

Measurements of the forward energy flow and forward jet production with CMS

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Measurements with CMS detector at LHC

- CMS has a very good forward pseudorapidity coverage
 $-6.6 < \eta < 5.2$

HF calorimeter:

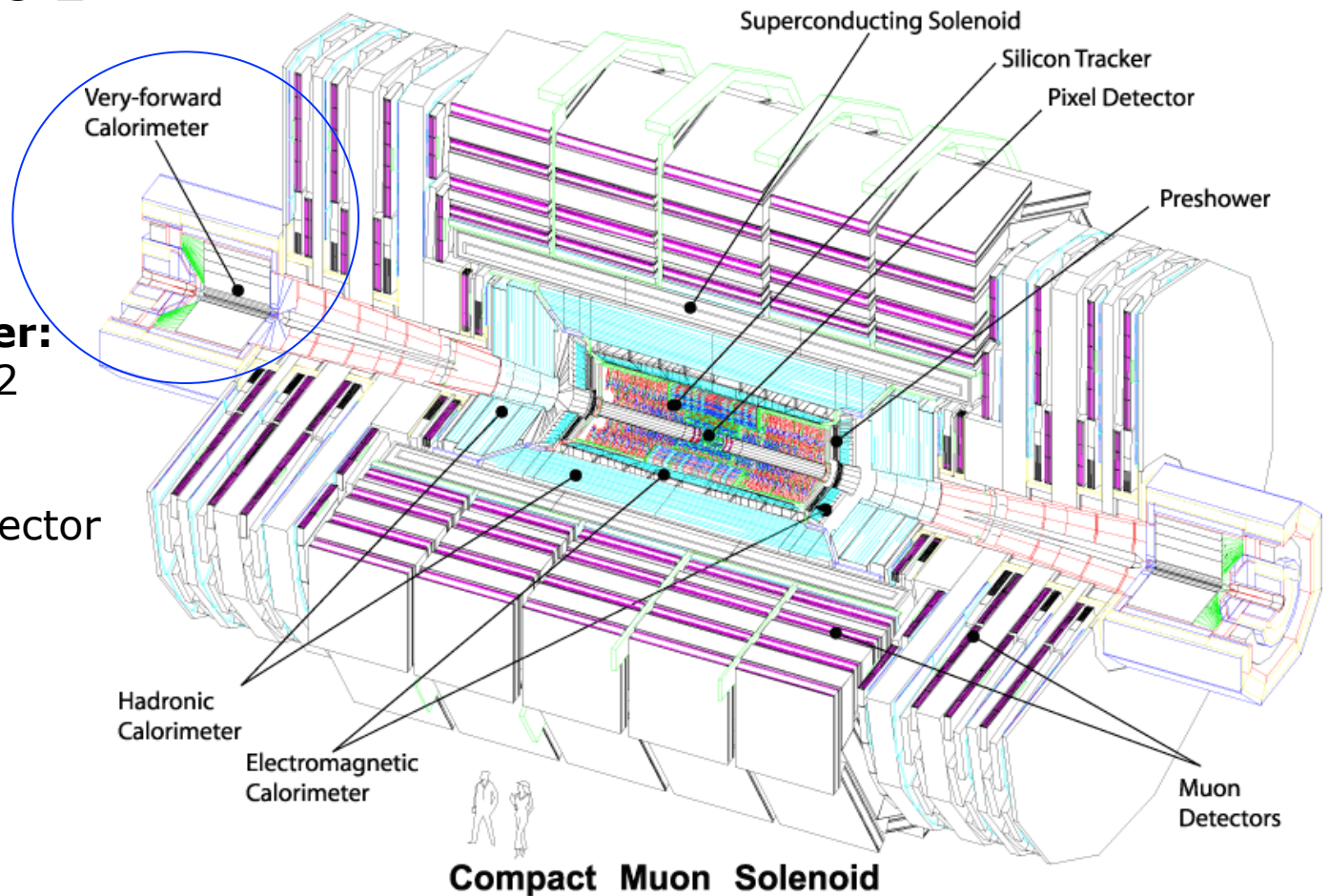
$2.9 < |\eta| < 5.2$

11.2m from IP

iron/quartz

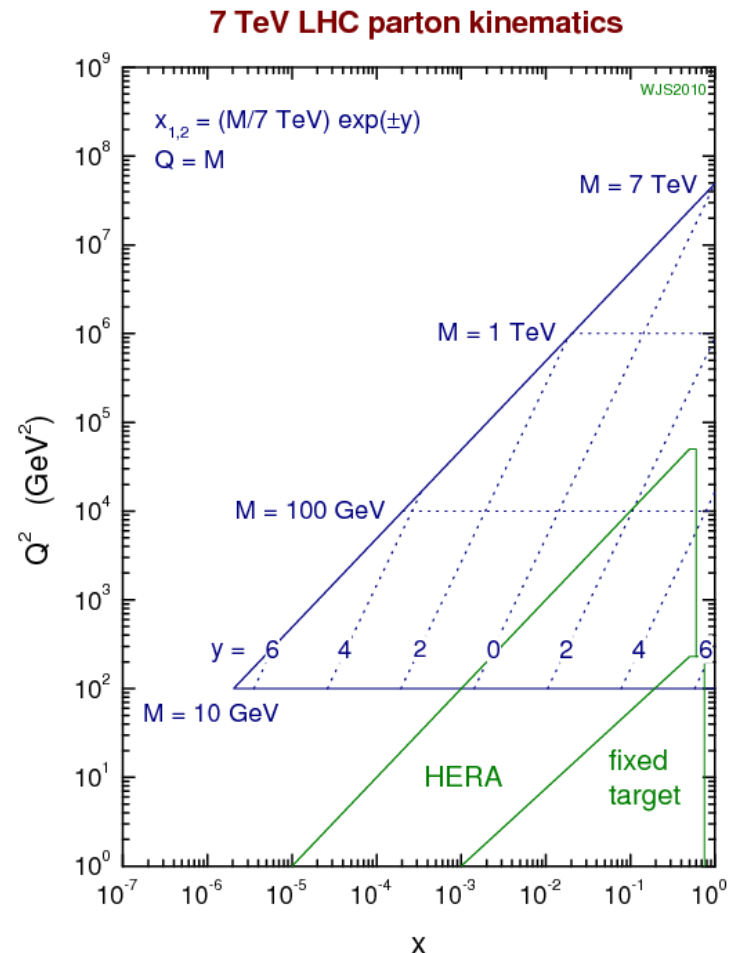
Cherenkov detector

13 rings in η



Forward physics

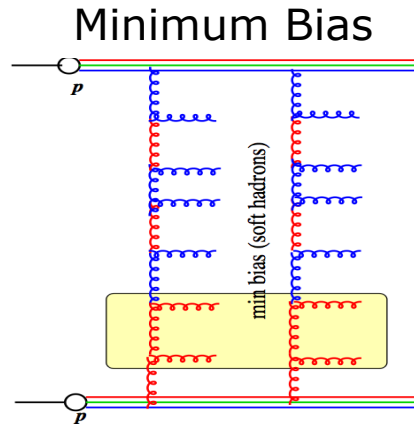
- Why going forward?
 - LHC is a small x QCD machine: access to low x values ($\eta \sim 5$: $x \sim 10^{-5}$)
- Energy flow in forward region:
 - sensitive to parton radiation & MPI
 - key to understand UE activity
 - complementary to central region
- Forward jet production:
 - sensitive to underlying partonic QCD, parton radiation and PDF's
 - scattering between $x_2 \ll x_1$ partons
 - access to low-x QCD where PDF's less constrained & deviations from DGLAP are expected
- Forward & central jets:
 - sensitive to MPI
 - study different types of parton radiation dynamics: DGLAP, BFKL, CCFM



Forward energy flow measurement

- Measurement of energy flow in region: $3.15 < |\eta| < 4.9$ for centre-of-mass energies 900 GeV and 7 TeV $\frac{1}{N} \frac{dE}{d\eta}$

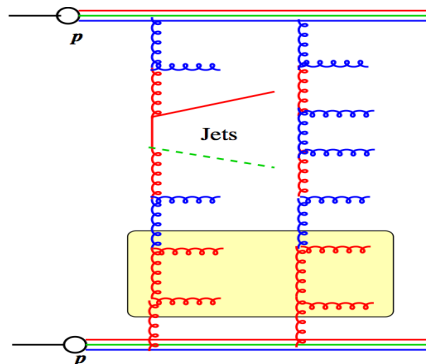
- 2 classes of events:



Events with a hard scale

central dijets: $|\eta| < 2.5$

$p_T > 8(20)$ GeV at 900 GeV(7 TeV)

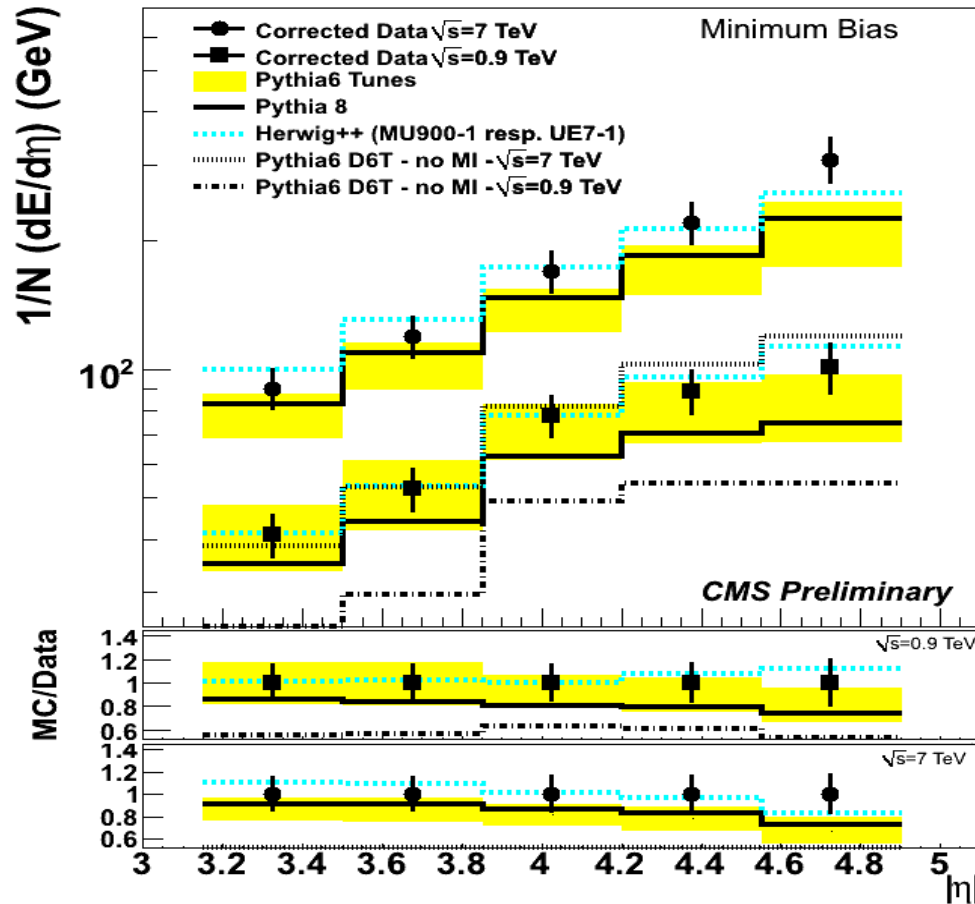


- Event selection:
 - trigger: charged particles in region $3.9 < |\eta| < 4.4$ + presence of beams
 - further cleaning:
 - good vertex conditions + removal of beam-induced background
 - Data corrected to hadron level, definition:
 - unstable particles decay ($\tau < 10^{-12}$ s),
 - $3.15 < |\eta| < 4.9$, ν & μ excluded,
 - diffractive events suppressed (at least 1 particle in $3.9 < |\eta| < 4.4$)
 - Largest systematic uncertainties:
 - Energy scale 10%
 - HF simulation 3-9% (MB), 6-18% (dijet)
 - Model uncertainty 1-3% (MB), 4-17% (dijet)
- Total: 11-14% (MB), 13-22% (dijet)

Forward energy flow: MinBias

- Energy flow at 900 GeV and 7 TeV:

CMS-PAS-FWD-10-011



- We see a rise with η , corresponds to flat E_T flow
- Increase in E_T flow from 900 GeV to 7 TeV similar to increase in N_{ch}
- 900 GeV: measurement similar to UA1 results

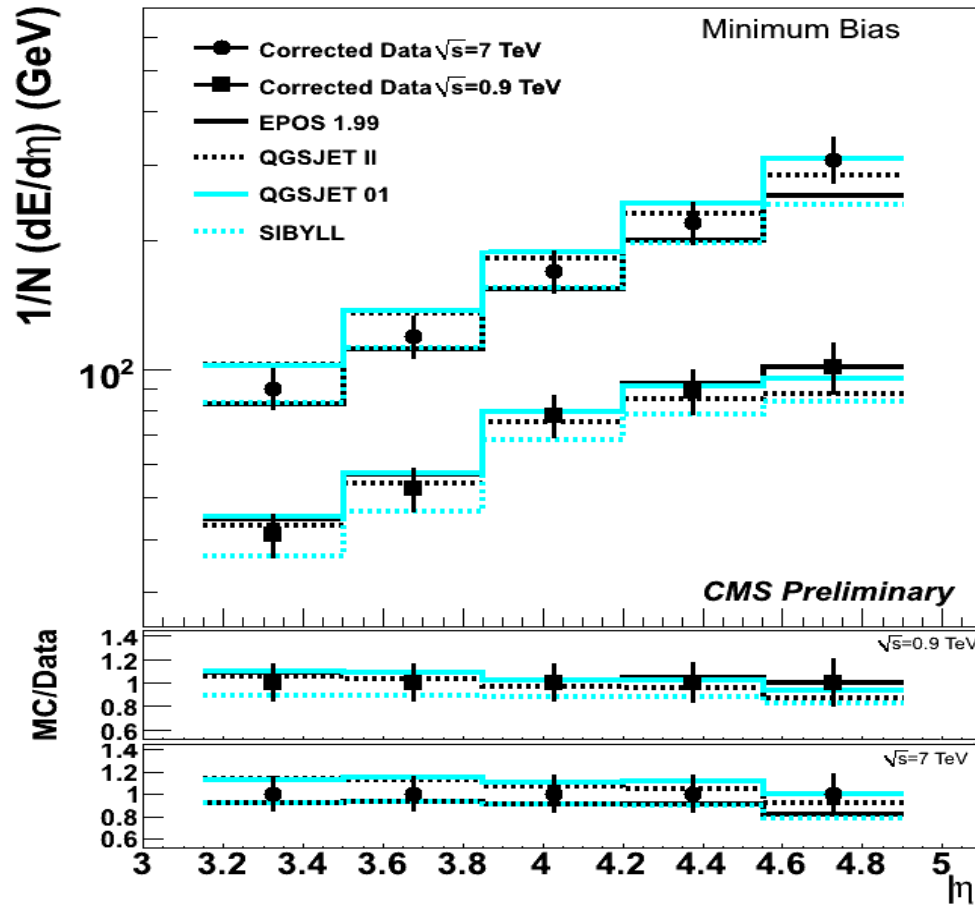
Comparison to MC:

- Predictions without MPI: too low
- HERWIG: tunes work
- Pythia: large spread between different (LHC) tunes

Forward energy flow: MinBias (II)

- Energy flow at 900 GeV and 7 TeV:

CMS-PAS-FWD-10-011



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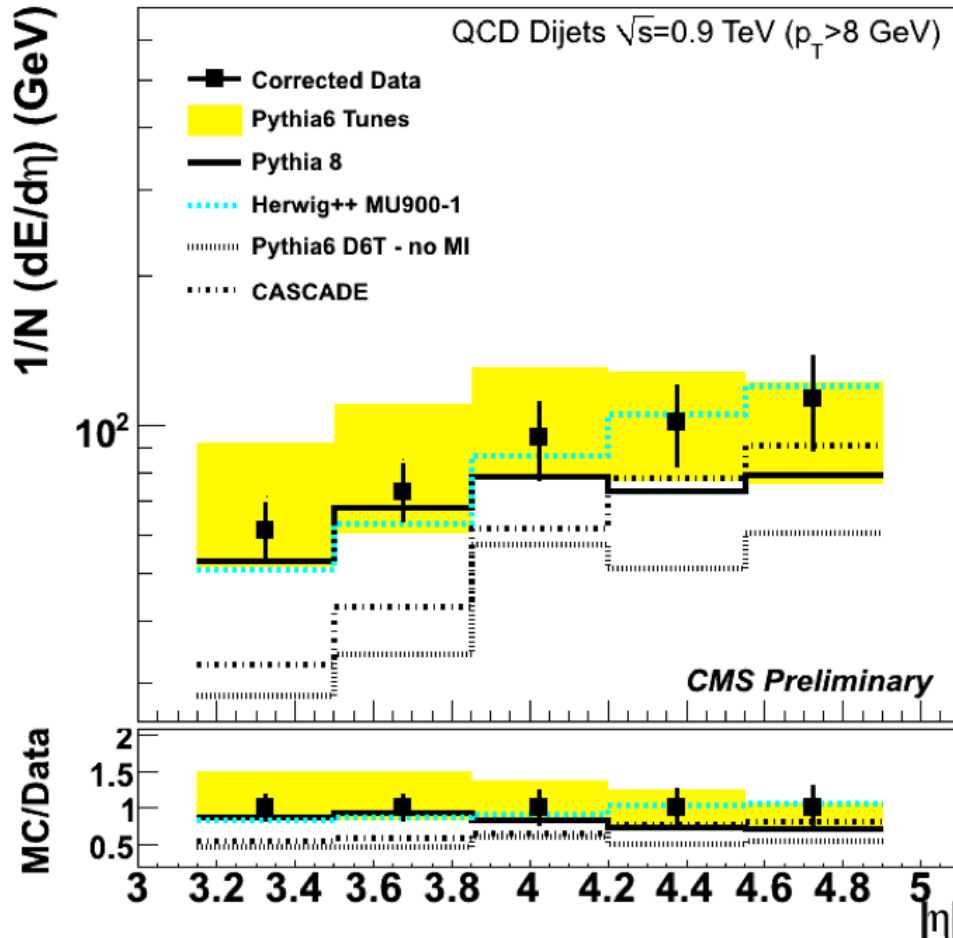
- Predictions without MPI: too low
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- Pythia: large spread between different (LHC) tunes

- pp generators used in Cosmic Ray physics work quite well out of the box !

Forward energy flow: Dijets

- Dijet energy flow at 900 GeV with $p_T > 8\text{ GeV}$:

CMS-PAS-FWD-10-011



- Flatter η dependence corresponds to decreasing E_T flow
- E_T flow much larger than at HERA

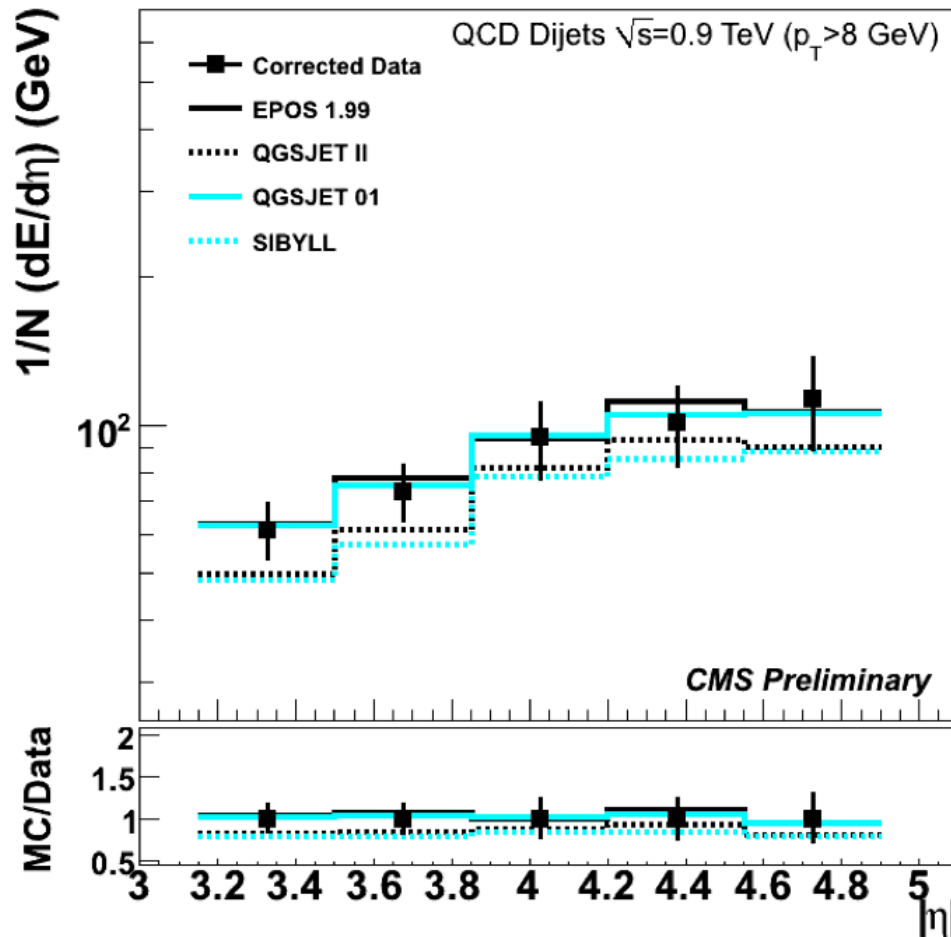
Comparison to MC:

- Predictions without MPI: too low
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- Pythia: tunes cover data
- CASCADE: increases faster

Forward energy flow: Dijets (II)

- Dijet energy flow at 900 GeV with $p_T > 8\text{ GeV}$:

CMS-PAS-FWD-10-011



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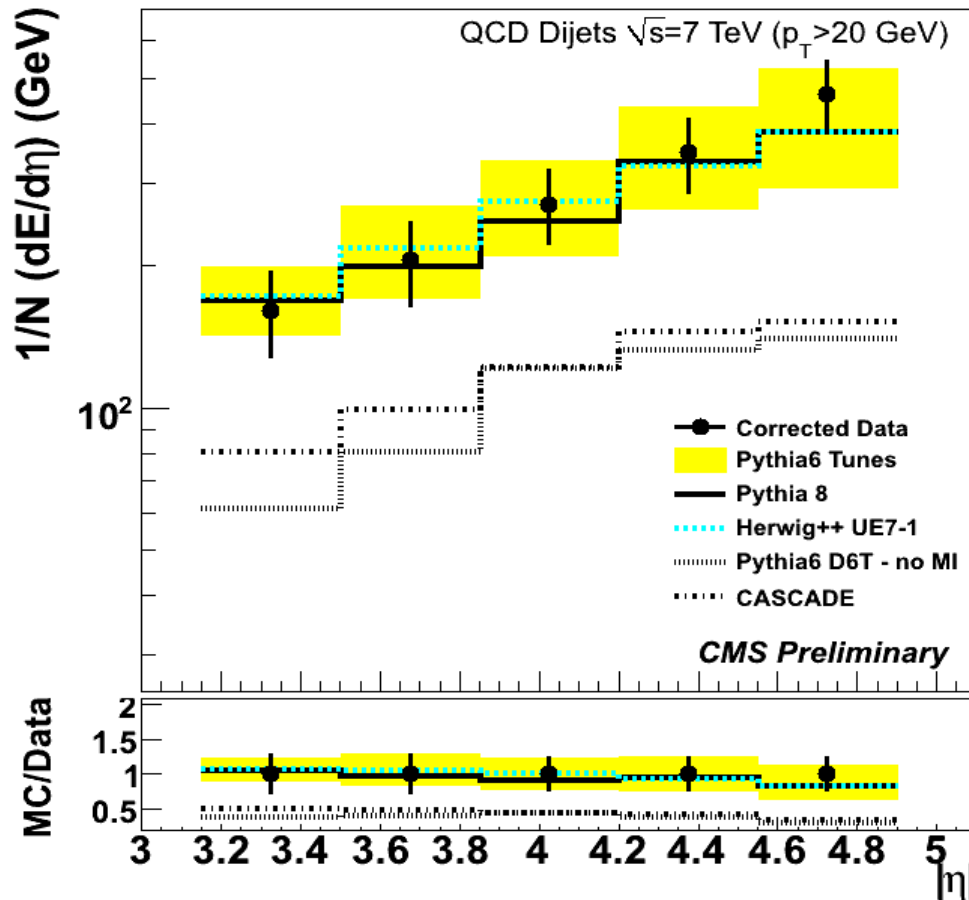
- Predictions without MPI: too low
- HERWIG: tunes work
- Pythia: tunes cover data
- CASCADE: increases faster

- pp generators used in Cosmic Ray physics: describe data well

Forward energy flow: Dijets (III)

- Dijet energy flow at 7 TeV with $p_T > 20\text{GeV}$:

CMS-PAS-FWD-10-011



- Flatter η dependence corresponds to decreasing E_T flow
- E_T flow much larger than at HERA

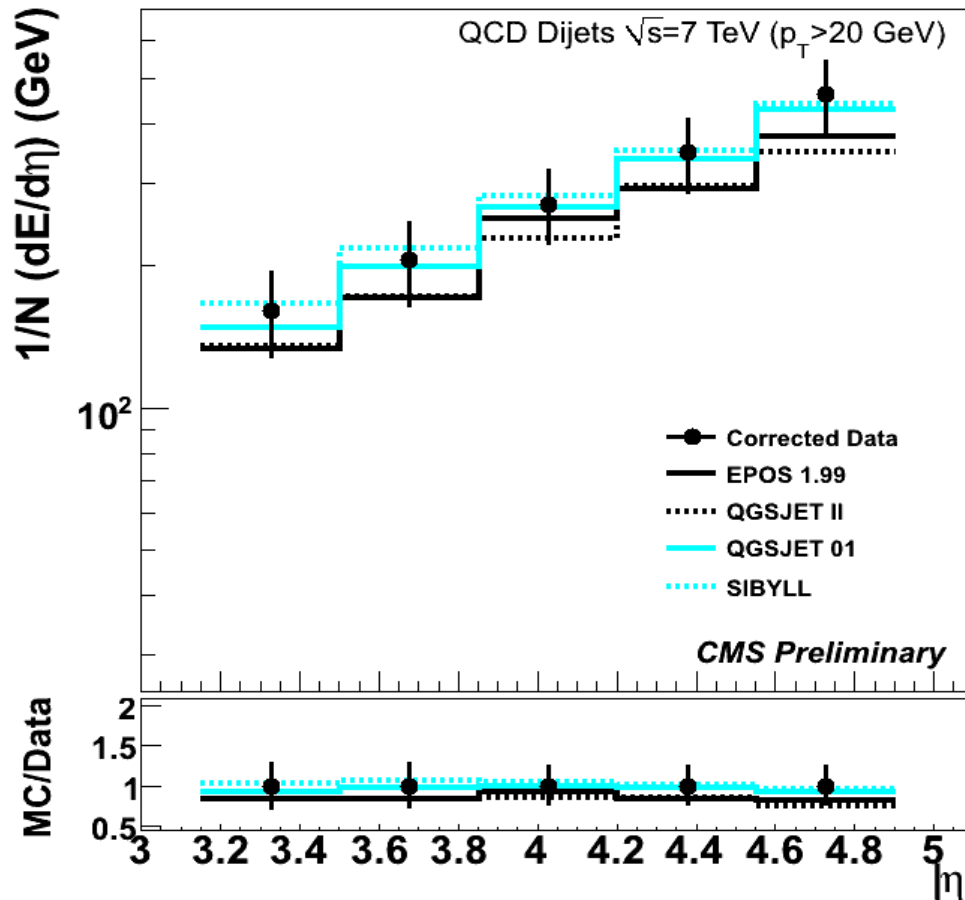
Comparison to MC:

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- HERWIG: tunes work
- Pythia: tunes cover data
- CASCADE: normalization?

Forward energy flow: Dijets (IV)

- Dijet energy flow at 7 TeV with $p_T > 20\text{ GeV}$:

CMS-PAS-FWD-10-011



- Flatter η dependence corresponds to decreasing E_T flow
- E_T flow much larger than at HERA

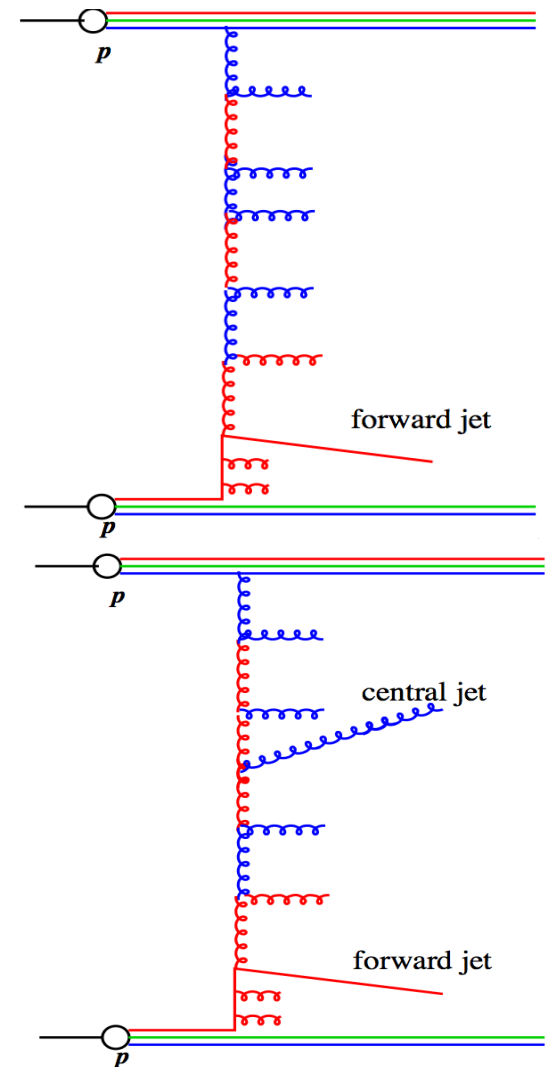
Comparison to MC:

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- pp generators used in Cosmic Ray physics: describe data well

Jets in forward region

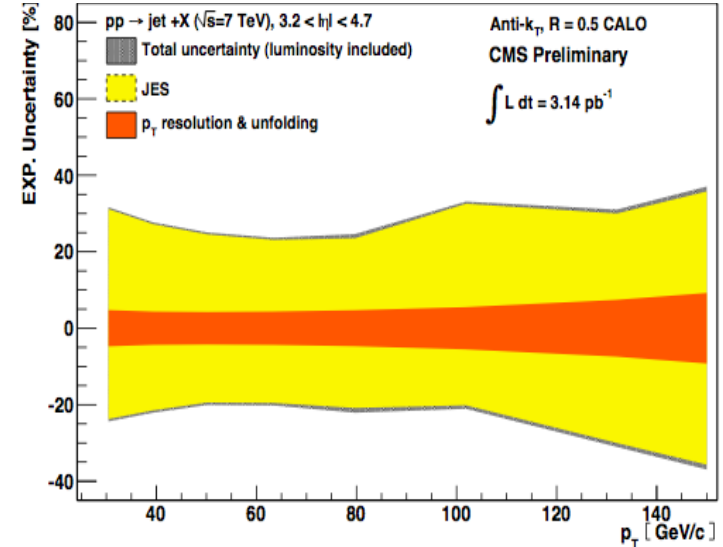
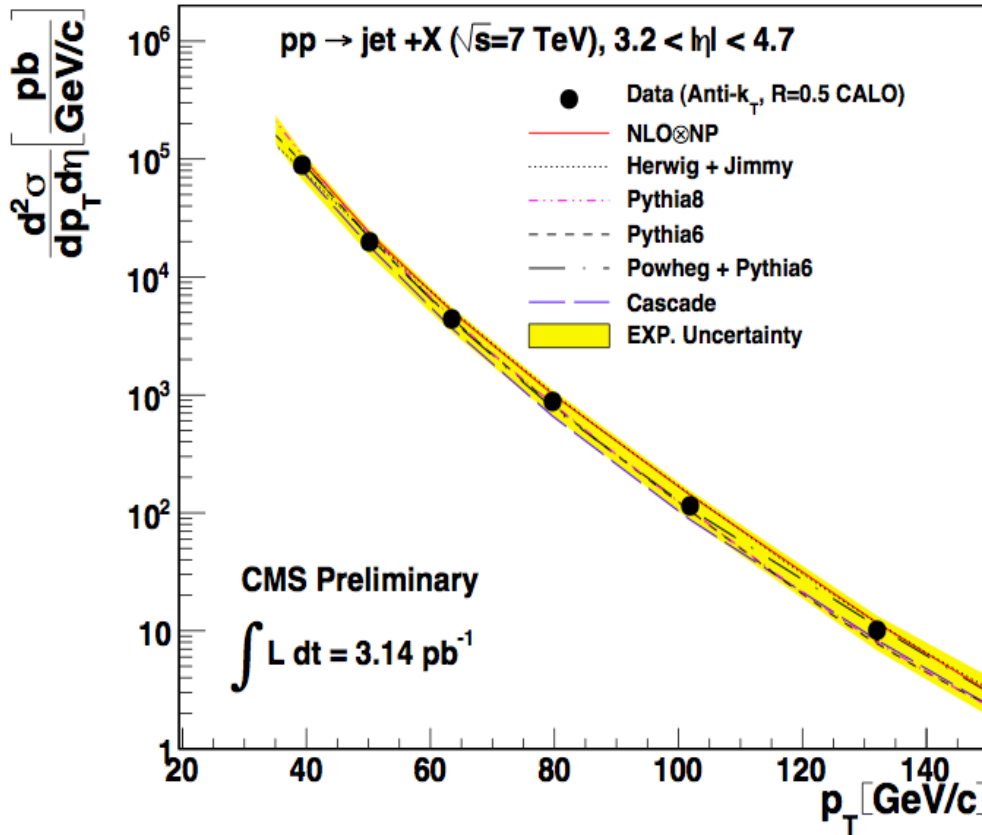
- Measurement of inclusive forward jets cross section at 7 TeV:
jets reconstructed with anti- k_T algorithm
 $R = 0.5$ between: $3.2 < |\eta| < 4.7$
 p_T range: 35 – 150 GeV/c
- Measurement of the cross section for **simultaneous** production of a central and a forward jet at 7 TeV:
central region: $|\eta| < 2.8$,
forward region: $3.2 < |\eta| < 4.7$
event accepted if at least 1 reconstructed jet (anti- k_T $R = 0.5$) with axis within each one of the η ranges is present & $p_T > 35$ GeV/c
- Both measurements corrected to hadron level



Inclusive forward jets

- Inclusive forward jet cross section at 7 TeV:

CMS-PAS-FWD-10-003



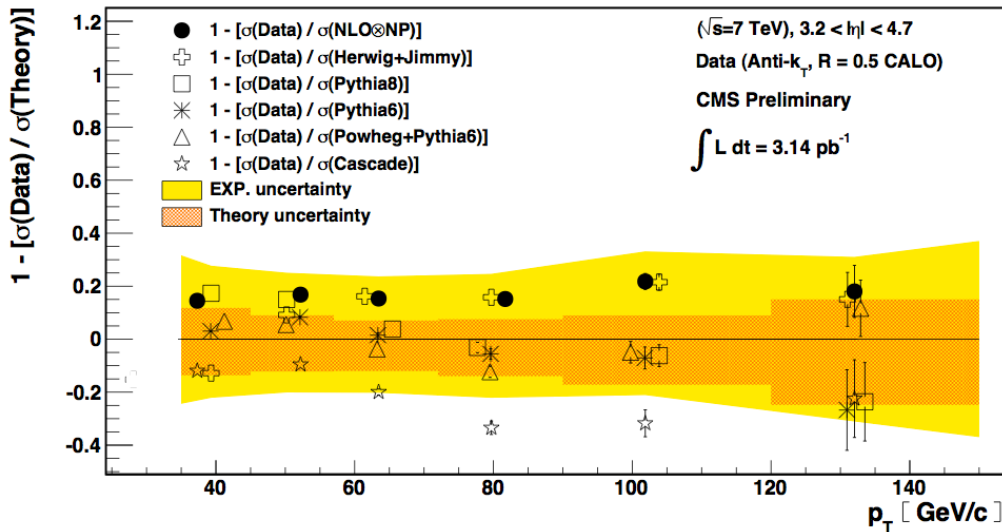
Systematic uncertainties:

- Jet energy calibration HF: 3-6%,
→ 20-30% on cross section
- p_T resolution: 3-6%
- Model dependence: 3%
- Uncertainty integrated luminosity: 4%

Total systematic uncertainty dominated by the absolute jet energy scale.

Inclusive forward jets (II)

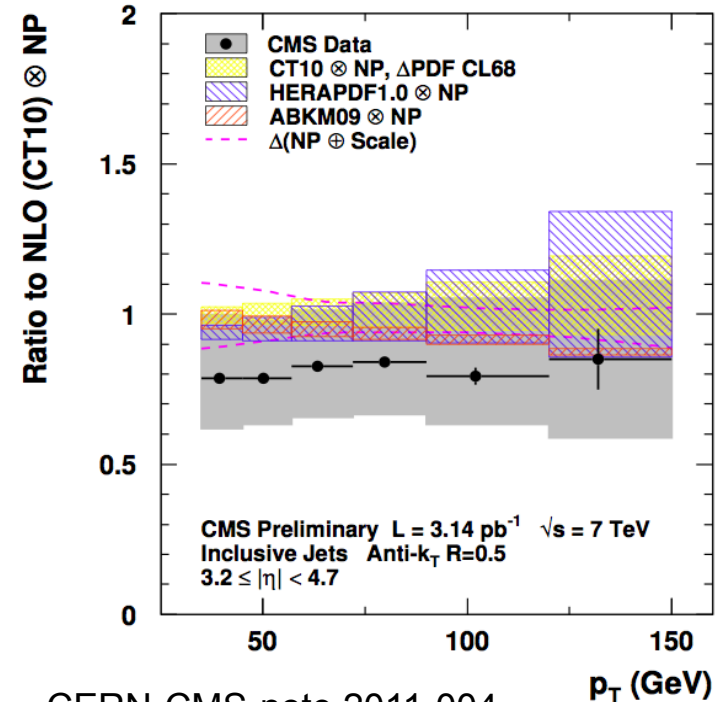
- Inclusive forward jet cross section at 7 TeV:



Within current experimental and theoretical uncertainties all calculations reproduce the measured forward jet cross section in the range p_T 35-150 GeV/c

Total systematic uncertainty dominated by the absolute jet energy scale.

CMS-PAS-FWD-10-003



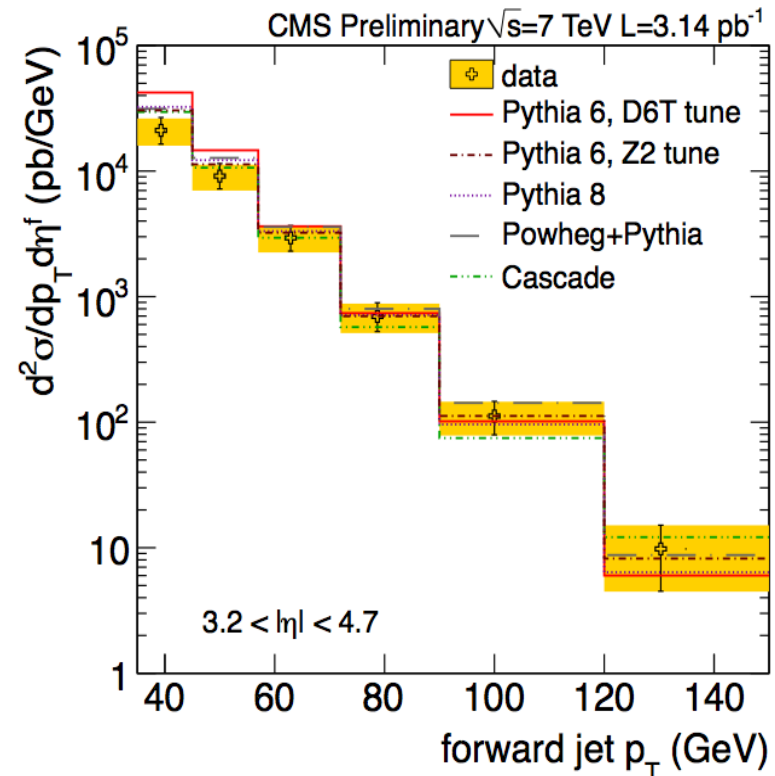
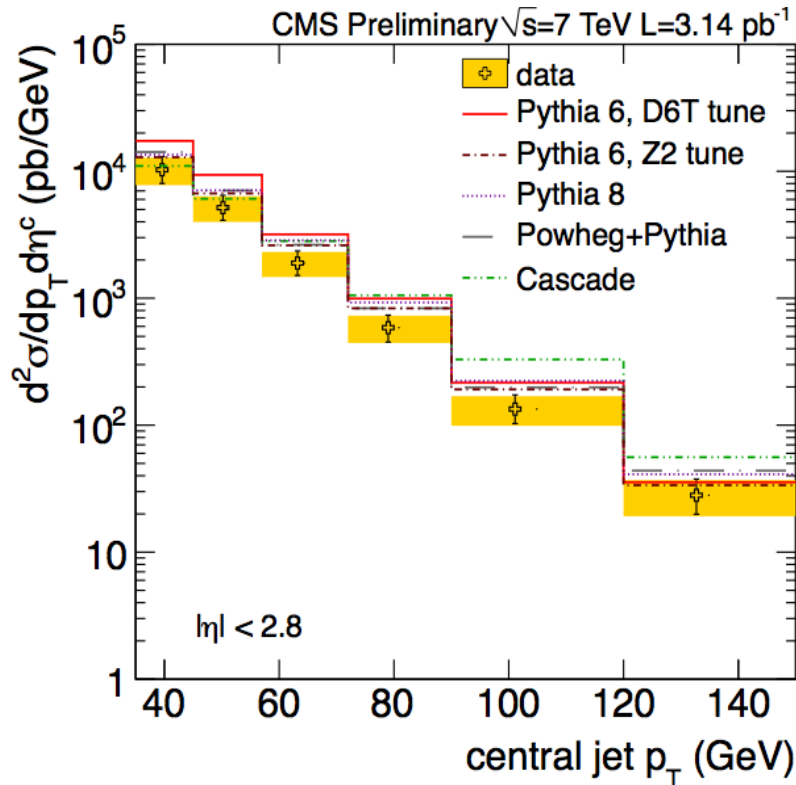
CERN-CMS-note 2011-004

PDF uncertainties largest at high p_T coming from large x partons

→ Forward jet measurements can constrain high x & low x parton distributions

Forward and central jets

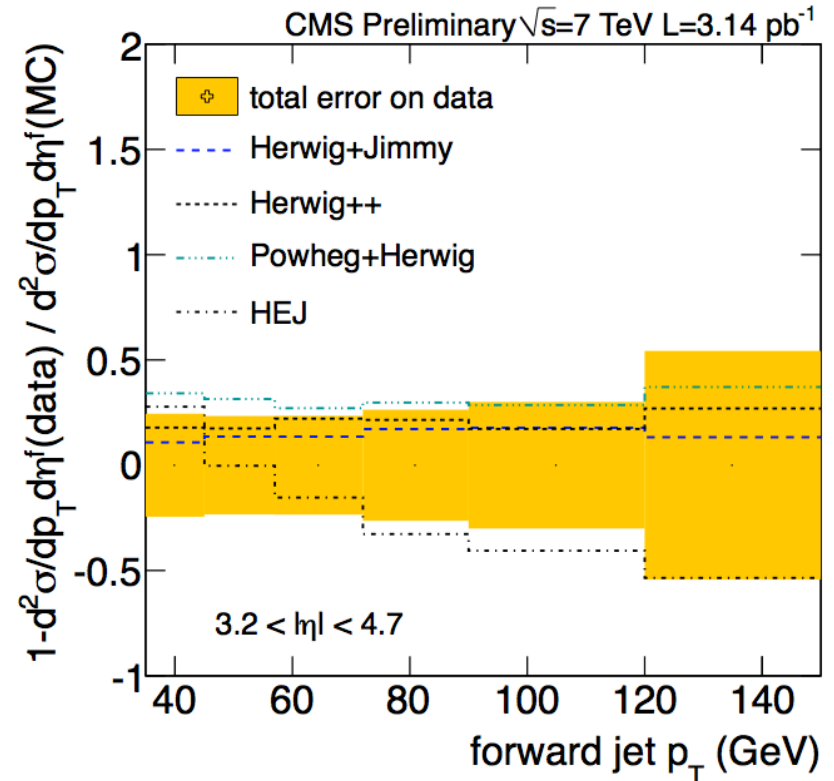
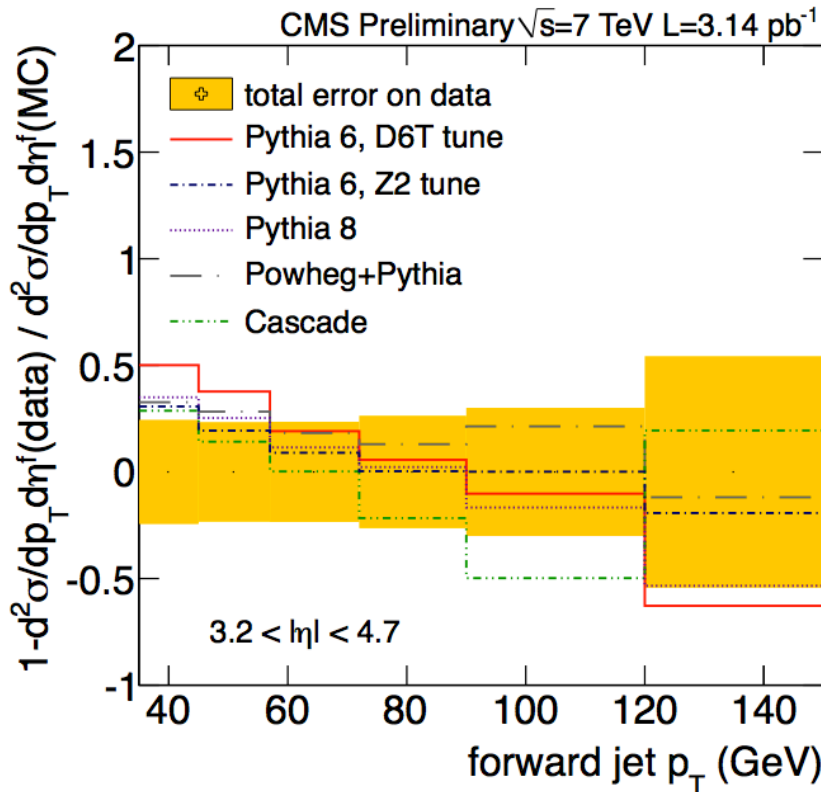
- Associated forward - central jet cross sections at 7 TeV: CMS-PAS-FWD-10-006



Systematic uncertainties similar to inclusive forward jet results:
Total systematic uncertainty dominated by the absolute jet energy scale.

Forward and central jets (II)

- Associated forward - central jet cross sections at 7 TeV: CMS-PAS-FWD-10-006



Pythia: tunes overestimate the jet spectra at low p_T values.
 HERWIG: gives better description
 Including NLO contributions (POWHEG): does not improve
 CASCADE: larger deviations to data

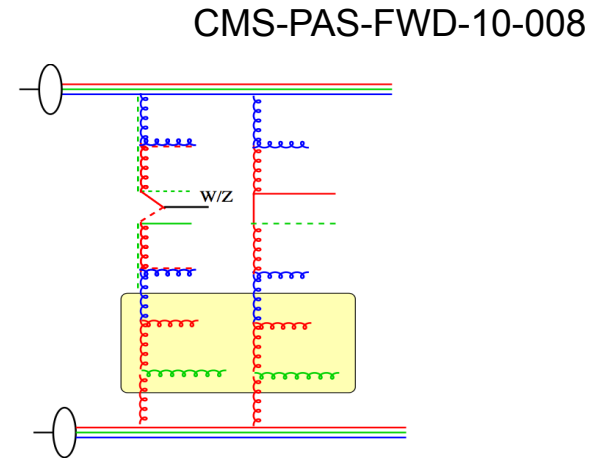
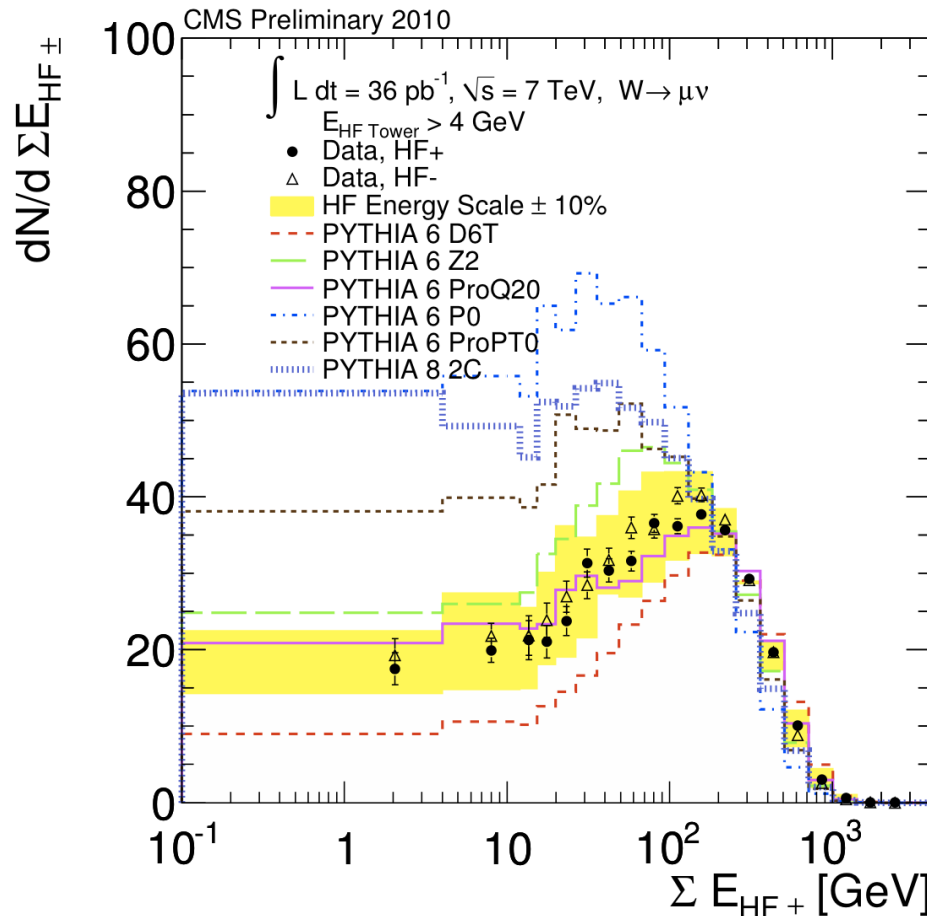
Summary

- First measurements at low & high p_T in forward region at 900 GeV & 7 TeV
 - Energy flow in $3.15 < |\eta| < 4.9$ measured for MinBias and Dijet events
 - Including Multiple parton interactions improves description of data
 - None of the MC models can describe all four energy flow measurements
 - Cosmic Ray models work quite well
 - Large spread of Pythia 6 tunes illustrates that forward data is complementary to central UE measurements to improve MC generators
 - Inclusive forward jet cross section
 - Provides first test of perturbative QCD calculations in the forward region at highest energies
 - With current uncertainties the inclusive measurements can be described with MC+PS+MPI, small x MC and NLO calculations
 - Forward and central jet cross section
 - Allow study of different types of parton radiation dynamics
 - Correlations between forward and central region are a challenge for theory

Backup slides

Energy flow measurements with W/Z

- Measurement of forward energy flow using W/Z boson events at 7 TeV:



Look for W/Z with lepton in $|\eta| < 1.4$,
 then measure forward energy flow
 in HF: $3.0 < |\eta| < 4.9$

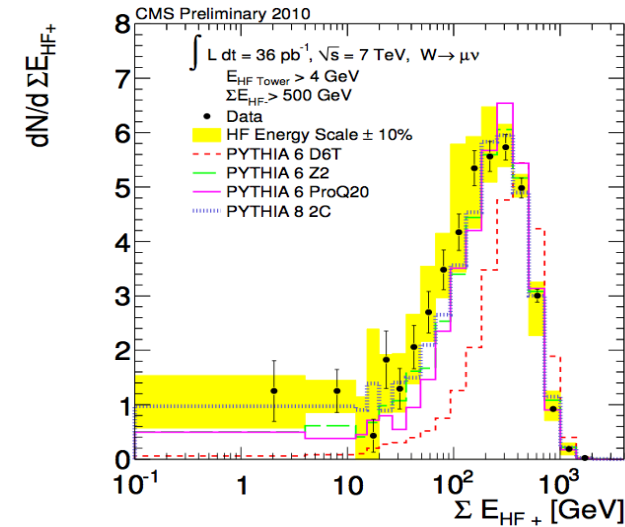
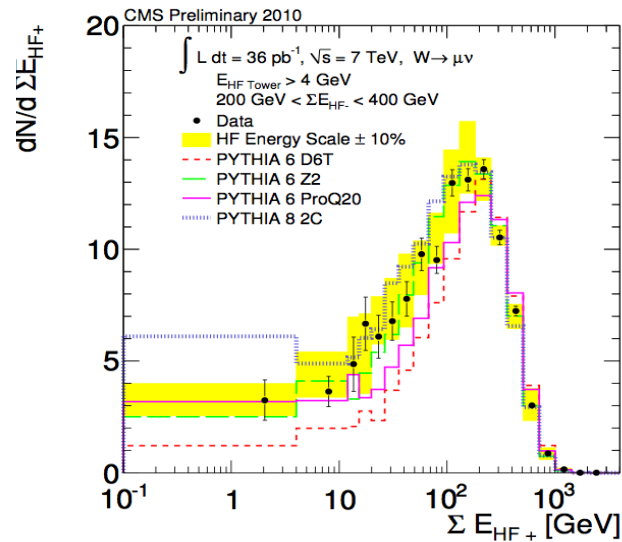
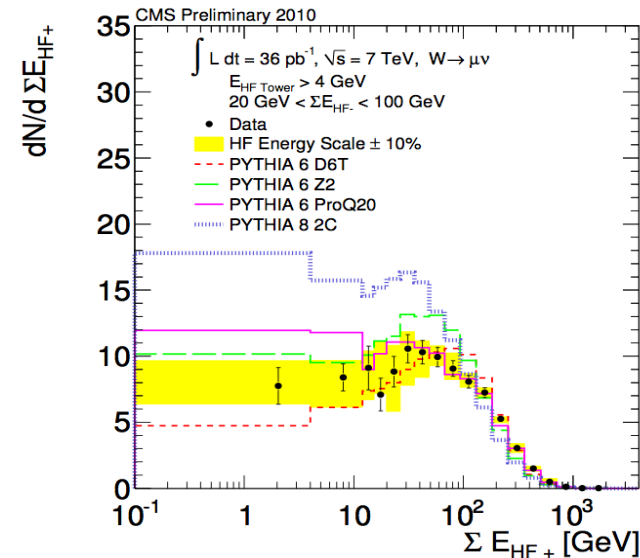
- Energy distribution in forward region sensitive to UE tunes
- Large differences in small and large energy region

Energy flow measurements with W/Z

- Measurement of forward energy flow using W/Z boson events at 7 TeV:

➔ Correlations between forward & backward energy flow:

CMS-PAS-FWD-10-008



- Energy distribution in forward/backward region strongly correlated
- Energy flow and it's correlations are not well described