ATLAS measurements of the energy flow at low x

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on behalf of the ATLAS collaboration

outline

- aim of study
- energy flow, physics quantities to study and samples
- ATLAS – η coverage and selection cuts
- low-x = forward/high rapidity

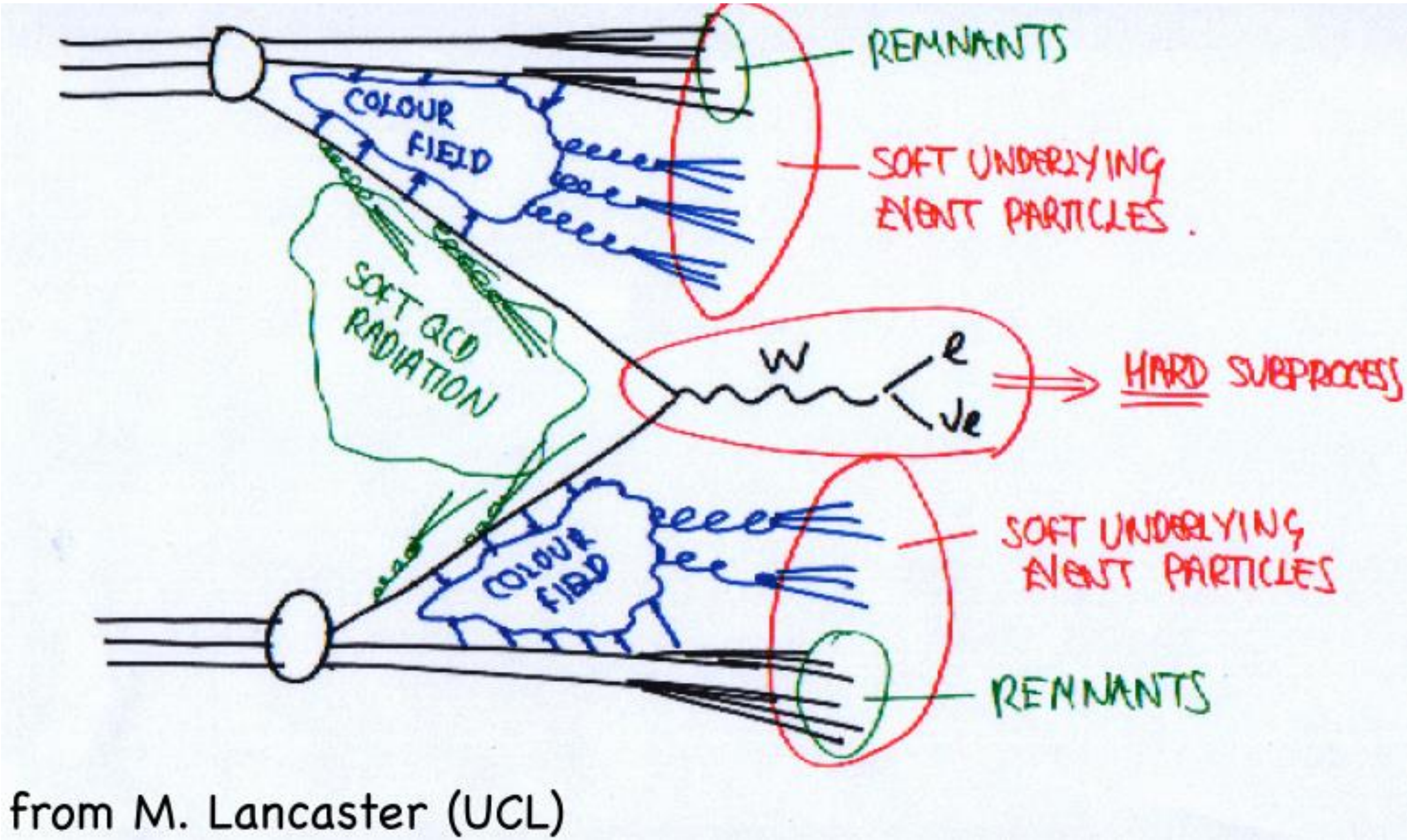
- ATLAS forward energy flow results

  based on JHEP11(2012)033, updated ATLAS-CONF-2012-164
  and Tim Martin's presentation
  http://indico.cern.ch/getFile.py/access?contribId=7&sessionId=1&resId=0&materialId=slides&confId=250772

- summary

aim of study

collisions around and above electro-weak symmetry breaking scale (~ 246 GeV) typically involving high momentum transfer



need: Monte Carlo generators accurately describing soft particle kinematics

energy flow and samples

we will study energy flow, via

event multiplicity: $\frac{1}{N_{\mathrm{evt}}}\frac{dN}{d\sum E_{\mathrm{T}}}$, E_{T} is transverse energy, $E_{\mathrm{T}} = E\sin\theta$ and θ is scattering angle

in bins of pseudorapity,

and via energy density: $\frac{d^2\sum E_{\mathrm{T}}}{d\eta d\varphi}$, where φ is azimuthal angle around the beam pipe

we will consider two samples

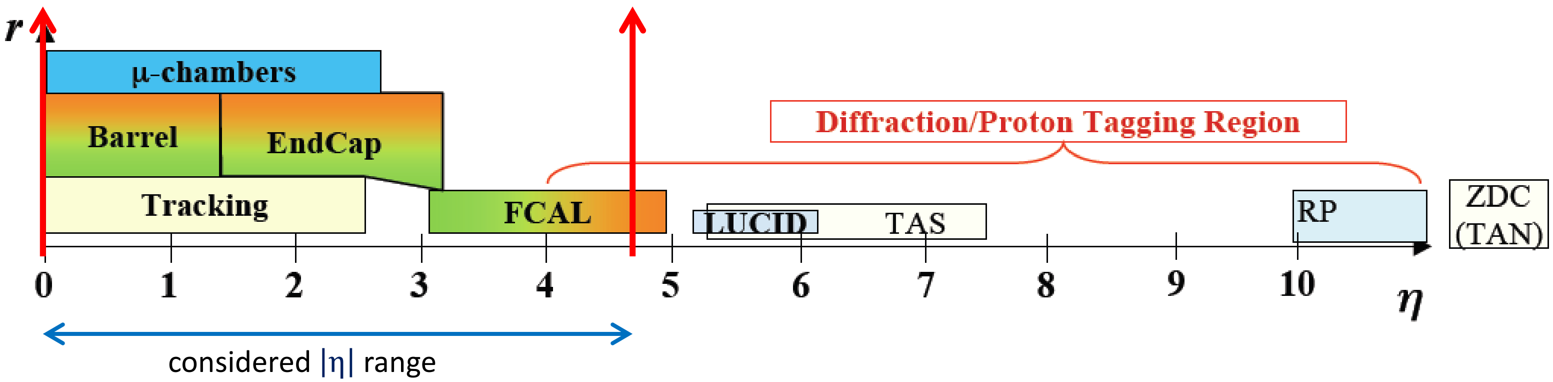
- min bias (MB) – in order to describe well soft particle kinematics
- dijet (DJ) – in order to describe hard parton-parton scattering

LHC run 2010, $\sqrt{s} = 7$ TeV

$\int L =$ 7.1 $\mu\mathrm{b}^{-1}$ minbias sample

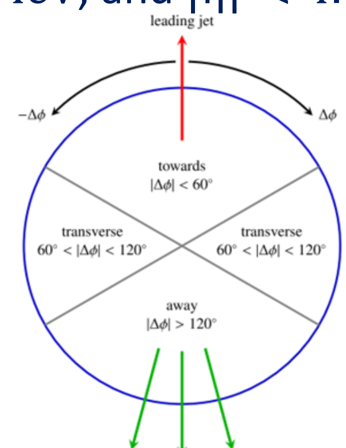
590 $\mu\mathrm{b}^{-1}$ dijet sample

ATLAS – η coverage and selection cuts



MC cuts:

charged (neutral) particles with momentum $p > p_{\min} = 500\ (200)$ MeV, and $|\eta| < 4.8$



MB:

- MB: $N_{\text{charged}} \geq 2$, with $p_{\mathrm{T}} > 250$ MeV and $|\eta| < 2.5$

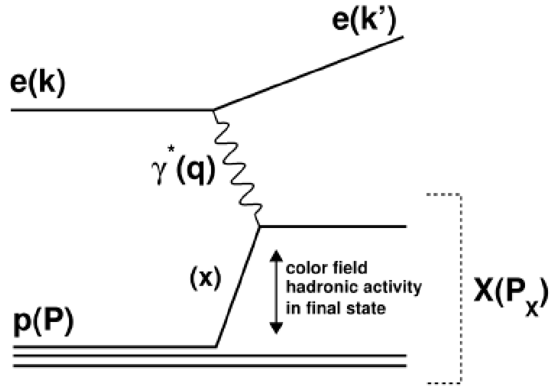
DJ:

- $E^{\text{jet}}{}_{\mathrm{T}} > 20$ GeV, $|\eta^{\text{jet}}| < 2.5$, anti-$k_t$ with radius $R = 0.4$
- back to back topology $|\Delta\varphi_{\text{jj}}| > 2.5$ and $E^{\text{jet1}}{}_{\mathrm{T}}/E^{\text{jet2}}{}_{\mathrm{T}} > 0.5$

data: MB has lowered cut on p_{T} to 150 MeV, clusters: calo seed cells $|E| > 4\sigma$, neighbors & surroundings 2σ

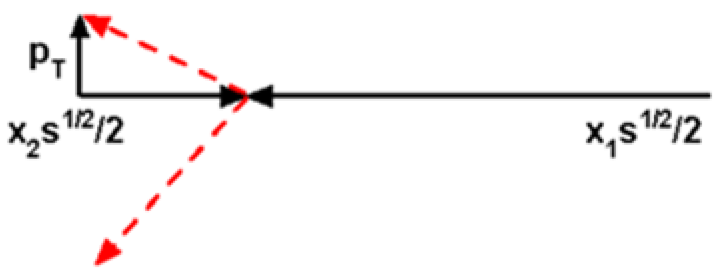
low-x = forward/high rapidity

what is x?

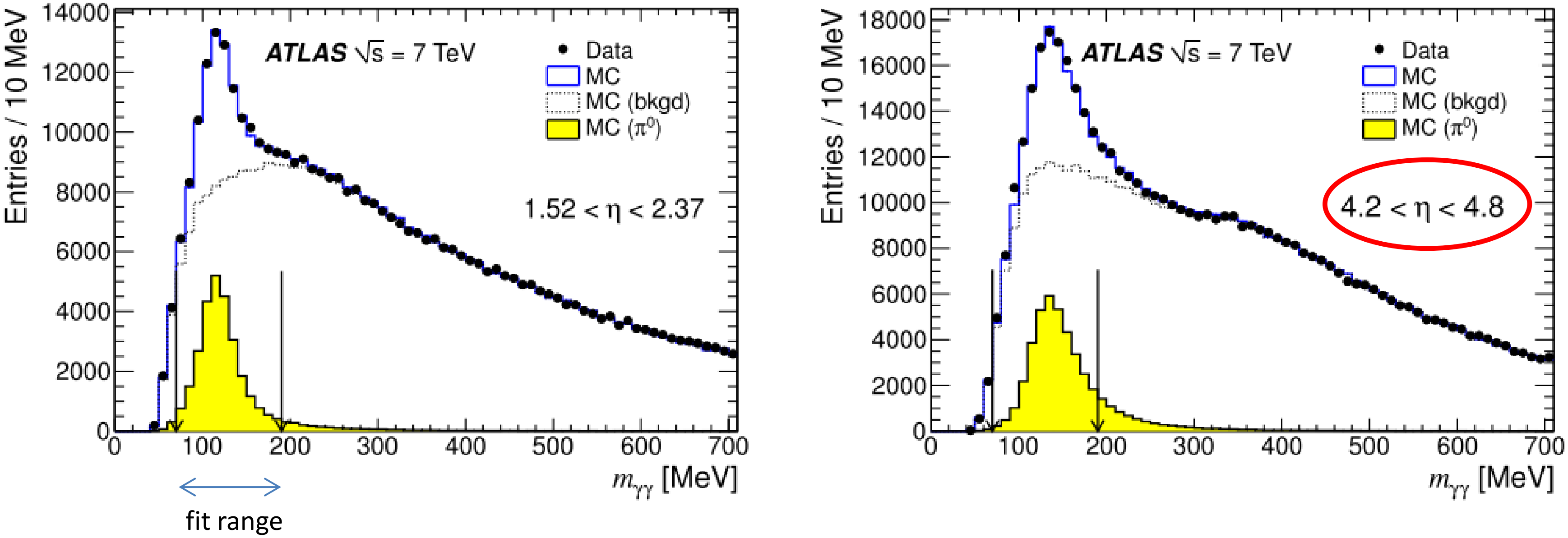


why low x = high rapidity?

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



reconstruction – energy scale calibration



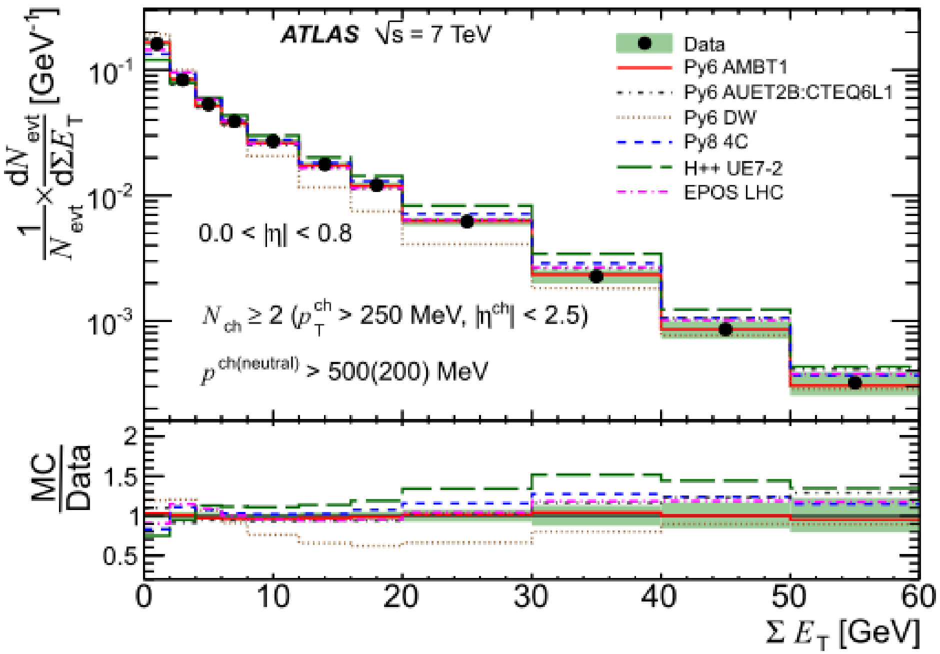
- energy response calibration using $\pi^0 \rightarrow \gamma\gamma$ candidates
- invariant mass for events exactly with 2 γ to suppress combinatorial background
- PYTHIA 6 AMBT1 used for signal and background
- typical scaling factor 2-3%, for some η regions 10%

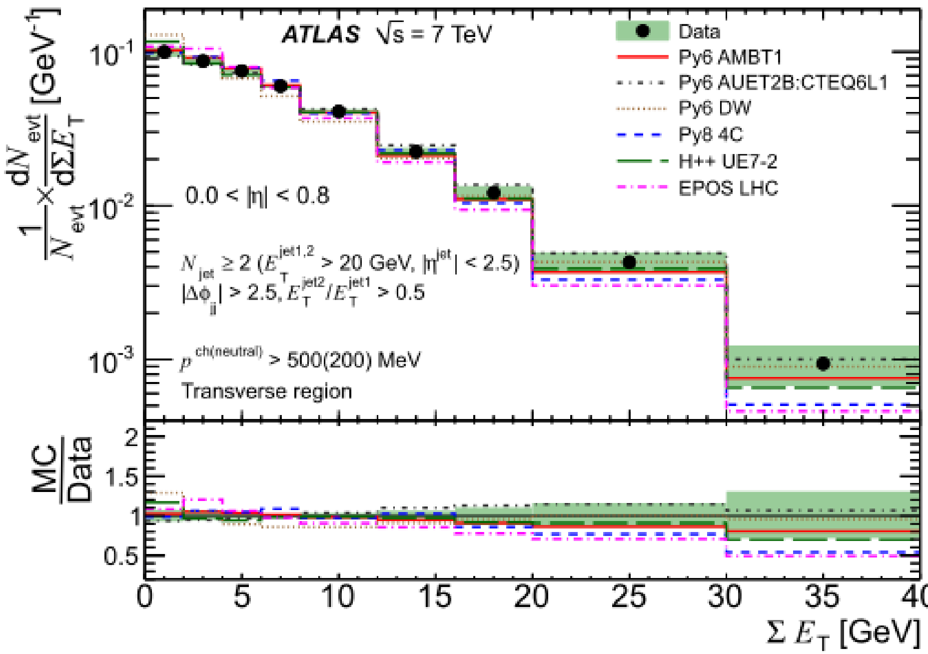
MC generators used

- PYTHIA 6 DW for 'old style' virtuality-ordered parton shower, no interleaving of MPI
- other PYTHIA 6 tunes and PYTHIA 8 p_{T}-ordered showers, MPI is interleaved in common sequence of decreasing p_{T} for initial-state (both) and final-state showers (PYTHIA 8 only)
  - Lund string hadronisation model
- HERWIG++ utilises angular-ordered parton shower, including a model for MPI but not interleaved with showering
  - cluster hadronisation model
- EPOS - primarily heavy-ion and cosmic showering MC – uses Gribov-Regge effective QCD-inspired theory to simultaneously describe hard and soft scatters → no use of PDFs
- Hydrodynamic evolution of p-p interaction calculated at high parton densities as it would be for heavy-ion collisions. EPOS LHC tune parameters derived from LHC minbias data

dijet transerse and minbias $\sum E_{\mathrm{T}}$ comparison in $|\eta|$ bins

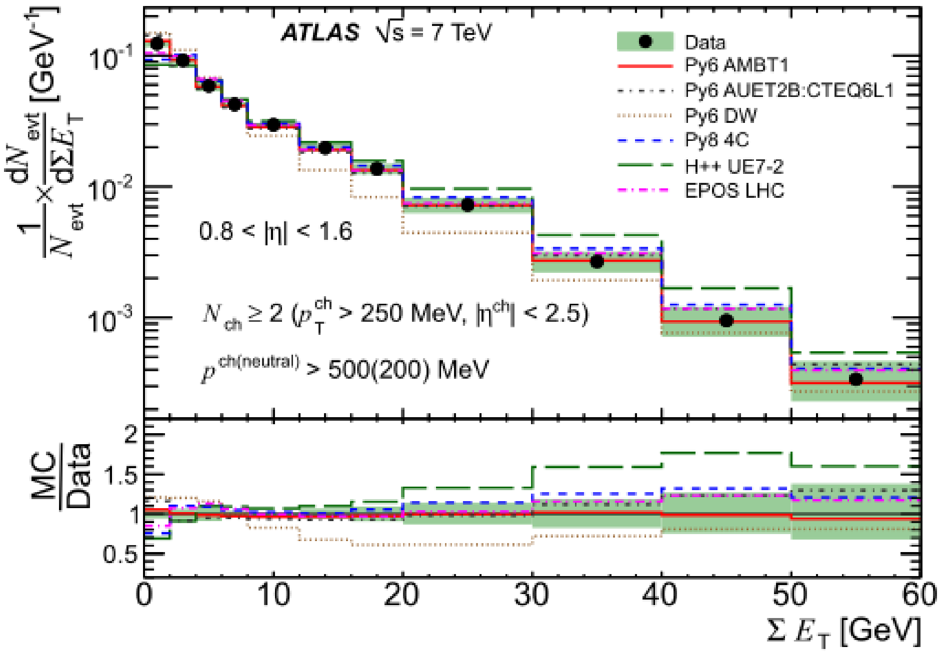
$0.0 < |\eta| < 0.8$

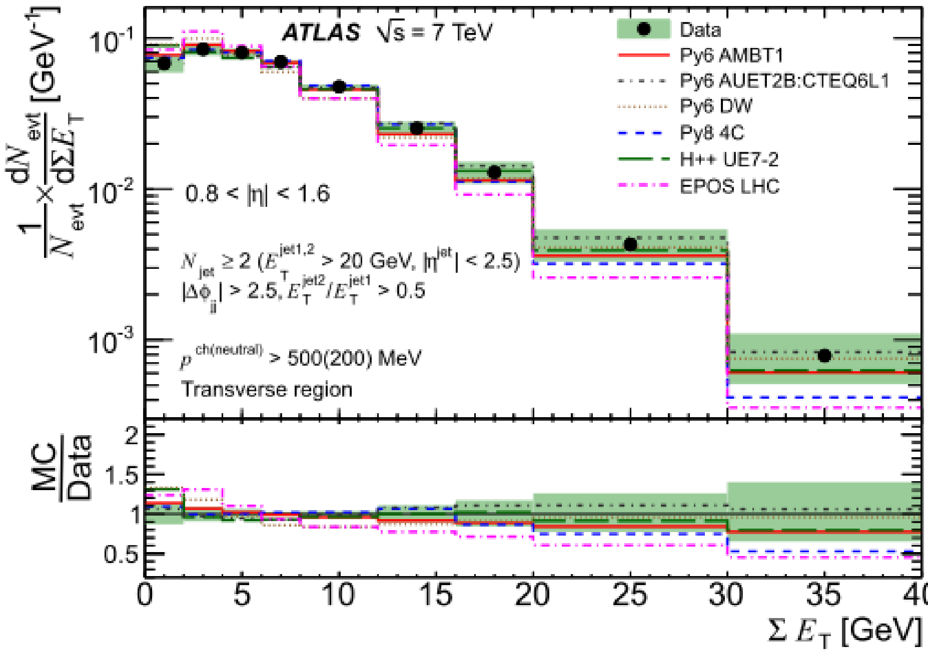




dijet transerse and minbias $\sum E_T$ comparison in $|\eta|$ bins

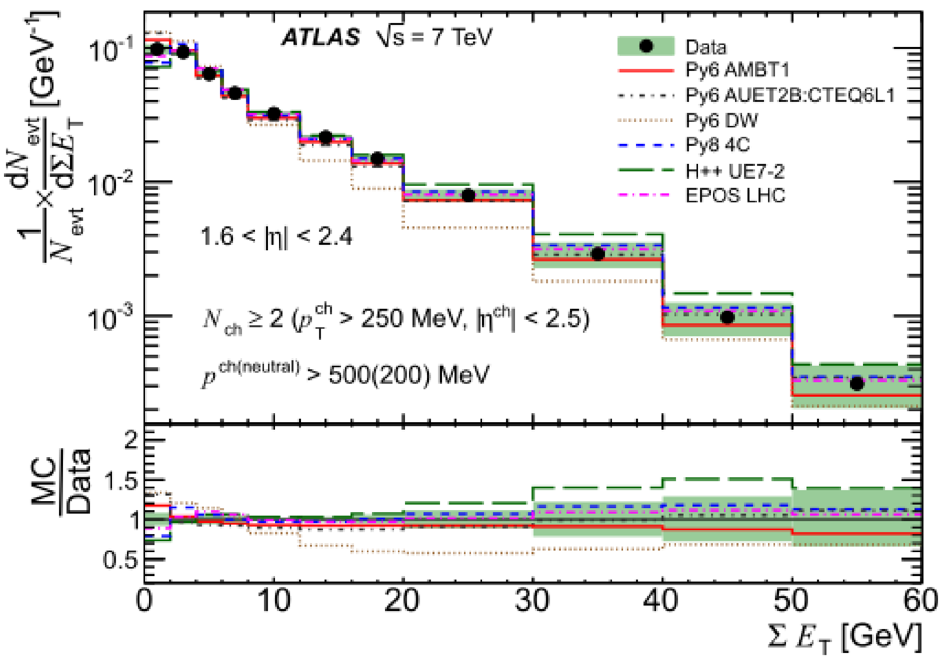
$0.8 < |\eta| < 1.6$

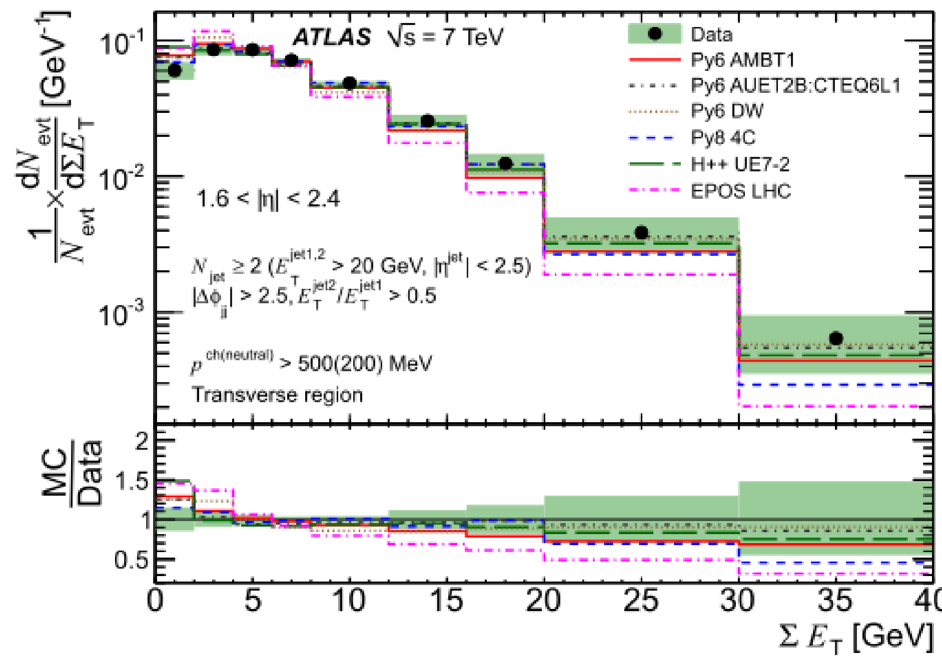




dijet transerse and minbias $\sum E_{\mathrm{T}}$ comparison in $|\eta|$ bins

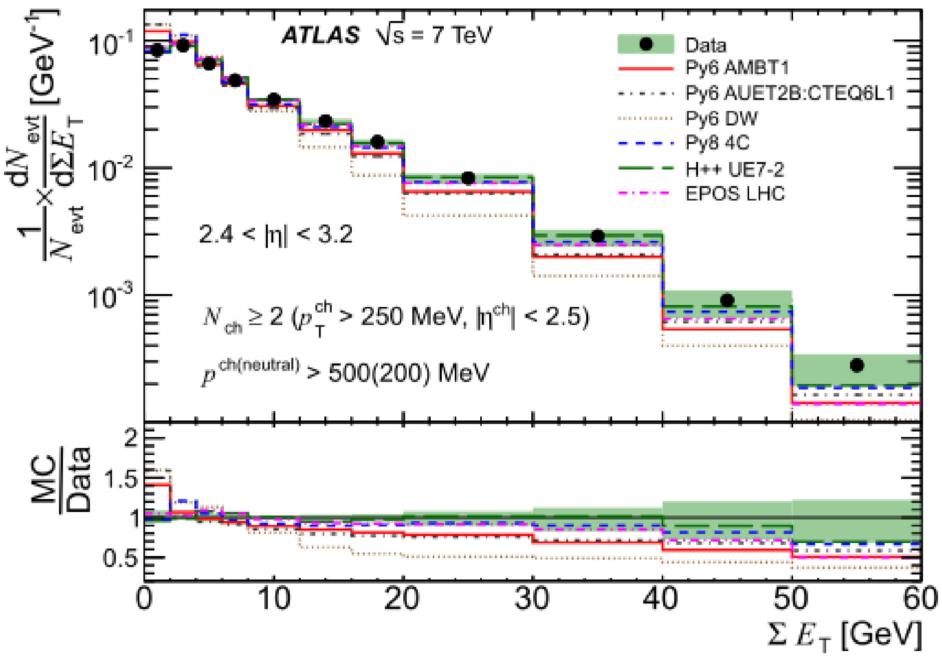
$1.6 < |\eta| < 2.4$

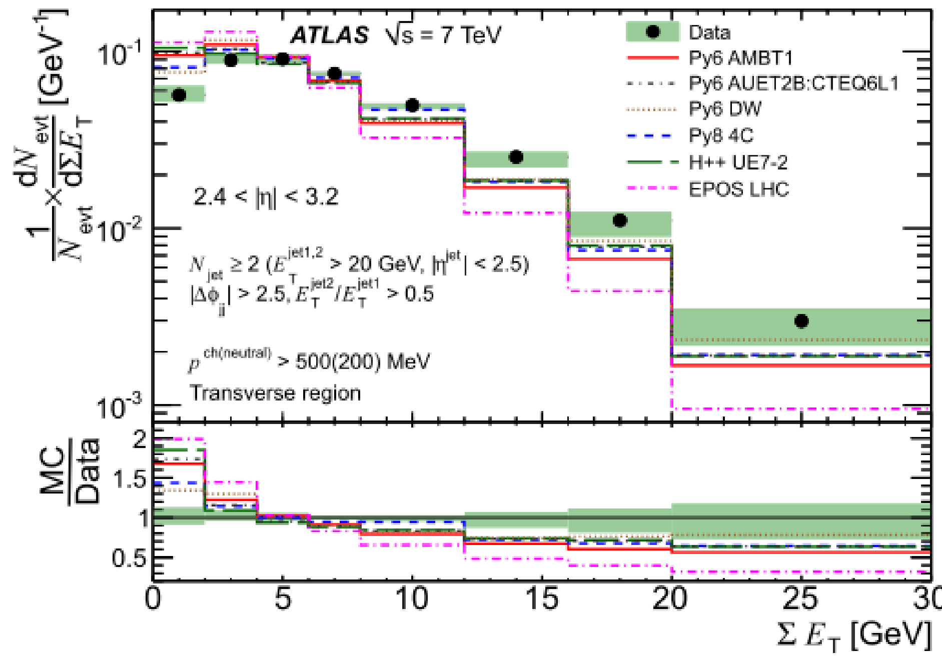




dijet transerse and minbias $\sum E_{\mathrm{T}}$ comparison in $|\eta|$ bins

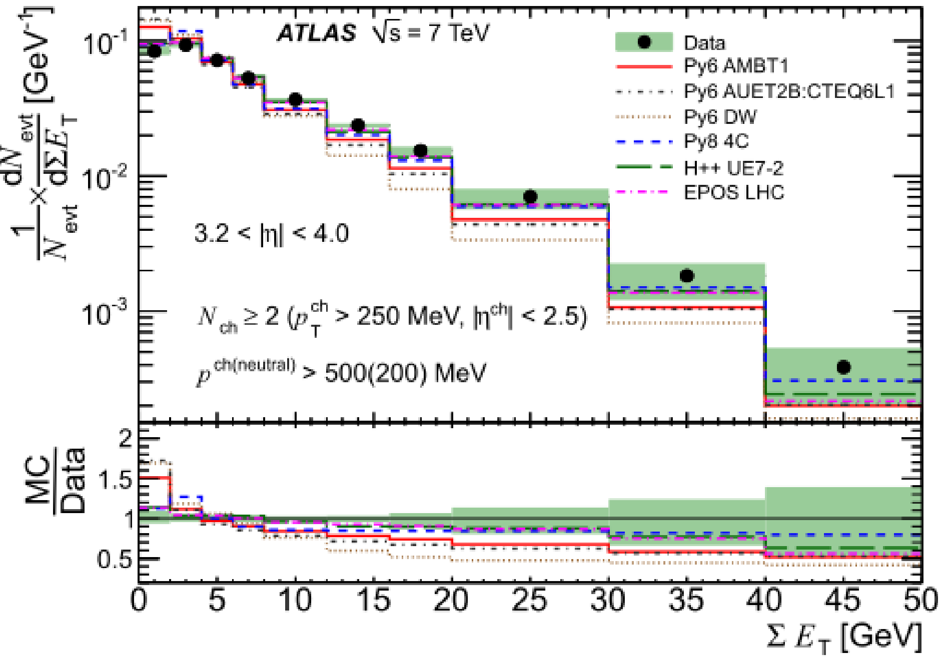
$2.4 < |\eta| < 3.2$

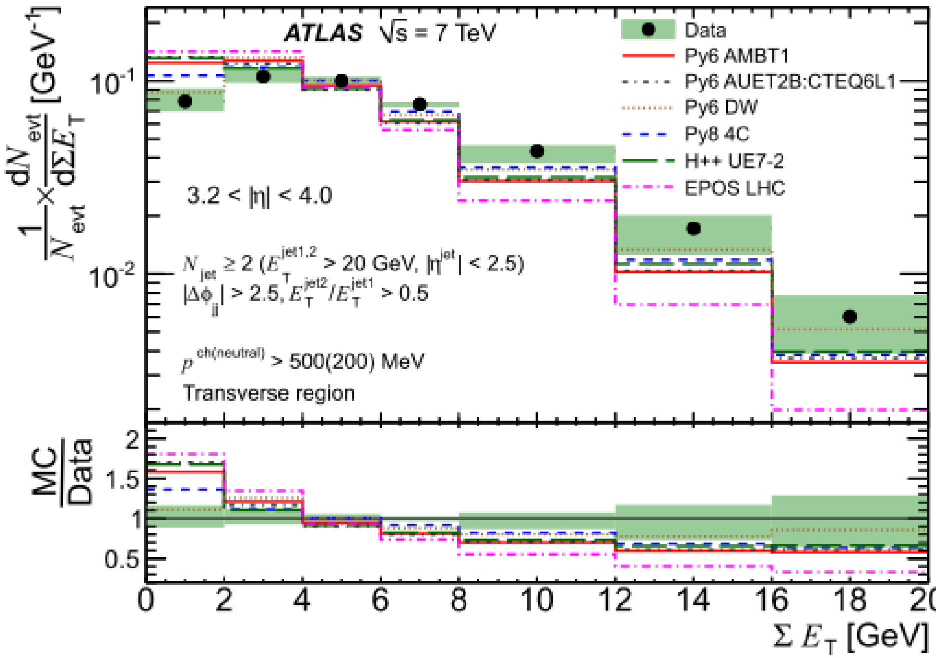




dijet transerse and minbias $\sum E_T$ comparison in $|\eta|$ bins

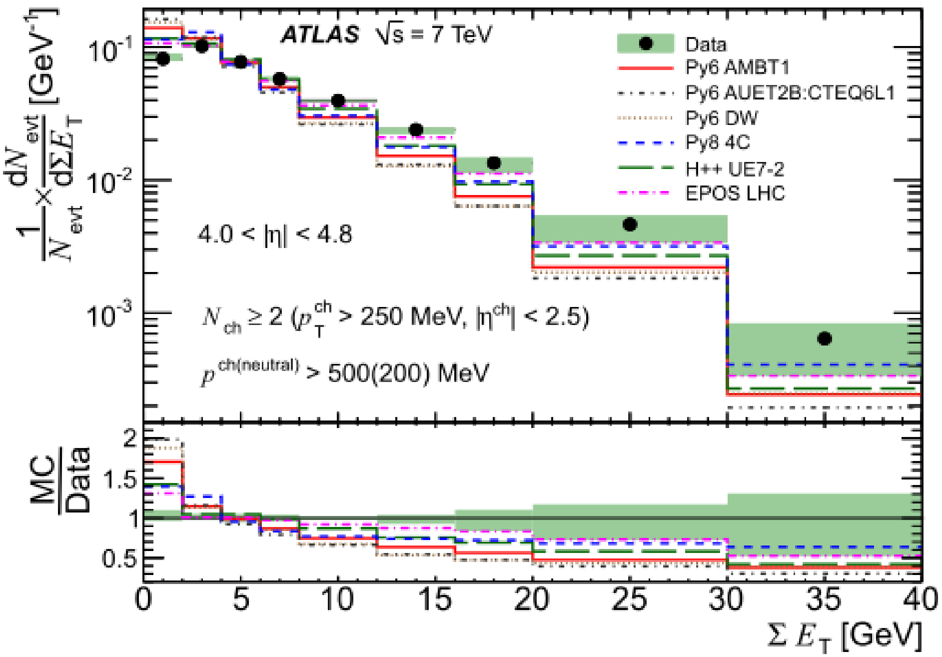
$3.2 < |\eta| < 4.0$

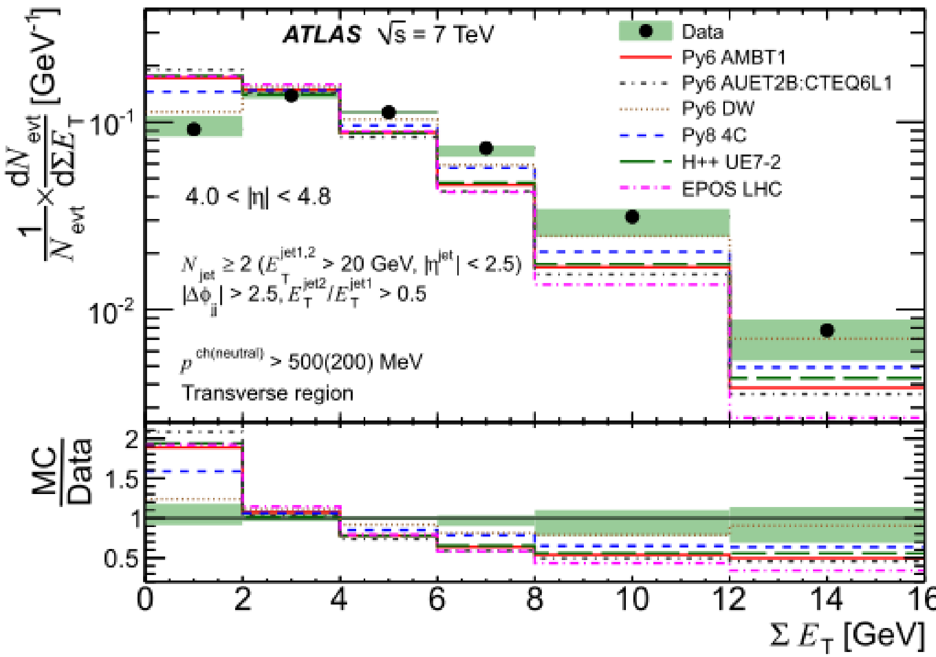




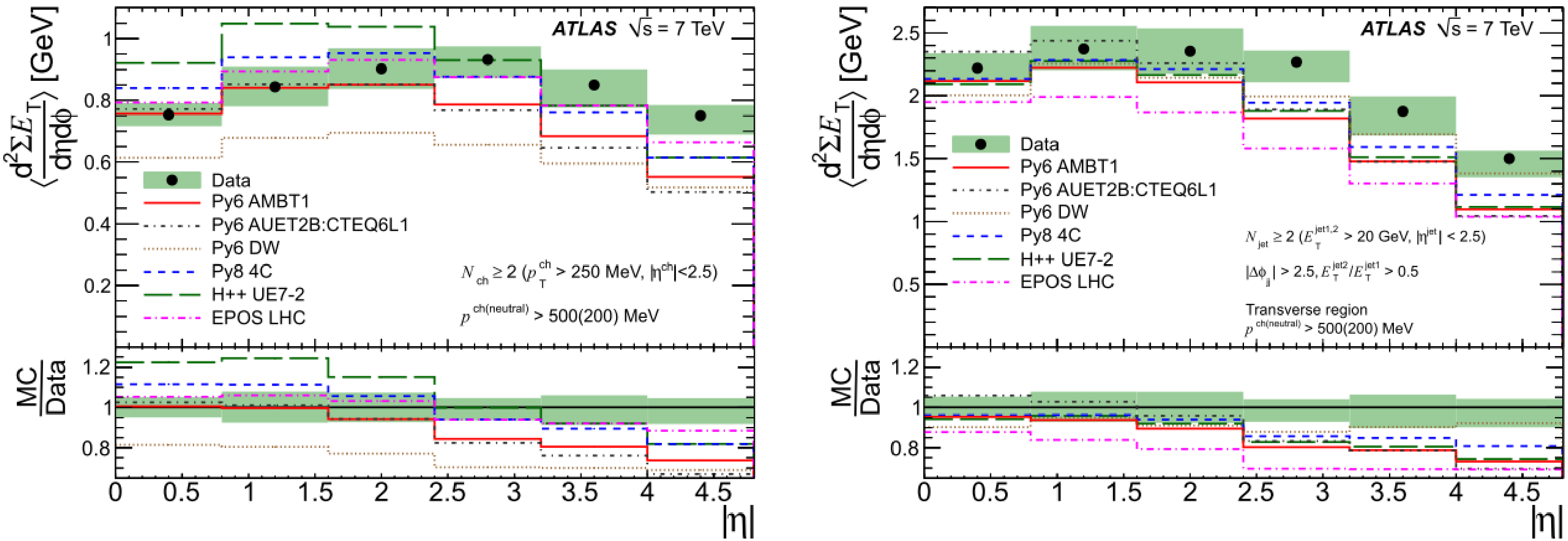
dijet transerse and minbias $\sum E_{\mathrm{T}}$ comparison in $|\eta|$ bins

$4.0 < |\eta| < 4.8$





transverse energy density

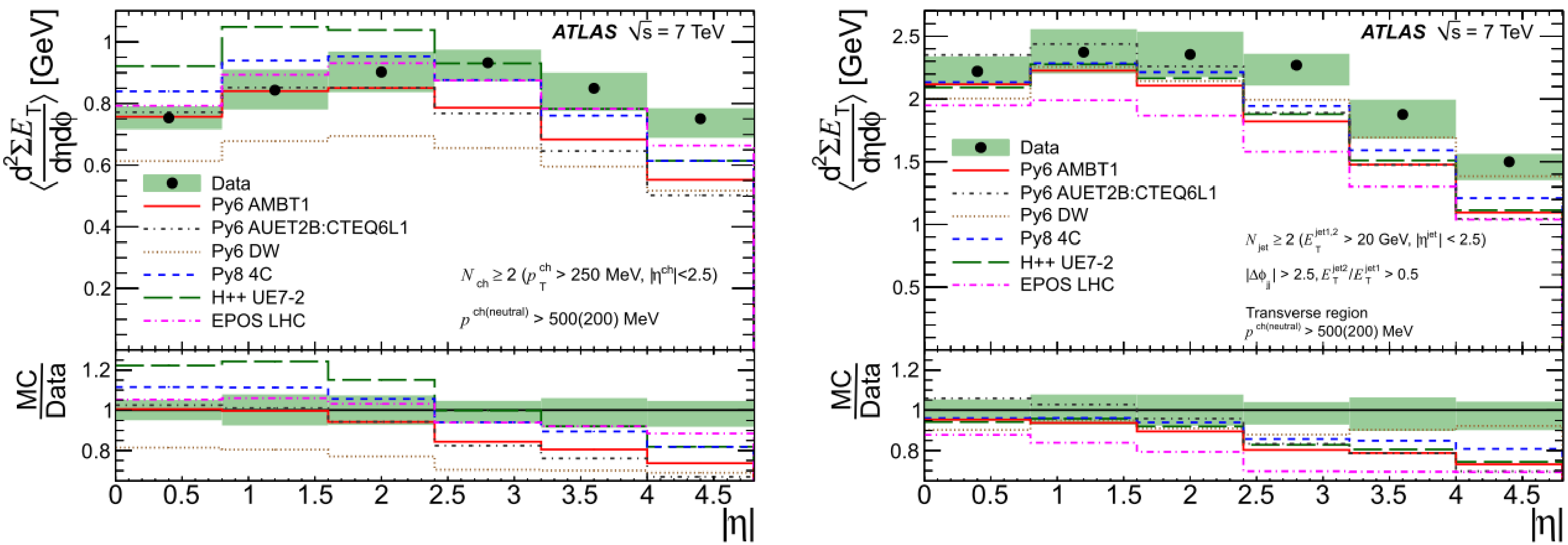


- central dip due to large fraction of low p_{T} particles, less prominent in dijet data due to hard scale

- central minbias well described by PYTHIA6 AMBT1 which is tuned in this region underestimated by 25% at high $|\eta|$

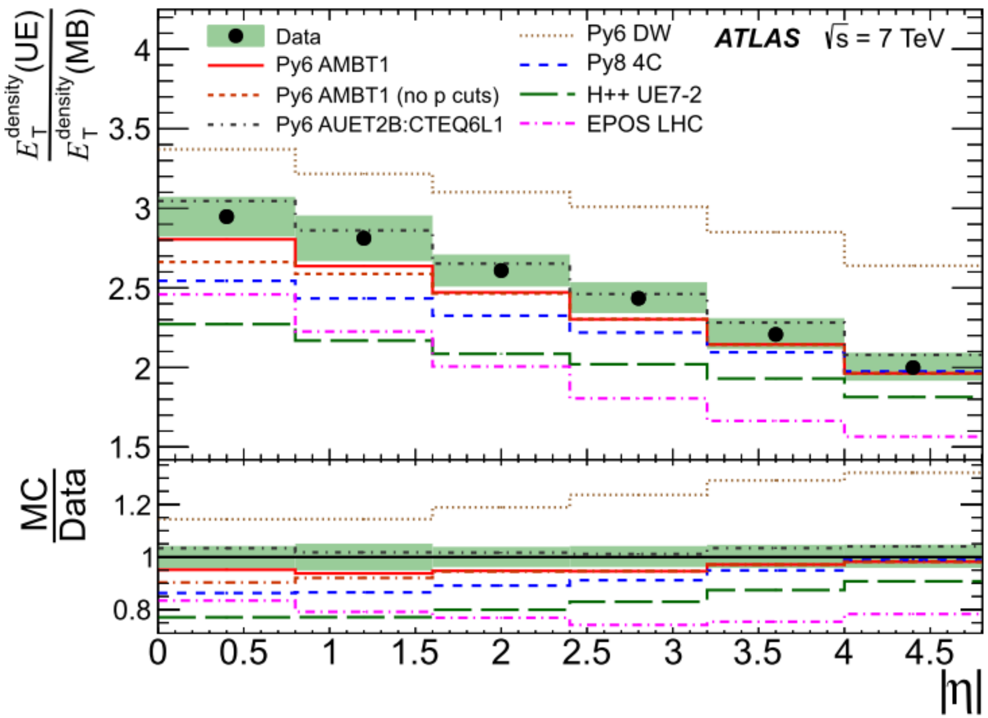
- PYTHIA6 DW always underestimates, but better describes $|\eta|$ evolution

transverse energy density



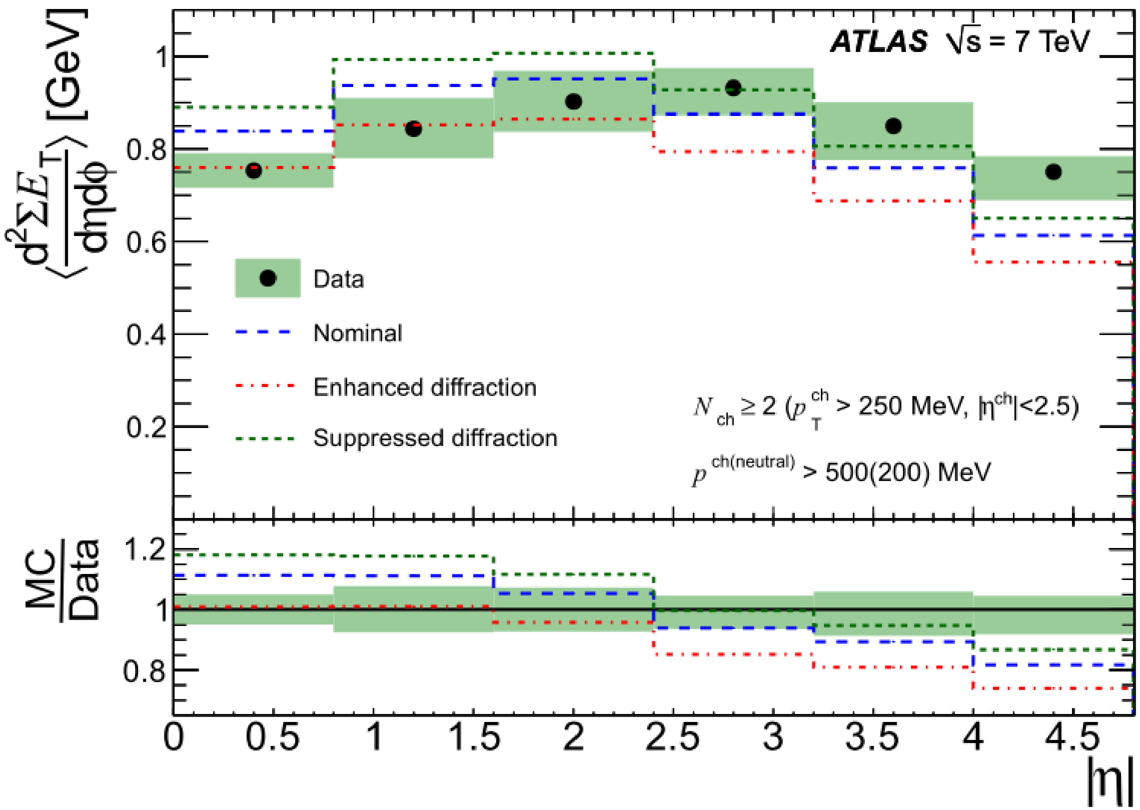
- MB: best description from EPOS LHC, falls faster with $|\eta|$
- with the exception of EPOS LHC and PYTHIA6 DW, appearance of some tunes to agree better in some regions is generally due to differences in levels of particle production
- all MCs shown, except EPOS LHC, do well for central dijet data

transverse energy density ratio



- dijet $E_\mathrm{T}{}^{\mathrm{density}}$ larger than minbias → hard scatter biases to small impact parameter
- sensitive to multi parton interactions
- reduction with η partly due to p cuts on particles in $\sum E_\mathrm{T}$ (cf. *no p* cuts curve).
- further decrease associated to additional UE in the central region from hard scatter

sensitivity of energy density: diffractive contribution

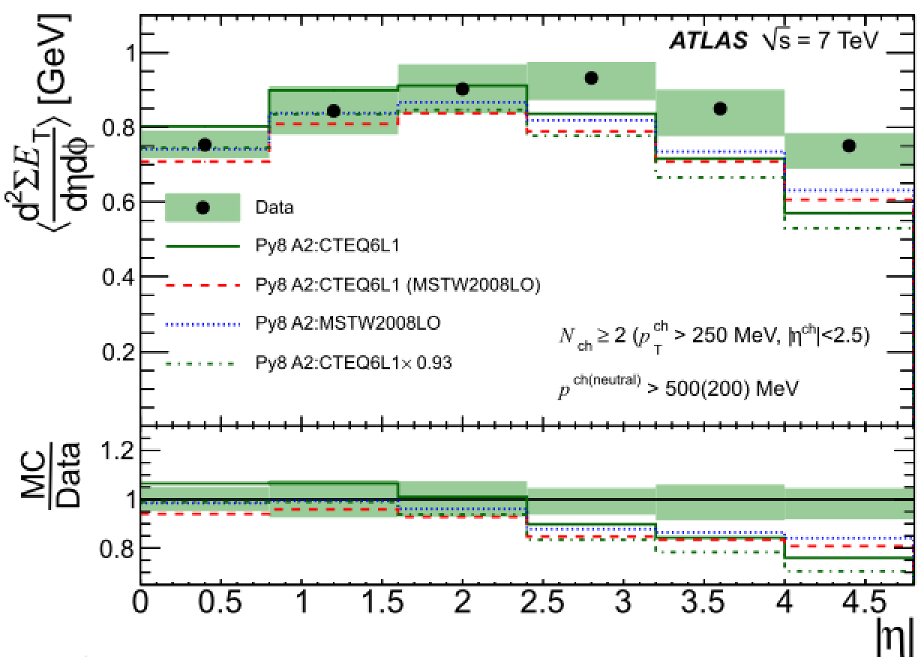


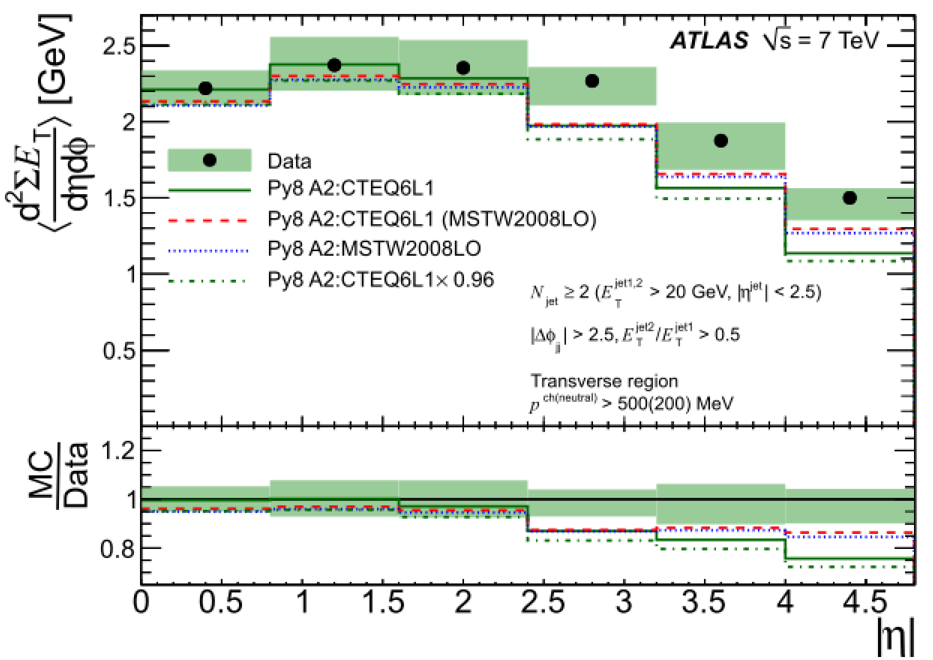
- compare nominal
  [N = 51, S = 12, D = 8] [mb]
  with
  [N, S/2, D/2] and [N, 2S, 2D]
- fewer particles in diffractive events:
  variation of cross section alters normalization
- shape of $E_{\mathrm{T}}{}^{\mathrm{density}}$ is not significantly affected

sensitivity of energy density: pdf contribution

sensitivity to choice of PDF in MC model was investigated with PYTHIA8 A2 family:

- tune A2:CTEQ6L1
- tune A2:CTEQ6L1 scaled to match A2:MSTW2008LO in central bin
- tune A2:MSTW2008LO
- tune A2:MSTW2008LO with A2:CTEQ6L1 parameters





underlying event with jets

aim: underlying event study for inclusive jet and exclusive dijet topologies

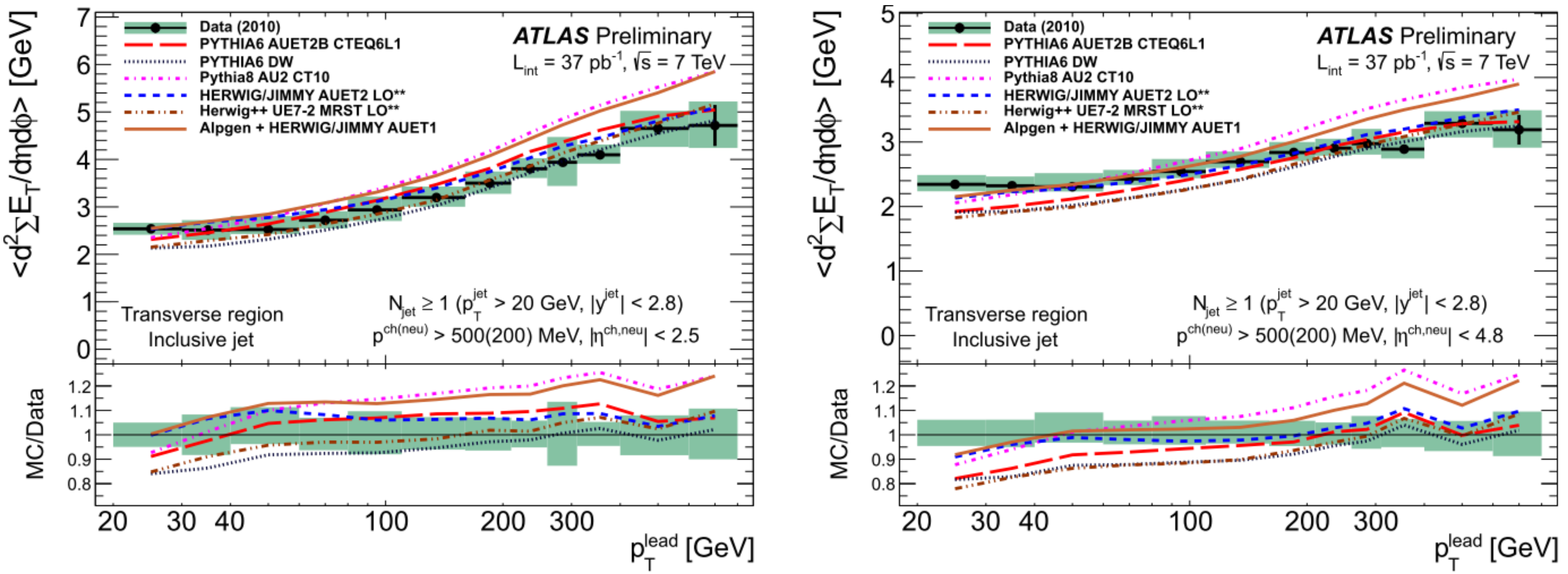
cuts

- inclusive: at least one jet with $p_{\mathrm{T}} > 20$ GeV and $|y| < 2.8$
- exclusive: exactly two jets with the same cut as for inclusive
  with $\left|\Delta\varphi_{\mathrm{jj}}\right| > 2.5$ && $E^{\mathrm{jet1}}{}_{\mathrm{T}}/E^{\mathrm{jet2}}{}_{\mathrm{T}} > 0.5$

- study central $|\eta| < 2.5$ and full $|\eta| < 4.8$ regions with charged (neutral) particles with $p > 500\ (200)$ MeV

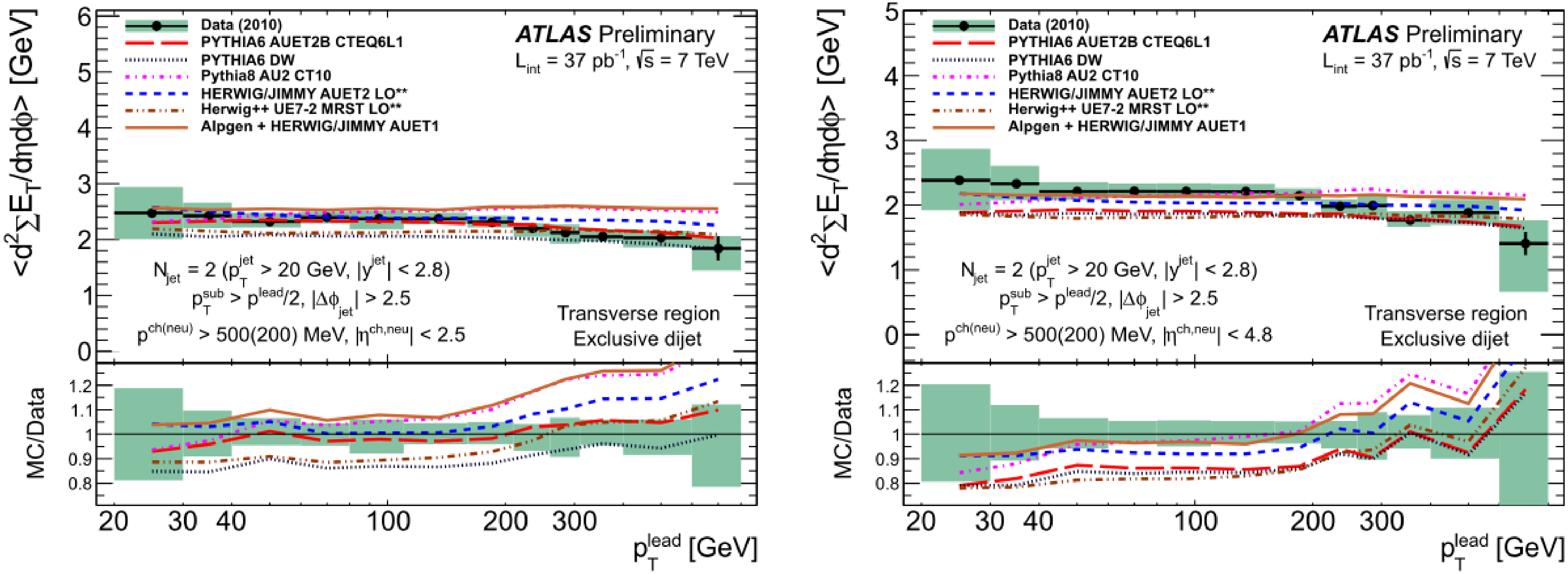
- plot average transverse energy density $\left\langle \frac{d^2 \sum E_{\mathrm{T}}}{d\eta d\varphi} \right\rangle$ in UE transverse region as a function of leading jet $p_{\mathrm{T}}{}^{\mathrm{lead}}$

inclusive jet UE



- average transverse energy density is lower when using the *full* range than the *central* one, most noticeably at high p_T^{lead}
- additional radiation associated with the hard scatter is concentrated more at mid rapidity
- in the MC models, the average transverse energy density falls faster than in case of data when moving over the full range for low p_T^{lead} but remains consistent with data for high p_T^{lead}

exclusive jet UE



- the average of transverse energy density in data is much flatter as a function of $p_T{}^{\mathrm{lead}}$
- instead of rising it falls slightly due to veto of high p_T tail
- no significant changes in data when moving from the *central* range to *full* one
  MC is observed to fall at low $p_T{}^{\mathrm{lead}}$

conclusion

- forward energy flow is in general underestimated by around 20–30%, with the exception of PYTHIA6 DW for dijet data and EPOS LHC for minbias data
- PYTHIA8 A2 is shown to have a better agreement if MSTW2008LO is used instead of CTEQ6L1
- current models are shown to be less able to model the energy density for an increasing η acceptance at lower values of ${p_{\mathrm{T}}}^{\mathrm{lead}}$ with both an inclusive jet and exclusive dijet selections