Low-x Physics Results from CMS

DIFFRACTION 2012, 13. September 2012

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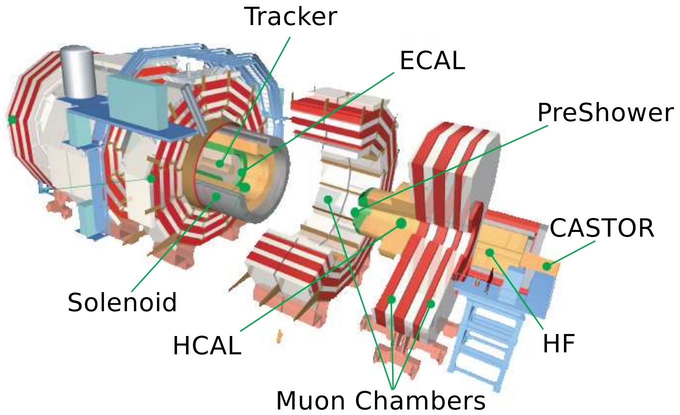
Outline

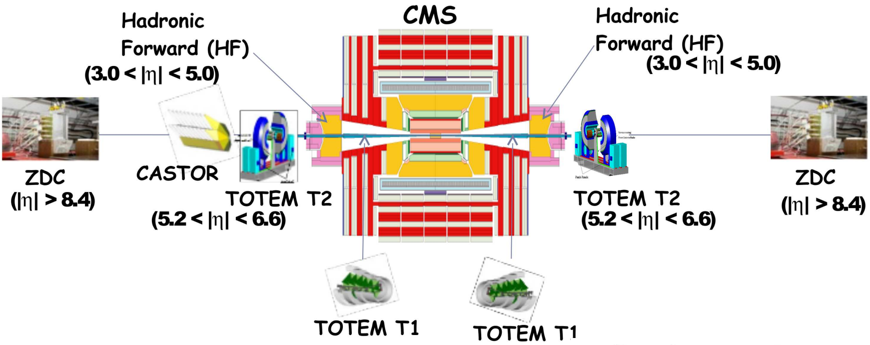
- CMS apparatus, Forward region
- Inelastic cross sections
- Inclusive forward jets
- Di-jets (forward-central, inclusive, exclusive)
- Very forward energy flow (pp and PbPb)
- Outlook: CMS+TOTEM
- Summary

Compact Muon Solenoid

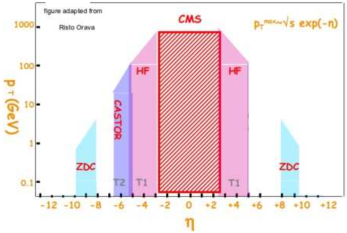


- 3.8T solenoidal magnet containing: silicon tracking, crystal ECAL and brass-scintillator HCAL. Also: outer muon chamber system.
- Forward instrumentation of CMS results in a very wide pseudorapidity coverage

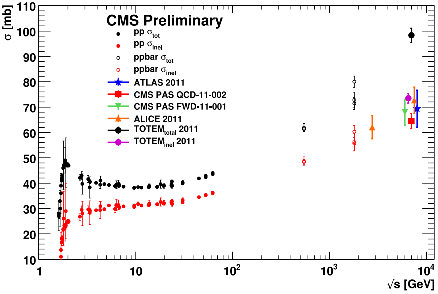
Forward Detectors



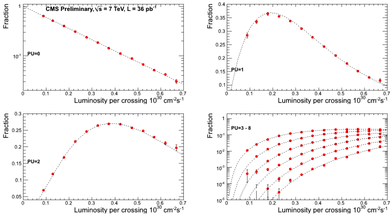
- CMS forward calorimeters (HF, CASTOR and ZDC) are all Quartz-Cherenkov type: radiation hard + fast
- Combination of CMS and TOTEM has full calorimetric and tracking coverage from $-6.6 < \eta < +5.2$



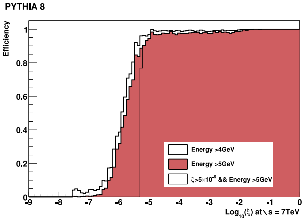
Inelastic Cross Section



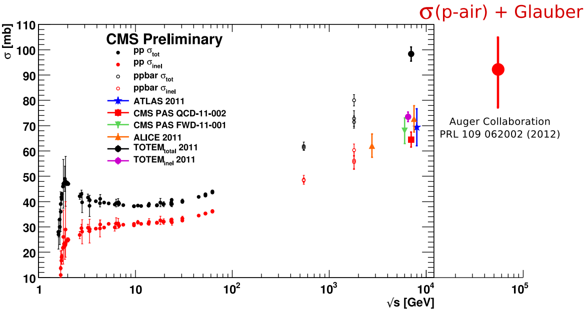
Pile-Up Counting FWD-11-001:



Event Counting QCD-11-002:



Inelastic Cross Section



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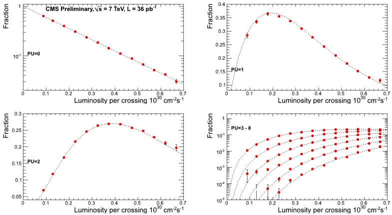
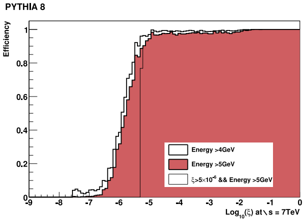
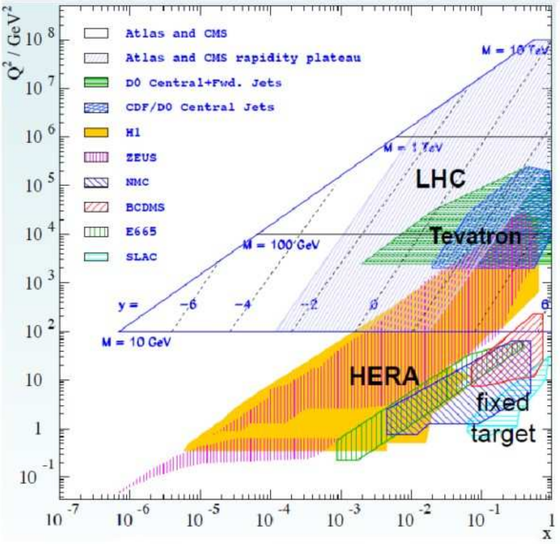


Event Counting QCD-11-002:



Forward Jets and Low-x

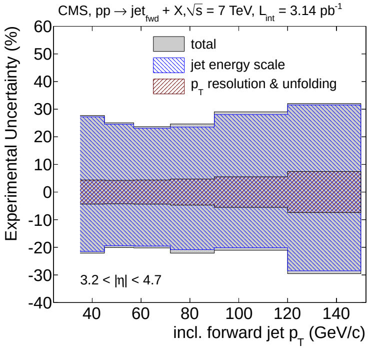


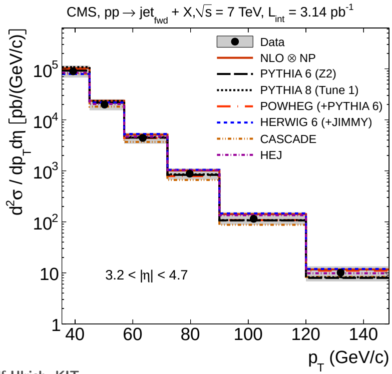
- Forward jets: asymmetric collision $x_1 \ll x_2$
- At LHC, down to $x \sim 10^{-6}$
- Example: Jets in HF with $p_{\mathrm{T}} > 35\,\mathrm{GeV}$: $x \sim 10^{-4}$
- Access to gluon densities at small x
- What is the evolution of partons at small x?
- What is the gluon saturation scale?

Inclusive Forward Jets

JHEP 6 (2012) 36

- Inclusive jets in HF ($3.2 < |\eta| < 4.7$)
- 3.14/pb 7TeV 2010 low pile-up data
- Single jet trigger with $p_{\mathrm{T}} > 15\,\mathrm{GeV}$
- Corrected to hadron level





Experimental uncertainties:

- Statistical uncertainties small, 1-10%
- JES, 20-30 %
- Resolution+correction, 3-6 %
- Luminosity, 4 %

Inclusive Forward Jet Data

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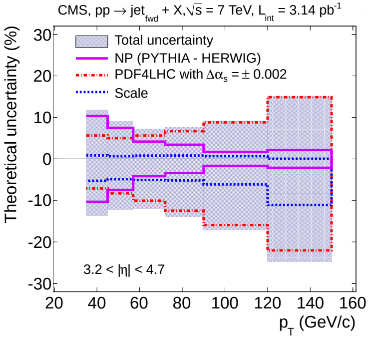
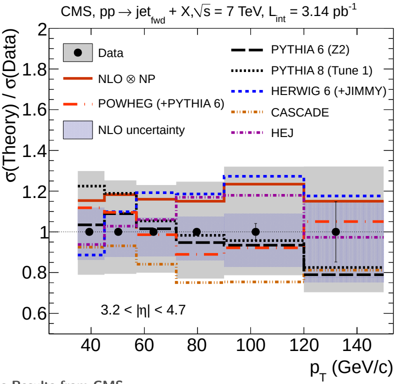


Theory uncertainties:

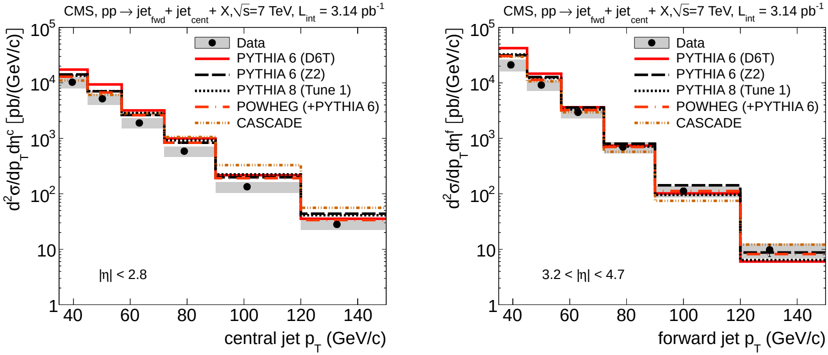
- Non-perturbative effects (hadronization) dominate at low p_T
- PDF uncertainties dominate at high p_T
- Scale uncertainty constant and not dominating



- Experimental uncertainties on same scale as theory uncertainties
- All models compatible with data:
  - DGLAP, NLO
  - BFKL-type HEJ
  - CCFM CASCADE a bit low
  - NLO 20 % above central value
- Need to reduce JES uncertainty

Central+Forward Jets

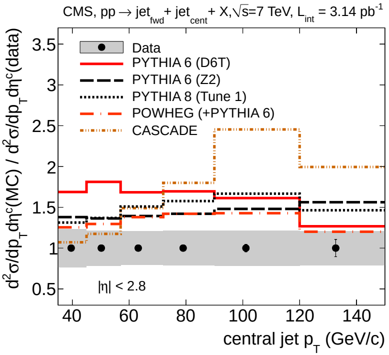
CMS-FWD-11-002

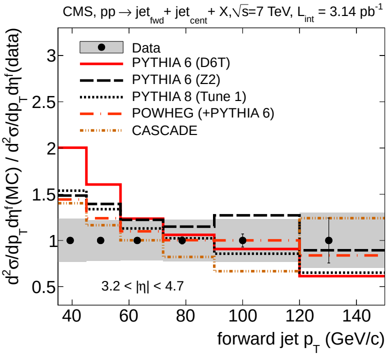


- $-5.2 < \eta < 5.2$
- Dijet trigger $(E_{\mathrm{T},1} + E_{\mathrm{T},2})/2 > 15\,\mathrm{GeV}$
- 3.14/pb 7TeV 2010 low pile-up data
- Analyze jets with $p_\mathrm{T} > 35\,\mathrm{GeV}$

Central+Forward Jets

CMS-FWD-11-002





- Central jet data ($|\eta| < 2.8$) normalization poorly described, shape agrees for most models.
- CASCADE predicts different shape
- Forward jet data ($3.2 < |\eta| < 4.7$) shape not described. Data has fewer low $p_{\rm T}$ jets compared to models

Ratio of Inclusive to Exclusive Jets

arXiv 1204.0696, EPJC

Data Selection

- 7 TeV 2010 data
- Single jet trigger > 15 GeV
- $p_{\mathrm{T}} > 35$ GeV
- Only one reco vertex

Event Samples

1. Exclusive: exactly one di-jet
2. Inclusive: all di-jets
3. Müller-Navelet (MN): subset of inclusive sample, but only most forward-backward jets selected

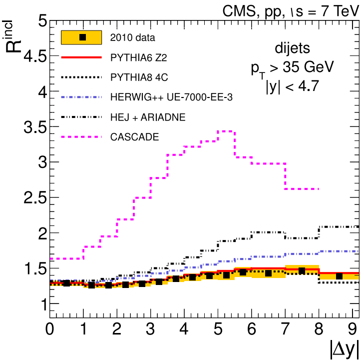
Analysis

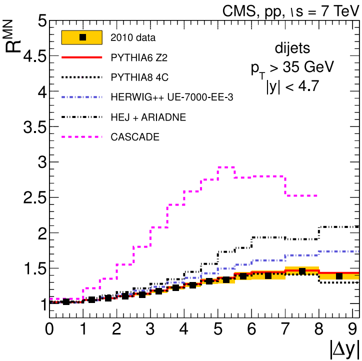
Cross section calculated as function of jet separation $|\Delta y|$. Ratios analyzed:

$$R_{\mathrm{incl}} = \frac{\sigma_{\mathrm{incl}}}{\sigma_{\mathrm{excl}}} \qquad R_{\mathrm{MN}} = \frac{\sigma_{\mathrm{MN}}}{\sigma_{\mathrm{excl}}}$$

Ratio of Inclusive to Exclusive Jets

arXiv 1204.0696, EPJC

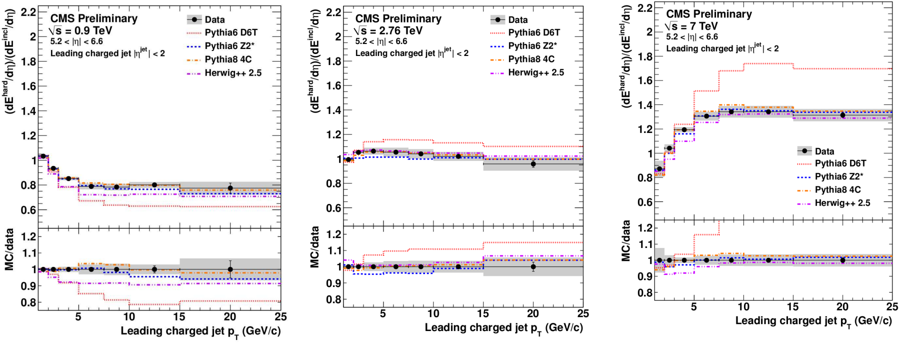




- R rises with $|\Delta y|$
- At largest $|\Delta y|$ R drops: kinematical limit
- PYTHIA Z2 and PYTHIA8 4C agree perfectly with data
- HERWIG predicts too high R
- HEJ+ARIADNE and CASCADE (BFKL motivated) predict much faster rise

Very Forward Energy Flow (Ratios)

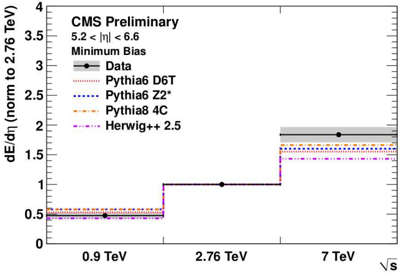
CMS-FWD-11-003

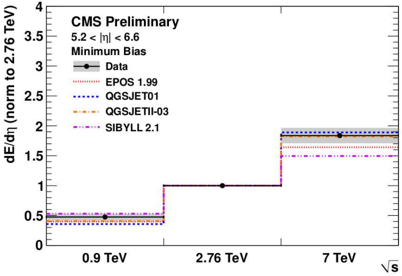


- Underlying event at forward rapidity
- 900GeV: Forward depletion for larger central scale
- 2.76TeV: Forward energy almost independent of central scale
- 7TeV: Forward energy correlated to central scale
- Tuned models do a good job in describing data

Very Forward Energy Flow (Relative)

CMS-FWD-11-003

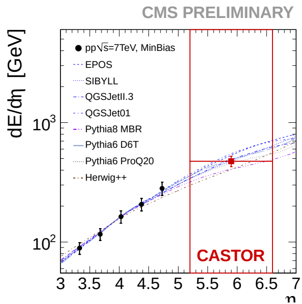




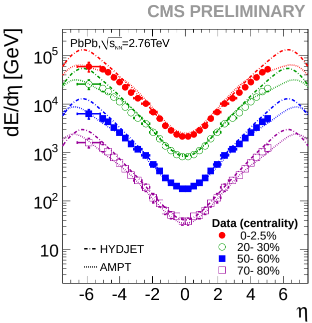
- Most models have too small slope
- SIBYLL has larger slope than data
- QGSJETII is the only model describing the data
- In general: the non-tuned cosmic-ray models perform very well

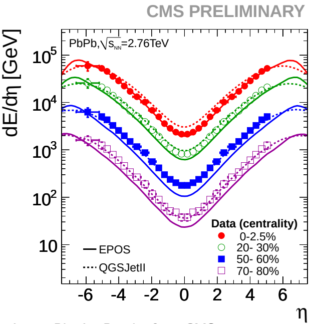
Very Forward Energy Flow in PbPb

CMS-HIN-12-006



- Energy scale of CASTOR determined from 7TeV pp data
- PbPb, $\sqrt{s_{\mathrm{NN}}}$ =2.76 TeV 2010 data analyzed
- Centrality determined with HF
- Hadron level corrected



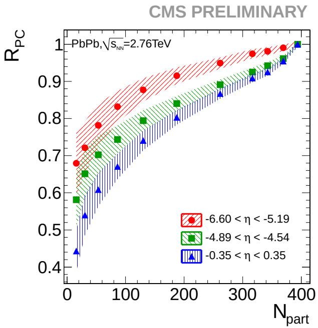


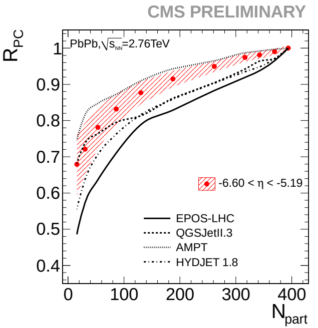
⇒ No model describes data over full acceptance range

Very Forward Energy Flow in PbPb (ratio)

CMS-HIN-12-006

$$R_{\mathrm{PC}}(\eta,\ N_{\mathrm{part}}) = \frac{\langle E\rangle(\eta,\ N_{\mathrm{part}})}{\langle E\rangle(\eta,\ N_{\mathrm{part}}^{\mathrm{max}})} \cdot \frac{N_{\mathrm{part}}^{\mathrm{max}}}{N_{\mathrm{part}}}$$





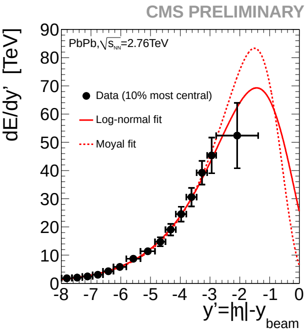
- Forward data exhibit different (less) centrality dependence
- Reflect structure of the nucleus at lower x
- All models are challenged in describing the forward data
- AMPT is best

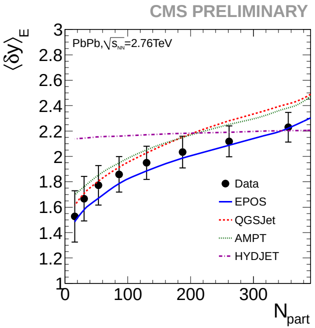
Very Forward Energy Flow in PbPb

CMS-HIN-12-006

Average energy weighted pseudorapidity:

$$\langle \delta y \rangle_{\mathrm{E}} = \frac{2}{E_{\mathrm{N}} N_{\mathrm{part}}} \int_{\infty}^{-y_{\mathrm{beam}}} y\prime \, \frac{dE}{dy\prime} \, dy\prime, \quad \text{where} \quad y\prime = |\eta| - y_{\mathrm{beam}}$$





- Very good pseudorapidity coverage of CMS
- Observe the energy dispersion of the Pb nucleus
- HYDJET cannot describe data
- EPOS works best

CMS+TOTEM

- First data taken in Dec 2011 (Halo muons and PbPb collisions)
- Data combined (offline) and performance checked:

- State of the art: TOTEM can trigger CMS, CMS can trigger TOTEM, Independent readout, Offline event merging
- Several analyses in progress: combined $dN/d\eta$ and $dE/d\eta$, diffraction in CMS with protons in RPs, etc.

Summary

- Very good acceptance coverage of CMS is a powerful tool to study low-x structure of hadrons
- Forward energy flow and forward jets are very good probes of low-x structure
- Jets in CMS up to $\eta = 6.6$ can go as far as $x = 10^{-6}$
- The combination of CMS calorimeters with TOTEM trackers in the forward region is opening up a new era of data analysis right now!