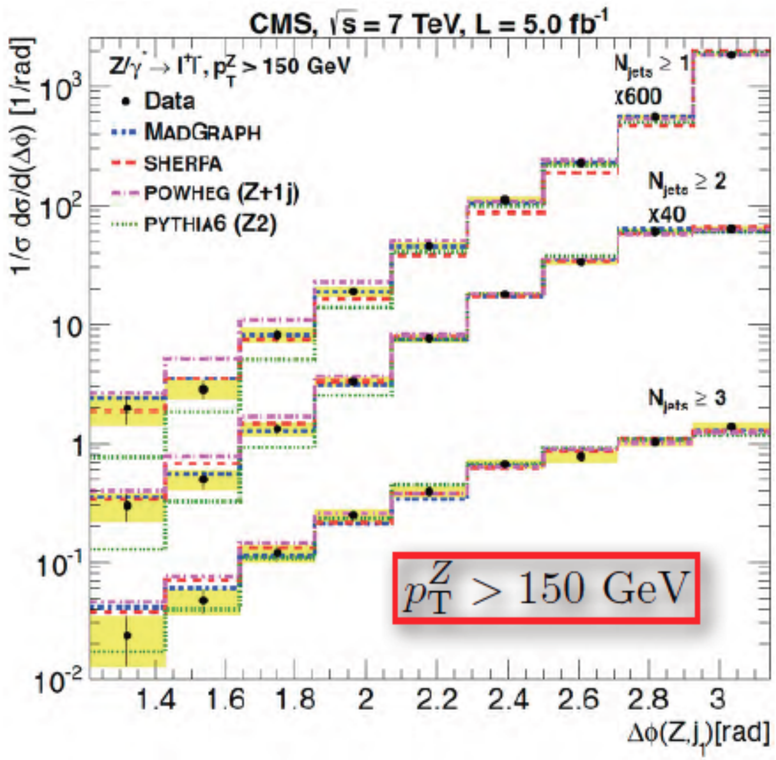


MadGraph and Powheg describe the data well, Sherpa describes data pretty well in 2 and 3 jet bin, off by 10% for 1 jet bin, Pythia6 is shifted to lower value

Z+jets - azimuthal correlations $\Delta\Phi(Z, j_1)$

Phys. Lett. B722 (2013) 238



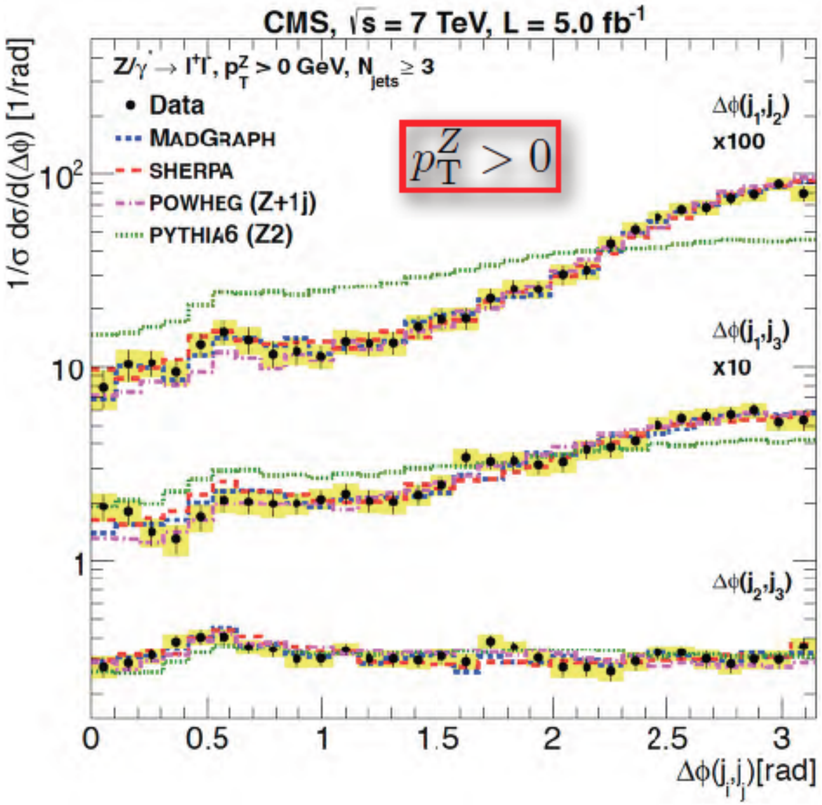


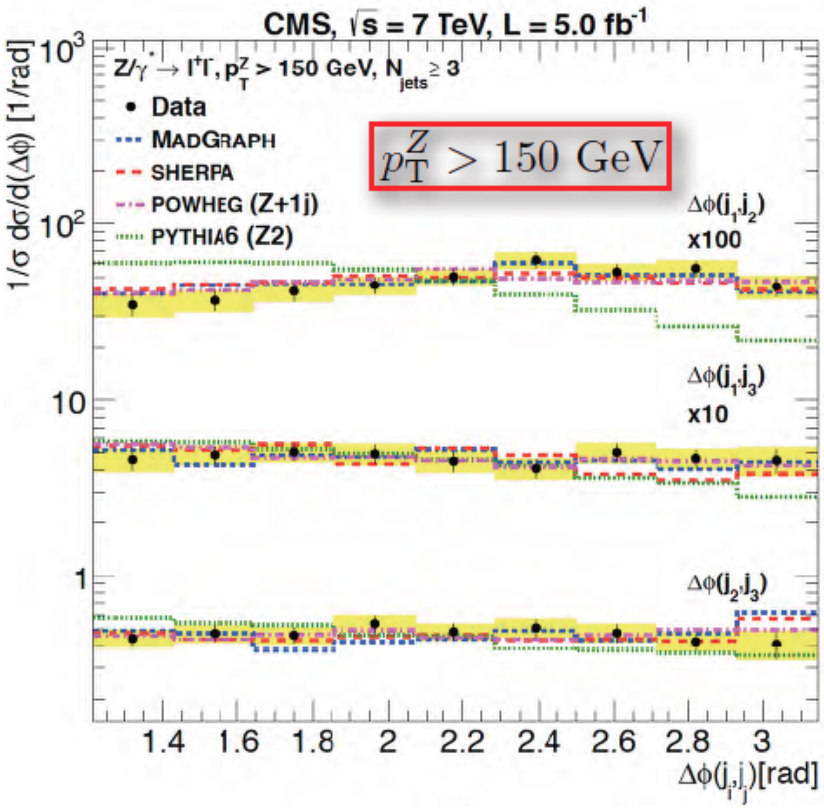
- $\Delta\Phi(Z, j_1)$: $\Delta\Phi$ between the Z and the leading jet for the inclusive multiplicities
  - $N_{jets} \geq 1, \geq 2, \geq 3$
  - normalized to unity
- $\Delta\Phi$ observable with largest systematics
  - 5-6% near 0, to 2% near π

- Agreement with POWHEG and SHERPA improve for larger multiplicities
- Multi-parton LO + PS do better than LO + PS !!
- PS important for NLO 1 jet in multijet environment

Z+jets - azimuthal correlations $\Delta\Phi(j_i, j_k)$

Phys. Lett. B722 (2013) 238





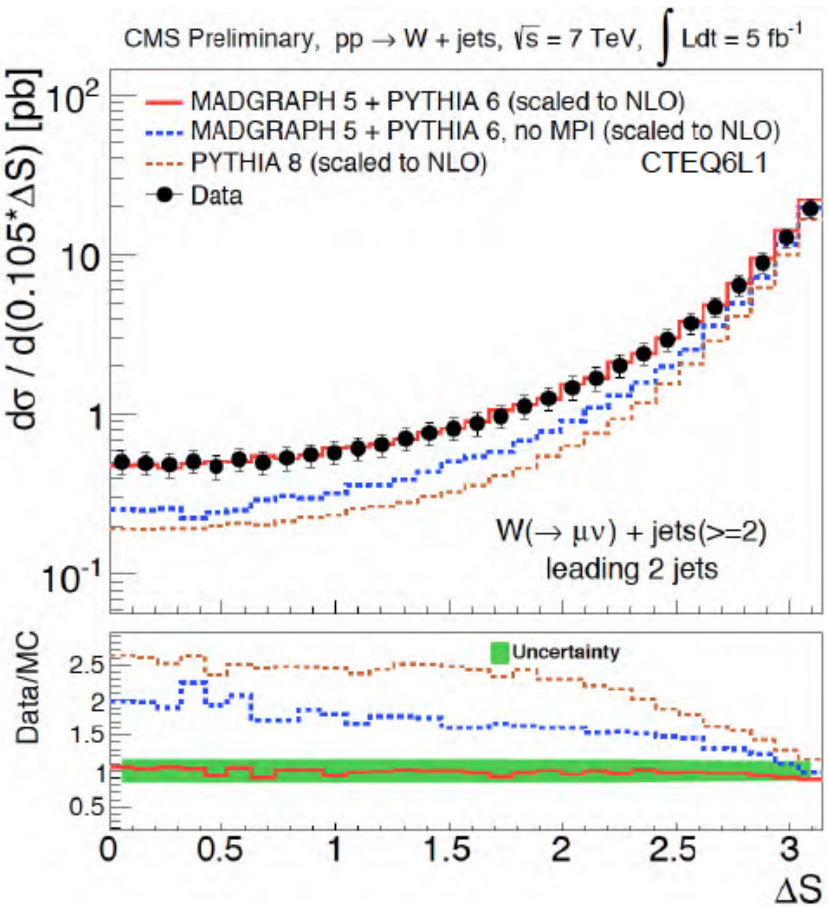
- $N_{jets} \geq 3$
  - $\Delta\Phi(j_1, j_2)$
  - $\Delta\Phi(j_1, j_3)$
  - $\Delta\Phi(j_2, j_3)$
  - normalized to unity

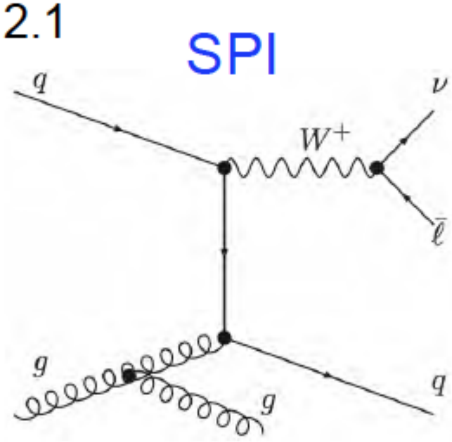
- Isotropic for $p_T^Z > 150$ GeV
  - improved agreement with PYTHIA consistent with increased phase space available for parton emission

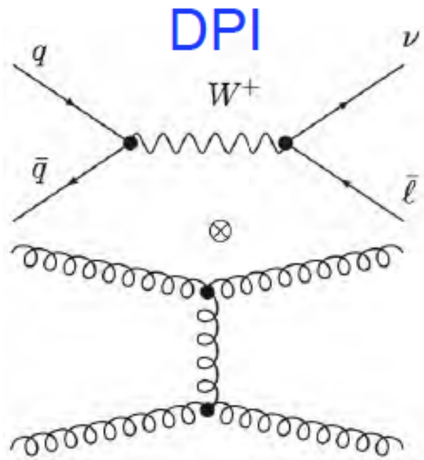
W + 2 jets - double parton interaction

CMS-FSQ-12-028

- One muon with $p_{T\mu} > 35$ GeV and $|\eta| < 2.1$
- $E_T^{miss} > 30$ GeV, $M_T > 50$ GeV
- Jets with $p_T > 20$ GeV and $|\eta| < 2.0$







- ΔS = ΔΦ between W and dijet system
  - ~random for DPI
  - ~back-to-back for SPI

- MadGraph+PYTHIA 6.4.25+Z2star tune
  - with multiple parton interaction: good description of the data
  - without multiple parton interaction: rate and shape not reproduced
- PYTHIA 8.165+4C tune
  - missing higher order diagram: predicts more back-to-back

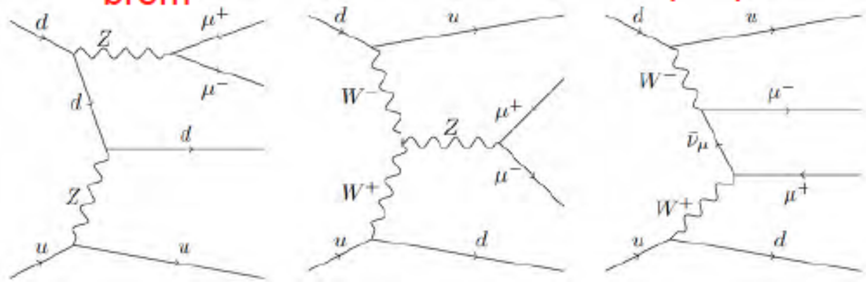
Z+jets - EW Z+2 forward jets

CMS-FSQ-12-019
arXiv:1305.7389

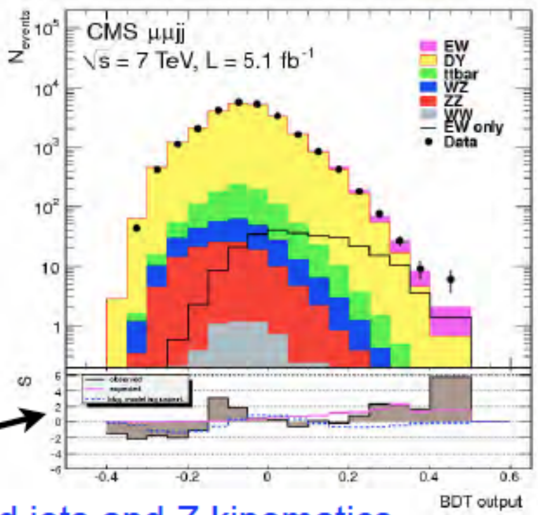
- Z production in association with two jets at order α^4_{EW}
  - includes TGC vertex (VBF), suppressed by a factor ~2.5 by interference terms
  - high p_T jets with large rapidity distance
- $\sigma(\mathrm{EW}\ \ell\ell jj)_{NLO}$ = 166 fb (DY ~ 29.3 pb!)
  - M_{jj} > 120 GeV, $M_{\ell\ell}$ > 50 GeV
  - p_{Tj} > 25 GeV, $|\eta_j|$ < 4
  - CT10 and $\mu_R = \mu_F$ = 90 GeV
- Optimized event selection (S/B ~ 11%)
  - leptons: $\ell\ell$ with $p_{T\ell}$ > 20 GeV, $|\eta_\ell|$ < 2.4
  - Z: $|M_{ee}-M_Z|$ < 20 GeV (15 GeV for μμ)
  - two leading p_T jets in $|\eta|$ < 3.6
    - $p_T(1)$ > 65 GeV; $p_T(2)$ > 40 GeV
    - M_{jj} > 600 GeV
  - central Z in jj rest frame
    - $|y^*| = |y_Z - (y_{j1} - y_{j2})/2| < 1.2$
- Signal extraction with MVA
  - Boosted decision tree, including tagged jets and Z kinematics

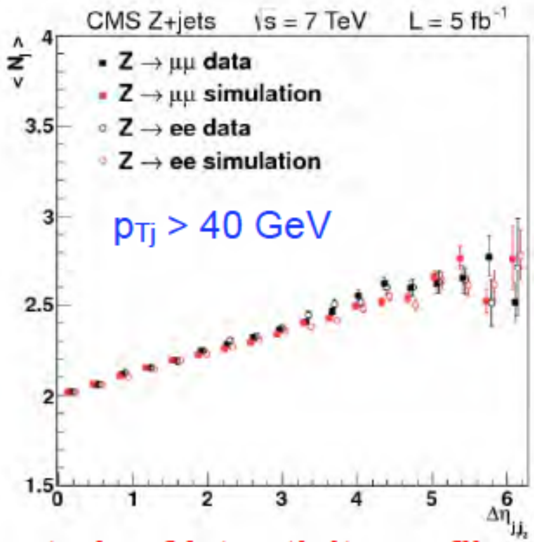
$$\sigma^{\mathrm{EWK}}_{\mathrm{meas},\ \mu\mu+ee} = 154 \pm 24(\mathrm{stat}) \pm 46(\mathrm{exp.syst.}) \pm 27(\mathrm{th.syst}) \pm 3(\mathrm{lumi})\ \mathrm{fb}$$

brem VBF multiperipheral



- Important benchmark processes in search for VBF H!!



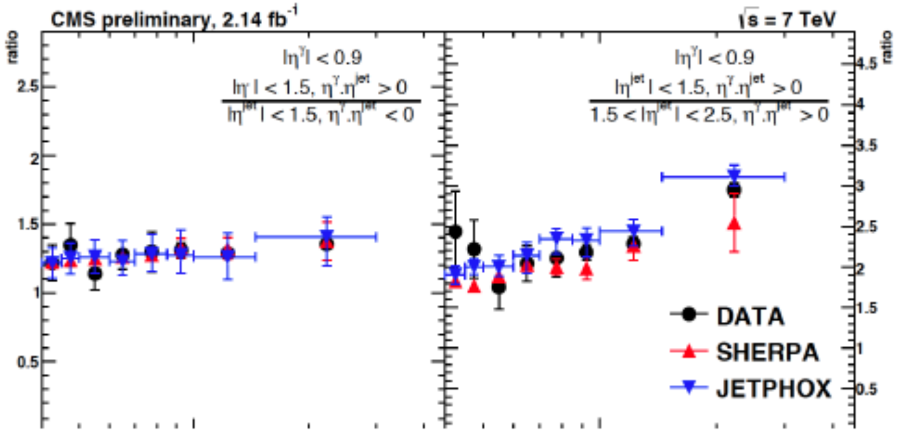


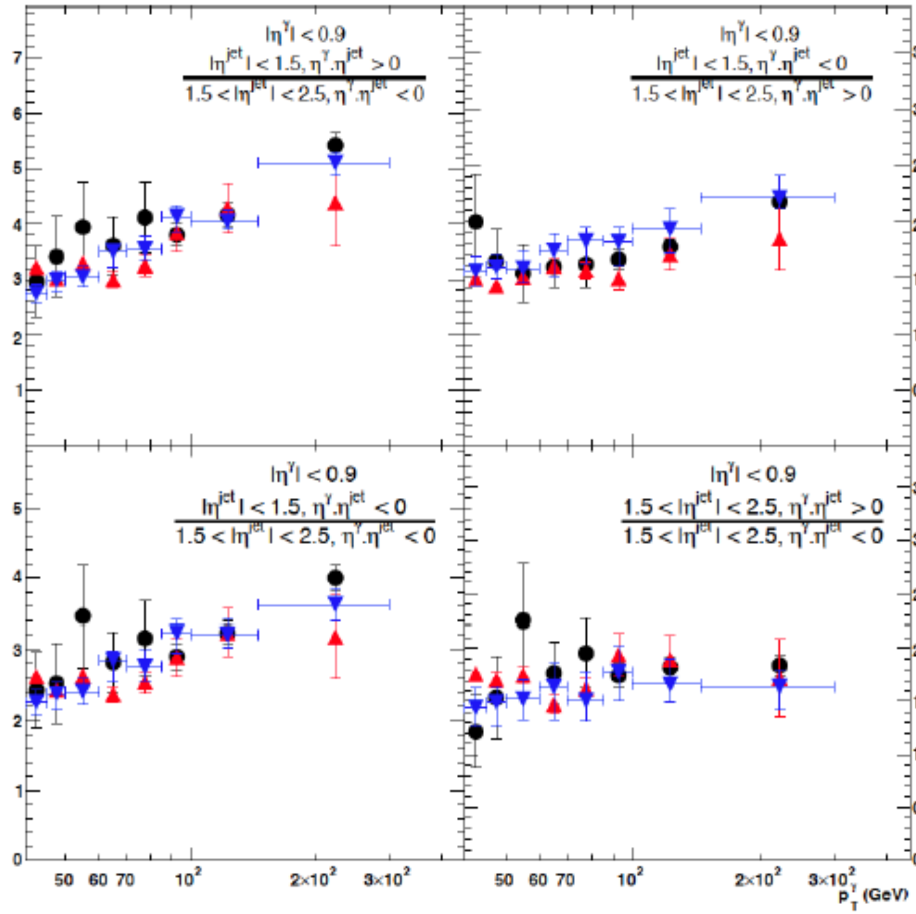
study of jet activity profiles: also for ΔΦ and H_T

- Jet activity profiles: MadGraph-based predictions in agreement with data (reco level)
- $\sigma(\mathrm{EW}\ \ell\ell jj)$ extracted (~2.6σ), compatible with prediction (NLO QCD corrections)

γ+jets

- Cross-section ratio between different regions





Ratios of cross-sections with different rapidity orientations between jets and the photon

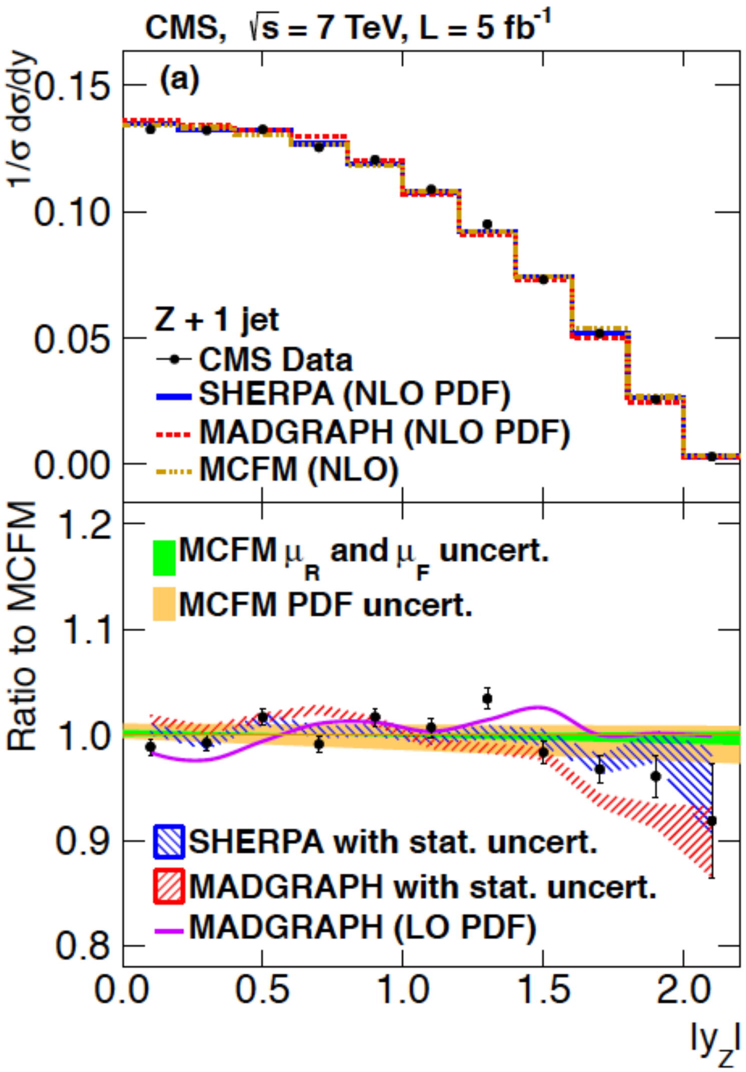
➡ reasonable well predicted by Sherpa and Jetphox

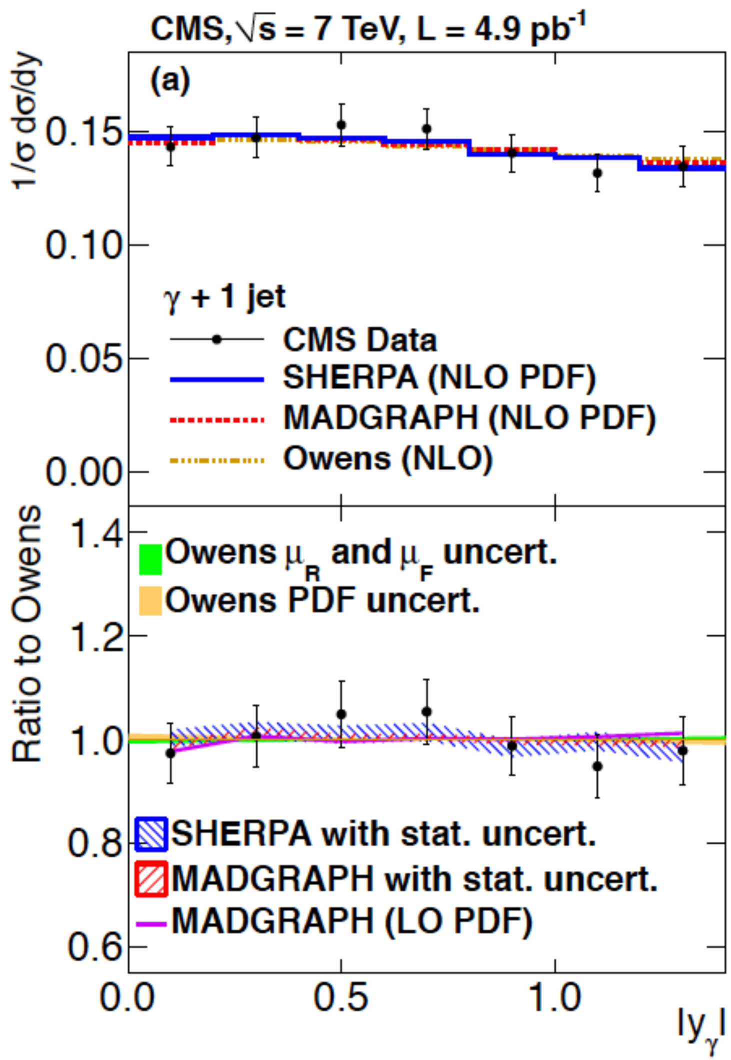
γ+jets: uncertainties

- Biggest uncertainty on the purity determination

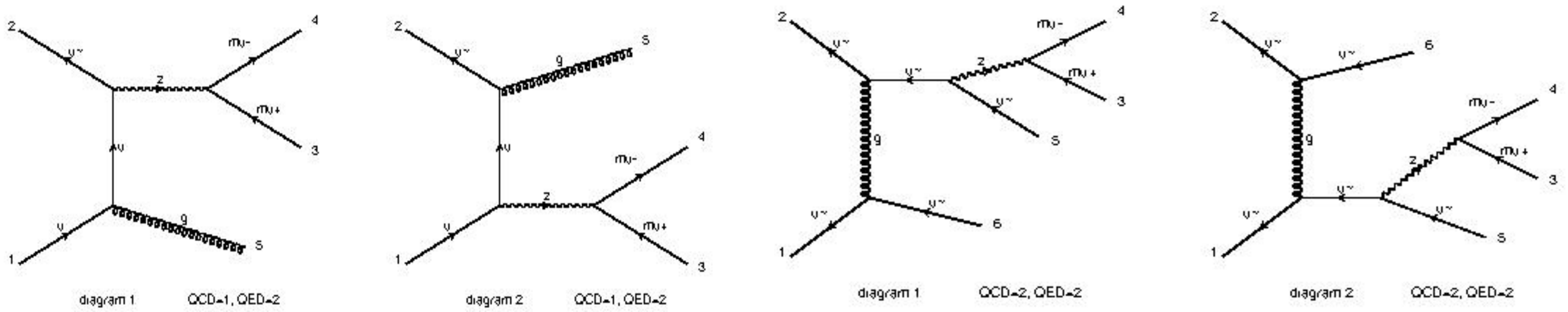
$\lvert\eta^{\gamma}\rvert < 1.4442$				
P_T^{γ} GeV	efficiency (%)	unfolding (%)	purity (%)	total (%)
40-45	2.5	2.1	4.9 - 9.3	5.9 - 9.9
45-50	1.2	2.5	4.9 - 17.0	5.5 - 17.2
50-60	4.5	2.6	4.2 - 13.4	6.7 - 14.4
60-70	4.5	2.4	3.7 - 11.4	6.3 - 12.5
70-85	4.5	1.2	4.6 - 5.7	6.6 - 7.4
85-100	4.5	1.4	2.2 - 3.1	5.2 - 5.6
100-145	4.5	1.4	1.8 - 2.5	5.0 - 5.4
145-300	4.5	1.2	1.4 - 2.6	4.9 - 5.3
$1.556 < \lvert\eta^{\gamma}\rvert < 2.5$				
P_T^{γ} GeV	efficiency (%)	unfolding (%)	purity (%)	total (%)
40-45	3.0	2.1	6.9 - 9.9	7.8 - 10.5
45-50	3.5	2.5	8.6 - 37.5	9.6 - 37.7
50-60	5.0	2.6	7.2 - 24.5	9.1 - 25.1
60-70	5.0	2.4	7.0 - 12.4	9.0 - 13.5
70-85	5.0	1.2 - 5.0	10.0 - 13.3	11.3 - 15.1
85-100	5.0	1.4 - 5.0	2.8 - 4.6	5.9 - 8.0
100-145	5.0	1.4 - 4.0	2.8 - 6.3	5.9 - 8.2
145-300	5.0	1.2 - 2.1	2.9 - 5.1	6.1 - 7.3

Z/Gamma + 1 Jet: y_V

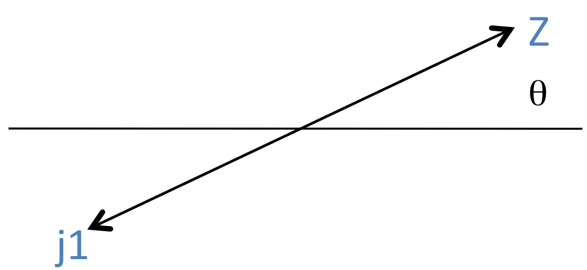




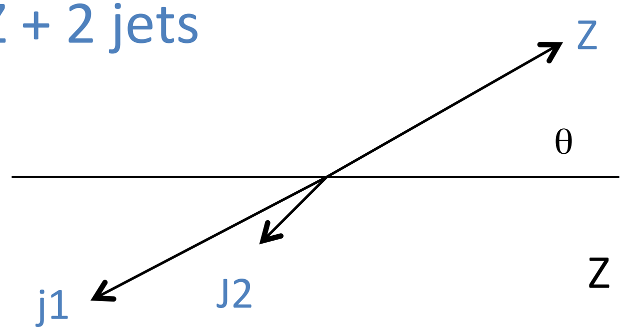
Merging/Matching

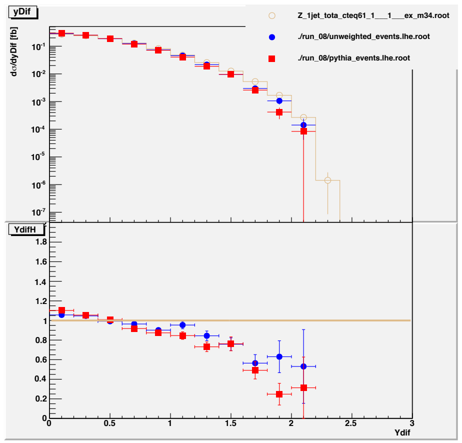


Z + jet



Z + 2 jets





Merging same for both MC
Conclude:
MLM(Madgraph) rejection vs CKKW(sherpa) weighting affects how events are "matched".