Testing QCD using forward and low-p_T jets, and diffraction at CMS

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for the CMS Collaboration

QCD and Hadronic Physics session - 23/07/15

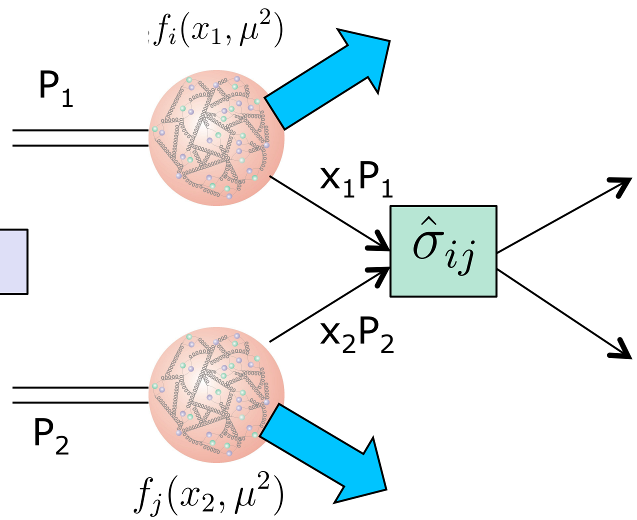
Outline

- Description of proton – proton collisions
- QCD at the LHC
- Study of forward and/or low-p_T jet final states
- Production of leading charged particles and jets at small p_T
- Dijet production with a large rapidity gap between the jets
- Summary

Description of proton-proton collisions

- Factorise the cross section as: $\sigma(P_1, P_2) = \sum_{i,j} \int dx_1 dx_2 f_i(x_1, \mu^2) f_j(x_2, \mu^2) \hat{\sigma}_{ij}(p_1, p_2, \alpha_S(\mu^2), Q^2/\mu^2)$

Collinear factorisation



Hard scattering cross section:
process dependent, short distance (high energy) interaction with small coupling, calculated with fixed order perturbation theory

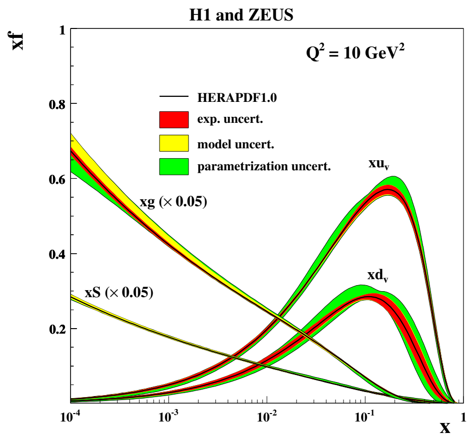
Process independent PDF's:
non-perturbative long distance interactions with high coupling

Evolution of PDF's driven by DGLAP equations:
$f(x,Q^2)$ determined by $f(x_0>x,\ Q_0^2<Q^2)$

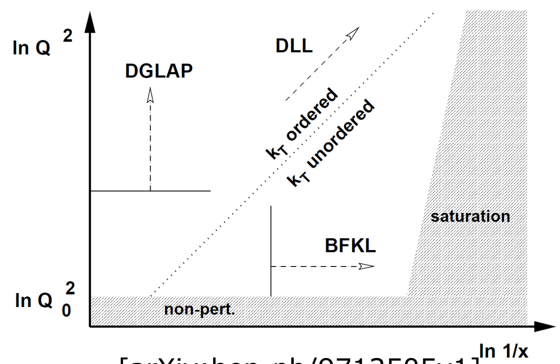
- Successful in describing many inclusive processes
- However: ➔ Valid for one hard momentum scale and not too low x (dilute hadron)
  ➔ Treatment of initial transverse momenta of the partons neglected
- Complemented with phenomenological models that add initial and final state radiation, and allow for multiple parton interactions

QCD at the LHC

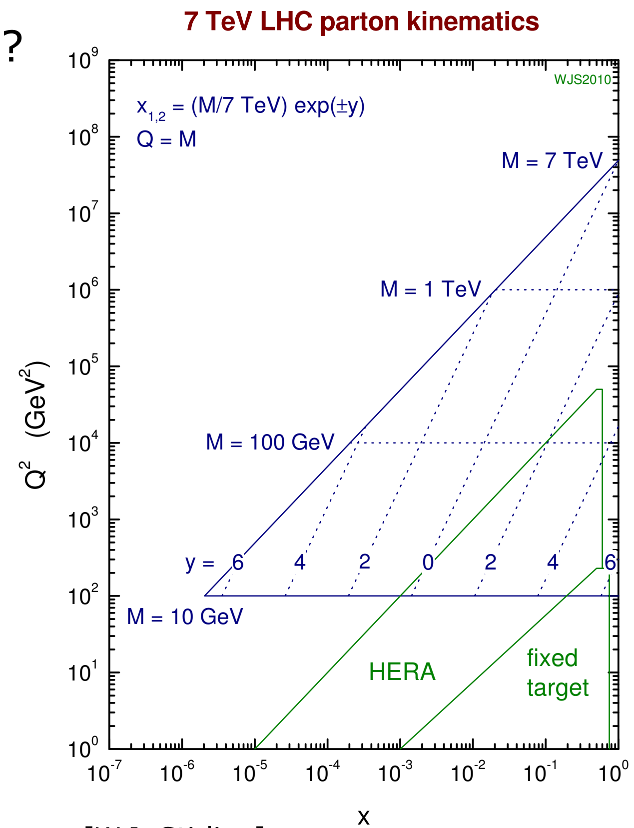
- What will happen in these new kinematic regions? Do the collinear approximations stay valid?
- Gluons dominate low-x region: saturation or recombination effects?



[JHEP 1001 (2010) 109]



[arXiv:hep-ph/9712505v1]

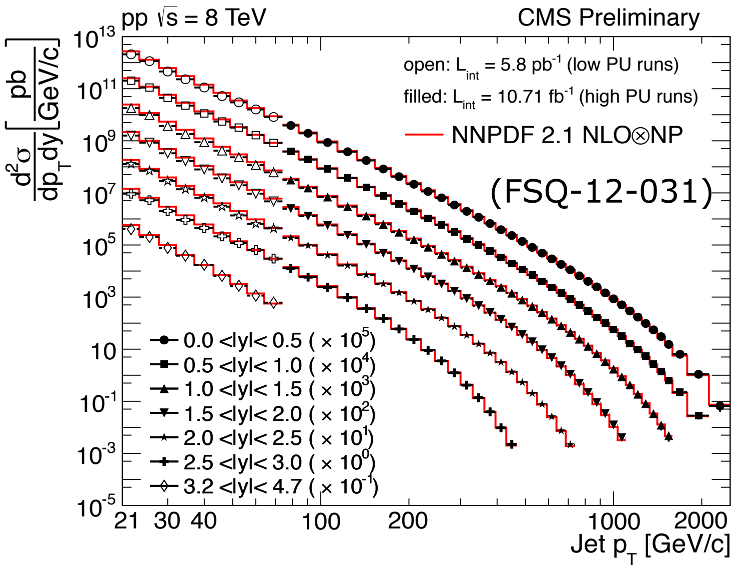


[W.J. Stirling]

- Need for k_T dependent, unintegrated pdf's?
- Will DGLAP break down and, e.g., BFKL take over?
- What is the role of multiple parton interactions (MPI) in all this?

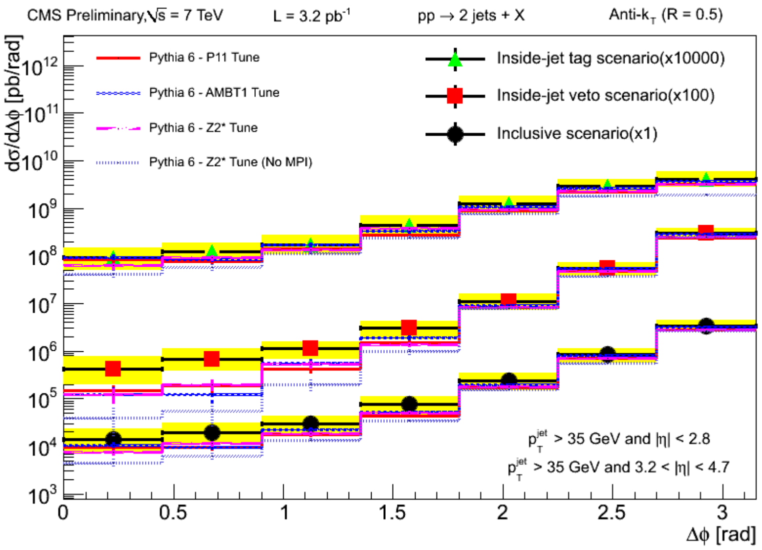
Study of forward and/or low-p_T jet final states

- The low-x region can be probed with very forward and/or low-p_T jets:



$$x \sim \frac{p_T}{\sqrt{s}} e^{-|\eta|}$$

(FSQ-12-008)



➔ Inclusive jet cross sections described within exp. uncertainties, not sensitive to non-DGLAP effects

➔ MPI have a clear effect on decorrelations between jets: might interfere with BFKL-like behaviour

Study of forward and/or low-p_T jet final states

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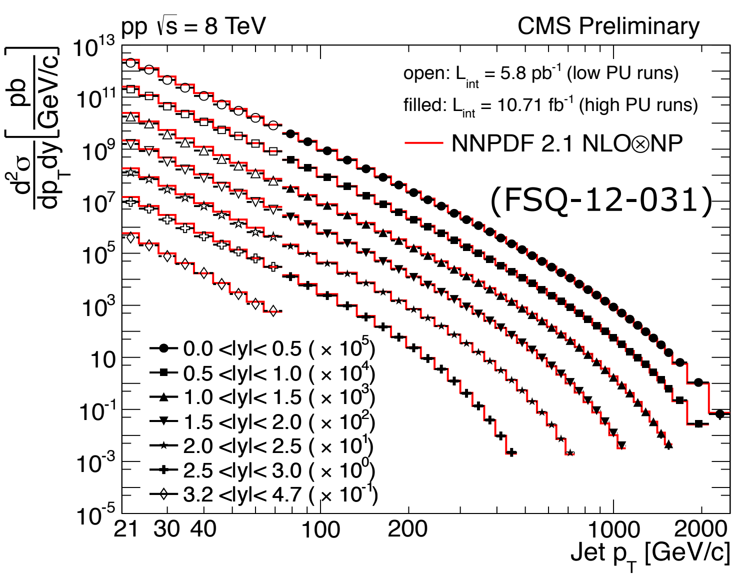

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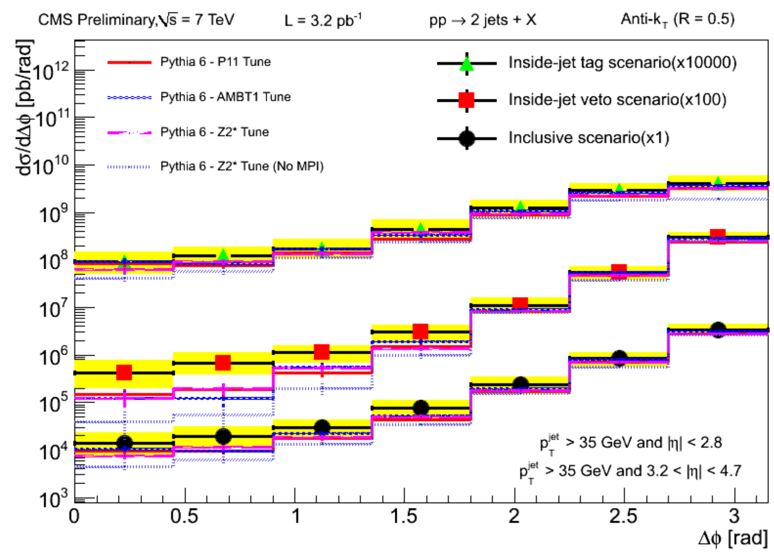
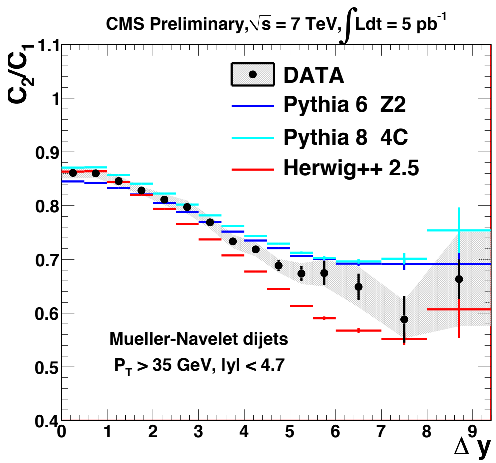
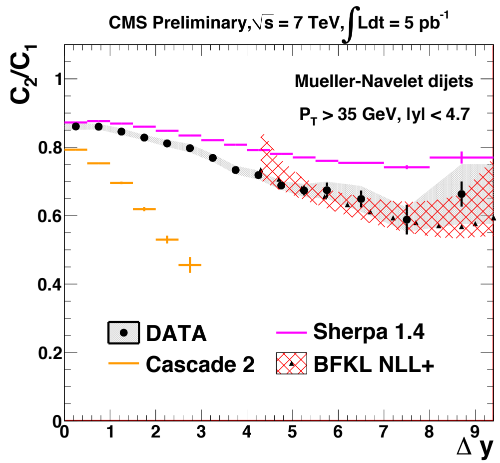






(FSQ-12-002)

➔ current kinematical domain lies in transition between regions described by DGLAP and BFKL approaches

Leading charged particles & jets at small p_T

- Study the production of leading charged particles and leading charged-particle jets at small p_T in pp collisions at $\sqrt{s}$ = 8 TeV (arXiv:1507.00233v1):

  - Most particles originate from non-pQCD semi-hard interactions ($p_T \sim 1 - 3$ GeV)
  - Partonic cross section diverges at low p_T and exceeds total inelastic pp cross section: needs to be tamed

$$\mathrm{d}\sigma/\mathrm{d}p_\mathrm{T}^2 \propto \alpha_S^2(p_\mathrm{T})/p_\mathrm{T}^4,$$

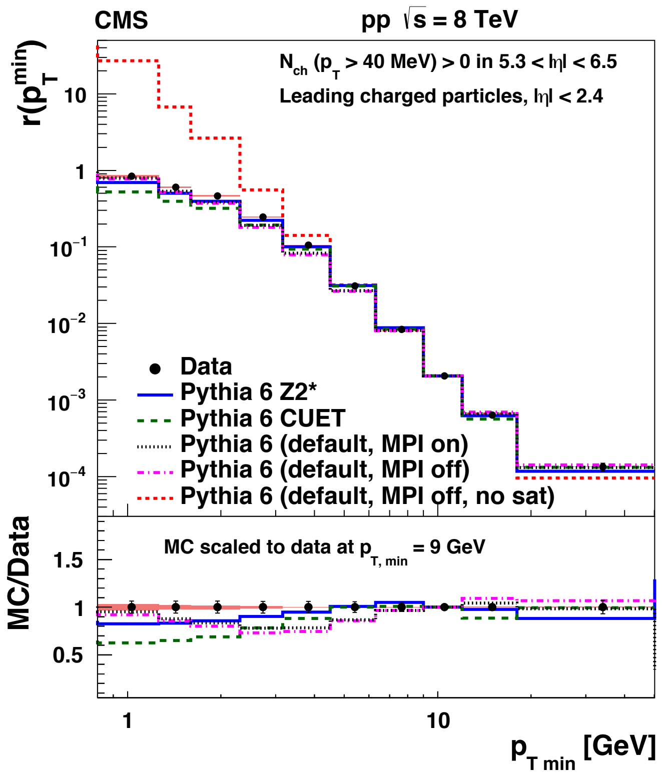
  ➔ sensitive to: momentum scale at which parton densities saturate, and MPI
  ➔ probe transition from perturbative to non-perturbative region

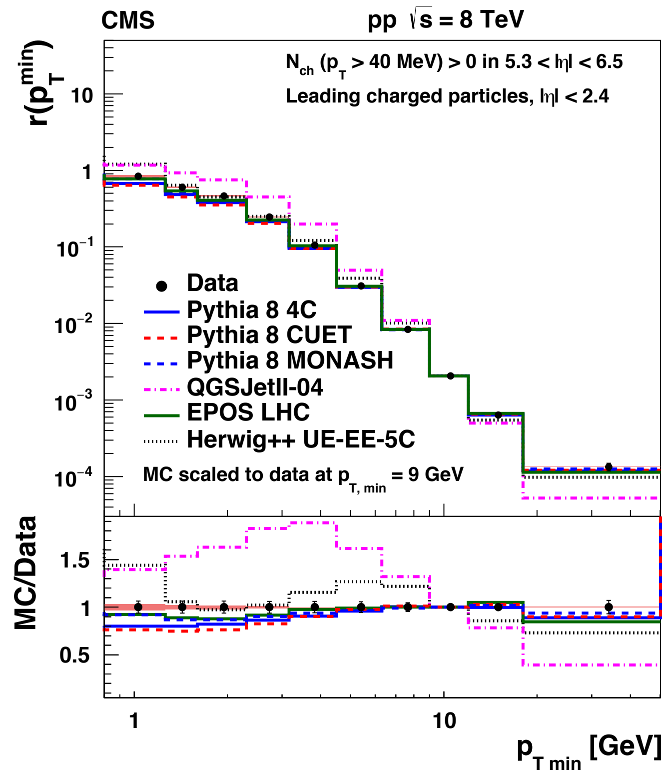
- Look at per-event yield of leading charged particles, and charged-particle jets integrated above a given $p_{T,min}$ ($p_{T,min}$ = 0.8 and 1.0 GeV resp.):

$$r(p_\mathrm{T}^\mathrm{min}) = \frac{1}{N_\mathrm{evt}} \int_{p_\mathrm{T}^\mathrm{min}} \mathrm{d}p_\mathrm{T}^\mathrm{lead} \left(\frac{\mathrm{d}N}{\mathrm{d}p_\mathrm{T}^\mathrm{lead}} \right)$$

N_{evt}: number of events with leading charged particle (p_T > 0.4 GeV, $|\eta|$ < 2.4)
N: number of events with a leading charged particle ($|\eta|$ < 2.4)
or leading jet ($|\eta|$ < 1.9, anti-k_T R=0.5) with $p_{T,lead}$.

Leading charged particles at small p_T



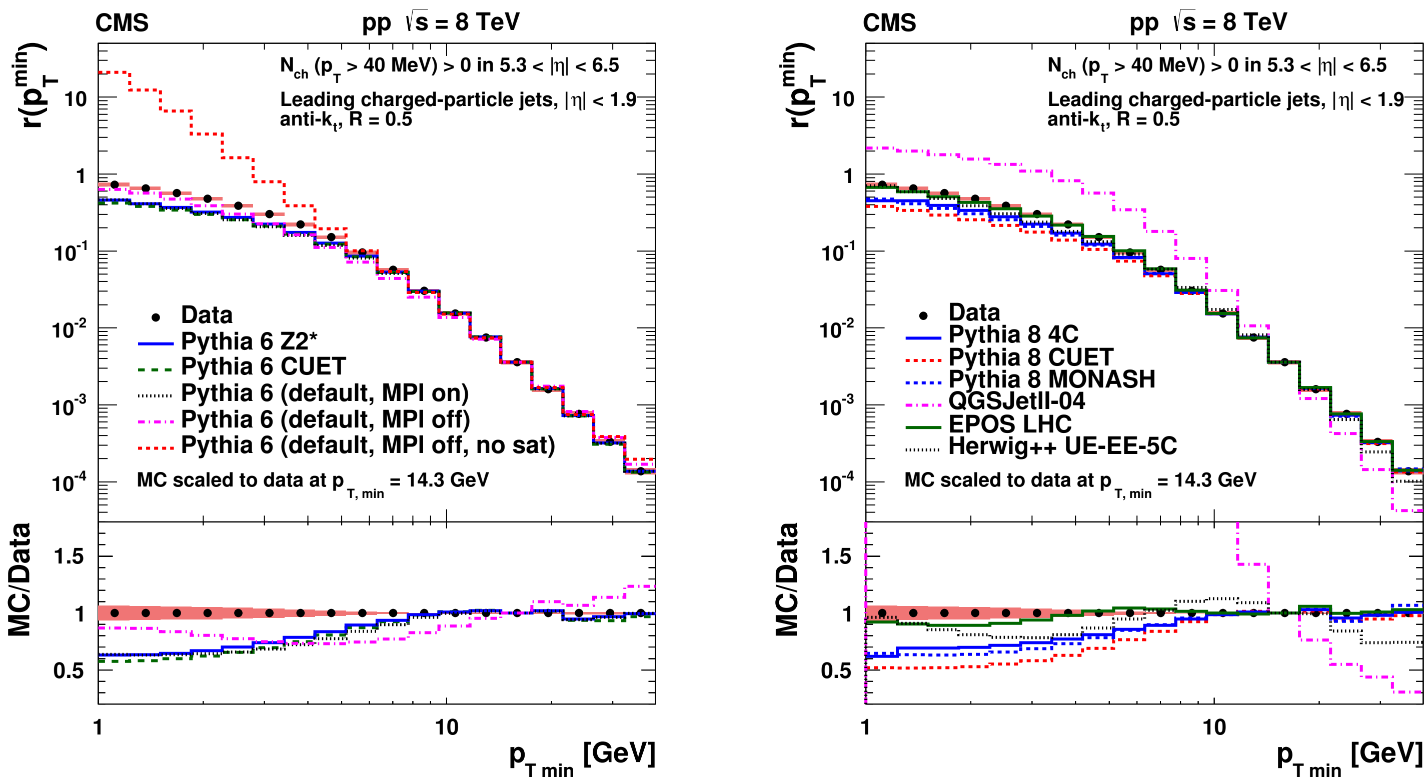


Predictions scaled to measured value at 9 GeV

Data best described by EPOS

- Regularisation of cross section turned off: order of magnitude discrepancy
  (Phenomenological approach in Pythia: $\frac{1}{p_T^4} \to \frac{1}{\left(p_T^2 + p_{T,0}^2\right)^2}$)
- Transition pert. to non-pert. region happens at $p_T \sim 1$ GeV $\gg \Lambda_{QCD}$
- Effect of MPI small

Leading charged particle jets at small p_T



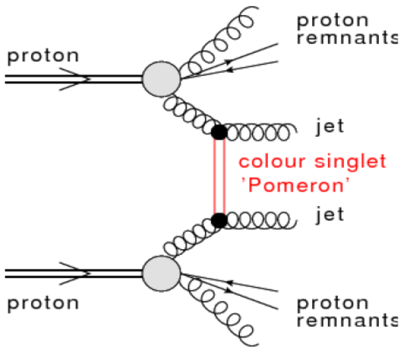
Predictions scaled to measured value at 14.3 GeV

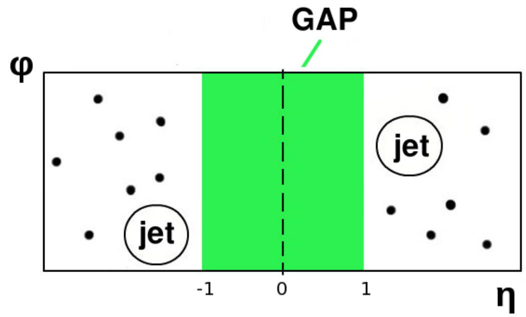
Data best described by EPOS

- Regularisation of cross section turned off: order of magnitude discrepancy
- Transition pert. to non-pert. region happens at $p_T \sim 1$ GeV $\gg \Lambda_{QCD}$
- Description at low $p_{T,min}$ worse for jets ➔ influence of MPI in jet cone

Dijet production with a large rapidity gap

- Dijet production with a large rapidity gap between the jets (FSQ-12-001):





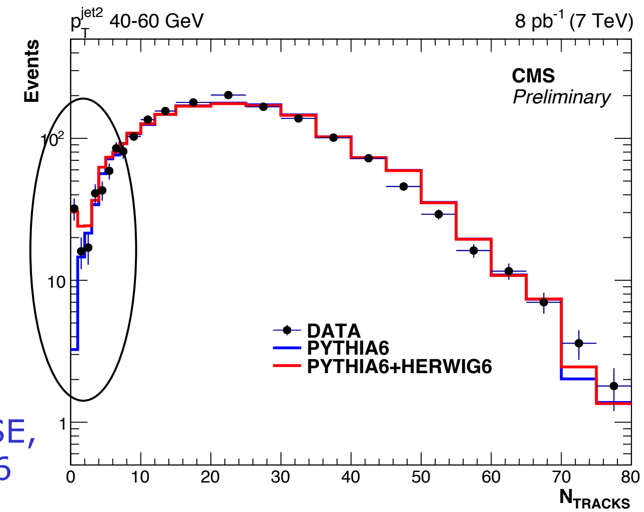
2 jets, p_T > 40 GeV, 1.5 < |η| < 4.5, opposite hemispheres

Rapidity gap:
fixed window inside |η| < 1

➔ diffractive process with large four-momentum squared transfer
➔ parton scattering through hard colour singlet exchange (CSE)

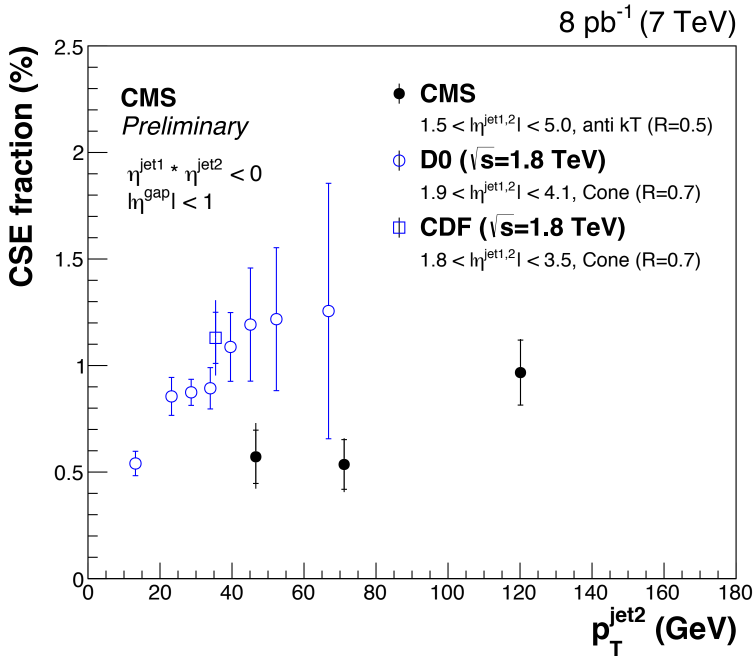
➔ study of these events may allow to disentangle BFKL dynamics from DGLAP evolution

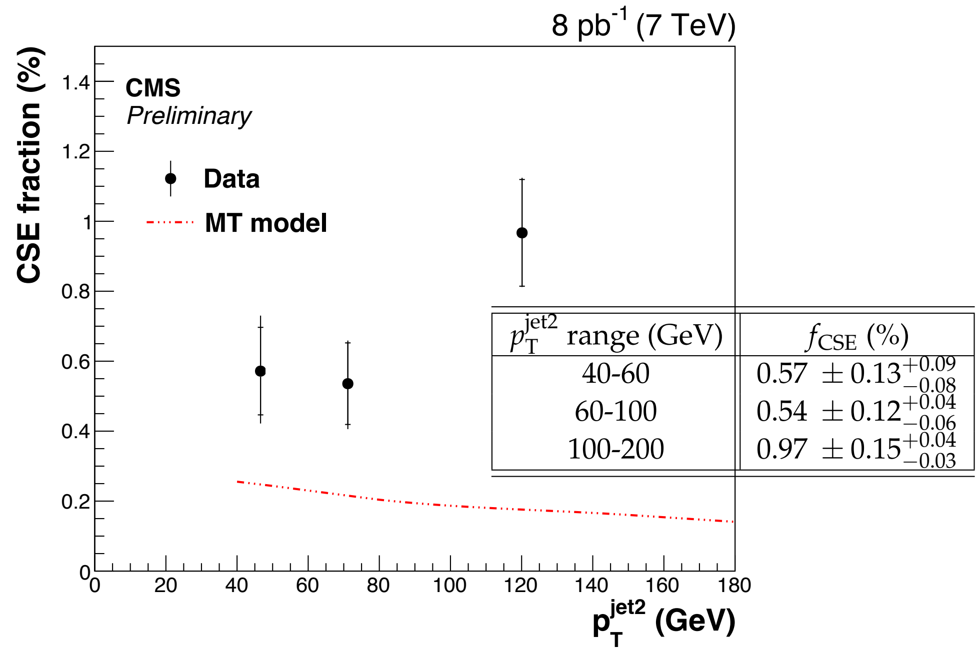
- Extract fraction of CSE events as function of $p_{T,jet2}$ (3 bins) and Δη between two leading jets



Contribution from CSE, described by Herwig6 (LL BFKL)

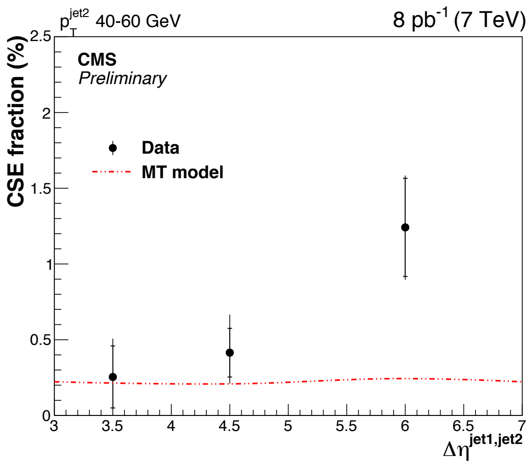
Dijet production with a large rapidity gap

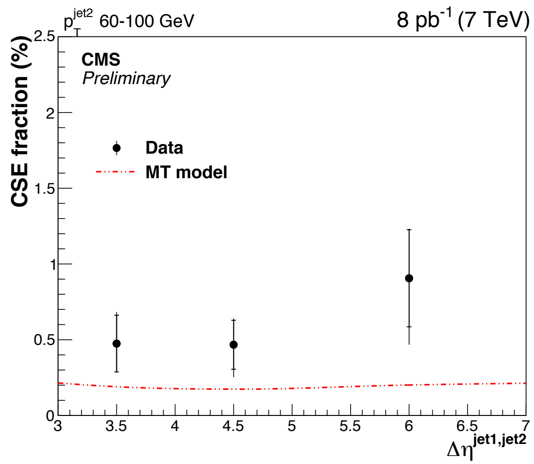




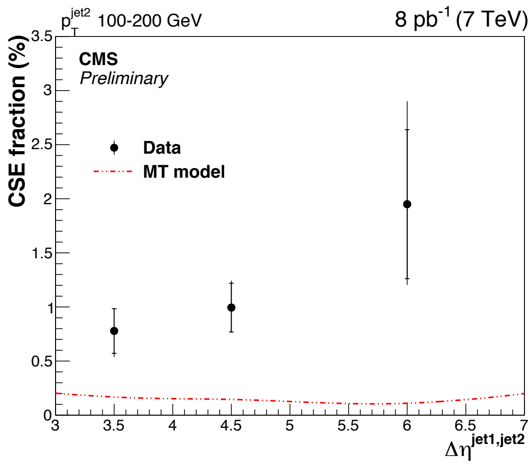
- Modest increase with $p_{T,jet2}$
- Suppression of the gap fraction with increasing $\sqrt{s}$:
  ➔ for $40 < p_{T,jet2} < 60$ GeV the value at 7 TeV is factor ~2 lower than at $\sqrt{s}$ = 1.8 TeV
  ➔ stronger contributions from rescattering processes
- Mueller and Tang model does not reproduce the rise with $p_{T,jet2}$ and underestimates the fraction of CSE events

Dijet production with a large rapidity gap





The fraction of CSE events increases with Δη



	f_{CSE} (%)		
$\Delta\eta_{jj}$ range	40-60 GeV	60-100 GeV	100-200 GeV
3-4	$0.25 \pm 0.20^{+0.15}_{-0.05}$	$0.47 \pm 0.19^{+0.09}_{-0.02}$	$0.78 \pm 0.21^{+0.07}_{-0.12}$
4-5	$0.41 \pm 0.16^{+0.19}_{-0.13}$	$0.47 \pm 0.16^{+0.06}_{-0.14}$	$0.99 \pm 0.23^{+0.11}_{-0.05}$
5-7	$1.24 \pm 0.32^{+0.11}_{-0.12}$	$0.91 \pm 0.32^{+0.07}_{-0.30}$	$1.95 \pm 0.69^{+0.66}_{-0.29}$

- Mueller and Tang model does not reproduce the rise with Δη and underestimates the fraction of CSE events

Summary

- CMS has studied the new kinematic regions of QCD extensively at the LHC:
  - with Run1 data at different centre-of-mass energies
  - using forward and/or low-p_T jet final states to probe low-x region

- What we learned so far:

➔ inclusive jet cross sections can be described within exp. uncertainties and are currently not sensitive to non-DGLAP effects

➔ MPI have a clear effect on decorrelations between jets and might interfere with BFKL-like behaviour

➔ current kinematical domain lies in transition between regions described by DGLAP and BFKL approaches: data at higher energies needed

➔ partonic cross section at low-p_T: influence of phenomenological dampening factor is clear at ~1 GeV $\gg \Lambda_{QCD}$. Sign of perturbative saturation?

➔ first observation of colour singlet exchange events at LHC!
CSE fraction suppressed at 7 TeV wrt lower energies: consistent with Tevatron data

➔ We look forward to 13 TeV data!