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# Leading charged particle and jet cross sections at small transverse momenta in pp collisions at $\sqrt{s} = 8$ TeV in CMS

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The production yields of leading charged-particle jets and charged particles in proton-proton collisions are measured at $\sqrt{s} = 8$ TeV based on a data sample collected with the CMS detector and corresponding to an integrated luminosity of 45 $\mu$b$^{-1}$. The charged-particle jets (charged particles) are measured in the pseudorapidity range $|\eta| < 1.9\,(2.4)$ for transverse momenta $p_T > 1\,(0.8)$ GeV. The measured yields integrated above a given minimum transverse momentum $p_{T,min}$ provide information on the mechanism by which the underlying parton-parton cross sections are unitarised approaching the low-$p_T$ non-perturbative domain. Predictions obtained from various Monte Carlo event generators are compared to the measurements. A large model sensitivity is seen.

*XXII. International Workshop on Deep-Inelastic Scattering and Related Subjects,*
*28 April - 2 May 2014*
*Warsaw, Poland*

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PoS(DIS2014)066

## 1. Introduction

The cross section for the production of jets with large transverse momenta in high energy proton-proton (pp) collisions is believed to derive from scattering of partons, a process that is described by perturbative quantum chromodynamics (pQCD). At small $p_T$ the partonic cross section $d\sigma/dp_T^2 \propto \alpha_S^2(p_T)/p_T^4$ is becoming very large and eventually the cross section $\sigma(p_{T,min}) = \int_{p_{T,min}} dp_T^2 d\sigma/dp_T^2$ exceeds the total inelastic pp cross section. At LHC energies ($\sigma_{inel} \approx 70$ mb [1]) this happens already at $p_{T,min}$ values of $\mathscr{O}(3\text{ GeV})$, much larger than $\Lambda_{QCD}$ [2, 3]. Event generators of hadronic collisions often tame such an infrared divergence with an effective parameter connected to the confinement scale of the hadron [4] such that the parton-parton cross section does not exceed the inelastic pp cross section.

In Ref. [5] a measurement of the leading jet cross section small $p_T$ integrated over $p_T > p_{T,min}$ is proposed as a direct measurement of the transition from the perturbative to the non-perturbative region. It is shown that this transition is also visible in cross sections defined in a limited range in pseudorapidity.

The results presented here are based on measurements of track-jets and single tracks.[1] The two states are complementary since the leading jets are expected to be more correlated to parton level compared to the leading tracks. On the other hand, the jets are sensitive to the underlying event via a jet pedestal effect, while the leading tracks are not.

The corrected, integrated leading-jet (charged-particle) $p_T$ distribution, normalised by the number of events, is measured as a function of the minimum transverse momentum, $p_{T,min}$:

$$\frac{\sigma(p_{T,min})}{\sigma_{vis}} = \frac{1}{N_{evt}} \int_{p_{T,min}} dP_{T,lead} \left( \frac{dN}{dP_{T,lead}} \right), \tag{1.1}$$

where $N_{evt}$ is the number of selected events, $N$ is the number of events with a leading jet (leading charged particle) with a transverse momentum of $P_{T,lead}$ within $|\eta| < 1.9$ ($|\eta| < 2.4$), and $\sigma_{vis}$ the cross section for all events with a central charged particle with $P_{T,lead} > 0.4$ GeV.

## 2. Event Selection

The data analysed in this publication were collected in July 2012 during a dedicated run with low pile-up. Minimum-bias events were triggered by the TOTEM [8] T2 telescopes, placed symmetrically on both sides of the interaction point. Pile-up is suppressed by selecting single-vertex events.

The data are corrected to stable-particle level, which is defined to include primary charged particles or decay products with proper lifetimes ($c\tau > 1$ cm). At this level events are selected if at least 1 charged particle with $p_T > 40$ MeV is present within the range $5.3<|\eta|<6.5$ and at least 1 charged particle with $p_T > 400$ MeV is found within $|\eta| < 2.4$. The latter requirement corresponds to the T2 trigger acceptance. Leading particles on stable-particle level are selected as the highest-$p_T$ particle from the collection of charged particles within $|\eta| < 2.4$ and with $p_T > 400$ MeV. Stable-particle level jets are clustered from the charged particles with $p_T > 400$ MeV and no restriction in $\eta$, by the anti-$k_t$ algorithm [9, 10, 11] with a radius parameter of 0.5. The leading jet

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[1] A detailed description of the presented analyses can be found in [6] and [7].

is then selected as the highest-$p_T$ jet from the collection of charged-particle jets with $p_T > 1$ GeV and $|\eta^{\text{jet}}| < 1.9$.

## 3. Results

In Figs. 1 and 2 the integrated cross-sections are shown for the leading charged particles and the leading charged-particle jets, respectively. The turn-over from the steeply-falling distribution to a flat distribution happens in the range between 1 and 10 GeV, but is different for the leading charged particle and the leading charged-particle jet measurement. When jets are clustered, more energy from additional particles is collected within the jet cone.

In the left panels (Figs. 1 and 2) the measured distributions are compared to predictions from the Monte Carlo event generators, PYTHIA6 [12] with tune Z2* and D6T, as well as PYTHIA6 default with and without MPI. Also shown is the impact of turning off the regularisation of the cross section completely ("PYTHIA6 (default, MPI off, no sat)" with PARP(81)=PARP(82)=0.). For illustration, the Monte Carlo predictions are scaled to the measured value of $\sigma(p_{\text{T leading}} > 9.0(14.3)\ \text{GeV})/\sigma_{vis}$ for leading charged particles (charged-particle jets). In the right panels PYTHIA8 [13] with tune 4C, HERWIG++ (version 2.5.0) [14] with tune UE-EE-3C [15] and the Monte Carlo generators used in cosmic ray physics, EPOS [16, 17] LHC tune and QGSETII-04 [18] are shown.

As seen in the figures, the approach implemented in PYTHIA and HERWIG does describe the general trend of the measurements but fails to describe the details of the transition, for all LHC tunes. The prediction of EPOS agrees much better with the measurements. In this model the cross sections for soft processes leads to a different MPI distribution compared to the other approaches.

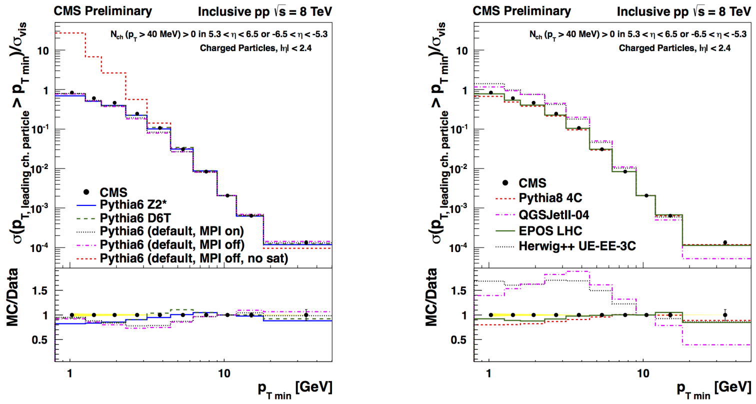

**Figure 1:** Normalised integrated $p_T$-distribution of the leading charged particle in $|\eta| < 2.4$. The data are compared to different predictions from various PYTHIA6 tunes (left) and various Monte Carlo event generators (right). The error bars indicate the statistical uncertainty and the shaded area the systematic uncertainty. The systematic uncertainties are only shown in the ratio plot. The Monte Carlo curves are normalised to the measured value of $\sigma(p_{\text{T leading ch.particle}} > 9.0\ \text{GeV})/\sigma_{vis}$.

## References

[1] G. Antchev *et al.* [TOTEM Collaboration], Phys. Rev. Lett. **111** (2013) 1, 012001.

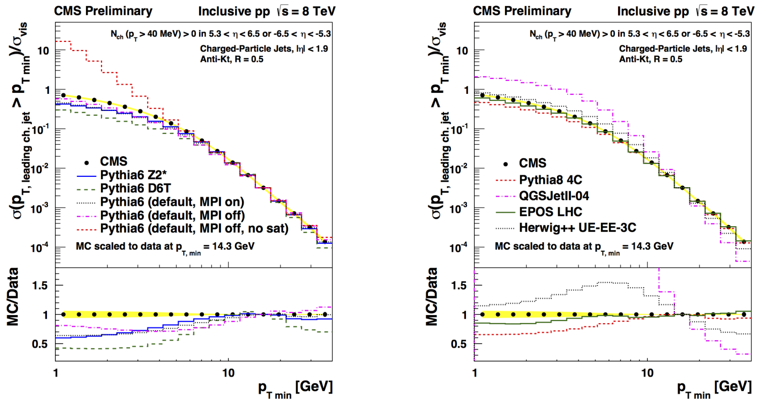

**Figure 2:** Normalised integrated $p_T$-distribution of the leading charged jet in $|\eta| < 2.0$. The data are compared to different predictions from various PYTHIA6 tunes (left) and various Monte Carlo event generators (right). The error bars indicate the statistical uncertainty and the shaded area the systematic uncertainty. The systematic uncertainties are only shown in the ratio plot. The Monte Carlo curves are normalised to the measured value of $\sigma(p_{\mathrm{T\,leading\ ch.jet}} > 14.32\ \mathrm{GeV})/\sigma_{vis}$.

[2] T. Sjostrand and M. van Zijl, Phys. Rev. D **36** (1987) 2019.

[3] T. Sjostrand and P. Z. Skands, JHEP **0403** (2004) 053 [hep-ph/0402078].

[4] J. Dischler and T. Sjostrand, Eur. Phys. J. direct C **3** (2001) 2 [hep-ph/0011282].

[5] A. Grebenyuk, F. Hautmann, H. Jung, P. Katsas and A. Knutsson, Phys. Rev. D **86** (2012) 117501 [arXiv:1209.6265 [hep-ph]].

[6] CMS Collaboration, CMS-PAS-FSQ-12-032.

[7] CMS Collaboration, CMS-PAS-FSQ-12-026.

[8] G. Anelli *et al.* [TOTEM Collaboration], JINST **3** (2008) S08007.

[9] M. Cacciari, G. P. Salam and G. Soyez, JHEP **0804** (2008) 063 [arXiv:0802.1189 [hep-ph]].

[10] M. Cacciari and G. P. Salam, Phys. Lett. B **641** (2006) 57 [hep-ph/0512210].

[11] M. Cacciari, G. P. Salam and G. Soyez, Eur. Phys. J. C **72** (2012) 1896 [arXiv:1111.6097 [hep-ph]].

[12] T. Sjostrand, S. Mrenna and P. Z. Skands, JHEP **0605** (2006) 026 [hep-ph/0603175].

[13] T. Sjostrand, S. Mrenna and P. Z. Skands, Comput. Phys. Commun. **178** (2008) 852 [arXiv:0710.3820 [hep-ph]].

[14] M. Bahr, S. Gieseke, M. A. Gigg, D. Grellscheid, K. Hamilton, O. Latunde-Dada, S. Platzer and P. Richardson *et al.*, Eur. Phys. J. C **58** (2008) 639 [arXiv:0803.0883 [hep-ph]].

[15] S. Gieseke, D. Grellscheid, K. Hamilton, A. Papaefstathiou, S. Platzer, P. Richardson, C. A. Rohr and P. Ruzicka *et al.*, arXiv:1102.1672 [hep-ph].

[16] K. Werner, F. -M. Liu and T. Pierog, Phys. Rev. C **74** (2006) 044902 [hep-ph/0506232].

[17] T. Pierog, I. .Karpenko, J. M. Katzy, E. Yatsenko and K. Werner, arXiv:1306.0121 [hep-ph].

[18] S. Ostapchenko, Phys. Rev. D **83** (2011) 014018 [arXiv:1010.1869 [hep-ph]].