Forward Physics at CMS

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Outline

- **Forward Energy Flow Measurement**
  - Physics Motivation
  - CMS Detector
  - Analysis Strategy and Event Selection
  - Forward Energy Flow Measurement and MC Comparison
- **Forward Jets Reconstruction**
  - Physics Motivation
  - Event and Jet Selection
  - Jet Size and Shape
  - p_T and η Spectrum
- **Conclusion**

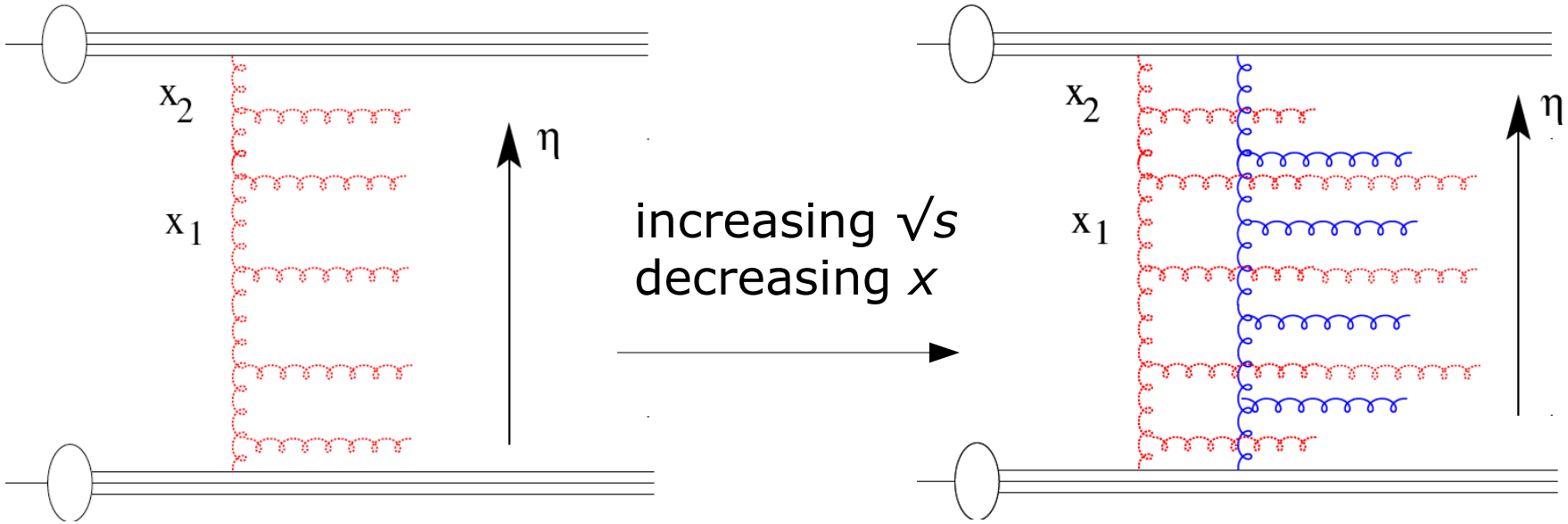
Measurement of the Forward Energy Flow at different √s (900 GeV, 2.36 TeV and 7 TeV)

[CMS PAS FWD-10-002]

Physics Motivation (I)

- Forward region probes small *x* content of the proton
  - parton densities might become very large
  - probability for more than one partonic interaction per event should increase

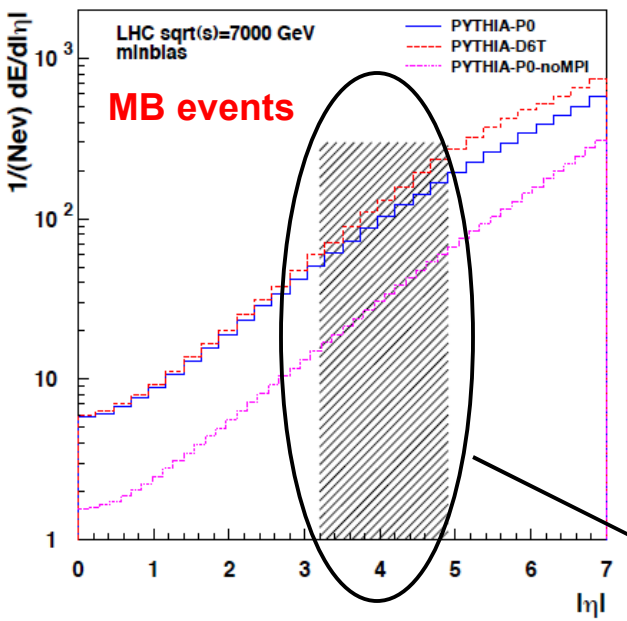
→ Measurement of the forward energy flow sensitive to
  - the modelling of parton radiation at large η
  - the description of the multiparton interaction



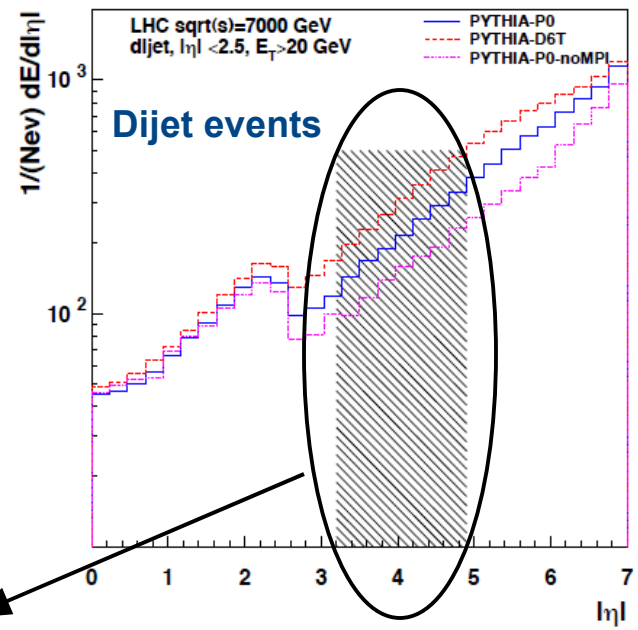
Physics Motivation (II)

- Energy flow as a function of η at $\sqrt{s}$ = 7 TeV for MB events and for events with a central dijet with $E_{T,jet}$ > 20 GeV and |η| < 2.5

- Predictions from PYTHIA using 2 sets of parameters tuned to describe TEVATRON data in central region (D6T and Perugia), together with predictions without multiparton interaction
  → Significant difference in the forward region |η| > 3

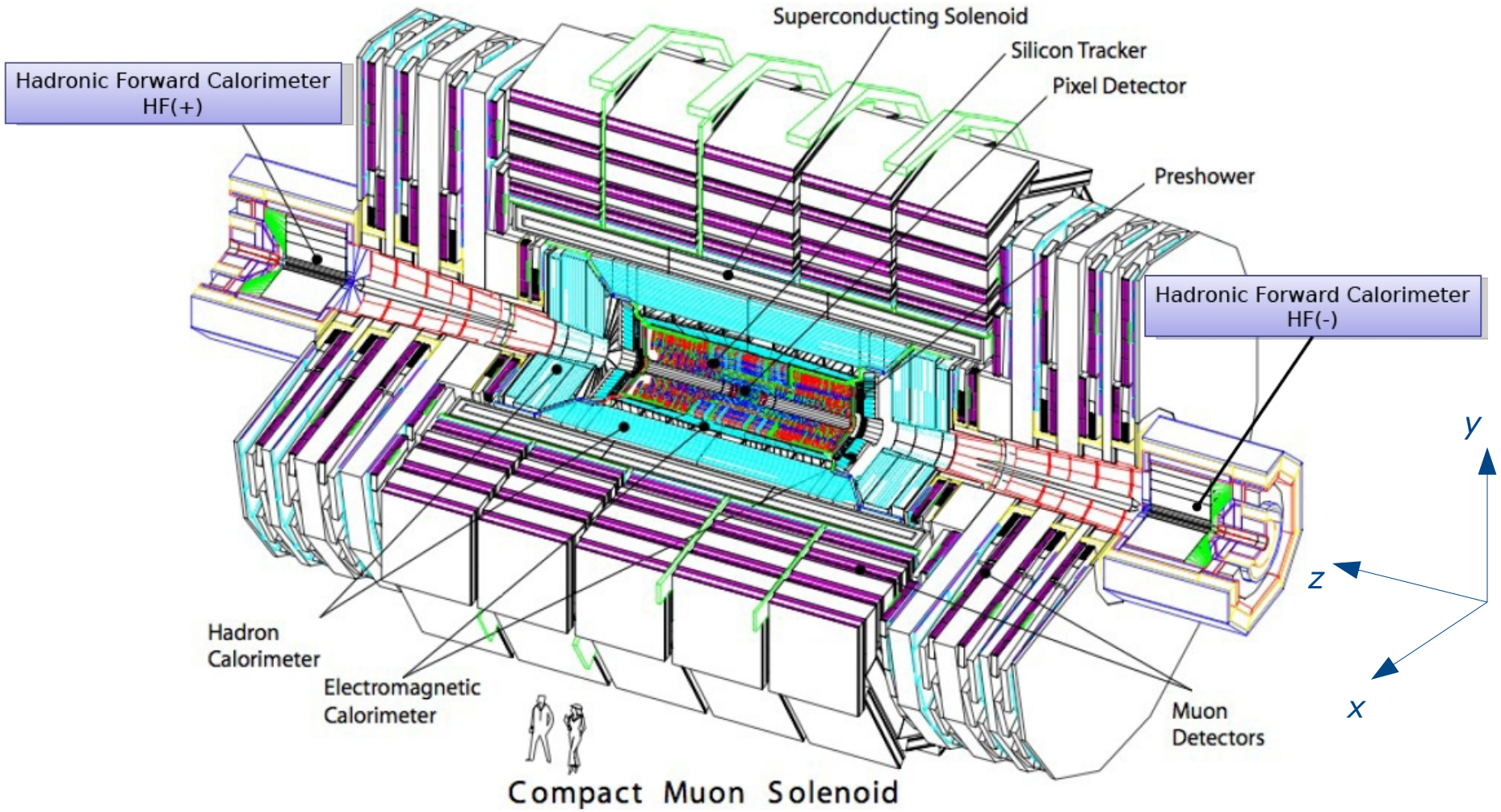


Input from forward measurement complementary to central studies to constrain MPI



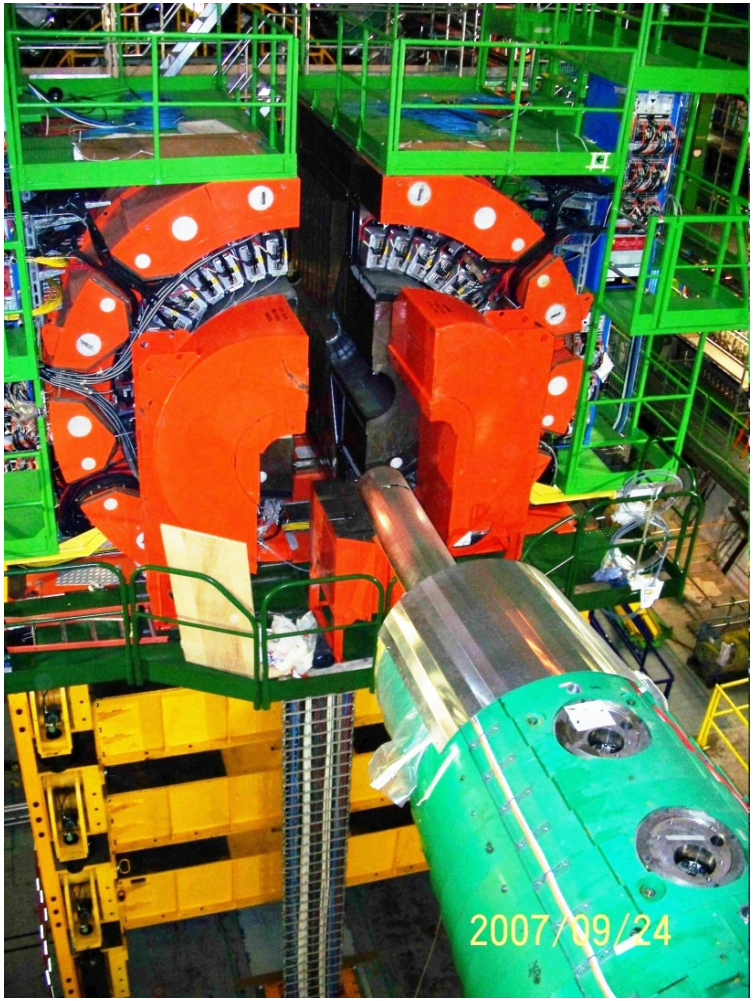
Measurement region

CMS Detector



Hadronic Forward calorimeters (HF)

- located at 11.2 m from IP on both sides of CMS

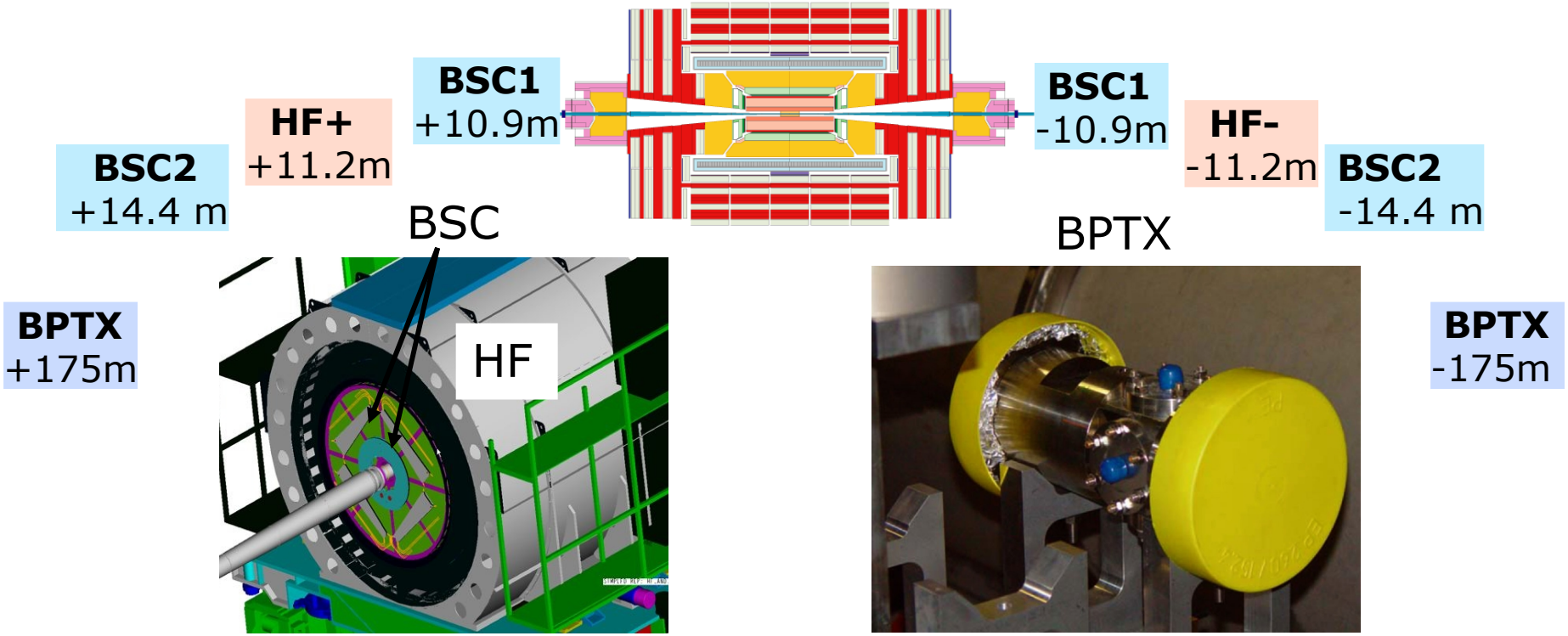


- rapidity coverage $2.9 < |\eta| < 5.2$
- Cerenkov calorimeter made of steel absorbers and embedded radiation-hard quartz fibers, light from the fibers detected by PMT
- 2 types of fibers: long (run over the full depth) and short (start at 22 cm from the front of HF)

→ possible to distinguish showers generated by e/γ from showers generated by hadrons

- 13 rings in η with a segmentation $\Delta\eta = 0.175$ (except for the 2 most inner rings and the most outer one)

Trigger System



- Beam Scintillator Counters BSC1
- located at ± 10.86 m from IP
- each BSC is a set of 16 tiles
- designed to provide hits and coincidence rates

- Beam Pick-up Timing for the eXperiments BPTX
- designed to provide precise info on the bunch structure and timing of the incoming beam

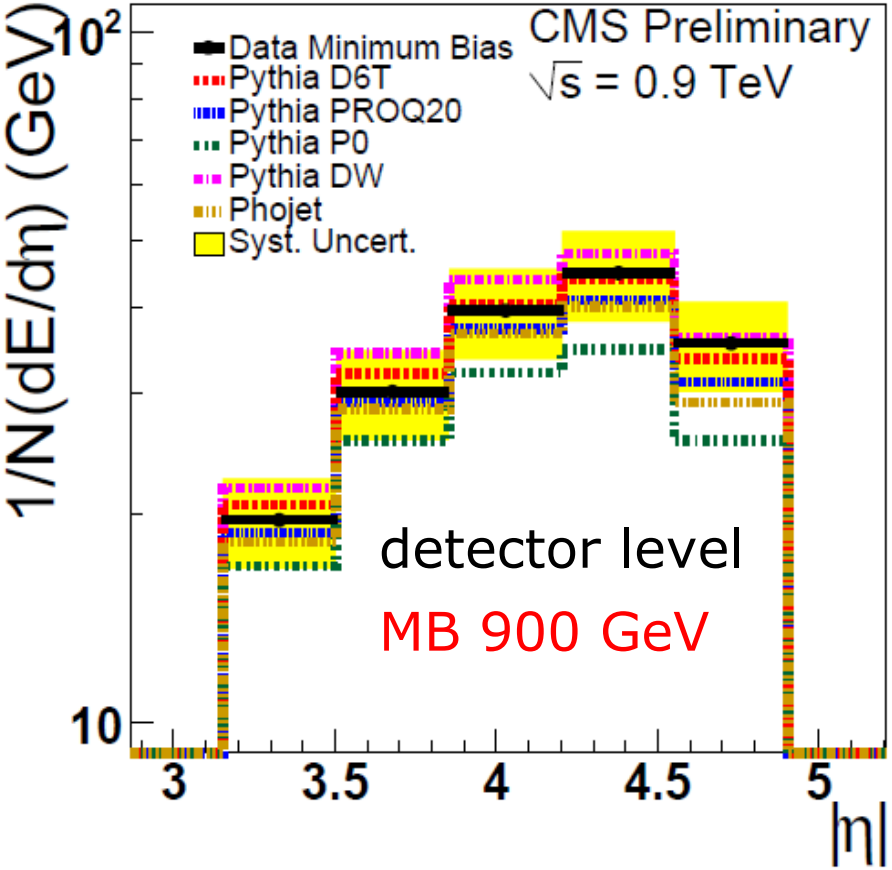
Analysis Strategy and Event Selection

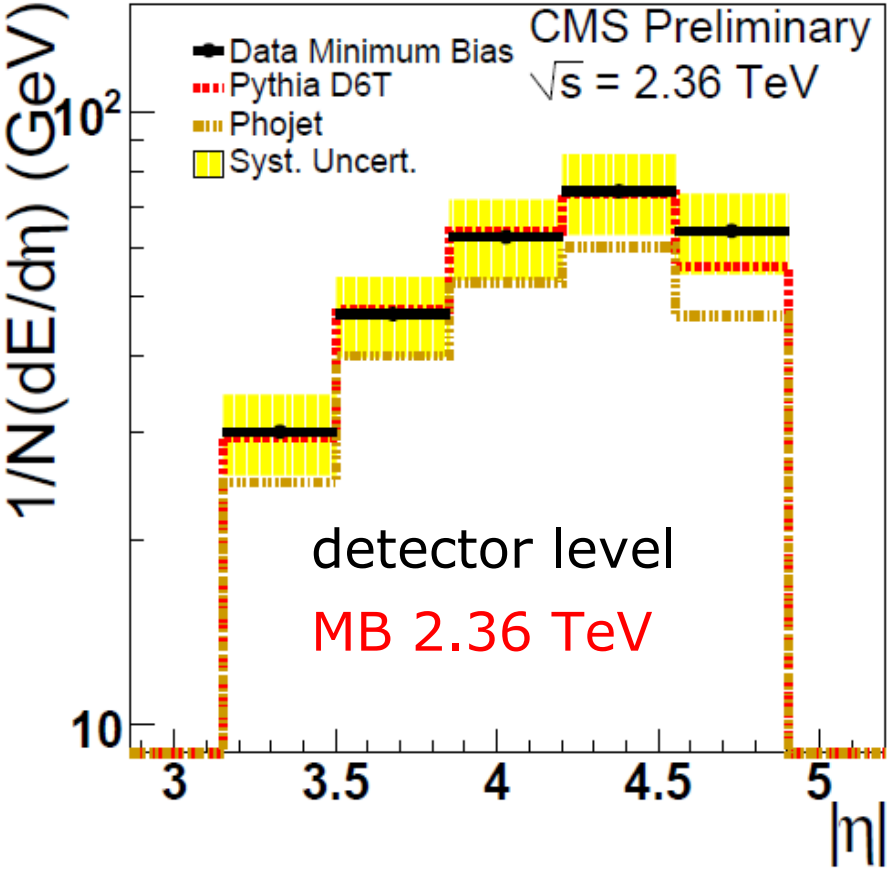
- Forward energy flow measured at 3 different $\sqrt{s}$ in 2 event classes
  - Minimum Bias events
  - Events with a hard scale provided by a central dijet system

- Minimum Bias events selection
  - Trigger signal in each of the BSC in coincidence with a signal from both BPTX (reject large fraction of diffractive events)
  - Good primary vertex
  - Rejection of beam halo candidates & beam background events
  - Rejection of events with large and isolated signal in HF
  - Sum all energy deposits in HF above noise threshold of 4 GeV

- Dijet events selection
  - Jets reconstructed by anti-k_T jet algorithm (R = 0.5)
  - At least two leading jets with $|\eta| < 2.5$ & $|\Delta\phi\ (j1,j2)-\pi| < 1$
  - $p_T > 8$ GeV ($\sqrt{s}$ = 900 GeV or 2.36 TeV), $p_T > 20$ GeV (7 TeV)

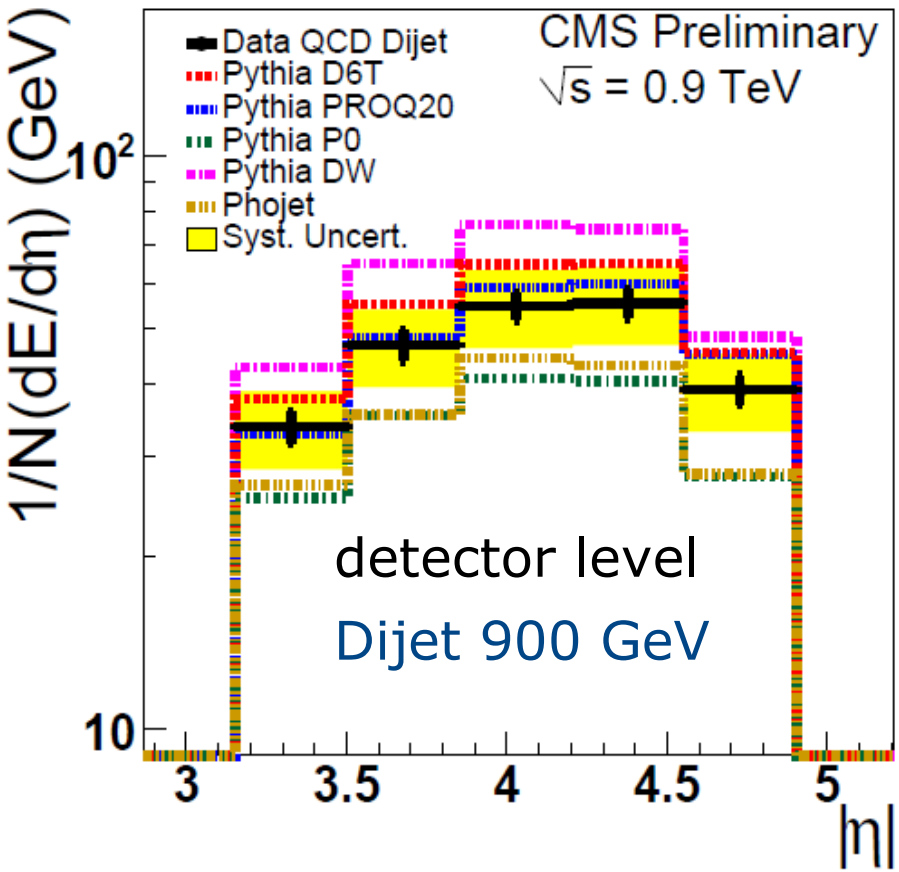
Energy flow - MB - 900 GeV & 2.36 TeV

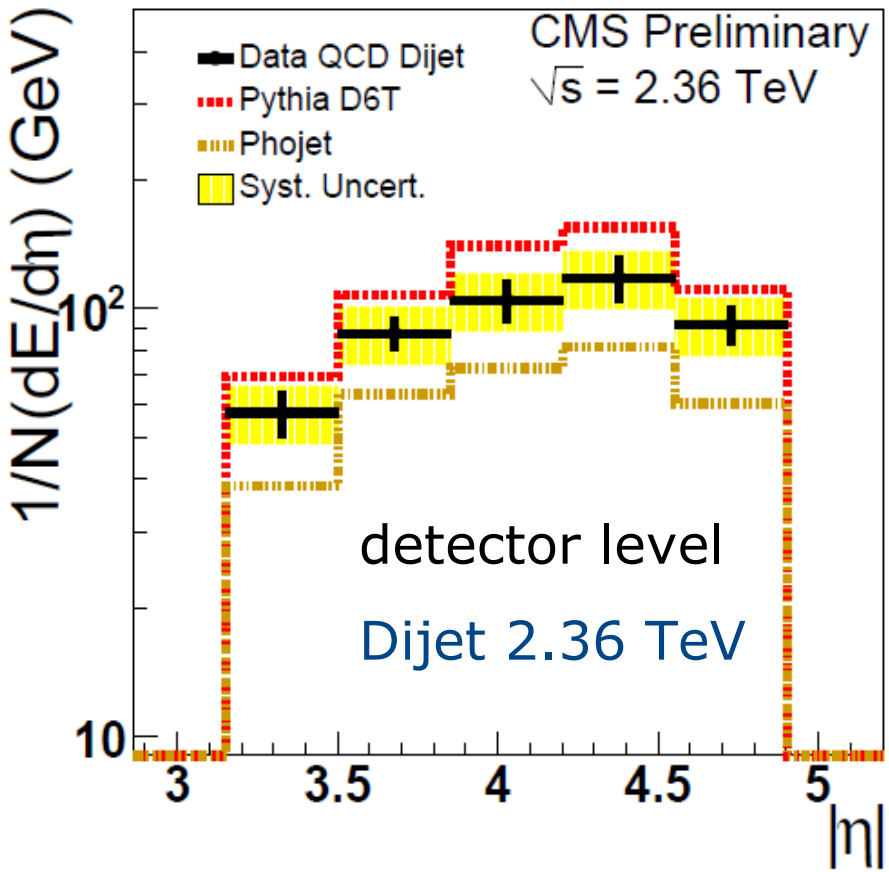




- Main systematic uncertainty: global HF energy scale: 15 %
- At $\sqrt{s}$ = 900 GeV & 2.36 TeV: data best described by D6T
  PHOJET below the data
- At $\sqrt{s}$ = 900 GeV: PROQ20, P0 below the data

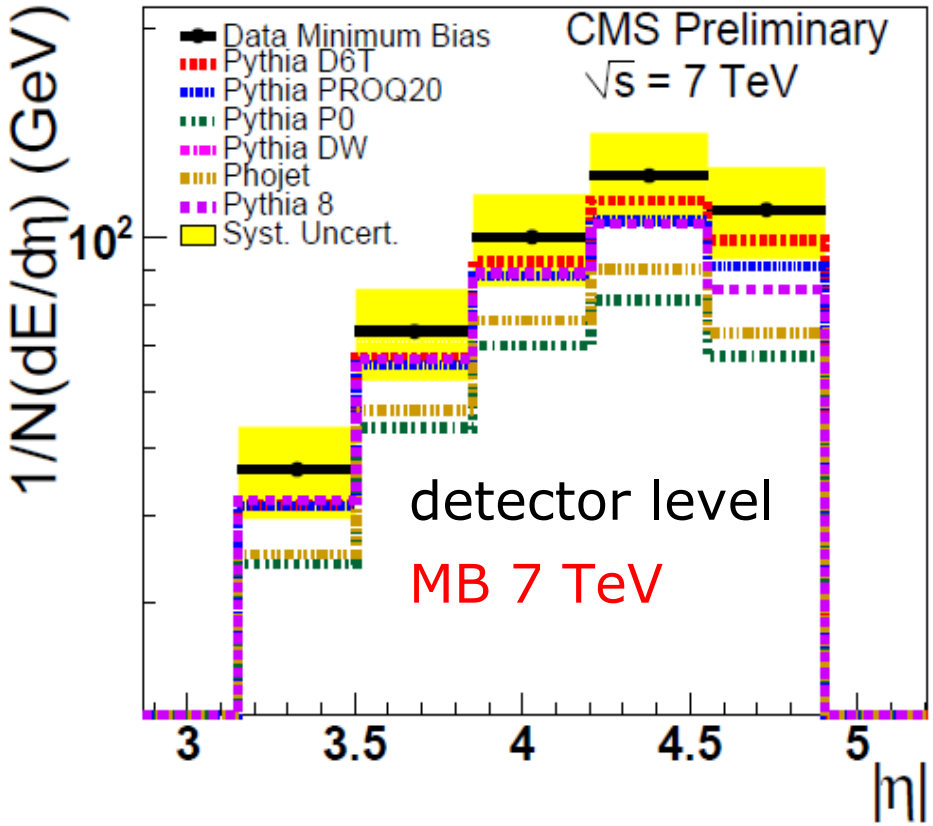
Energy flow - Dijet - 900 GeV & 2.36 TeV

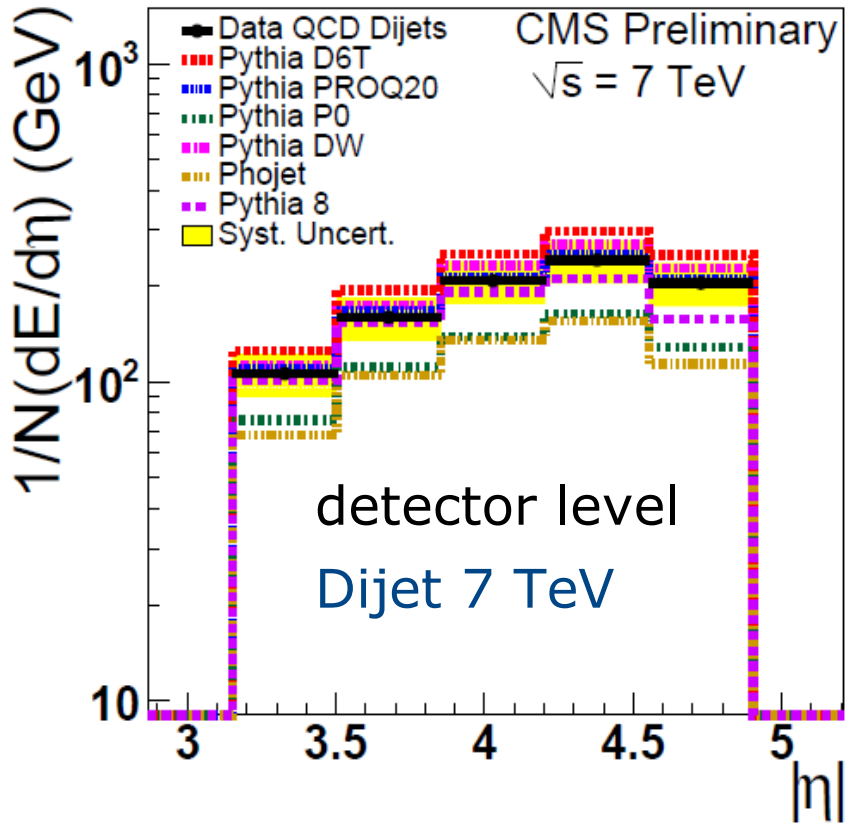




- At $\sqrt{s}$ = 900 GeV & 2.36 TeV: D6T too high compared to data
  PHOJET too low
- At $\sqrt{s}$ = 900 GeV: P0 below the data
  data best described by PROQ20

Energy flow – MB & Dijet - 7 TeV





- MB at $\sqrt{s}$ = 7 TeV: prediction below the data for all PYTHIA6 tunes
  PYTHIA8 also below the data, close to PROQ20
- Dijet at $\sqrt{s}$ = 7 TeV: data again best described by PROQ20
  PYTHIA8 reasonable description
  D6T too high, P0 and PHOJET too low

Forward Jets in proton – proton Collisions at √s = 7 TeV

[CMS DPS-2010/026]

Physics Motivation

- Jet production has never been investigated in such a forward region as the one covered by the CMS HF calorimeter

→ first measurement of forward jets in the range $3.2 < |\eta| < 4.7$

- Forward jets probe the low x region

- First step: validate jet reconstruction in the forward region

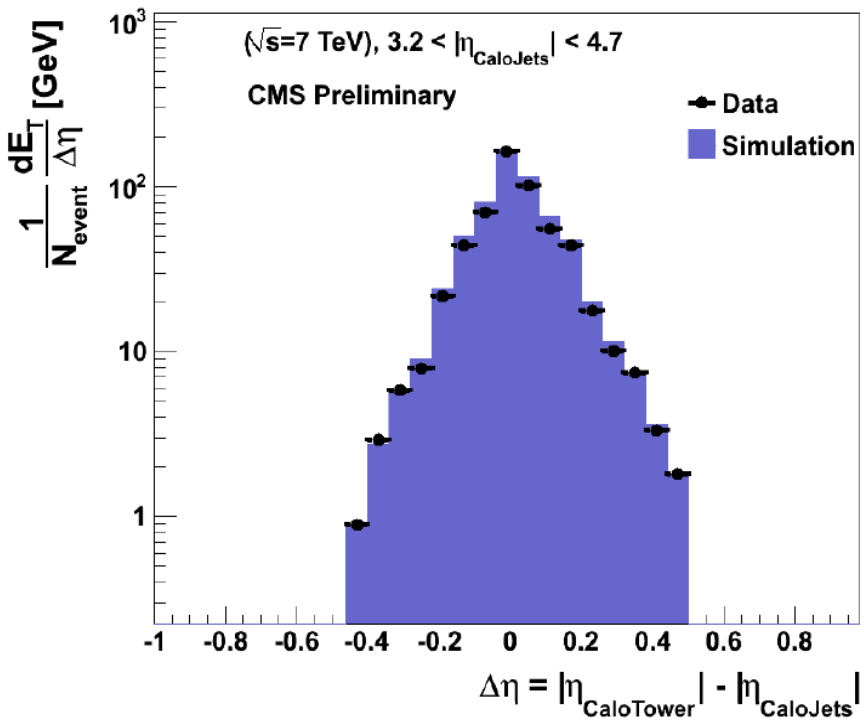
Event and Jet Selection

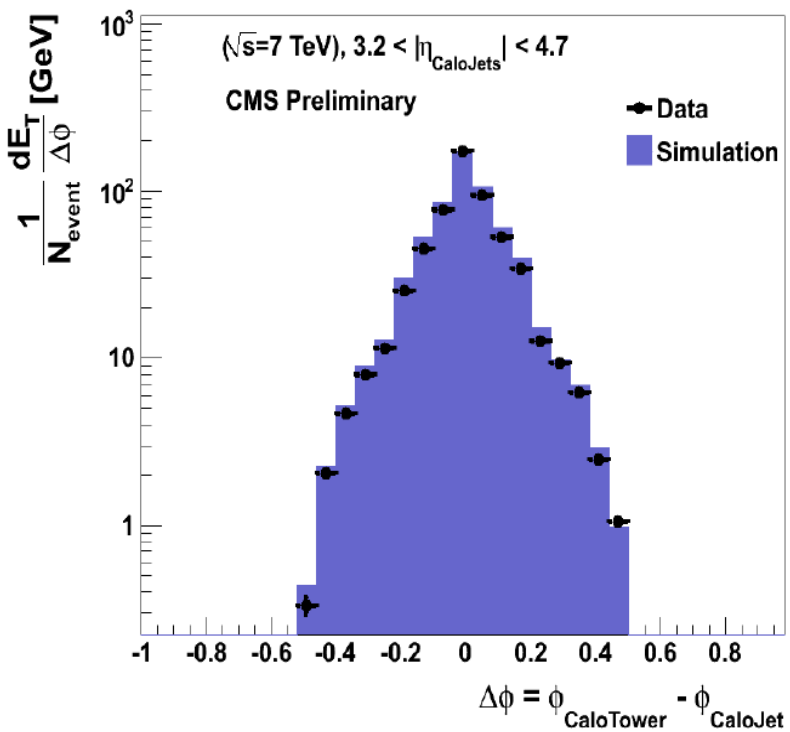
- Event selection similar to the Minimum Bias event selection
- Integrated luminosity $L \approx 10\ nb^{-1}$
- Jet reconstructed by anti-k_T jet algorithm (R = 0.5)
- Jet energy corrected
- $35 < E_T < 120$ GeV
- $3.2 < |\eta| < 4.7$

Jet Size and Shape

- Look at size and shape of calorimeter jets through the distribution of the transverse energy flow E_T around jet axis

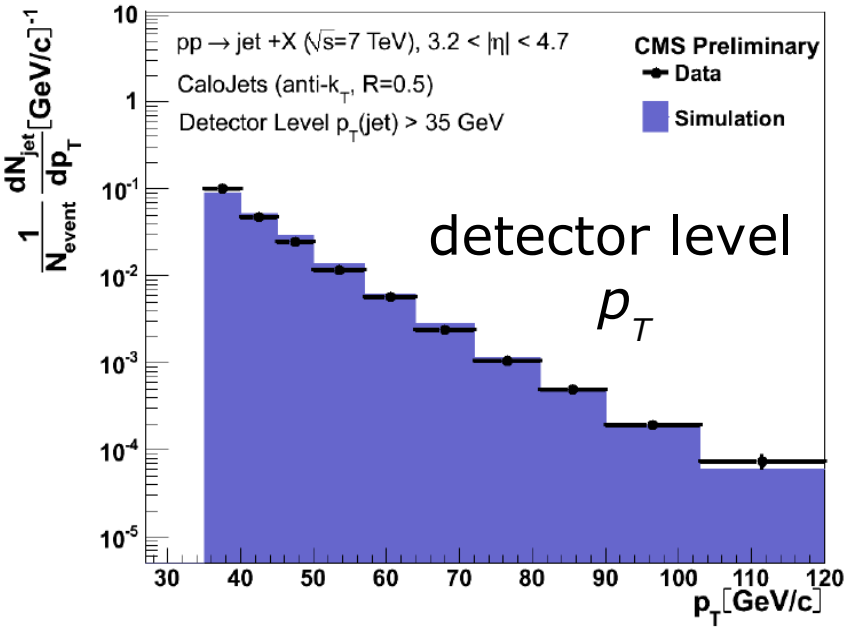
→ sensitive test of the description of data by MC (PYTHIA6 D6T)

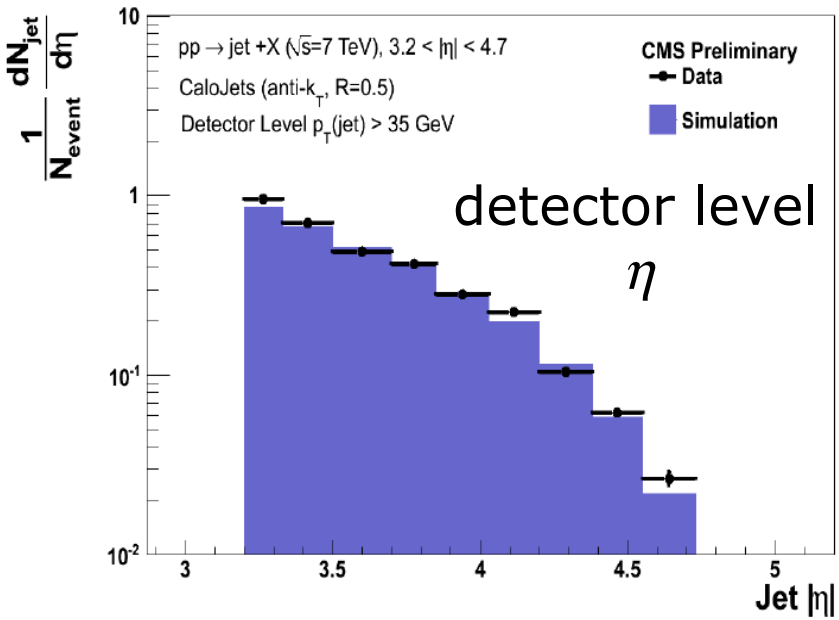




→ transverse energy flow E_T inside the jets well described by MC

p_T and η Spectrum





- 7 TeV data, detector level distributions
- no unfolding, no systematic uncertainties

  → reasonable agreement between data and MC (PYTHIA6 D6T)
- expected resolutions:
  - $\sigma(p_T)/p_T$ ~ 15 % at 20 GeV, ~ 12 % at 100 GeV
  - $\sigma(\Delta\eta)$, $\sigma(\Delta\varphi)$ ~ 0.035 at 20 GeV, ~ 0.025 at 100 GeV

Conclusion

- First measurement in hadron-hadron collisions of the forward energy flow in the region $3.15 < |\eta| < 4.9$, for MB events and for events with a hard scale defined by a central dijet system

- Increase with $\sqrt{s}$ reproduced by MC for dijet events, not for MB events → strongest increase in data than in the MC (for all tunes)

- None of the MC can describe all the measurements in all aspects, MB data energy flow at 7 TeV larger than any MC predictions

- MC tunes giving best description in forward region ≠ those giving best description of charged particle spectra in central region (DW)
  → forward region provides further input for MC tuning
  constrains parton radiation modelling at large η

- Measurement of forward jets in the HF acceptance and validation of the forward jet reconstruction with 7 TeV data

Back Up

Minimum Bias Events Selection

- Trigger signal in each of the BSC scintillators in coincidence with a signal from both BPTX detectors
- Primary vertex with $|z| < 15$ cm
  transverse distance from z axis < 2 cm
  at least 3 tracks used in the vertex fitting
- Rejection of beam halo candidates
- Rejection of beam background events (fraction of high-quality tracks > 25 % for events with more than 10 tracks)
- Noise threshold of 4 GeV for the uncorrected energy in HF (value determined through measurement of energy deposits in HF in non-interaction events)
- Rejection of events with large and isolated signal in HF consistent with noise (charge particle traversing a PMT window)

Statistics – PMT hits – Diffraction

√s	900 GeV	2.36 TeV	7 TeV
MB sample	177475	10245	3713294
Dijet sample	433	86	4292
PMT hits	1117	84	56425
fraction SD-DD in MB sample	5%	4%	2%

Systematic Uncertainties

- Main systematic uncertainty: global HF energy scale: 15 % (MB energy flow measured separately in HF+ and HF-: $\Delta < 10$ %)
- Channel-by-channel miscalibration: channel response randomly varied between ±15% → effect on energy flow < 1 %
- Influence of remaining calorimetric noise: noise threshold in HF increased to 4.5 GeV → effect on energy flow ~ 2 %
- Influence of remaining noise from PMT hits: alternative rejection algorithm is used → effect on energy flow < 3 %
- η measured wrt origin of CMS reference system: for events with a vertex far from that point, energy flow is shifted → estimate this effect by dividing the sample in 3: $|z| < 4$ cm, $4 < |z| < 9$ cm, $9 < |z| < 15$ cm → effect on energy flow < 1 %

PYTHIA MPI tunes

- Perturbative 2-to-2 partonic cross-section is regularized in PYTHIA by the introduction of a cutoff p_{T0}:

$$\sigma \propto 1/(p_T^2 + p_{T0}^2)^2$$

- p_{T0} governs the description of the amount of MPI: larger MPI activity for smaller values of p_{T0}

- $p_{T0}(\sqrt{s}) = p_{T0}(\sqrt{s_0})\,(\sqrt{s}/\sqrt{s_0})^{\varepsilon}$

	$p_{T0}(\sqrt{s_0})$	$\sqrt{s_0}$	ε
D6T	1.84	1.96	0.16
PROQ20	1.9	1.8	0.22
P0	2.0	1.8	0.26
DW	1.9	1.8	0.25

Integrated Luminosity 2010