Recent CMS results on low-x QCD

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on behalf of
CMS Collaboration

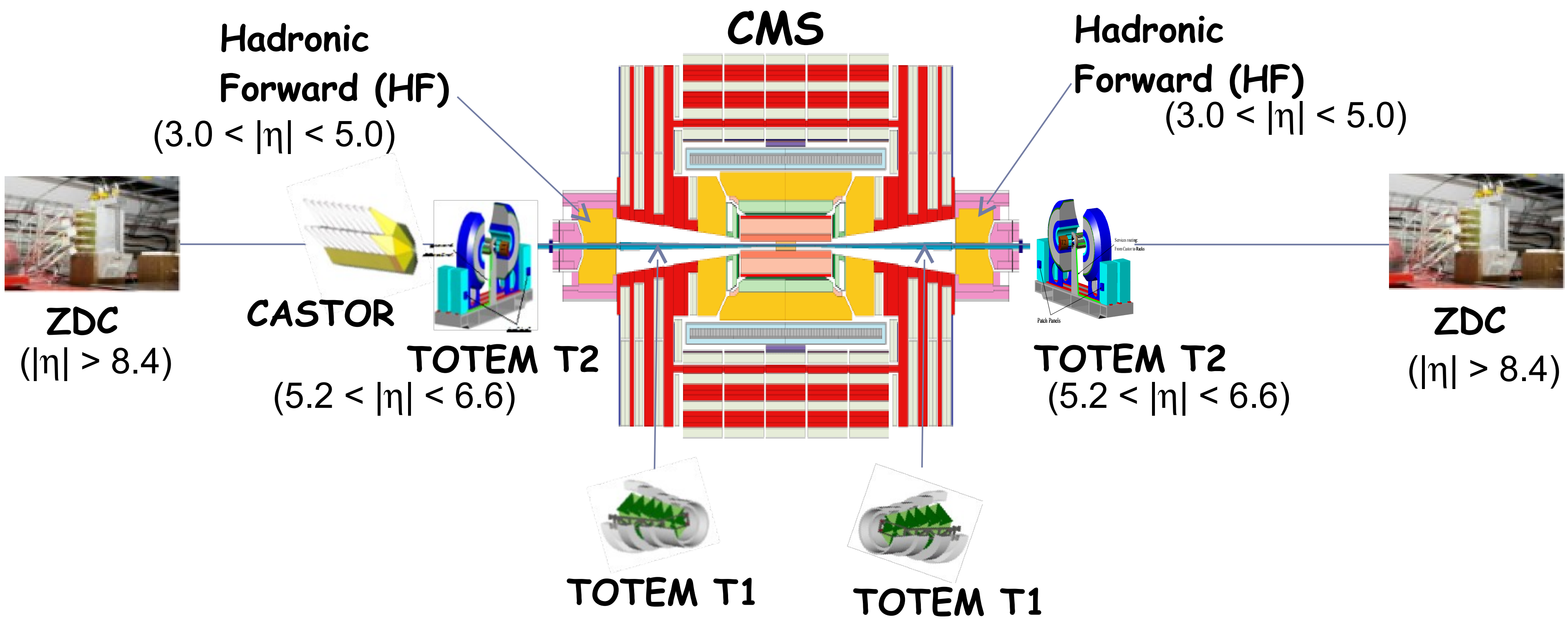
27.06.2012

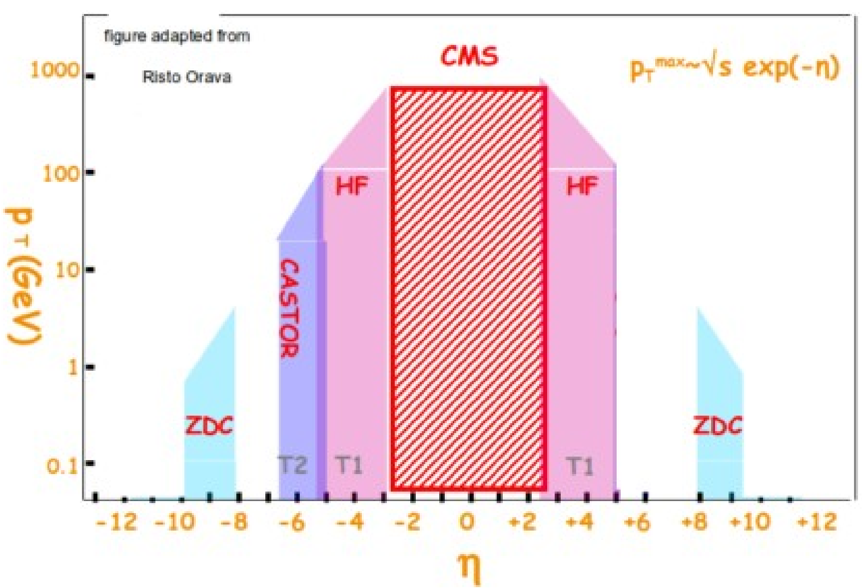
Low-X Meeting

The Outline

- Apparatus
- Energy flow in the forward region
- Forward jets spectrum
- Correlations between jets
- Outlook and Summary

CMS at forward rapidities





- **H**adronic **F**orward calorimeters (HF)
- **Z**ero **D**egree **C**alorimeter (ZDC)
- **C**entauro **A**nd **ST**range **O**bjects **R**esearch (CASTOR) – calorimeter

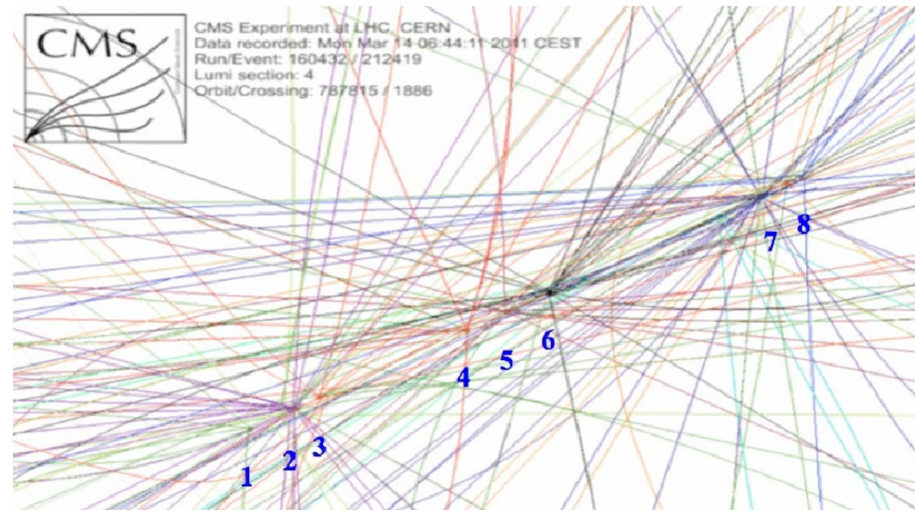
  → Pure calorimetric detectors

\+ Totem (T1/T2)

  → tracking detectors

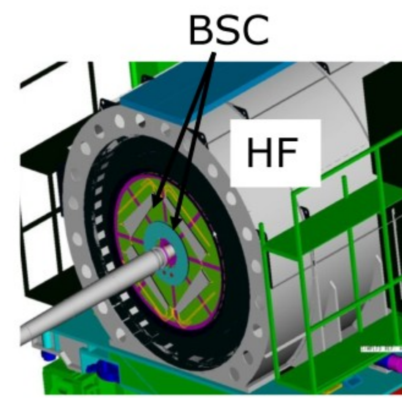
CMS at forward rapidities

- Here only results from 2010(09) – CMS alone



- Low pile-up data – with forward calorimetric detectors alone it is very difficult to ascribe a given object to a given vertex

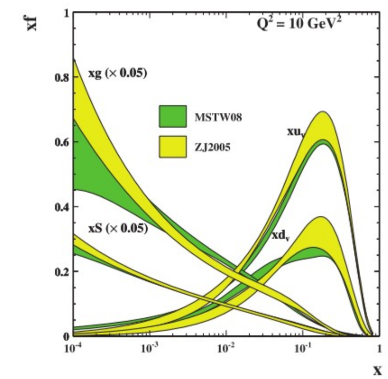
- Minimum bias trigger:
  → Beam Scintillator Counters
  ~11 m from IP at both sides
  coincidence → single diffractive dissociation suppressed



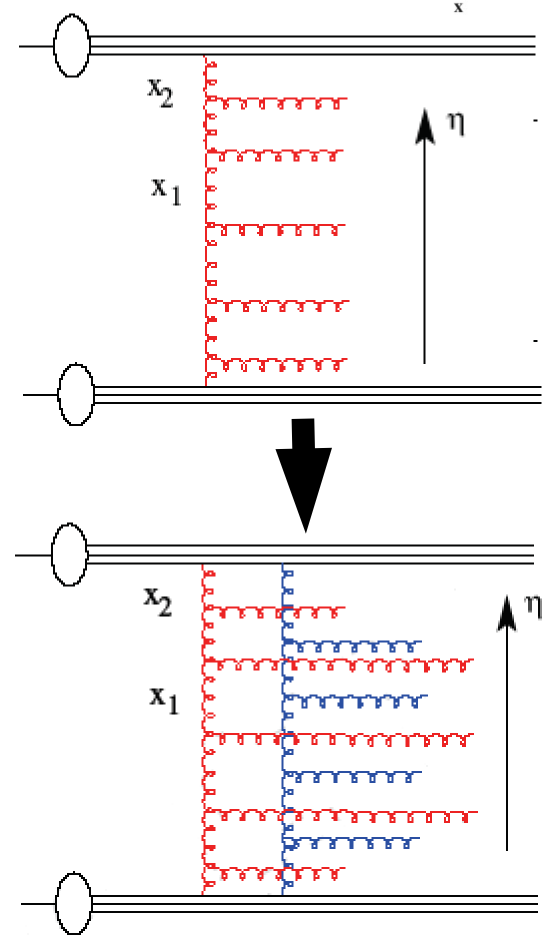
- Two kinds of observables:
  - energy flow → total energy deposits (~1 nb^{-1} enough)
  - distribution of (calorimetric) jets and correlations between jets

Forward energy flow

- At very large centre of mass energies, the momentum fraction of the proton carried by the partons in the hard scattering (x_1, x_2) can become very small and the parton densities become very large.



- Probability for more than one partonic interaction per event increases.
  - This approach is described in the models of multiparton interactions.
  - Models implemented in Monte Carlo event generators need parameters to be adjusted to describe the measurement.
  - See: Sunil Bansal talk on Thursday here – only results from forward CMS detectors presented

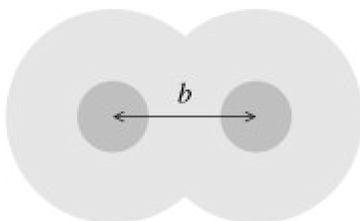


Forward energy flow

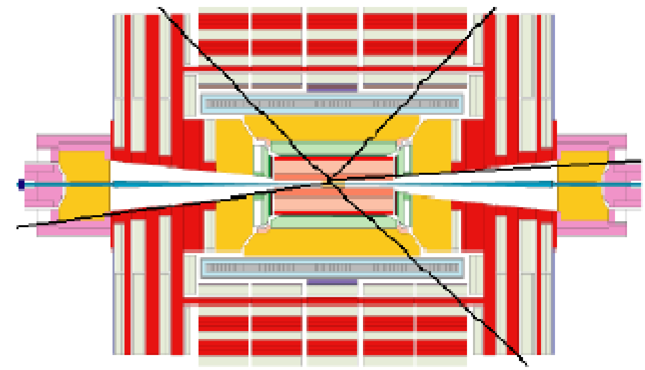
Measurement for HF: $3.15<|\eta|<4.9$

FWD-10-011,
JHEP 1111 (2011) 148

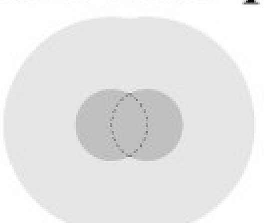
Minimum bias



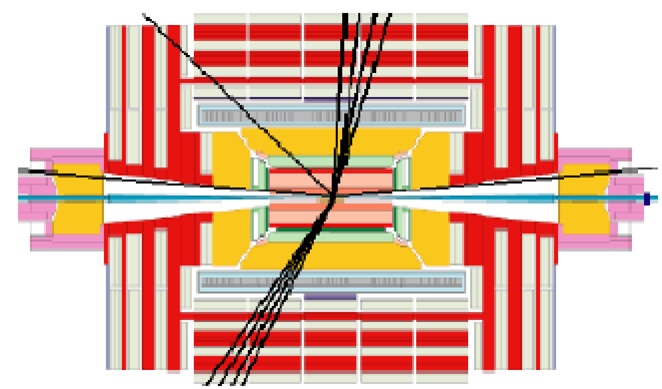
activity at both sides of IP
(coincidence between BSC) +
vertex reconstructed
(diffraction highly reduced)



Hard scale $\hat{p}_T$



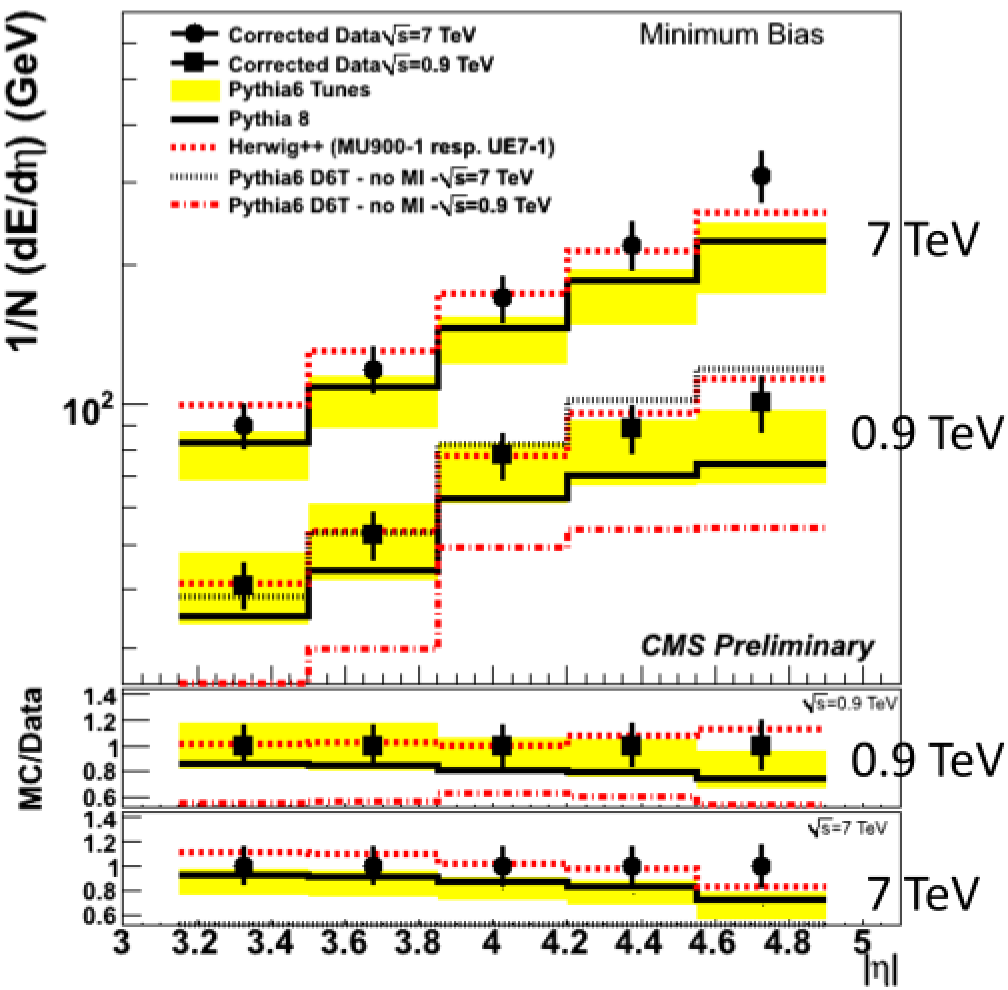
Central jets: |h| < 2.5
Back-to-back:
$|\Delta\varphi(jet_1, jet_2) - \pi| < 1$
Scale:
900 GeV → pT > 8 GeV
7000 GeV → pT > 20 GeV



- Energy flow should rise with energy
- Energy flow should rise from MB to di-jet sample
- Test different models (and tunes) of MPI

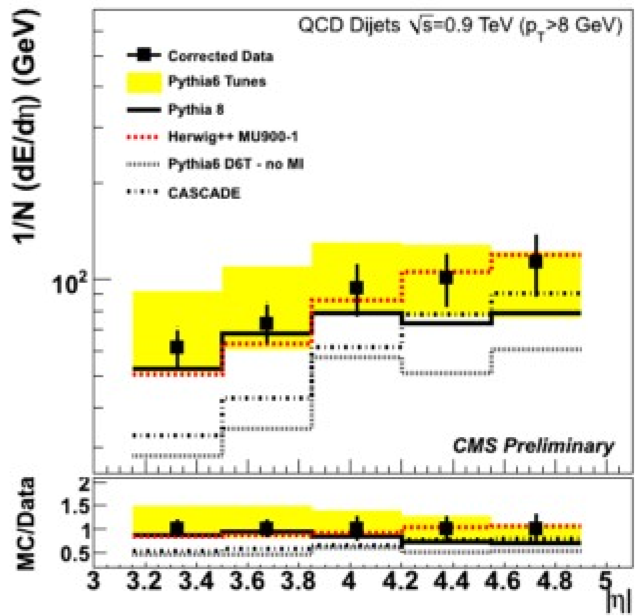
Forward energy flow

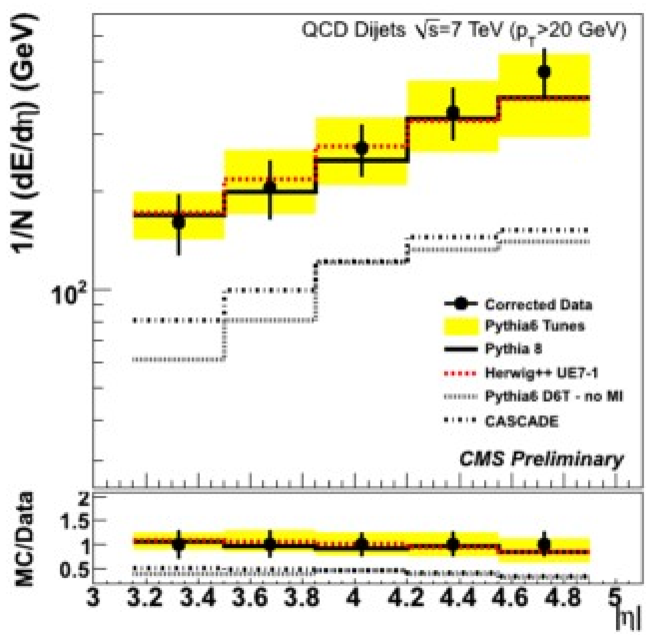
Minimum Bias sample



- Pythia 6 band (~20%) composed from different tunes, including those tuned to LHC central region data (Z2, P11, AMBT1) → do not do well
- Pythia 8 flatter than data
- Herwig++ describes data at both cms energy with some problems at highest rapidities
- Significant contribution from MPI interactions (Pythia6 without MPI interaction ~ 40% below data)

Forward energy flow



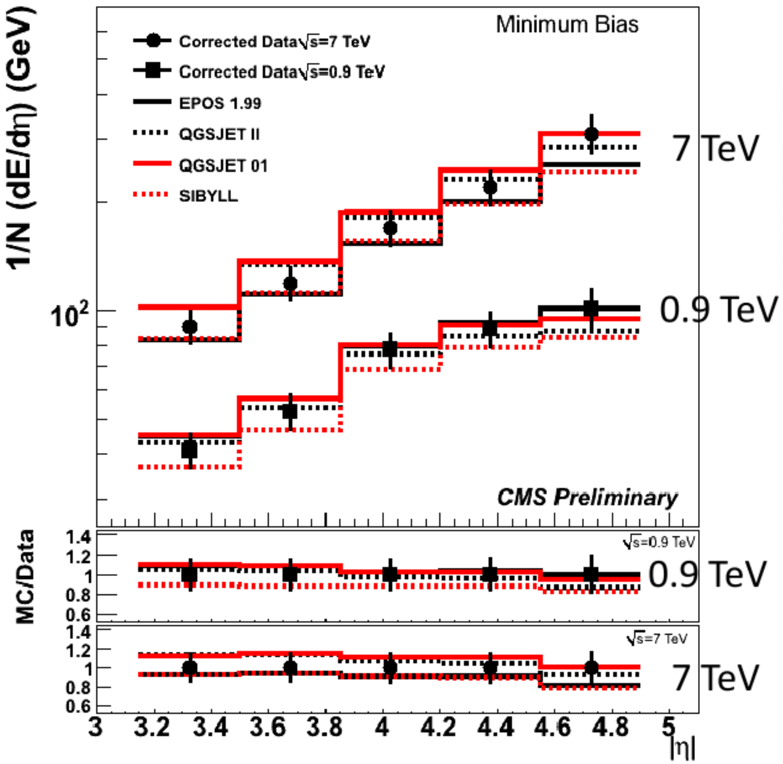


Dijet sample

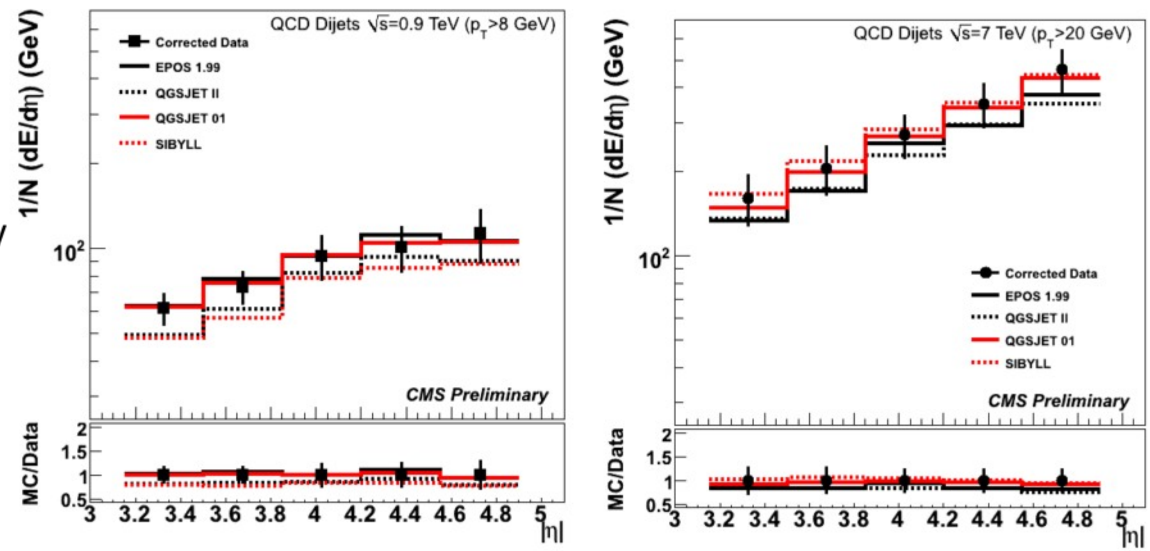
- Energy flow larger than in minimum bias sample central events are selected with scale cut
- Pythia 6 band envelopes the data
- Pythia 8 describes the data at 7 TeV
- Herwig++ (2.5) well describes data at 7 TeV
- Large contribution from MPI (switching off MI reduces energy flow by factor of two)

Forward energy flow

Minimum Bias sample



Dijet sample

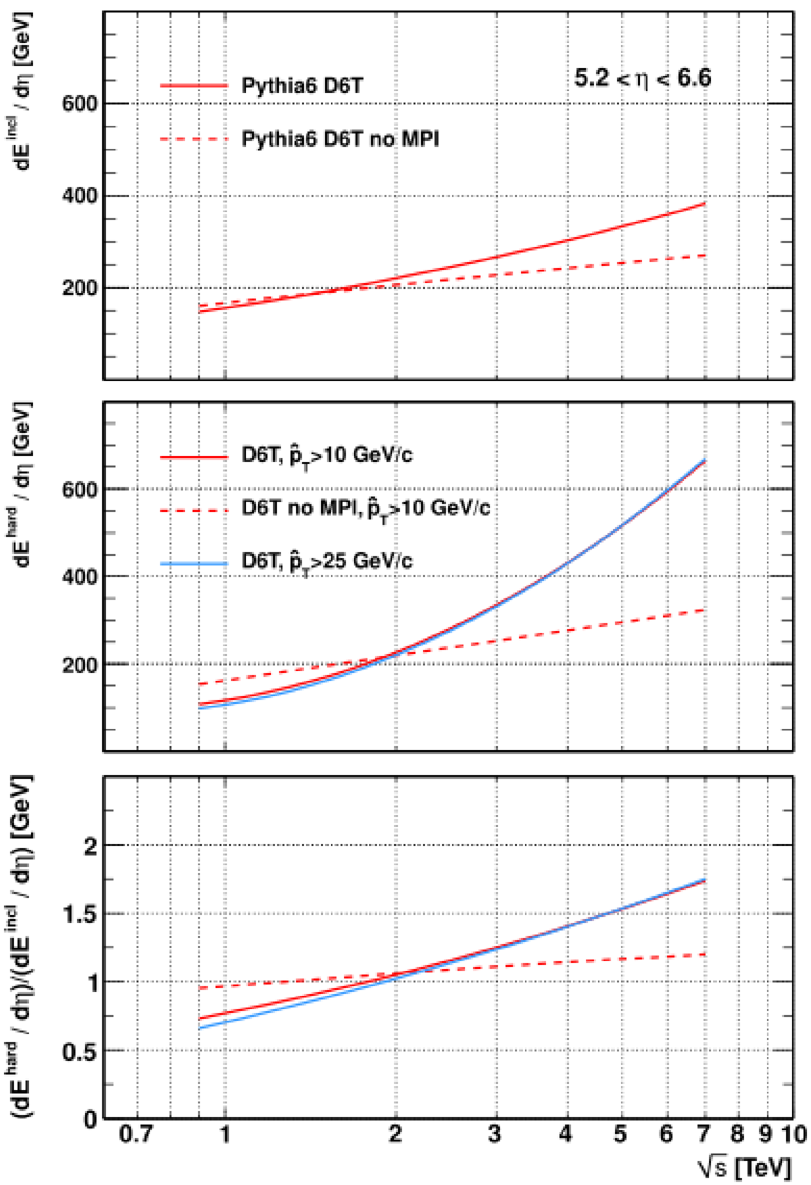


- Hadronic MCs for cosmic-ray physics do well for both energies and for both samples
- QGSJET 01 seems to be the best

Forward energy flow

FWD-11-003

Measurement for CASTOR: -6.6<η<-5.2



In Minimum Bias sample (non-diffractive)

- Energy density not much affected by MPI
- Slow rise energy density with int. energy
- Slow rise effects coming from MPI

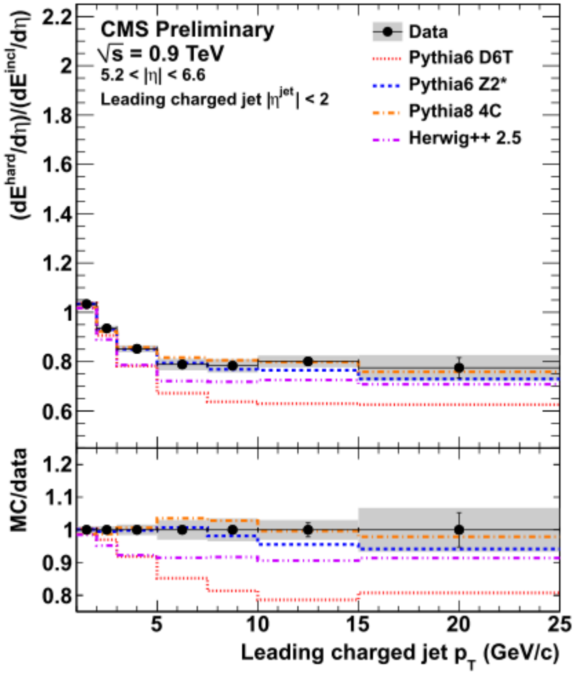
In dijet sample (hard scale set):

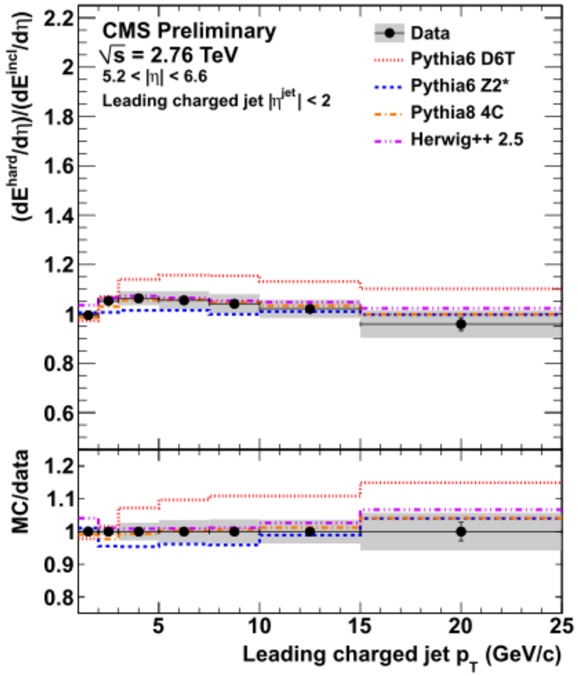
- Energy density strongly affected by MPI
- Strong rise with int. energy

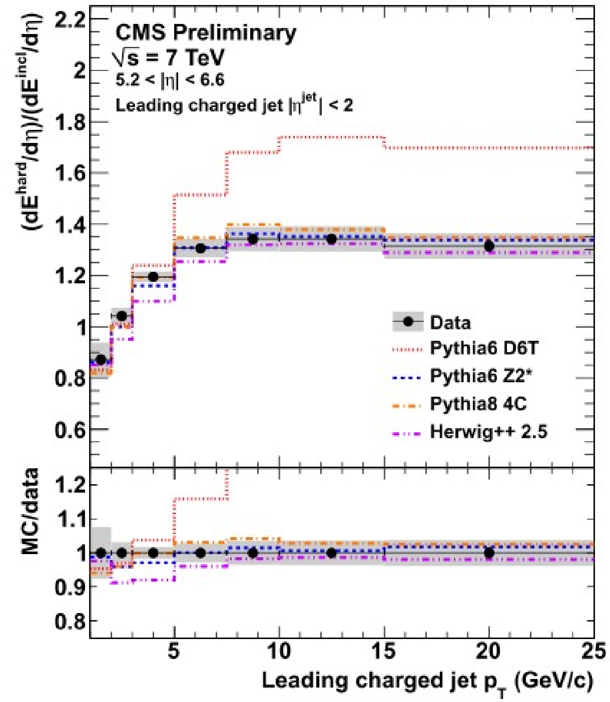
Ratio of energy density:

- Minimizes the calibration effect
- Most of the systematics cancels

Forward energy flow







- E(MB)>E(hard scale)
- Increase in central activity depletes proton remnant

- E(MB)≈E(hard scale)

- E(MB)<E(hard scale)
- Fast rise of forward activity at small pT
- plateau at higher pT

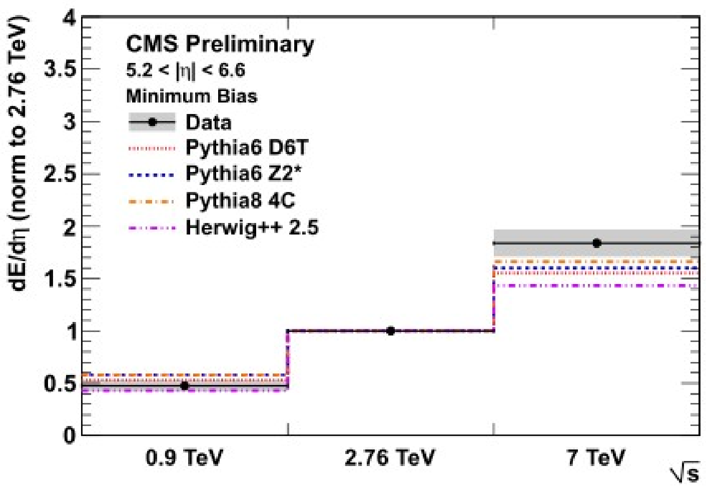
- Good description by the PYTHIA LHC tunes: Z2*, 4C
- Pre-LHC tunes fail: D6T
- Herwig++ 2.5 describe the data well

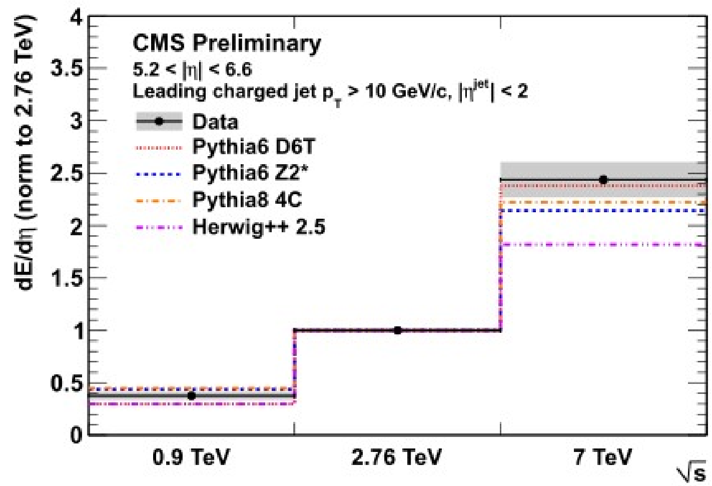
Forward energy flow

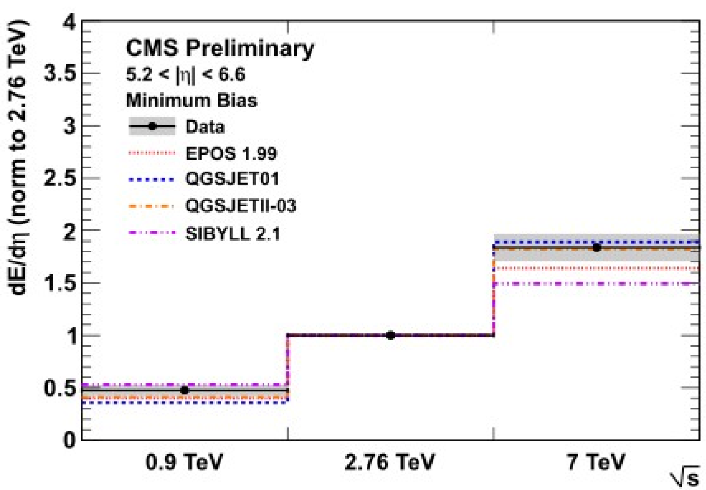
- Normalization to 2.76 TeV sample done separately for MB and dijets (pT>10 GeV)

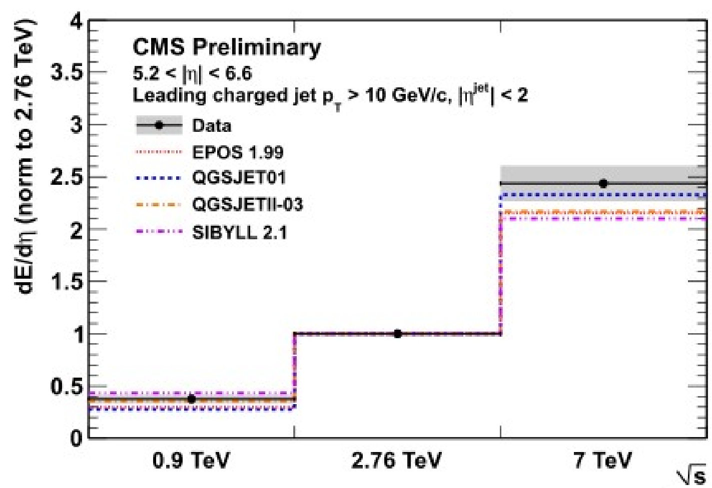
Minimum Bias

Dijet (pT>10 GeV)





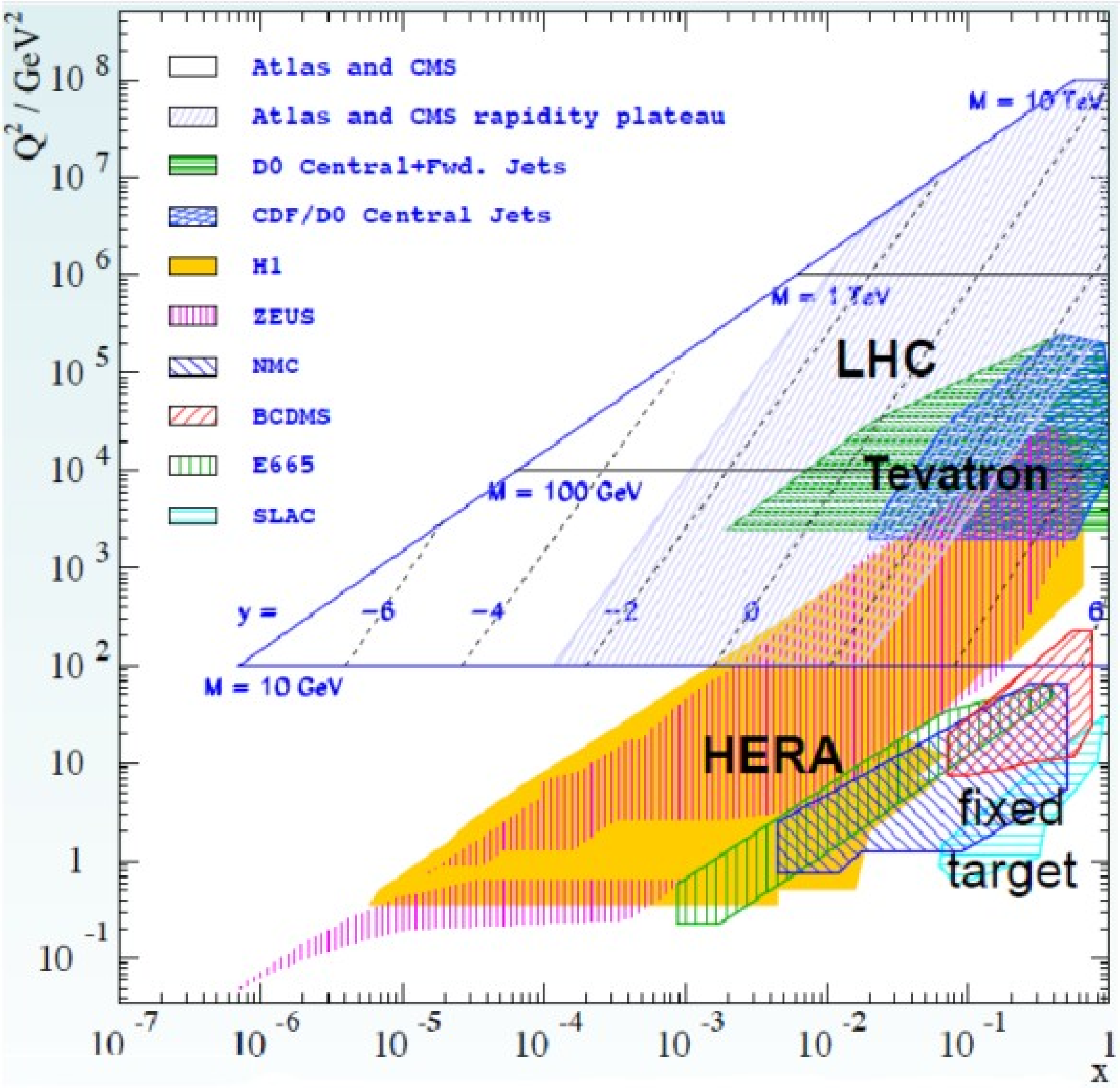




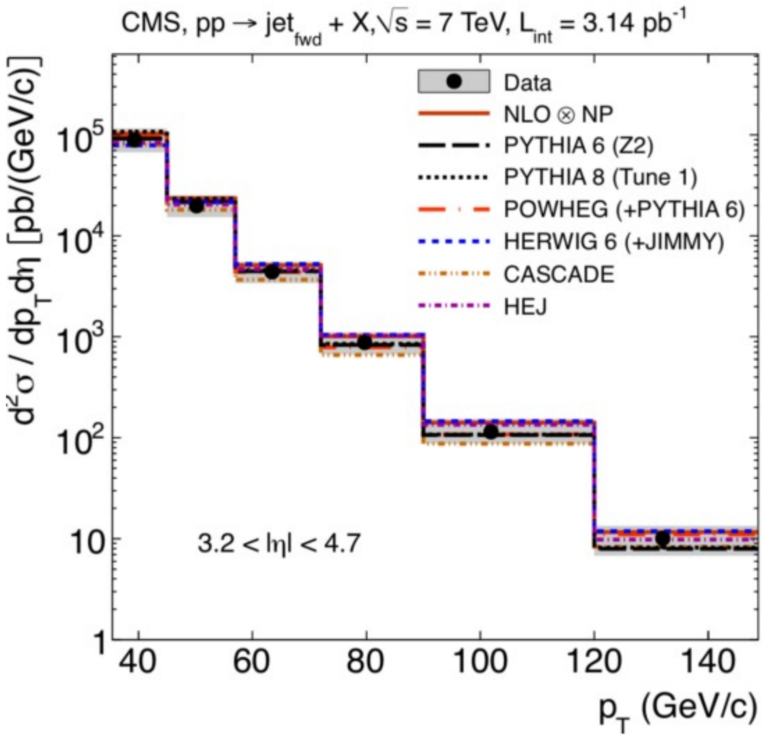
- Ratio increase faster in events with hard scale
- MB sample: PYTHIA, HERWIG do not describe the rise at 7 TeV
- MB sample: QGSJET as the only one describes it well
- Dijet sample: PYTHIA and QGSJET Are the best

Forward jets

- Forward jets in LHC – access to $x \sim 10^{-6}$
- Forward jets appear usually in asymmetric collisions $x_1 \ll x_2$
- Forward jet in HF with pT>35 GeV: $x \sim 10^{-4}$
- Access to gluon densities at small x
- BFKL vs DGLAP – correlation between jets



Inclusive forward jets

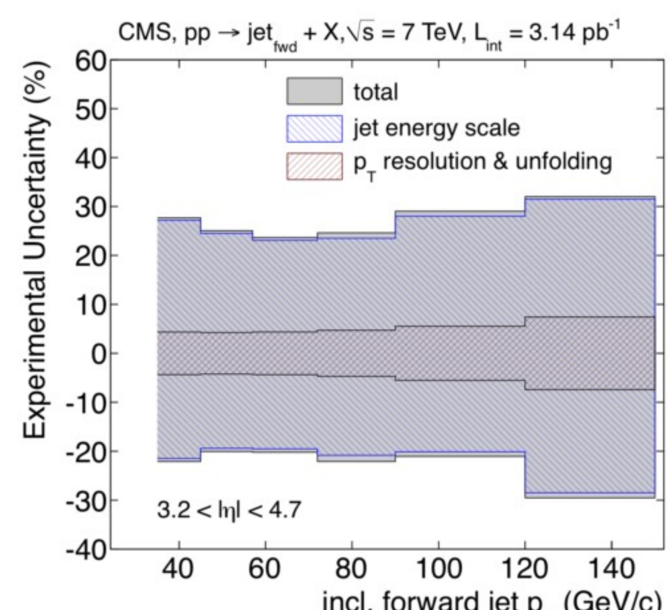


FWD-11-002, JHEP 1206 (2012) 036

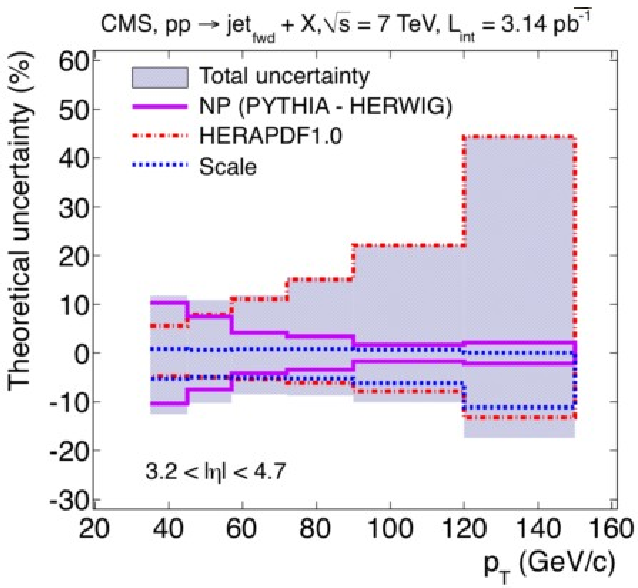
- 3.2 < |η(jet)| < 4.7
- 3.14 pb^{-1} from 7 TeV 2010 (low pile-up)
- Single jet trigger with pT>15 GeV
- pT and η dependence remove using dijet and jet+photon events
- Fully corrected to the hadron level

Experimental uncertainties:

- statistical unc. small (1-10%)
- energy scale unc. ~6% → scales to 20-30% for the jets cross section
- resolution + detector->hadron corrections: 3-6%
- Luminosity uncertainty: 4%



Inclusive forward jets



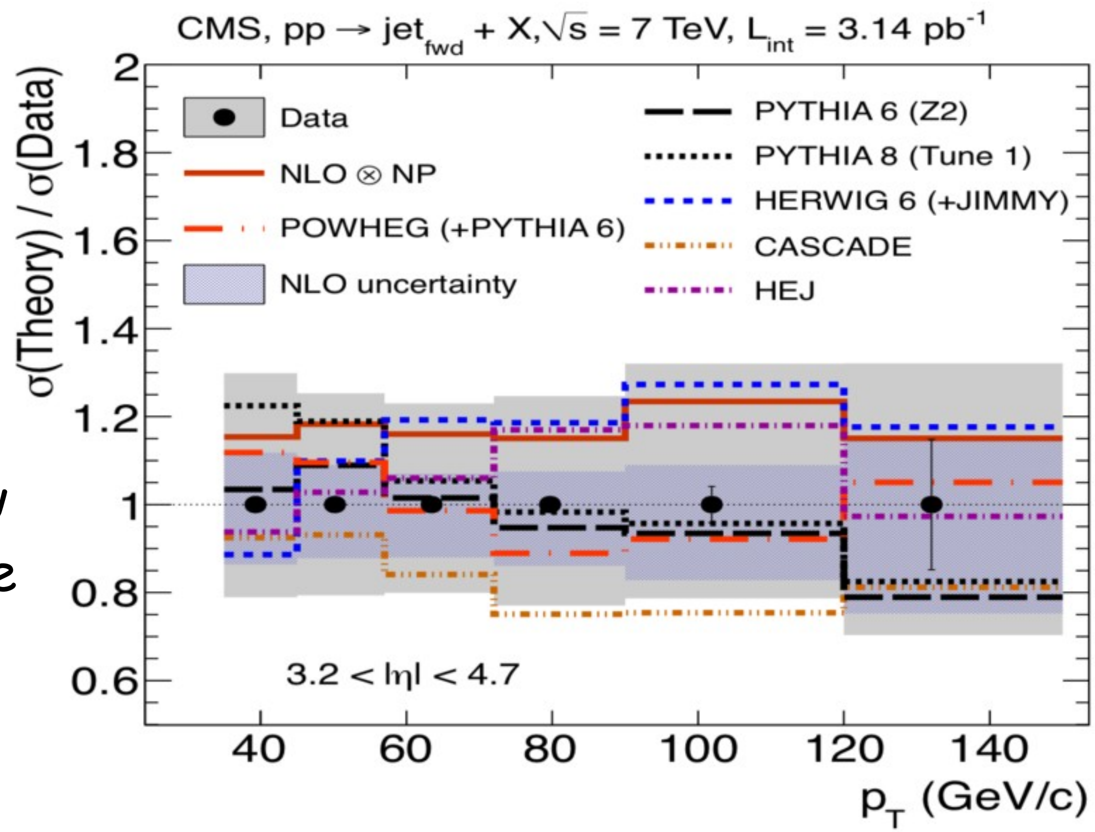
Theoretical uncertainties:

- Non perturbative effects (model difference in hadronisation corrections) – dominates at low pT, 10%
- PDF uncertainties dominate at large pT, up to 40%
- Scale uncertainty 5-10%

Results:

- Fixed order QCD, NLO+PS and DGLAP MC describe the data
- BFKL-type HEJ describes the data
- CCFM CASCADE seems to be below
- NLO is 20% above the central value

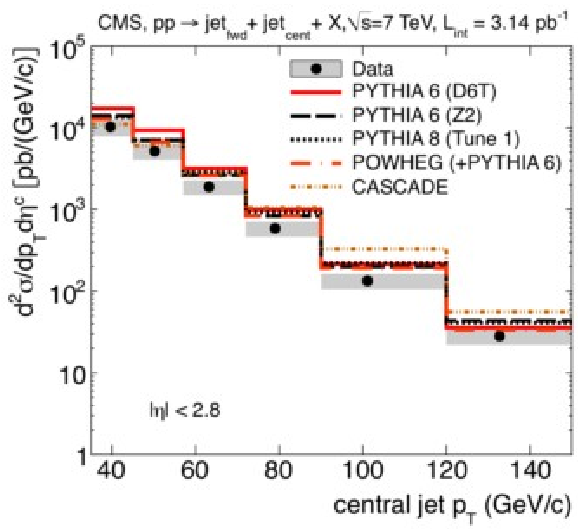
→ reduce the energy scale unc.

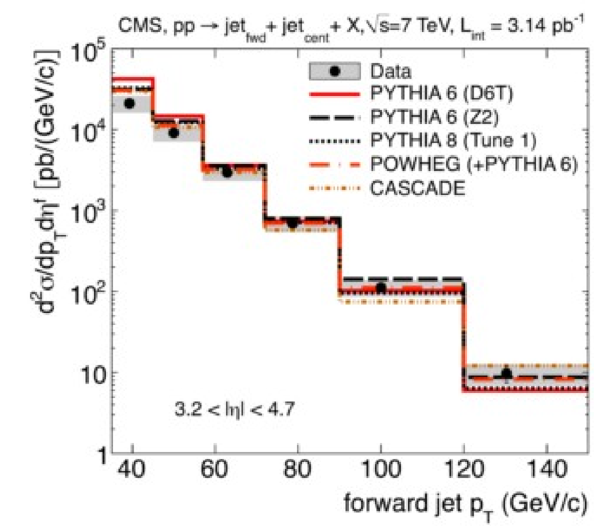


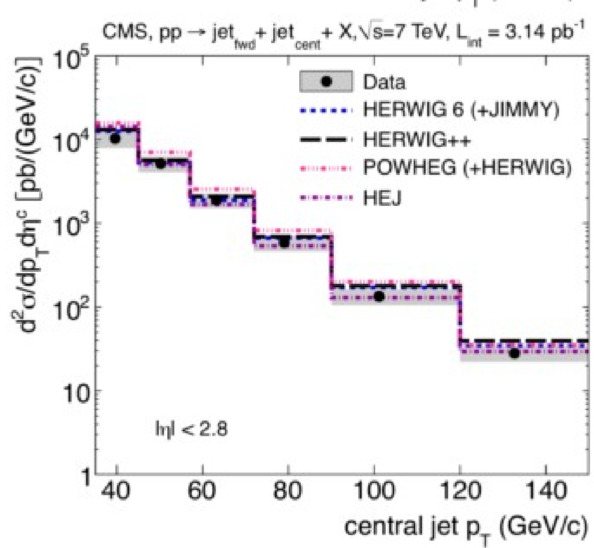
Forward – central jets

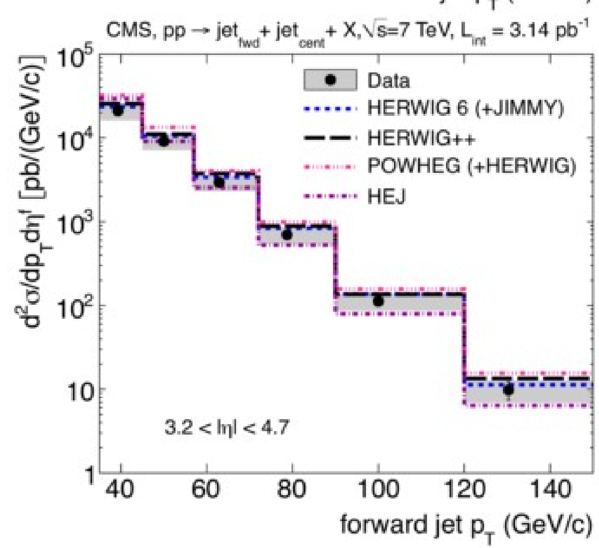
- Similar selection of events with a pair → forward + central jets
- For a central jet: $|\eta(jet)| < 2.8$

Central jet / **Forward jet**

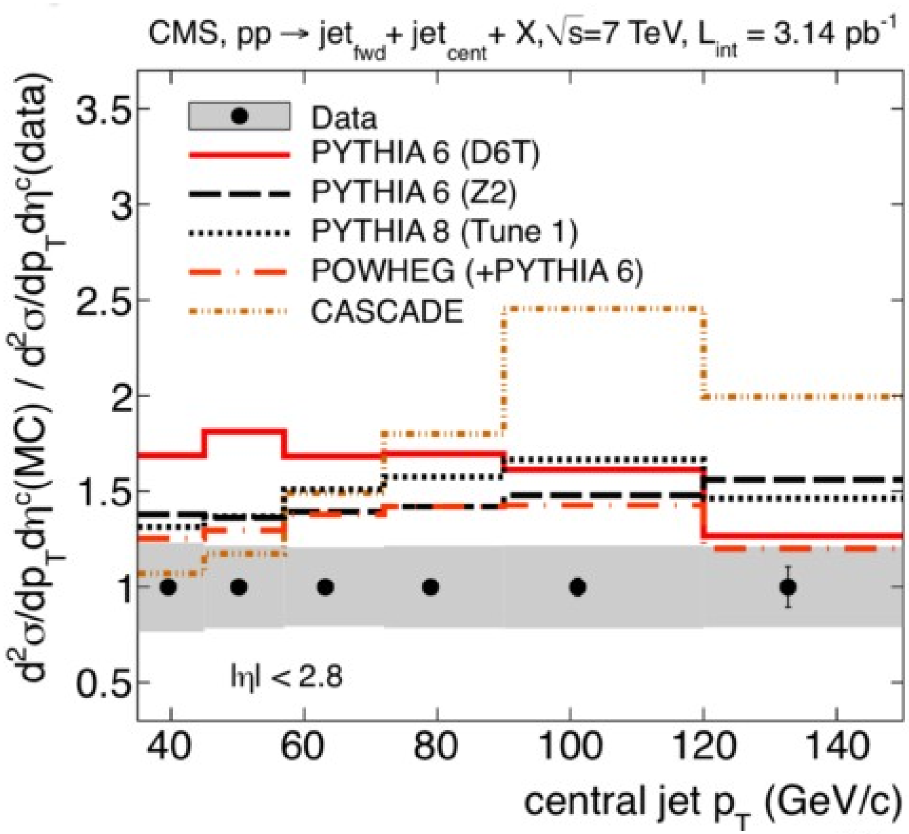






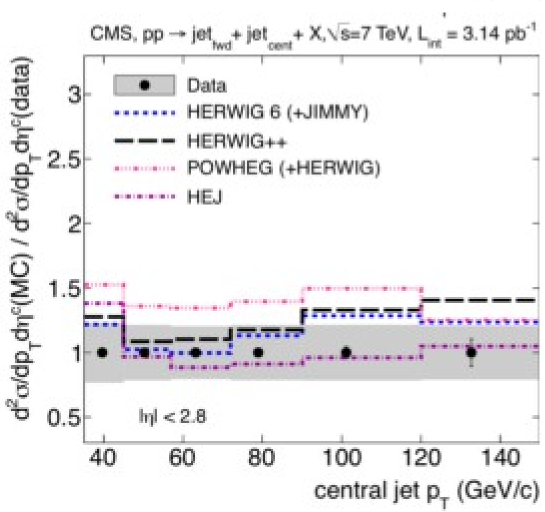


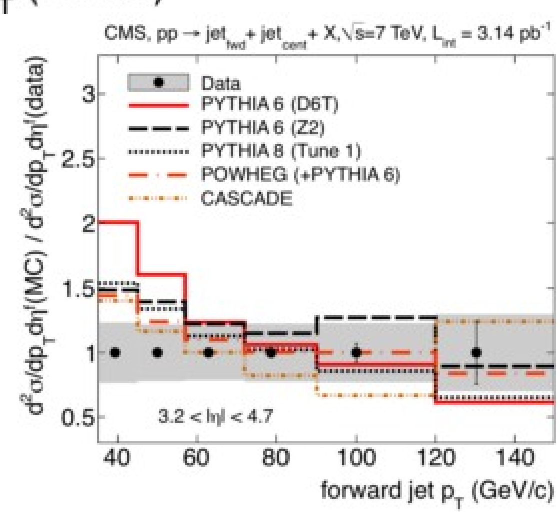
Forward – central jets

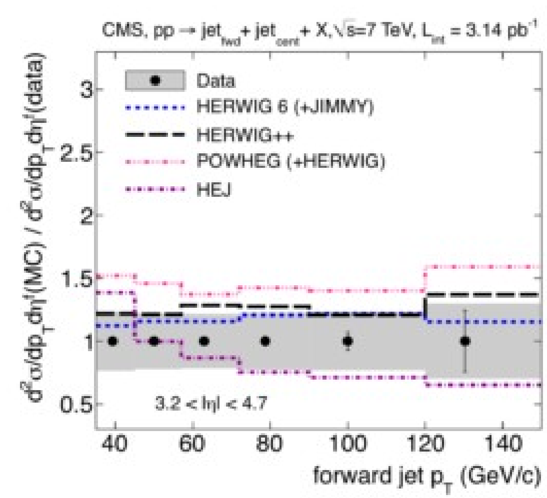


Results:

- Large discrepancies, especially for central jets
- Models overshoot the data
- HERWIG6 and HERWIG++ do the best job
- Also HEJ is OK
- CASCADE predicts different behaviour
- For forward jets most of the models predict steeper shape (more low-pT events)







Dijet production with large rapidity separation

FWD-10-014, sub. EPJC arXiv:1204.0696

- Three samples of dijets are being defined. In all samples:
  - a pair of calorimetric jets with pT > 35 GeV and |y| < 4.7

  (1) Exclusive sample: exactly two jets (defined with above requirements) are allowed for an event.

  (2) Inclusive sample: each pair of selected jets is taken

  (3) Muller-Navelet (MN) sample: a subset of inclusive sample where only most forward-backward jets are selected

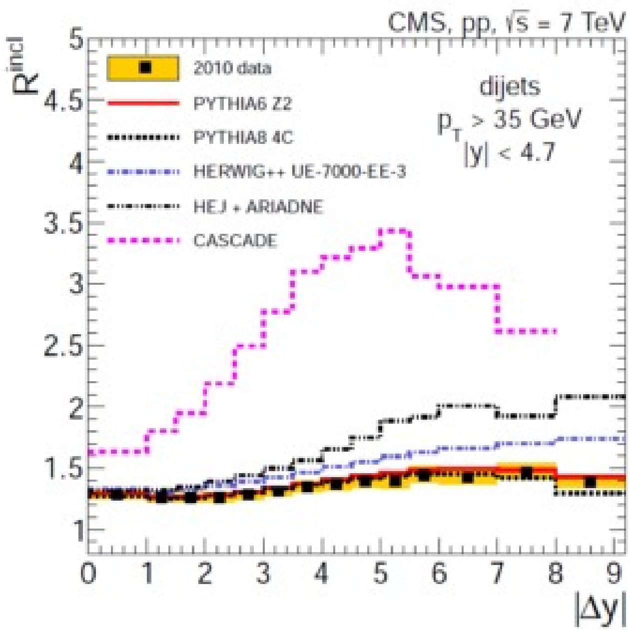
- A cross section for events from the sample is calculated as a function of $|\Delta y|$ between the jets

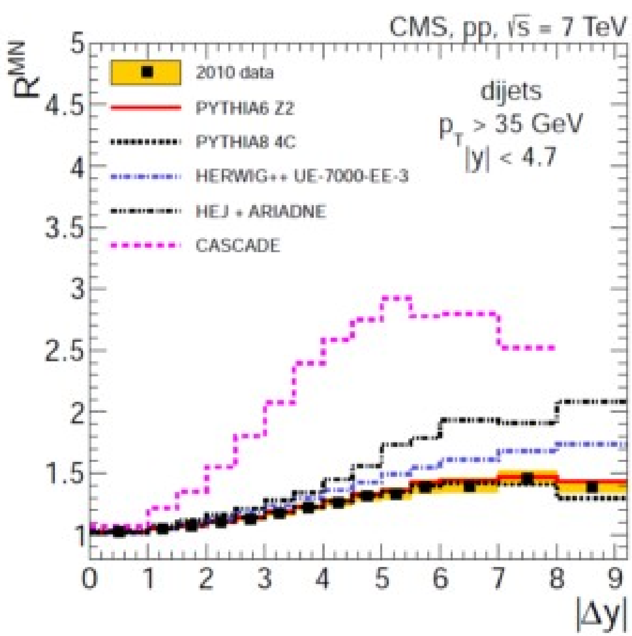
- Finally cross-section ratios:

$$R_{incl} = \frac{\sigma_{incl}(\text{dijet})}{\sigma_{excl}(\text{dijet})},\ R_{MN} = \frac{\sigma_{MN}(\text{dijet})}{\sigma_{excl}(\text{dijet})}$$

- Probe effects beyond the collinear factorization → increasing phase space in $|\Delta y|$ → radiation probability increases

Dijet production with large rapidity separation





- σ(inclusive) = 1.2-1.4 σ(exclusive)
- R rises with |Δy| as expected
- For largest |Δy| the drop in R is observed - kinematic limit
- PYTHIA Z2 and PYTHIA8 4C agrees perfectly with the data
- HERWIG++ predicts higher R at medium and large rapidity separation
- HEJ+ARIADNE and CASCADE (BFKL-motivated generators) predict much faster rise of R
- Keep in mind – pT > 35 GeV, what will happen at lower pT ?

New results for LowX 2013...

- Results for 8 TeV:
  - energy flow in HF and in CASTOR
  - inclusive forward jets and forward-central jets

- Common analysis CMS-TOTEM: $dE/d\eta$ and $dN/d\eta$ (ridge effect?)

- Most forward-backward jets correlations (Mueller-Navelet events) - dedicated trigger, and characteristics of these events

- Jets in CASTOR and correlation studies using these jets

- Energy flow in heavy ions

- Energy flow and jets in pPb collisions (planned for this autumn)

Summary

- Two main observables – energy deposits and jets in forward detectors under control.

- Energy flow measurement shows a big role of multiple interactions and underlying event at forward rapidities. An important information for tuning of the models.

- BFKL signatures were not found in the forward jets analyses (need to move down with pT cut?). In the central-forward correlation studies a discrepancies with the existing models are seen.

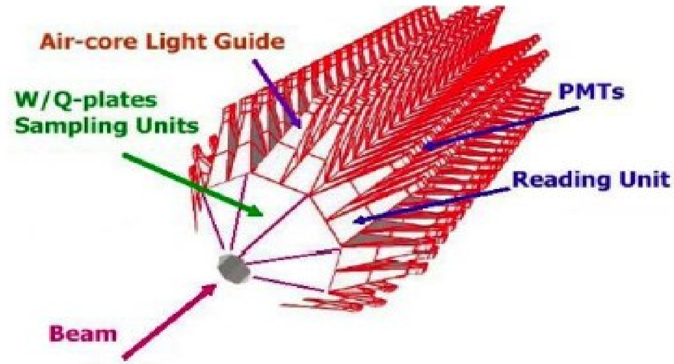
- More results expected soon.

Spares

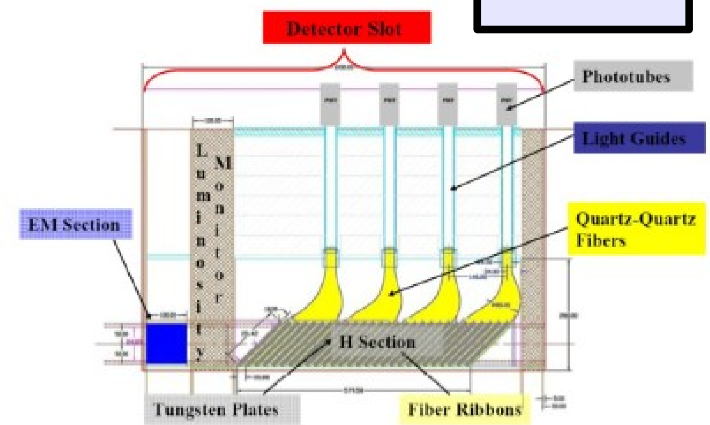
CMS Forward

HF

CASTOR

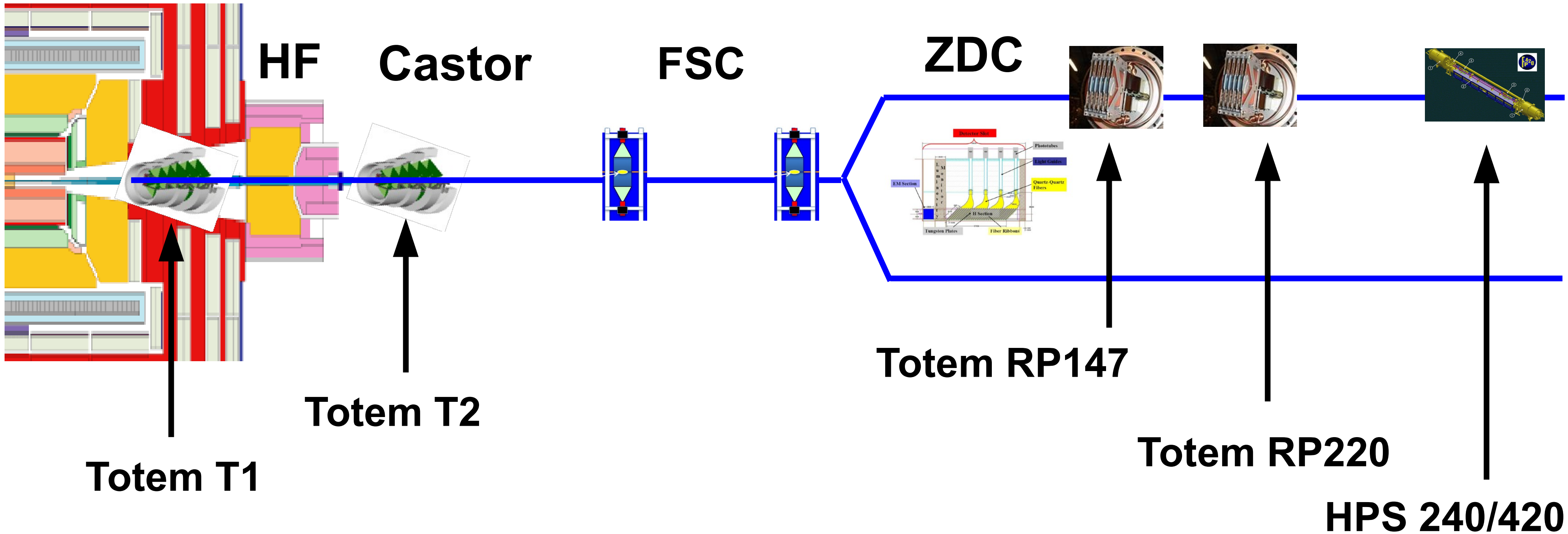


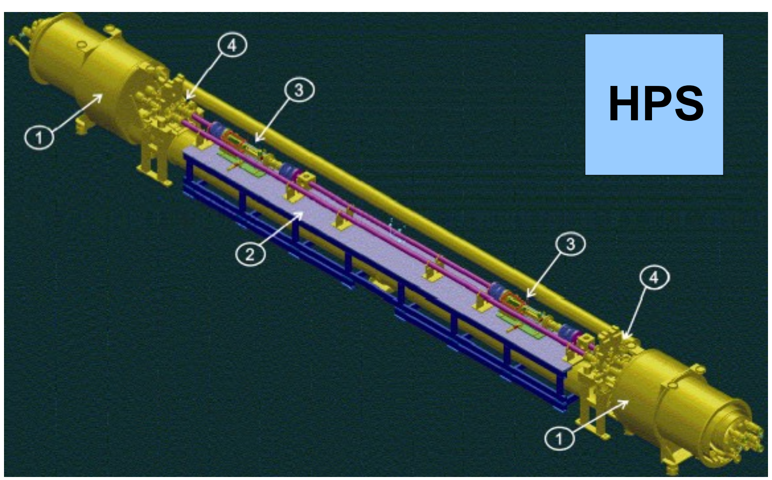
ZDC



- **HF**
  - rapidity coverage: $\mathbf{2.9} < |\eta| < \mathbf{5.2}$
  - at 11.2 m from IP
  - steel absorbers and embedded radiation -hard quartz fibers for fast collection of Cherenkov light
  - segmentation in η et ϕ: 0.175 × 0.175
- **CASTOR**
  - rapidity coverage: $\mathbf{-6.6} < \eta < \mathbf{-5.2}$
  - at 14.3 m from IP
  - alternate tungsten absorbers and quartz plates
  - segmentation in ϕ: 16 sectors
  - 14 modules (2EM+12HAD)
- **ZDC**
  - rapidity coverage: $|\eta| > \mathbf{8.4}$
  - at **140** m from IP
  - tungsten/quartz Cherenkov calorimeter with separated EM and HAD sections
  - detection of neutrals (γ, π^0, n)

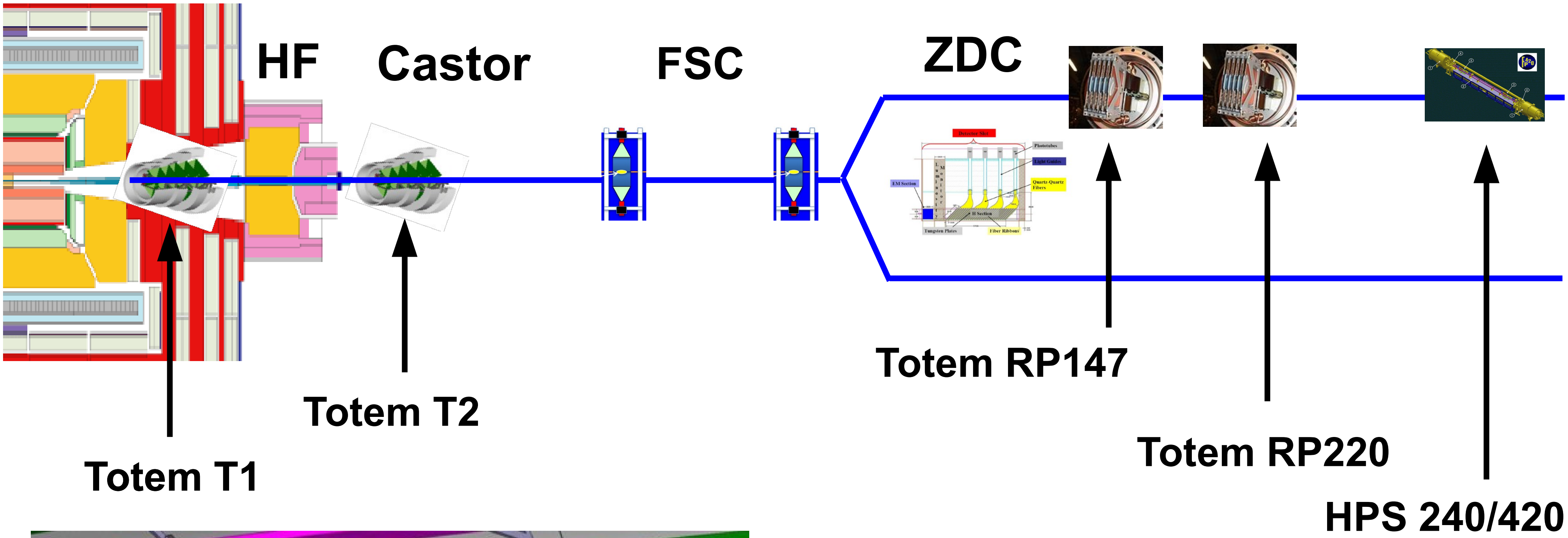
CMS Forward

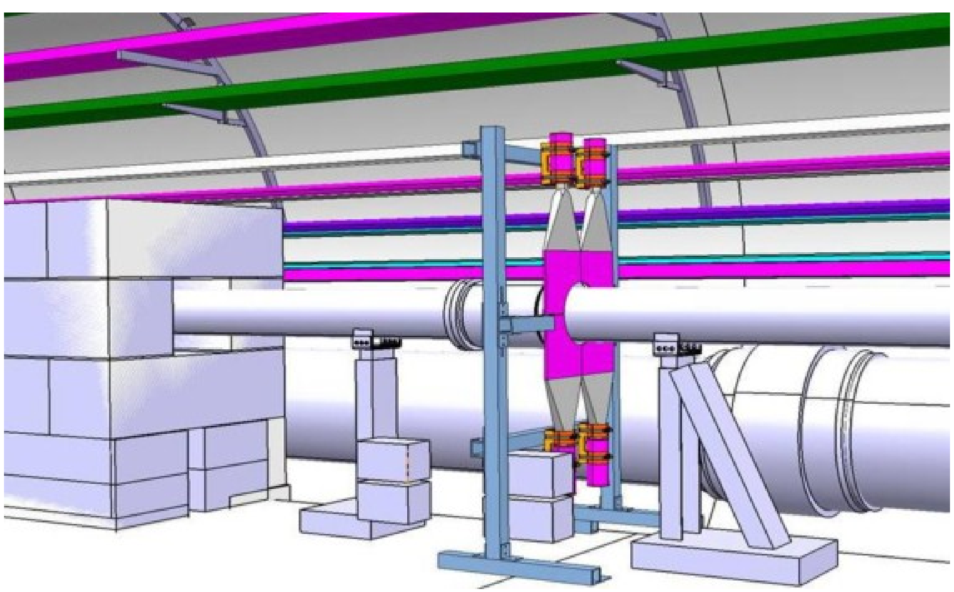




- High Precission Spectrometer (HPS)
- Two parts: 240 m i 420 m from IP
- Precise trackers for proton momentum reco.
- Detection of time – vertices separation
- Installation 2014 - 2018

CMS Forward





- 3 stations of scintillation detectors
- Cover: $6 < |\eta| < 8$
- Rapidity gap detection
- Installation in 2011
- Useful – low pile-up running