Forward Energy and Particle Flow with CMS

Deniz Sunar Cerci

Adiyaman University

On behalf of the **CMS Collaboration**

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Outline

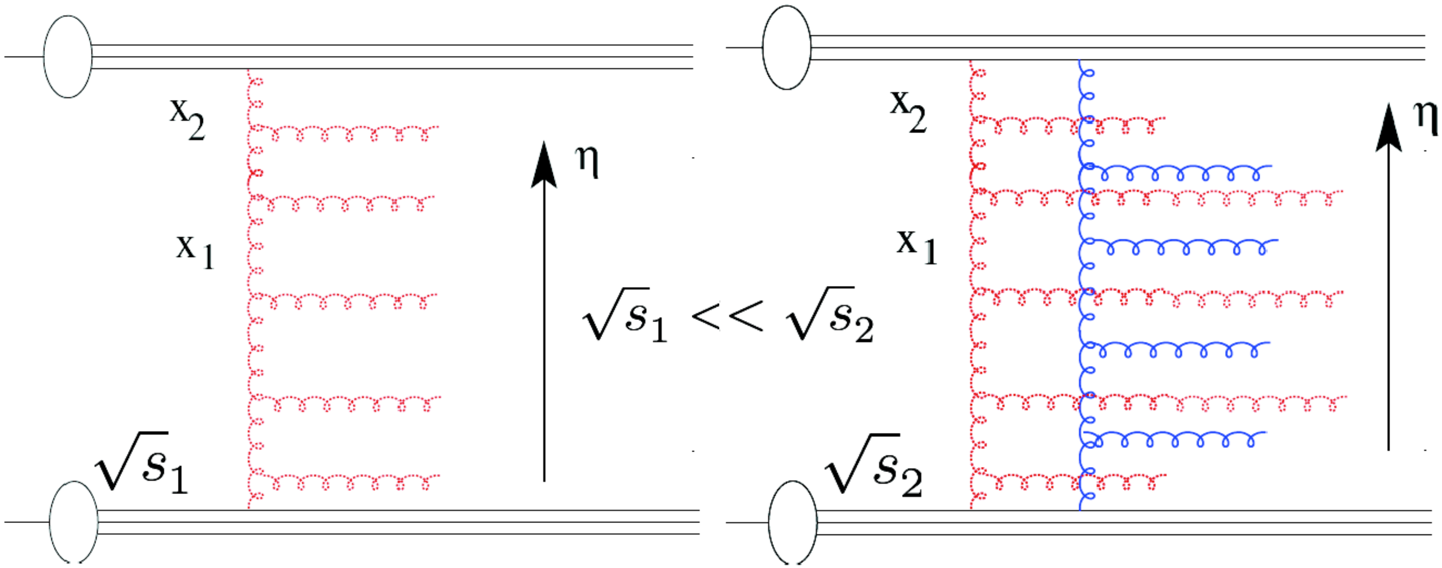
1. Energy Flow
   - Why energy flow measurement?
   - Forward detectors
   - From **small energy deposition** to **high pt jets** in forward region

2. Larger energies in the forward region: Forward Jets
   - Motivation
   - Forward jet spectra

3. Conclusion

Why Energy Flow Measurement?

- In the forward region ($3.15 < |\eta| < 4.9$) has **never** been reported at **hadron colliders**.
- **Directly sensitive** to the amount of **initial state parton radiation** and to **multiple interactions.**
- **Discriminate** between **different models** of multiparton radiation and also improve our **understanding of the basic process** responsible for multiparton radiation.
- At **very large** $\sqrt{s}$ the momentum fraction of the proton carried by the parton in the hard scattering (x_1, x_2) can become **very small** and the parton densities become **very large**.
- Extrapolation to larger energies is **very uncertain**.
- Implemented in MC event generators: need **parameters** to be adjusted to describe the measurements (parameters tuned to data from Tevatron $|\eta| < 3$).



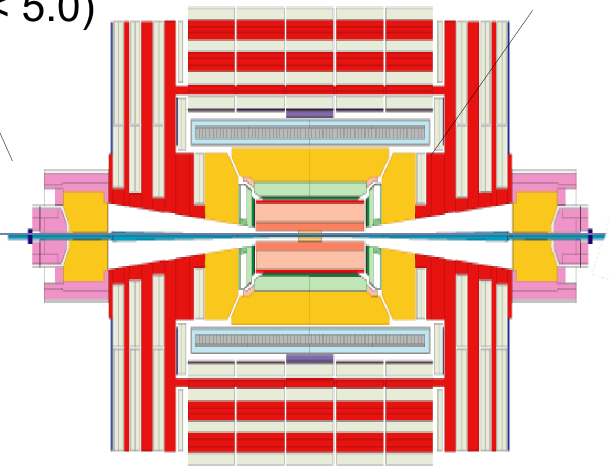
CMS: Forward Detectors

Hadronic Forward (HF)
(3.0 < |η| < 5.0)

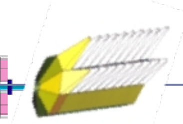
Hadronic Forward (HF)

140m

ZDC
(|η| > 8.1)



(5.2 < |η| < 6.6)

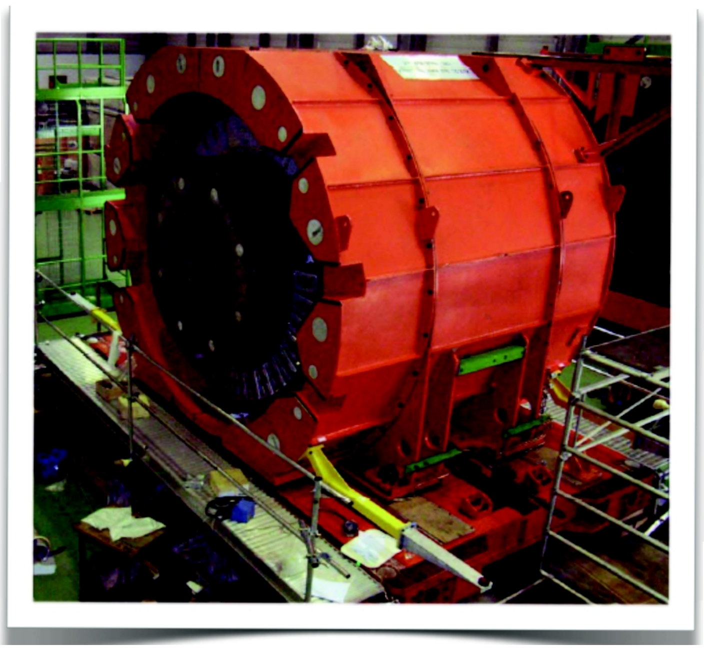


CASTOR

140m

ZDC
(|η| > 8.1)

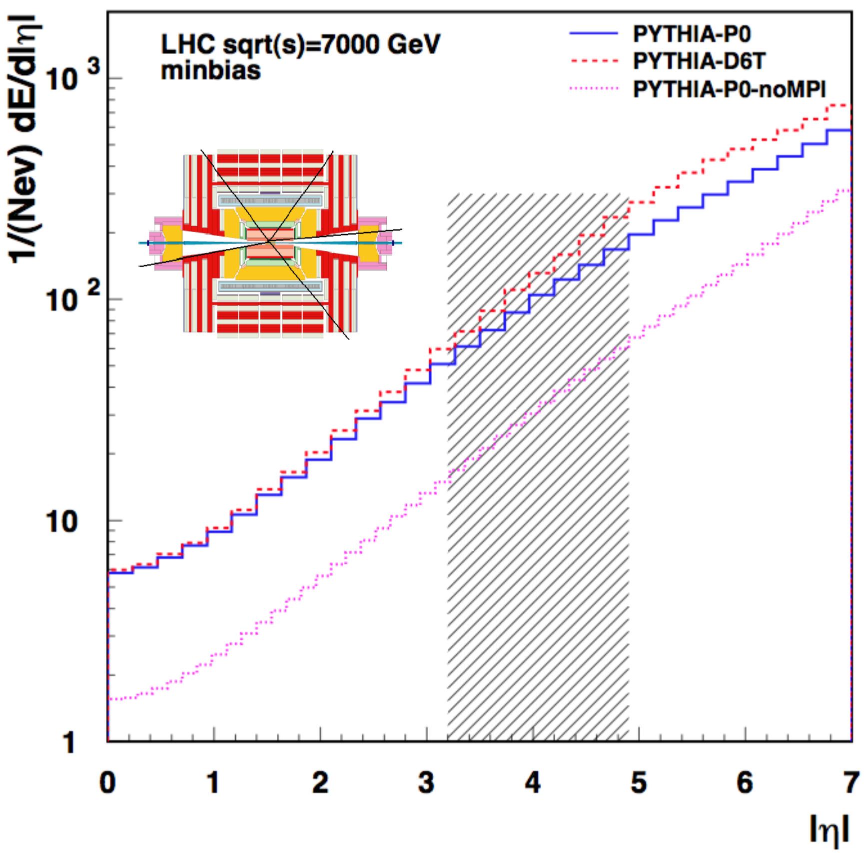
HF Detector

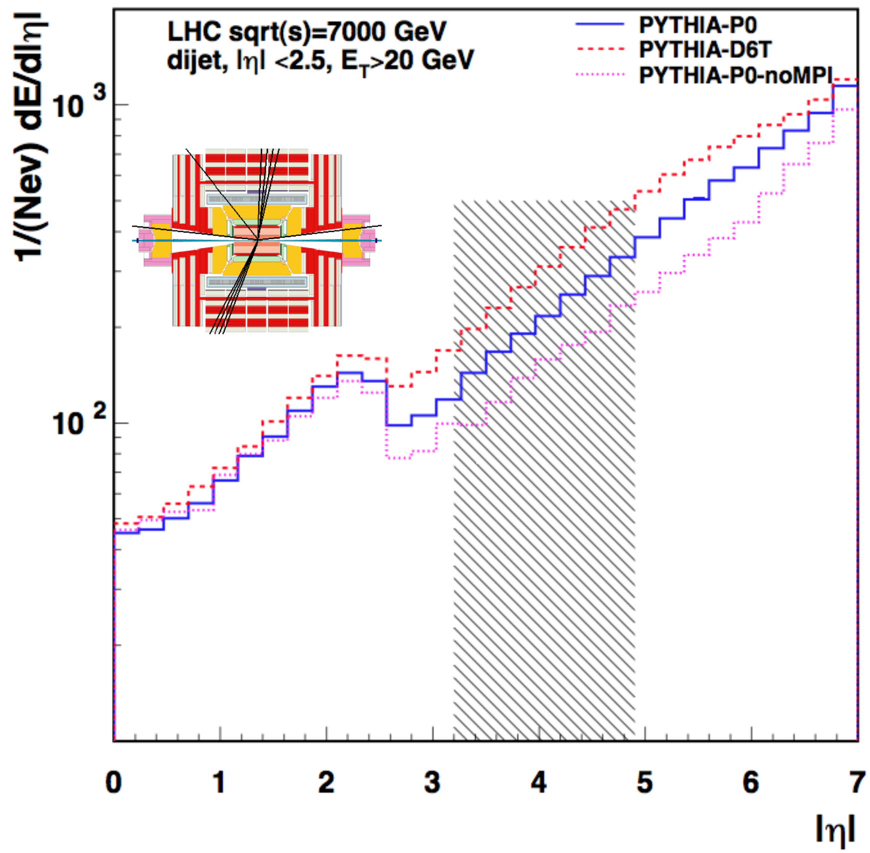


- @11.2 m from interaction point
- Rapidity coverage: **3 < |η| < 5**
- Steel absorbers/quartz fibers (Long+short fibers)
- 0.175x0.175 η/φ segmentation

Energy Flow: Predictions

- **Different predictions** giving **different results** are available.
- Energy flow in central region at low √s does not change much with tunes.
- Significant difference observed in the **large pseudorapidity** region (|η| > 2).
- The difference still appears when one includes the MPI.
- Prediction at generator level for Pythia6 tunes **with MPI** and **no MPI** scenario.





Event Selection

- LHC collision data sets with pp interactions @ 0.9, 2.36 and 7 TeV.
- @ least 1 reconstructed primary vertex (PV) to reject non-IP collision events.
- Require primary vertex to be consistent with the beam spot centre to within 15 cm in *z* direction and have at least three tracks associated with it.

$$E_{FLOW}(dijet) = \frac{1}{N_{dijet}} \frac{\Delta E}{\Delta \eta}(dijet)$$

$$E_{FLOW}(minbias) = \frac{1}{N_{minbias}} \frac{\Delta E}{\Delta \eta}(minbias)$$

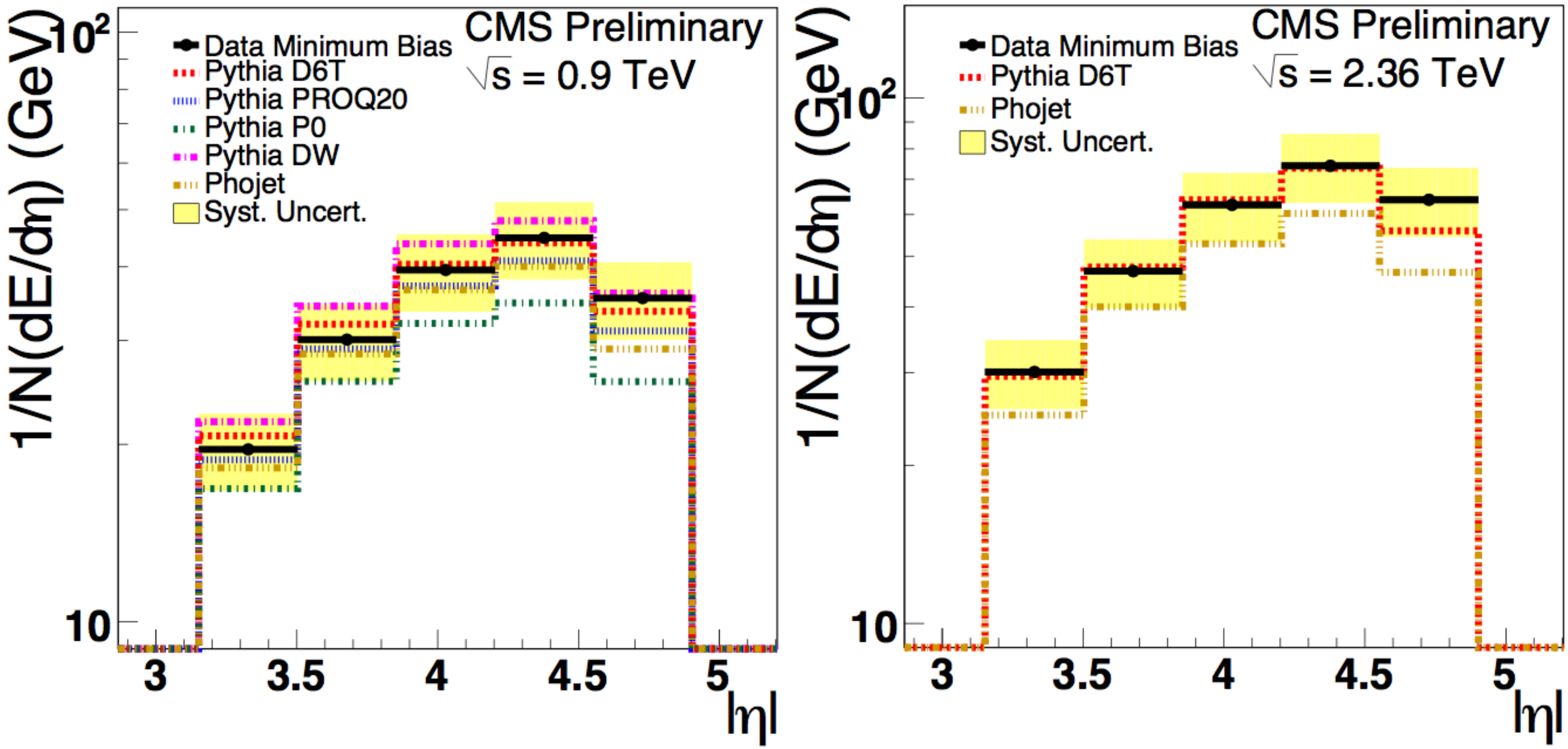
Minimum Bias Sample: All events trigger with MB trigger activity on both sides of IP + vertex reconstructed.

Dijet Sample : Jets (Anti-k_T algorithm with R = 0.5)

p_T > 8 GeV for 0.9 & 2.36 TeV

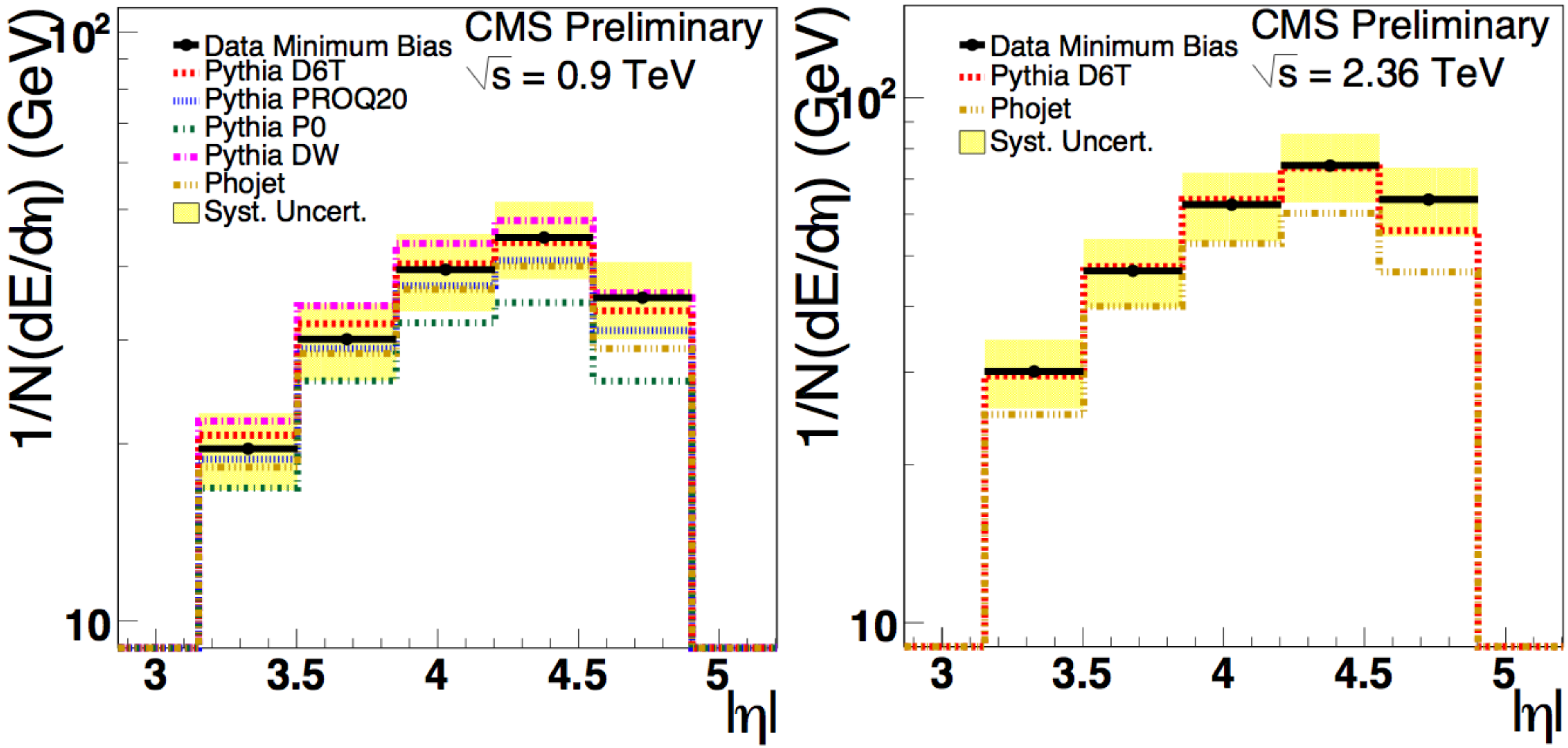
p_T > 20 GeV for 7 TeV

Results: MinBias (0.9 / 2.36 TeV)



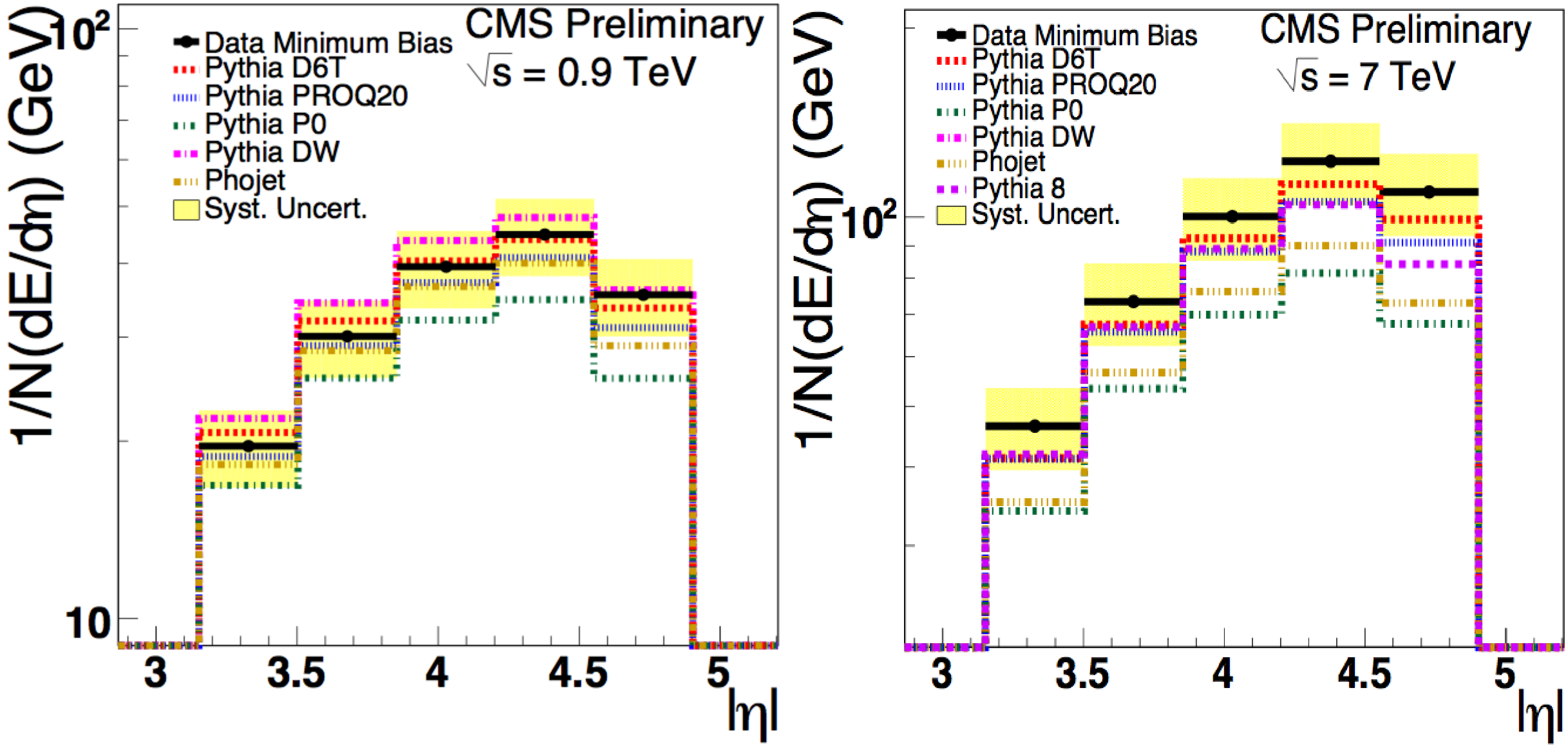
- Uncorrected data (shown as points), the predictions from PYTHIA tunes & PHOJET (shown histogram).
- Error bars corresponds to statistical errors.
- Shaded yellow bands represent the systematic uncertainties of the measurements (largely correlated point-to-point).

Results: MinBias (0.9 / 2.36 TeV)



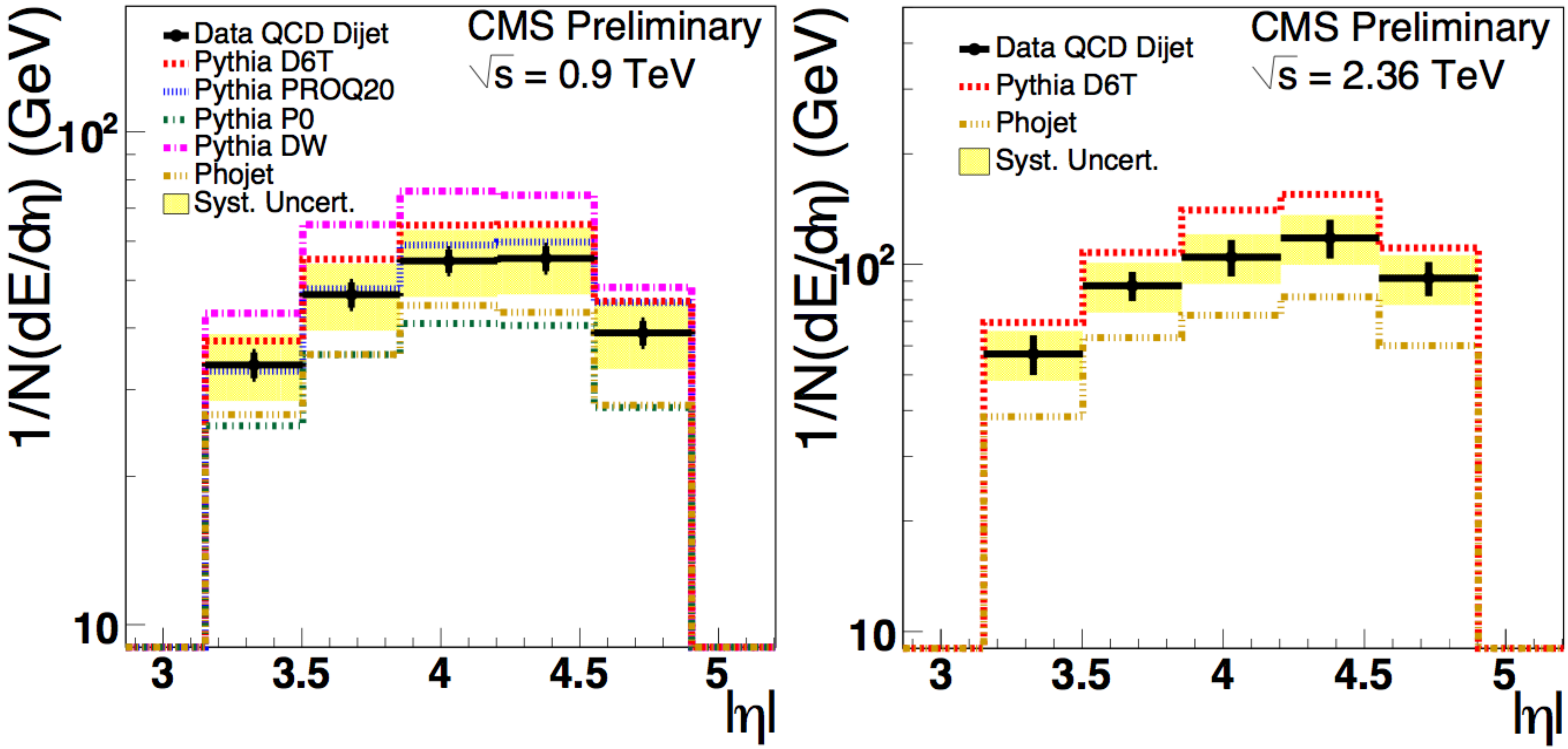
- **Clear tendency** of Fwd. Energy flow to increase more strongly in data than MC with **increasing $\sqrt{s}$.**
- Data is **best described** by D6T tune, PROQ20 & P0 and PHOJET underestimate data.

Results: MinBias (0.9 / 7 TeV)



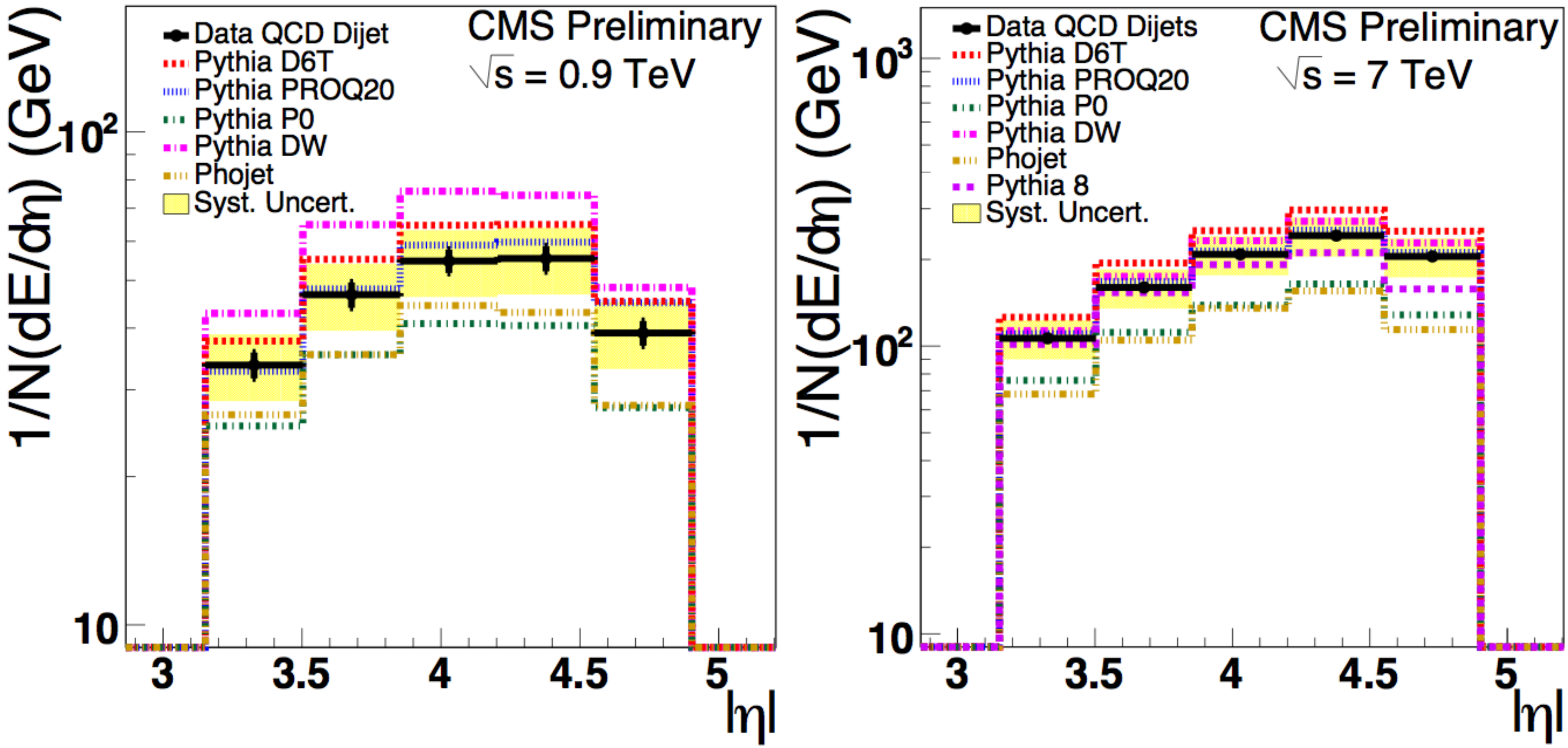
- **Significant increase** with increasing √s about factor of 3.
- At √s = 7 TeV: MC predictions describe the data more or less.
- MC models are tuned at low energies in the central region @ 7 TeV .
- All are below, only a few of MC models are within the systematic uncertainity.

Results: Dijet (0.9 / 2.36 TeV)



- **Significant increase** of energy flow with **increasing √s** is about factor of 2.
- This increasement is reproduced by the MC simulations.
- Large spread of MC predictions which cover the data.

Results: Dijet (0.9 / 7 TeV)



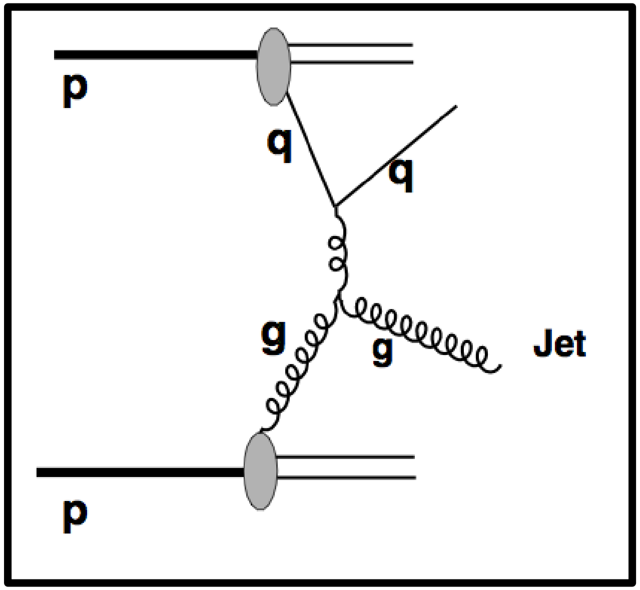
- **Increase** of data is about factor of 5 @ |η| = 4.5.
- MC predictions which describe the data @ 0.9 TeV are **too low** @ 7 TeV (blue curve).

2. Larger energies in the forward region:

Forward Jets

Motivation

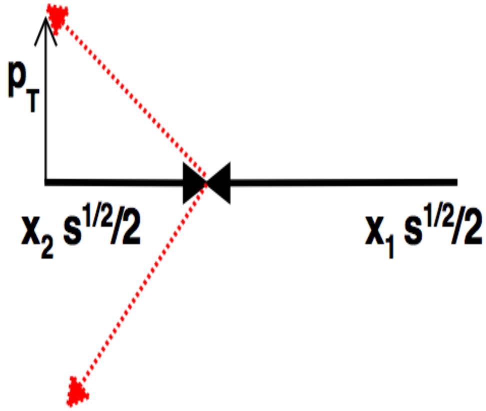
- CMS with its large calorimetric coverage ($|\eta| < 5.2$) can provide **first measurements** on forward jet production which was **never investigated before.**



- Longer term prospects:
  - Forward jets probe the low-x domain; in 2->2 process:

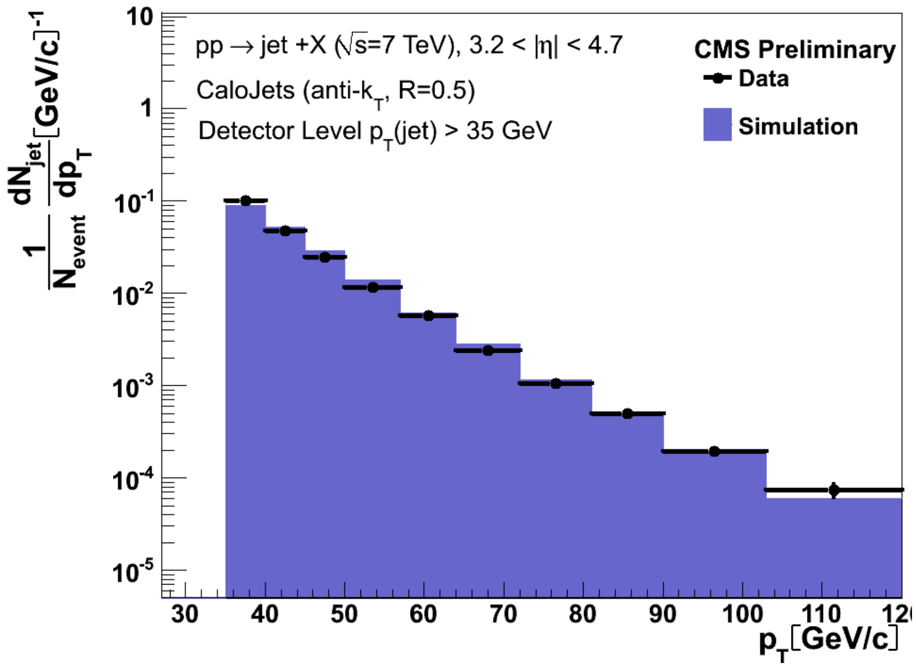
$$x_2^{min} \approx \frac{p_T}{\sqrt{s}} \cdot e^{-y} = x_T \cdot e^{-y}$$

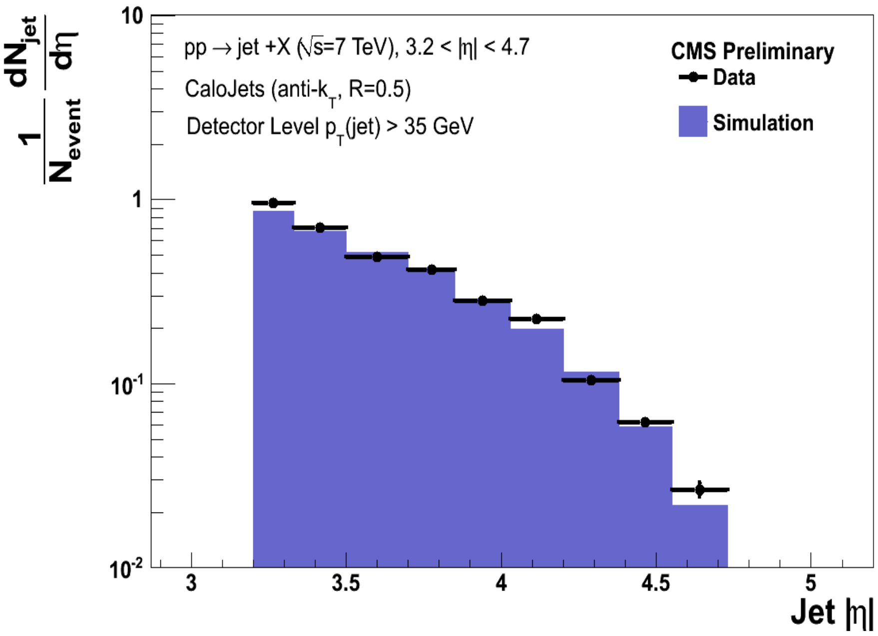
every 2 units of y: x_2^{min} decreases by factor of 10.



- First step: validate jet reconstruction in the **forward region**.

Forward Jet Spectra





- Large energy deposition in the forward region with the forward jets is **also** measured.
- Only the **detector level** p_T and |η| spectra **no unfolding** and **no systematic** effects are shown.
- Going to a harder scale process, the energy deposition in the forward region increases.
- Reasonable description of data is given by the MC, for larger scale processes description becomes better.

Conclusion

- **1st time measurement of energy flow** (at detector level) in hadron hadron collisions in the forward region of $3.15 < |\eta| < 4.9$ is presented.
  - ➔ Minimum bias events and events having a hard scale defined by a dijet samples are considered.

- The increase in forward energy flow with **increasing s** is significant and is reproduced by MC simulations for events with dijets, whereas **it is not** described for MinBias events.

- None of the MC simulations can describe all energy flow measurements in all aspects.

- Measurement of the energy flow in the forward region provides further input to the tuning MC event generators.
  - ➔ Constrains the modelling of parton radiation at high energies and at large rapidities.

- Measurement of large energy deposition in the forward region with the forward jets is **also presented**.

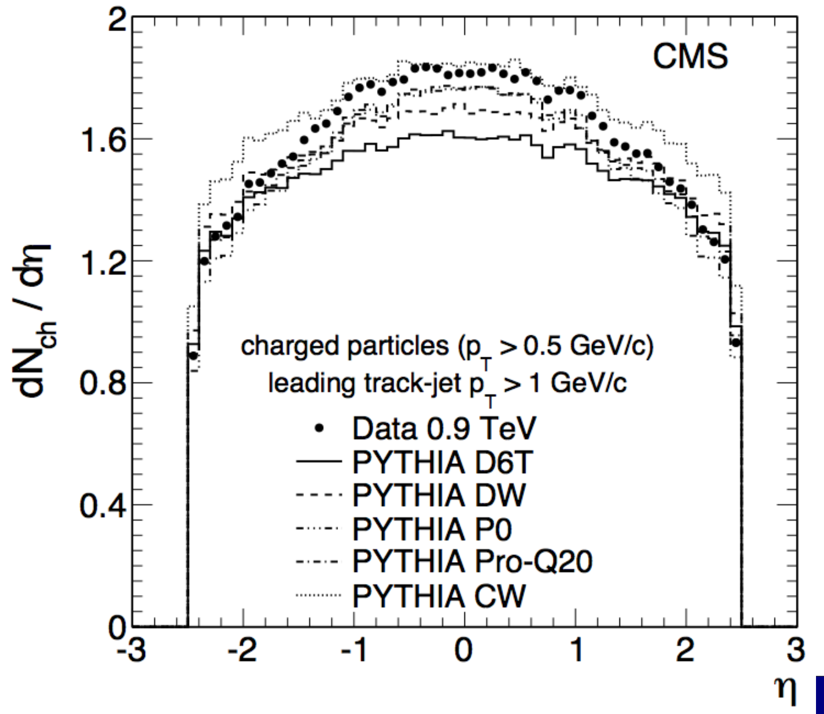
- Going to a harder scale process, the energy deposition in the forward region increases.

Backup

Monte Carlo: Tunes

		D6T (108)	DW (103)	Pro-Q20 (129)	P0 (320)
pdfs		CTEQ6L	CTEQ5L	CTEQ5L	CTEQ5L
p_{t0}	PARP(82)	1.84 GeV	1.9 GeV	1.9 GeV	2.0 GeV
E_0	PARP(89)	1.96 TeV	1.8 TeV	1.8 TeV	1.8 TeV
ϵ	PARP(90)	0.16	0.25	0.22	0.26
fragmentation	standard	standard	standard	professor LEP tune	professor LEP tune
Q^2_{max} factor (ISR)	PARP(67)	2.5	2.5	2.65	1.0
Q^2_{max} factor (FSR)	PARP(71)	4.0	4.0	4.0	2.0

- LEP data revisited better fragmentation tunes.
- More Tevatron data included better underlying-event tunes.
- LEP + Tevatron tunes combined: new generation of tunes.
- Tunes available for BOTH new and old MPI models + Systematic
  HARD / SOFT / CR / PDF variations (incl LO)



Event and Jet Selection

- Only runs with stable beam and fully operating detector were used which correspond to an integrated luminosity of $\mathcal{L} =\sim 10\ \text{nb}^{-1}$.
- Cleaning cuts were imposed to remove events whose timing was not consistent with the LHC bunch crossing time as well as to reject beam halo events.
- Accept events to have a high-quality primary vertex, within ± 15 cm of the nominal interaction point along the proton beam axis.
- Jets were reconstructed using anti-k_T jet clustering algorithm with the radius $R = 0.5$.
- The Calorimeter Jets were corrected for energy loss and effects due to non-linear response of the CMS calorimeter.
- $35 < p_T(Jet) < 120$ GeV and $3.2 < |\eta(Jet)| < 4.7$