

Measurements of Forward Energy Flow and Forward Jet Production with CMS

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on behalf of the CMS Collaboration

DESY

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① Introduction

Motivation

Experimental Setup

② Forward Jets

Inclusive Forward Jet Spectrum

Simultaneous Production of Forward and Central Jets

③ Forward Energy Flow

Energy Flow in Minimum Bias and Di-jet Events

Energy Flow in Z/W Events Including Rapidity Gap Studies

④ Summary

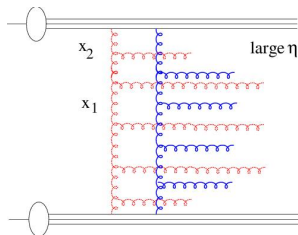
Motivation

High energy collisions

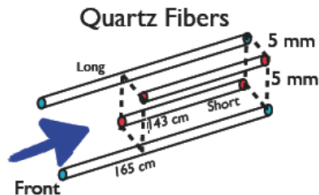
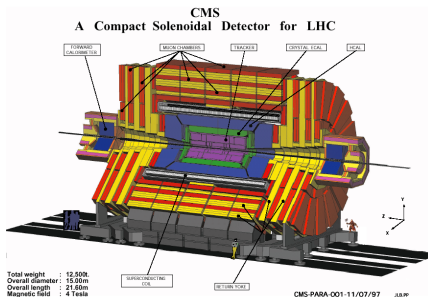
- Large parton densities are important
- Large phase space for QCD emissions
- High probability for multi-parton interactions

Forward region

- High sensitivity for additional radiation and multi-parton interactions
- Large phase space region can be explored



Hadronic Forward Calorimeter at CMS



Hadronic Forward (HF)

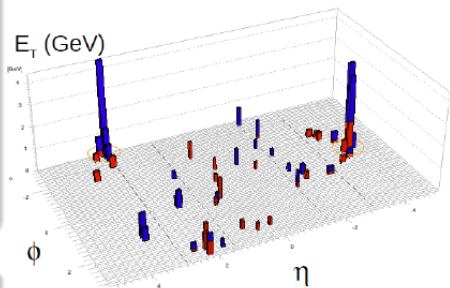
- Coverage: $2.9 < |\eta| < 5.2$
- Steel absorber with quartz fibres
- $\Delta\eta \times \Delta\phi = 0.175 \times 0.175$
- Alternating long (165 cm) and short (starting after 22 cm) fibres: identification of electrons and photons possible

Jets

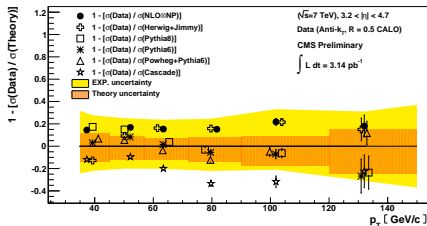
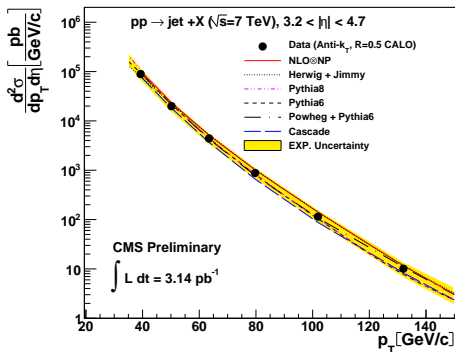
- Jets built from Calorimeter information
- Anti- k_T algorithm with $R = 0.5$
- Application of jet quality criteria
- Consider jets with $p_T > 35$ GeV in $3.2 < |\eta| < 4.7$

Conditions

- Integrated luminosity: 3.14 pb^{-1}



Forward Jet Cross Section

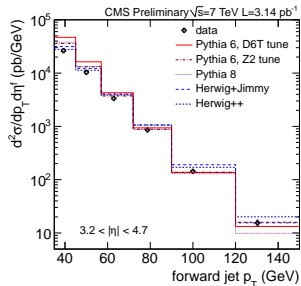
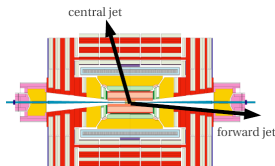
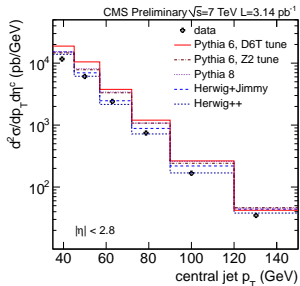


Corrections to hadron level utilising bin-by-bin method

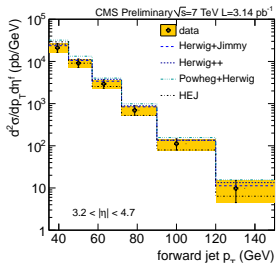
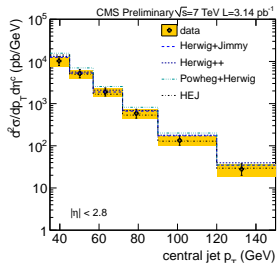
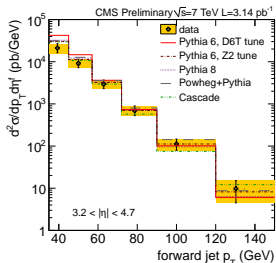
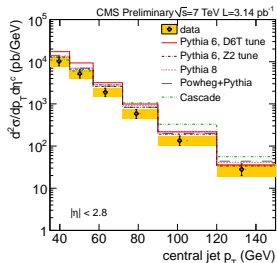
- Systematic uncertainties: Jet energy scale (20–30%), p_T resolution (3–6%), luminosity (4%)
- Theoretical uncertainties: Non-perturbative effects, pdf checks, variations of μ_r and μ_f by a factor of 2

Simultaneous production of central and forward jets

- Leading jet in central and forward region are investigated
- $p_T > 35$ GeV
- Central region: $|\eta^c| < 2.8$
- Forward region: $3.2 < |\eta^f| < 4.7$



Forward and Central Jet Cross Sections



Corrections to hadron level

- Utilisation of bin-by-bin method

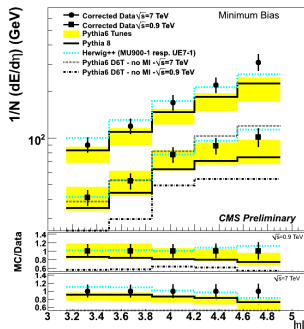
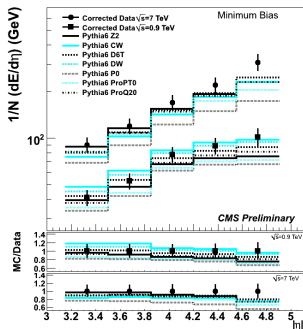
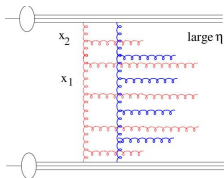
Experimental uncertainties

- Jet Energy Scale (25%)
- Model dependence (5–15%)
- Luminosity (4%)

Forward Energy Flow – CMS PAS FWD10-011

Minimum Bias events

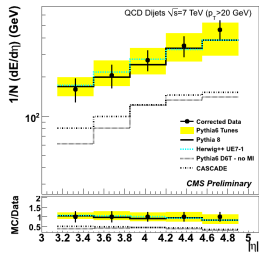
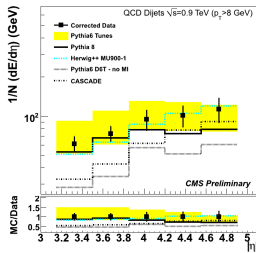
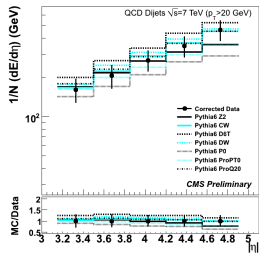
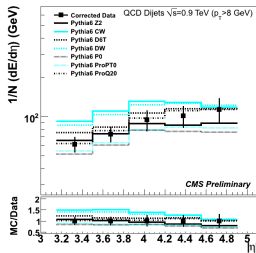
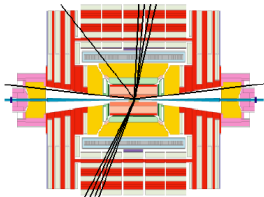
- Analysis of 900 GeV ($231 \mu\text{b}^{-1}$) and 7 TeV ($206 \mu\text{b}^{-1}$) collisions
- Data are corrected to hadron level utilising bin-by-bin corrections
- Dominating uncertainties: global energy scale (10%) and model dependence (up to 17%)



Forward Energy Flow in Di-jet Events

Di-jet events

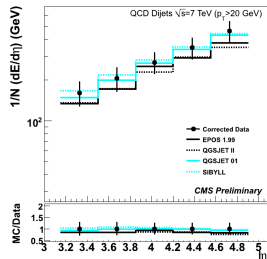
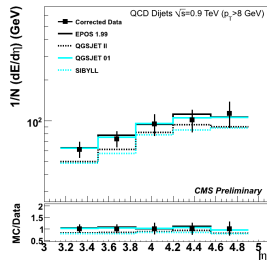
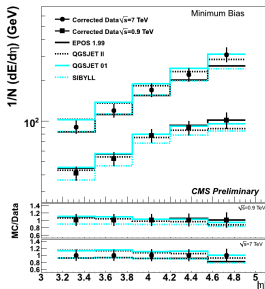
- Anti- k_T jets with $R = 0.5$
- $p_T > 8/20$ GeV for 900 GeV/7 TeV
- Two jets back-to-back in $|\eta| < 2.5$



Comparison to Cosmic Ray Generator Predictions

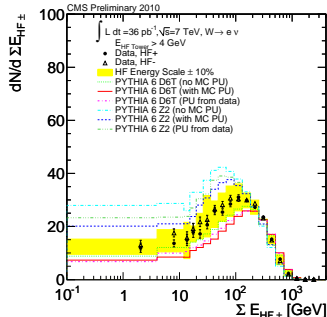
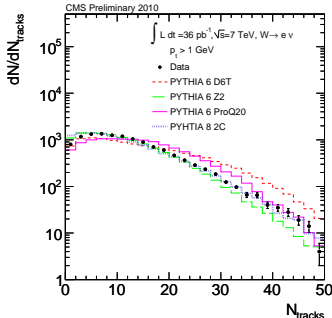
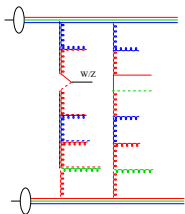
Cosmic ray generators

- Built for cosmic ray analyses
- Dedicated for forward region
- Multiple pomeron exchanges but also DGLAP evolution



Selection of W events

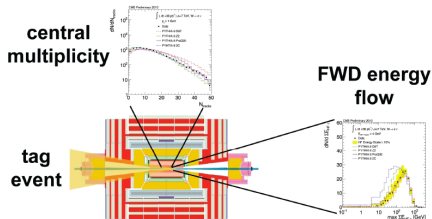
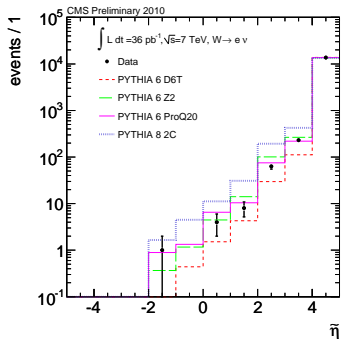
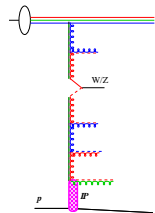
- Leptonic decays: $W \rightarrow l\nu$ with $l = e/\mu$
- $p_T(l) > 25 \text{ GeV}$, $\cancel{E}_T > 30 \text{ GeV}$, $M_T(l + \nu) > 60 \text{ GeV}$
- Study of Z events leads to very similar results
- Integrated luminosity: 36 pb^{-1}



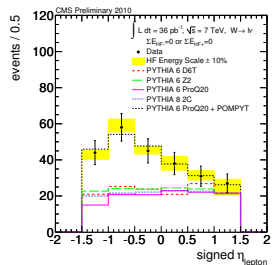
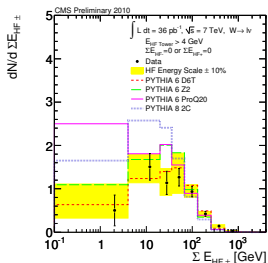
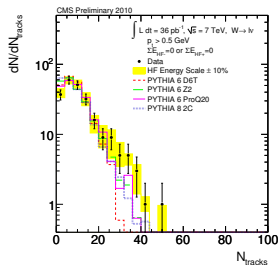
Rapidity Gaps in Z/W Events

Definition of rapidity gaps

- No activity above noise threshold in HF on one side
- $\tilde{\eta} = \min(\eta_{max}, -\eta_{min})$



Analysis of Gap Events



Correlations in gap events

- η of leptons with respect to the gap: positive sign when lepton and gap are in the same hemisphere
- Asymmetry: -0.22 ± 0.06 for W events
- Only POMPYPY predicts asymmetry
- POMPYPY is based on diffractive production

Summary

Forward jets

- Measurement of inclusive forward jet production in good agreement with theoretical predictions
- Simultaneous production of forward and central jets in reasonable agreement with theoretical predictions

Forward energy flow

- Forward energy flow in Minimum Bias and Di-jet events only partially described by DGLAP MCs, but well modeled by cosmic ray MCs
- Forward energy flow and gap studies in W/Z events show significant differences to theoretical predictions

Conclusion

- Investigating this phase space region is crucial for a complete picture of QCD and important for improving our models