

# **MPI@LHC 2014**

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## **Book of Abstracts**



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**Double Parton Scattering / 28****A Light-Front approach to double parton distribution functions within constituent quark models****Author(s):** Matteo Rinaldi<sup>1</sup>**Co-author(s):** Marco Traini<sup>2</sup> ; Vicente Vento<sup>3</sup> ; sergio scopetta<sup>4</sup><sup>1</sup> *Perugia University and INFN, Perugia*<sup>2</sup> *Dipartimento di Fisica, Università degli studi di Trento, and INFN - TIFPA, Via Sommarive 14, I - 38123 Povo (Trento), Italy*<sup>3</sup> *Departament de Física Teòrica, Universitat de València and Institut de Física Corpuscular, Consejo Superior de Investigaciones Científicas, 46100 Burjassot (València), Spain*<sup>4</sup> *Perugia University and INFN***Corresponding Author(s):** matteo.rinaldi@pg.infn.it

Double parton correlations, not easily predictable in QCD, relevant to access the 3D structure of the proton, are encoded in the so called double parton distribution functions (dPDFs), which can be measured in principle through high energy proton-proton and proton-nucleus collisions, at, {it e.g.}, the LHC (see Ref. [1] for general reports).

In a recent paper of ours [2], the dPDFs have been evaluated within non relativistic constituent quark models (CQM) in the valence region. In this scenario double correlations between two acting particles are already described in the model without any additional prescription, at variance with what happens, for example, in independent particle models, such as the MIT bag model in its simplest version. In the CQM framework the dynamical origin of the correlations can be clarified with the possibilities of establishing which, among the addressed features, are model independent. Recent relevant results, obtained in a relativistic light-front scheme, able to overcome some drawbacks of the previous calculation, such as the so called “poor support problem”, will be presented [3]. The approach is an extension of that firstly introduced in Ref. [4], developed in Ref. [5] and then widely used. In ref. [3], correlations in transverse momentum

have been addressed thanks to the exact treatment of the boosts. Moreover, thanks to the Poincaré covariance of the approach, the evaluated double spin correlations show the expected symmetries.

The study of the QCD evolution of the model results for the valence sector, which is possible thanks to the property of good support, has been also completed.

At the low values of  $x$  presently studied at the LHC the correlations become less relevant, although they are still important for the spin-dependent contributions to unpolarized proton scattering.

[1] M. Diehl, D. Ostermeier and A. Schafer, JHEP 1203, 089 (2012);  
A. V. Manohar and W. J. Waalewijn, Phys. Rev. D 85, 114009 (2012);  
J. R. Gaunt and W. J. Stirling, JHEP 1003, 005 (2010).

[2] M. Rinaldi, S. Scopetta and V. Vento, Phys. Rev. D 87,114021, (2013).

[3] M. Rinaldi, S. Scopetta, M. Traini and V. Vento, arXiv:1409.1500 [hep-ph].

[4] P. Faccioli, M. Traini, V. Vento, Nucl. Phys. A 656, 400-420 (1999).

[5] S. Boffi, B. Pasquini and M. Traini, Nucl. Phys. B 649, 243 (2003).

**Underlying Event / 23**

## **A new Colour Reconnection model within Pythia**

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In this talk I will present a new model for the treatment of colours within the non-perturbative part of the Pythia event generation. This includes both a new treatment of colours in the beam remnant as well as a new model for colour reconnections. The aim of the model has been to include more of the SU(3) colour structure of QCD. The model has been implemented in Pythia 8, and comparisons to earlier models, as well as data, will be presented.

**Underlying Event / 42**

## **ATLAS MPI Tunes**

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We present the 2014 ATLAS tunes of Pythia 8, which use the most recent and complete LHC dataset, along with data from the Tevatron and LEP. Separate new tunes are made to soft inelastic collisions, and to distributions that are sensitive to shower and underlying event models. The effect of varying both leading and next-to-leading order parton distribution functions is also considered, and demonstrates that the tune output is largely insensitive to the PDF choice as long as LO and NLO PDFs are not exchanged.

**MPI and small x and diffraction / 6**

## **Associated boson production in the forward acceptance**

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The forward production cross-section in pp collisions for the production of a Z boson in association with another particle or jet provides information about parton distributions inside the proton, the charm and beauty production mechanism, and double-parton scattering. We present recent results of associated production of a Z boson with a D meson, any jet, or a b-tagged jet. The total Z and W cross-sections, as well as the forward-backward asymmetry are also reported.



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## Closing

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**MPI and small  $x$  and diffraction / 20**

## Compact expressions for off-shell amplitudes

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High-energy factorization requires scattering amplitudes with off-shell external partons. These are in general more complicated to calculate than amplitudes for which all partons are on-shell. For the latter, compact expressions can be found with relatively little effort using BCFW recursion. We show that this approach can be generalized to amplitudes with off-shell gluons.

**MPI in collisions with nuclei / 41**

## Constraints for small- $x$ gluon nPDFs from p+Pb collisions at the LHC

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The gluon nuclear parton distribution functions (nPDFs) at small  $x$  are not well constrained in the present global analyses as the currently available data are mainly sensitive to the quark PDFs. At the moment the most promising source for further constraints is the proton-lead collisions at the LHC. In a recent publication we have quantified which  $x$  regions are probed with inclusive pion and direct photon production at different rapidities using NLO perturbative QCD. We found that the direct photons carry more sensitivity to small- $x$  partons than the pions at the same rapidity and by imposing an isolation cut for the direct photons this sensitivity can be further increased. The prediction for the rapidity dependence of the nuclear modification factor for isolated photons is presented together with its uncertainties using EPS09 nPDF set. We consider also the yield asymmetry between forward and backward rapidities which could be used in global analyses if there are no accurate p+p baseline available.

**Double Parton Scattering / 32**

## Conventional versus single-ladder-splitting contributions to double parton scattering for gluon induced processes

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We will present our recent results of the double parton distributions (dPDF) studies [1]. Both conventional and those corresponding to parton splitting dPDFs, are calculated and compared for different two-parton combinations. The conventional and splitting dPDFs have very similar shape in  $x_1$  and  $x_2$ . We will present a first quantitative evaluation of the single-ladder-splitting contribution to double parton scattering (DPS) production of two S- or P-wave quarkonia, two Higgs bosons and  $c\bar{c}c\bar{c}$ . The ratio of the single-ladder-splitting to conventional contributions will be discussed as a function of centre-of-mass energy, mass of the produced system and other kinematical variables. Using a simple model for the dependence of the conventional two-parton distribution on transverse parton separation (Gaussian and independent of  $x_i$  and scales), we find that the 2v1 contribution is as big as the 2v2 contribution discussed in recent years in the literature. This means that the phenomenological analyses of  $\sigma_{eff}$  including only the conventional DPS mechanism have to be revised including explicitly the single-ladder-splitting contributions discussed here. The differential distributions in rapidity and transverse momenta calculated for conventional and single-ladder-splitting DPS processes are however very similar which causes their experimental separation to be rather difficult, if not impossible. The direct consequence of the existence of the two components (conventional and splitting) is the energy and process dependence of the empirical parameter  $\sigma_{eff}$ . This will be illustrated for the considered processes.

[1] J.R. Gaunt, R. Maciula, and A. Szczurek, Phys. Rev. D90, 054017 (2014).

**Double Parton Scattering / 55**

## DPS and Determination of $\sigma_{eff}$

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We will report on recent studies done by the CMS experiment on DPS and the determination of  $\sigma_{eff}$

**Double Parton Scattering / 35**

## DPS and the Higgs signal strength at the LHC

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We shall discuss the sources of an enhancement of the DPS contribution to the production of colour and flavour singlet, neutral, spin 0 final states at the LHC. Our focal point will be the Double Drell-Yan Process (DDYP) and its contribution to the Higgs boson searches irreducible background. We shall propose an experimental method to pin down the size of this contribution.

**MPI in collisions with nuclei / 49**

## DPS cross sections in proton-nucleus and nucleus-nucleus collisions

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Simple generic expressions to calculate DPS cross sections in p-A and A-A collisions, as a function of the corresponding single-parton cross sections, are presented. Expected event rates for J/psi+J/psi, J/psi+Upsilon, J/psi+W, J/psi+Z, Upsilon+Upsilon, Upsilon+W, Upsilon+Z, and same sign W+W production in their (di)leptonic decay modes, after typical acceptance and efficiency losses, are given for p-Pb and Pb-Pb collisions at the LHC.

**Double Parton Scattering / 58**

## DPS measurements with CMS

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We present recent results on Double Parton Scattering (DPS) studies using data collected during Run 1 of the LHC with the CMS experiment. Double parton scattering is investigated in several final states including vector bosons and multi-jets. Measurements of observables designed to highlight the DPS contribution are shown and compared to MC predictions from models based on multiple partonic interactions (MPI) phenomenology.

**MPI and small x and diffraction / 27**

## Dijet production at HERA and tests of QCD factorisation

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The exclusive production of dijets in diffractive deep inelastic lepton-proton scattering has been measured. Jets have been reconstructed in the photon-Pomeron ( $\gamma$ -IP) centre-of-mass system frame using the exclusive  $k_T$  algorithm. The cross section for the exclusive production of dijets is given as a function of the angle between the plane defined by exchanged photon and dijet system and the plane defined by the incoming and scattered lepton momenta in the  $\gamma$ -IP rest frame. It is compared to theoretical predictions of models based on boson-gluon fusion and two-gluon exchange processes.

Dijet production with a leading proton detected in the very forward proton spectrometer are measured both in deep-inelastic scattering and in photoproduction. The

DIS measurements are complemented by measurements of dijet production with an associated rapidity gap. The validity of QCD Factorisation is discussed by comparing HERA diffractive jet measurements in DIS and in photoproduction to NLO calculation. Cross section ratios are also explored in order to profit from cancellations of systematic uncertainties.

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## Discussion (DPS and UE)

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## Discussion (small-x and collisions with nuclei)

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### Double Parton Scattering / 3

## Dissecting Soft Radiation with Factorization

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An essential part of high-energy hadronic collisions is the soft hadronic activity that underlies the primary hard interaction. It can receive contributions from soft radiation from the primary hard partons, secondary multiple parton interactions (MPI), and factorization violating effects. The invariant mass spectrum of the leading jet in Z+jet and H+jet events is directly sensitive to these effects. We

use a QCD factorization theorem to predict the dependence on the jet radius  $R$ , jet  $p_T$ , jet rapidity, and partonic process for both the perturbative and nonperturbative components of primary soft radiation and compare these results with PYTHIA8 and HERWIG++. The perturbative soft initial state radiation has a contribution that depends on the jet area in the same way as the underlying event. This degeneracy is broken by the jet  $p_T$  dependence. In addition, the size of this soft ISR contribution is proportional to the color state of the initial partons, yielding the same positive contribution for  $gg \rightarrow Hg$  and  $gq \rightarrow Zq$ , but a negative interference contribution for  $q\bar{q} \rightarrow Zg$ .

## Double Parton Scattering / 30

### Double open charm production at the LHC within single- and double-parton scattering

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We discuss production of two pairs of  $c\bar{c}$  within a simple formalism of double-parton scattering (DPS). Surprisingly large cross sections, comparable to single-parton scattering (SPS) contribution, are predicted for LHC energies.

We compare results of exact calculations of single-parton scattering (SPS) and double-parton scattering (DPS) for production of  $c\bar{c}c\bar{c}$  and for  $D - D$  meson-meson correlations [1,2]. Each step of DPS is calculated within  $k_t$ -factorization approach, i.e. effectively including next-to-leading order corrections.

The SPS calculations are performed in collinear approximation with exact matrix element for  $gg \rightarrow c\bar{c}c\bar{c}$  subprocess as well as with approximate matrix elements in high-energy approximation.

The cross section for the exact calculation is bigger only at small invariant masses and small rapidity difference between two  $c$  quarks (or two  $\bar{c}$  antiquarks).

We compare our predictions for double charm production ( $DD$  meson-meson pairs) with recent results of

the LHCb collaboration for azimuthal angle  $\varphi_{DD}$ , dimeson invariant mass  $M_{DD}$  and rapidity distance between

mesons  $Y_{DD}$ . The predicted shapes are similar

to the measured ones, however, some strength seems to be lacking.

Possible missing contribution within the framework of DPS mechanism is suggested.

Our calculations clearly confirm the dominance of DPS in the production of events with double charm. Finally, we emphasize possible significant contribution of DPS mechanism to inclusive charmed meson spectra measured recently by ALICE, ATLAS and LHCb.

[1] R. Maciula, and A. Szczurek, Phys. Rev. D87, 074039 (2013).

[2] A. van Hameren, R. Maciula and A. Szczurek, Phys. Rev. D89, 094019 (2014).

## MPI in collisions with nuclei / 46

### Double parton interactions in $\gamma p, \gamma A$ collisions in the direct photon kinematic

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We derive expressions for the the differential distributions and total cross section of double- parton interaction in direct photon interaction with proton and nuclei. We demonstrate that in this case cross section is more directly related to the nucleon generalized parton distribution than in the case of couple parton interactions in the proton - proton collisions.

We focus on production of two dijets each containing charm (anticharm) quarks and carrying  $x_1, x_2 > 0.4$  fractions of the photon momentum. Numerical results are presented for the case of ultraperipheral AA and pA

collisions at LHC and  $\gamma p$  collisions at HERA.

We find that p - Pb and Pb- Pb collisions at the LHC should produce a significant number of double parton interactions –  $\sim 6 \cdot 10^4$  for Pb-Pb, and  $\sim 6.6 \cdot 10^3$  for p-Pb collisions for jet cut off

$p_t > 5$  GeV, making it feasible to use these processes for model independent determination of two parton GPDs in nucleon and in nuclei.

The LeHC for  $\sqrt{s} = 1300$  GeV the rate is  $2 \cdot 10^8$  events for the luminosity  $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$  and time scale of  $10^6$  s for the same transverse cutoff.

## Double Parton Scattering / 48

### Double parton scattering in W+jets

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The productions of jets in association with a vector boson are important processes for understanding the effect of QCD radiation on forward and central jet activity and can be used to study the contribution of multi-particle interactions. ATLAS results are compared with predictions from Monte Carlo simulations and next-to-leading order perturbative QCD predictions corrected for non-perturbative effects, which include multiple parton interactions and hadronisation effects. The contribution of double and multiple parton scattering plays a sizable contribution to vector bosons produced in association with light and heavy flavour jets, in the region of low jet transverse momentum. An explicit study of double-parton scattering using W+dijet events is presented, along with a measurement of the effective cross section.

## MPI in collisions with nuclei / 19

### Double scattering production of two $\rho^0$ mesons and four pions in~heavy ion UPCs

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We will discuss a possibility to study the  $\rho^0$  mesons production in ultrarelativistic ultraperipheral heavy ion collisions. We evaluate for the first time differential distributions for

exclusive production of two  $\rho^0(770)$  mesons (four charged pions) in the double scattering (photon-Pomeron) process [1]. The results will be compared with the contribution of two-photon mechanism discussed previously in the literature [2]. The double scattering mechanism populates large dimeson invariant masses and large rapidity distance between mesons. The resulting distributions for four pions will be presented and compared to the STAR data. Predictions for the LHC will be shown. We will discuss a possibility of identifying the double scattering mechanism at the LHC energy. The above analysis includes the smearing of  $\rho^0$  mass which was presented recently by the ALICE Collaboration.

[1] M. Klusek-Gawenda and A. Szczurek, Phys. Rev. C **89** (2013) 024912,

[2] M. Klusek, W. Schafer and A. Szczurek, Phys.Lett. B **674** (2009) 92.

## Double Parton Scattering / 31

### Effects of double-parton scattering for the rapidity-distant-jet production at the LHC

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We discuss production of four-jet final state in the  $pp \rightarrow jjjjX$  reaction at the LHC through the mechanism of double-parton scattering (DPS) [1].

Each step of the DPS is calculated within the so-called factorized Ansatz in the LO collinear approximation. The LO pQCD calculations are shown to give a reasonably good description of the recent CMS and ATLAS data on inclusive jet production.

Relative contribution of DPS is growing at large rapidity distance between jets.

This is consistent with our experience from previous studies of double-parton scattering effects in the case of open and hidden charm production.

The calculated differential cross sections as a function of rapidity distance between the most distant jets

are compared with recent results of LL and NLL BFKL calculations for Mueller-Navelet (MN) jet production at  $\sqrt{s} = 7$  TeV.

The DPS contribution to the production of large rapidity distant jets is carefully studied also at the nominal LHC energy and in different jets transverse momenta range.

The differential cross section as a function of dijet transverse momenta as well as two-dimensional ( $p_T^{min} \times p_T^{max}$ )-plane correlations for the DPS mechanism are also presented. Some ideas how the DPS effects could be studied in the case of double dijet production are suggested.

[1] R. Maciula and A. Szczurek, Phys. Rev. D **90**, 014022 (2014).

## Double Parton Scattering / 38

### Electroweak boson production in double parton scattering

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We study the  $W^+W^-$  and  $Z^0Z^0$  electroweak boson production in double parton scattering using QCD evolution equations for double parton distributions. In particular, we analyze the impact of splitting terms in the evolution equations on the double parton scattering cross sections. Unlike the standard terms, the splitting terms are not suppressed for large values of the relative momentum of two partons in the double parton scattering. Thus, they play an important role which we discuss in detail for the considered processes

**MPI in collisions with nuclei / 40**

## Evidence for x-dependent proton color fluctuations in pA collisions at the LHC

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We argue that the pattern of violation of the Glauber picture for centrality dependence of the rate of forward jet production observed in pA collisions at the LHC provides evidence that configurations in the proton containing a parton with large  $x_p$  interact with a significantly smaller than average cross section and have smaller than average size. Implementing effects of the fluctuations of the interaction strength and using the ATLAS analysis of the dependence of the hadron production at backward rapidities on the number of wounded nucleons, we make quantitative predictions for the centrality dependence of the jet production rate as a function of the interaction strength  $\sigma(x_p)$ . For  $x_p=0.6$  we find  $\sigma(x_p) \sim \sigma_{\text{tot}}(pp)/2$  which sheds a light on the origin of the EMC effect.

**MPI and small x and diffraction / 7**

## Exclusive hadron and multiple hadron production in the forward acceptance

Olivier Leroy<sup>1</sup>

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An updated measurement of exclusive  $J/\psi$ ,  $\psi(2S)$  vector meson production at the LHC is presented. The measured integrated and differential cross-sections are compared to several theoretical predictions. The data are sufficiently sensitive to distinguish between LO and 'NLO' predictions. The forward reach of the LHCb detector probes small values of  $x$ , and these results can be used to constrain the gluon PDF down to  $x=5E-6$ . Recent results on multiple charmonium production are also presented.



**MPI and small x and diffraction / 56****Exclusive processes at CMS**Laurent Forthomme<sup>1</sup><sup>1</sup> *Universite Catholique de Louvain (UCL) (BE)*

Measurements of exclusive processes with the CMS detector during Run 1 of the LHC are presented. The results can be divided in rapidity gap-based, such in diphoton and dielectron analyses, or track-based exclusivity for analyses of the dimuons and W boson pairs production. These results are presented in the perspective of future experimental and phenomenological studies of the rapidity gap survival probabilities and rescattering effects.

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**Excursion - Informations**Maciej Marek Trzebinski<sup>1</sup><sup>1</sup> *Polish Academy of Sciences (PL)***Corresponding Author(s):** maciej.trzebinski@cern.ch**MPI and small x and diffraction / 37****Forward Drell-Yan cross-section beyond single scattering approximation**Leszek Motyka<sup>None</sup> ; Mariusz Sadzikowski<sup>1</sup> ; Tomasz Stebel<sup>2</sup><sup>1</sup> *Jagiellonian University*<sup>2</sup> *J***Corresponding Author(s):** tomasz.stebel@uj.edu.pl

We present twist expansion of differential cross-sections of forward Drell-Yan (DY) process at high energies. The expansion of all invariant DY form-factors is performed assuming GBW saturation model, and the saturation scale plays the role of the hadronic scale of OPE. It is shown that the Lam-Tung relation is satisfied at twist 2 and broken at twist 4. The results open the way for a forthcoming analysis of multiple scattering and higher twist effects in DY process at the LHC.

**Double Parton Scattering / 2****Glauber Gluons and Multiple Parton Interactions**Jonathan Gaunt<sup>1</sup><sup>1</sup> *DESY*

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Using hadronic transverse energy  $E_T$  as an example, I argue that certain ‘MPI sensitive’ observables do not obey the standard factorisation with hard, collinear and soft functions. I show that the breakdown in this factorisation for MPI sensitive observables occurs at the level of two Glauber gluons exchanged between spectator partons, and link the diagrams containing such exchanges to events with an additional scattering (i.e. events with MPI).

**Double Parton Scattering / 52**

## Higgs boson as a gluon trigger: the study of QCD in high pile-up environments

Hans Van Haevermaet<sup>1</sup>

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In the forthcoming high-luminosity phase of the LHC many of the most interesting measurements for precision QCD studies are hampered by large pile-up conditions, especially at not very high transverse momenta. However, with the recently discovered Higgs boson, which couples in the heavy top limit directly to gluons, we have access to a novel production process to probe QCD by a colour-singlet current. In this study we investigate observables in Higgs boson and Drell-Yan production, and test if they can yield results that are stable in high pile-up environments, and are sensitive to (small-pT) QCD physics in gluon fusion processes. We present results of Monte Carlo event generator calculations for a few specific examples.

**MPI and small x and diffraction / 36**

## High-energy resummation effects in Mueller-Navelet jets production at the LHC

Bertrand Ducloue<sup>None</sup> ; Lech Szymanowski<sup>None</sup> ; Samuel Wallon<sup>None</sup>

We study the production of two forward jets with a large interval of rapidity at hadron colliders, which was proposed by Mueller and Navelet as a possible test of the high energy dynamics of QCD, within a complete next-to-leading logarithm framework. We show that using the Brodsky-Lepage-Mackenzie procedure to fix the renormalization scale leads to a very good description of the recent CMS data at the LHC for the azimuthal correlations of the jets. We argue, based on the comparison of the lowest order non trivial corrections  $\mathcal{O}(\alpha_s^3)$  to the cross section with predictions of an exact calculation, that the inclusion of next-to-leading order corrections to the jet vertex significantly reduces the importance of energy-momentum non-conservation which is inherent to the BFKL approach.

**Underlying Event / 67**

## Improving the forward rapidity gap description in Herwig++

Miroslav Myska<sup>1</sup>

<sup>1</sup> *Czech Technical University (CZ)*

Improving the forward rapidity gap description in Herwig++

**Double Parton Scattering / 45**

## Interference DPDs and polarization in double $c\bar{c}$ (remote talk?)

Tomas Kasemets<sup>1</sup>

<sup>1</sup> *DESY*

We discuss limits on the double parton distributions describing interferences and correlation effects. We present results for the double  $c\bar{c}$  cross section including spin correlations and discuss their effects in the double D0 final state.

**Double Parton Scattering / 10**

## Interparticle correlations in double $J/\psi$ production at hadron colliders

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We focus on the problem of disentangling the single (SPS) and double (DPS) parton scattering modes in the production of  $J/\psi$  pairs at the LHC conditions. Our analysis is based on comparing the shapes of the differential cross sections and on studying their behavior under imposing kinematic cuts. On the SPS side, we consider the leading-order  $O(\alpha_s^4)$  contribution with radiative corrections (taken into account in the framework of the  $k_t$ -factorization approach) and the subleading  $O(\alpha_s^6)$  contribution from pseudo-diffractive gluon-gluon scattering represented by one-gluon exchange and two-gluon exchange mechanisms. We come to the conclusion that disentangling the SPS and DPS modes is hardly feasible on the basis of azimuthal correlations, while the rapidity difference looks more promising, provided the acceptance of the experimental detectors has enough rapidity coverage.

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## Introduction

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**Underlying Event / 33**

## Jets in multiparticle production in and beyond geometry of proton-proton collisions at the LHC

Igor Dremin<sup>1</sup> ; Mark Strikman<sup>None</sup> ; Maxim Azarkin<sup>1</sup>

<sup>1</sup> *Russian Academy of Sciences (RU)*

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Experimental findings of CMS on properties of jets and underlying events at high multiplicities in proton-proton interactions at 7 TeV are interpreted as an indication of increasing role of central collisions with small impact parameters. We find an indication that the rates of different hard processes observed by CMS and ALICE universally depend on underlying event charged-particles multiplicity until it becomes four times more than average. It is shown that the increase of the overlap area of colliding protons is not sufficient for explanation of the rate of jet production in events with charged-particle multiplicity three times higher than average and some new mechanisms are necessary like interaction of protons in rare configurations of higher than average gluon density. Such mechanisms are not properly accounted in the present Monte Carlo event generators.

### MPI and small x and diffraction / 11

## Kinematic corrections to Quarkonia production in the NRQCD approach

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This note represents an attempt to explicitly estimate the effect of final state gluon radiation on the experimental observables. We stress that the energy of the emitted gluons is bounded from below, because the emission of soft colored quanta is prohibited by confinement.

The simulation is organized as follows. First, we generate the production of a color-octet  $c\bar{c}$  state in a usual perturbative way, but with a mass value slightly higher than the nominal  $J/\psi$  mass. After that we generate a two-body decay  $c\bar{c}[8] \rightarrow J/\psi + X$ . We do not specify the nature of the state  $X$ , since the only property of importance is its mass  $m_X$ .

The message of this note is that one should not take the momentum of the intermediate colored state as literally the momentum of the final  $J/\psi$ . We find that the kinematic effect is nearly insensitive to the mass of the emitted quantum  $m_X$  and is only sensitive to the mass difference between the octet state and  $m_\psi$ . Numerically, the corrections amount to as much as +30% to -50% and, if taken into account, may have dramatic influence on the extracted values of the color-octet matrix elements when fitting the data.

### MPI and small x and diffraction / 43

## Kinematical constraint and the CCFM equation

Michal Deak<sup>1</sup>

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The importance of application of the kinematical constraint on the evolution of unintegrated parton density functions in the BFKL formalism was studied in recent publications. In this talk we focus on the role of the kinematical constraint in the CCFM equation. We compare numerical results obtained by solving different versions of the CCFM equation in regards of the way how the kinematical constraint was applied.

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## LHCb plans for Run II and beyond

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LHCb has shown its unique capabilities for production measurements in the forward acceptance. This will only become more important at higher centre of mass energies. The installation of the HERSCHEL forward counters in the LHC tunnel for Run II will greatly increase LHCb's capabilities to identify exclusive hadron production. We will present plans for Run II and give an outlook for the LHCb upgrade in Run III.

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## LHCb results in proton-nucleus collisions at the LHC

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The production of  $J/\psi$  and  $Y$ -mesons decaying into dimuon final state is studied at the LHCb experiment, with rapidity  $1.5 < y < 4.0$  or  $-5.0 < y < -2.5$  and transverse momentum  $p_T < 15$  GeV/c, in proton-lead collisions at a proton-nucleon centre-of-mass energy of 5 TeV. The analysis is based on a data sample corresponding to an integrated luminosity of 1.6/nb. The forward-backward production ratio and the nuclear modification factor are determined for  $J/\psi$  and  $Y(1S)$ . Indication of forward backward production asymmetry is observed. There is also an indication of  $J/\psi$  and  $Y(1S)$  production suppression with respect to proton-proton collisions in forward region and anti-shadowing effect in backward region. Results on vector boson production are also presented.

**Double Parton Scattering / 14**

## Latest Higgs Physics Results from the ATLAS Experiment

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The latest Higgs Results from the ATLAS Experiment will be presented, covering measurements of properties of the discovered Higgs particle and searches for new scalar particles beyond the Standard Model.

**Underlying Event / 66**

## **MPI in Herwig++**

Andrzej Konrad Siodmok<sup>1</sup>

<sup>1</sup> *CERN*

MPI in Herwig++

**Underlying Event / 64**

## **MPI in PYTHIA**

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MPI in PYTHIA

**Underlying Event / 65**

## **MPI in Sherpa**

Korinna Christine Zapp<sup>1</sup> ; Korinna Christine Zapp<sup>2</sup> ; Korinna Christine Zapp<sup>None</sup> ; Korinna Zapp<sup>3</sup> ; Korinna Zapp<sup>4</sup>

<sup>1</sup> *CERN*

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<sup>4</sup> *University of Heidelberg*

MPI in Sherpa

**MPI and small x and diffraction / 25**

## **MPI in low-x QCD measurements at CMS**

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The interpretation of searches for BFKL and saturation phenomena at the LHC depends on a good understanding of the role of multiparton interactions (MPI), which may produce similar experimental signatures. In this talk we discuss recent measurements of integrated leading minijet cross sections in p-p collisions at 8 TeV, and of dijet azimuthal correlations at 7 TeV, performed with the CMS detector. The minijet cross sections are sensitive to the unitarity bound set by the total inelastic cross section, while the correlation measurements are used to search for BFKL effects. The results are compared to models with and without MPI, illustrating the size of the MPI contribution to different observables.

**MPI in collisions with nuclei / 68**

## Manifestations of soft multiparton interactions

Sergey Ostapchenko<sup>1</sup> ; Sergey Ostapchenko<sup>2</sup>

<sup>1</sup> *Norwegian University for Science and Technology (NTNU)*

<sup>2</sup> *University of Karlsruhe*

I'll discuss a phenomenological treatment of soft multiparton interactions in the framework of the Gribov's Reggeon Field Theory. Relations of the soft MPIs to various characteristics of proton-proton and proton-nucleus collisions will be analysed. Finally an impact of soft MPIs on characteristics of cosmic ray induced extensive air showers will be investigated.

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## Measurement of associated Z-boson with prompt charmonium production at the ATLAS experiment

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Recently ATLAS has reported first observation of associated vector-boson and prompt charmonium production in the W+J/psi channel with the 7 TeV pp collision data. This is a key observable to further the understanding of quarkonium production mechanisms. We present new result in this programme: the observation of associated Z-boson + prompt J/psi production with 8 TeV pp collision data and measure its production rate. We estimate the relative contributions to the signal from single and double parton scattering and discuss possible implications of this novel final state for study of multiple parton interactions. Single parton scattering cross-sections are compared to cutting-edge theoretical calculations in the colour singlet and color octet formalisms.

**MPI and small x and diffraction / 15**

## Measurement of the total cross section of pp collisions at sqrt(s)=7 TeV from elastic scattering with the ATLAS detector

Patrick Michel Puzo<sup>1</sup>

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The ATLAS measurement of the total p-p cross section at the LHC at  $\sqrt{s}=7$  TeV is presented. In a special LHC run with high betastar beam optics corresponding to an integrated luminosity of 80 inverse microbarn the elastic scattering process is measured in the range of the momentum transverse  $t$  from  $-t=0.0025$  GeV<sup>2</sup> to  $-t=0.38$  GeV<sup>2</sup> with the ALFA detector of ATLAS. From the extrapolation of the differential elastic cross section to  $t=0$  GeV<sup>2</sup> using the optical theorem the total cross section  $\sigma(pp\rightarrow X)$  is extracted with the luminosity-dependent method. In addition the nuclear slope of the elastic  $t$ -spectrum, the total elastic and inelastic cross sections are determined.

**Underlying Event / 53**

## Measurement of the underlying event activity using charged particle jets in proton-proton collisions at 2.76 TeV

Wei Yang Wang<sup>1</sup>

<sup>1</sup> *National University of Singapore (SG)*

A measurement of the underlying event activity is performed in proton-proton collisions at  $\sqrt{s}=2.76$  GeV, using data collected by the CMS experiment at the LHC. The average multiplicity and scalar-pT sum densities of charged particles in the azimuthal region transverse to the leading charged particle jet at central pseudorapidities are studied. A steep rise of the underlying event activity is seen with increasing leading jet pT up to a few GeV/c, above which a slower rate of increase is observed. By dividing the transverse region into the minimum and maximum activity ones on each side of the leading jet, further information on the dynamic of the UE is obtained. The results are compared to predictions of several QCD-inspired models providing constraints for the tuning parameters involved in these.

**Underlying Event / 16**

## Measurements of event shapes, particle production and their correlations with the ATLAS detector

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The evolution of the event shape variables, such as the transverse thrust, thrust minor and transverse sphericity have been studied for minimum bias events as a function of momentum scale. In addition the high-energy pp collisions at the LHC provide unique opportunity to study particle flow and event shapes of the hadronic final state particles.

The measurements of production properties of mesons and baryons at  $\sqrt{s}=7$  TeV using pp collision data collected with the ATLAS experiment at the LHC are presented and compared to predictions. The measurement of the differential production cross section of the  $\phi(1020)$ -meson as a function of the transverse momentum and rapidity is presented. In addition the measurement of transverse polarization of  $\Lambda$  and  $\Lambda^-$  hyperons produced in minimum bias events is presented. The polarization is measured in bins of the transverse momentum and Feynman- $x$  variable and in the experimentally accessible phase space it is found to be consistent with zero, as predicted by the Standard Model.

Bose-Einstein correlations provide a unique opportunity for detailed understanding of the space-time geometry of the hadronization region, for determining the size and shape of the source from which particles are emitted and for interpreting of quark confinement effects. The ATLAS collaboration has performed a measurement of Bose-Einstein correlations of the pairs of charged particles in p-p collisions at 900 GeV and 7 TeV up to very high charged-particle multiplicities.



**MPI and small x and diffraction / 51****Measurements of event shapes, particle production and their correlations with the ATLAS detector**Robert Astalos<sup>1</sup><sup>1</sup> *Comenius University (SK)***Corresponding Author(s):** robert.astalos@cern.ch

The evolution of the event shape variables, such as the transverse thrust, thrust minor and transverse sphericity have been studied for minimum bias events as a function of momentum scale. In addition the high-energy pp collisions at the LHC provide unique opportunity to study particle flow and event shapes of the hadronic final state particles.

The measurements of production properties of mesons and baryons at  $\sqrt{s}=7$  TeV using pp collision data collected with the ATLAS experiment at the LHC are presented and compared to predictions. The measurement of the differential production cross section of the  $\phi(1020)$ -meson as a function of the transverse momentum and rapidity is presented. In addition the measurement of transverse polarization of  $\Lambda$  and  $\Lambda^-$  hyperons produced in minimum bias events is presented. The polarization is measured in bins of the transverse momentum and Feynman-x variable and in the experimentally accessible phase space it is found to be consistent with zero, as predicted by the Standard Model. Bose-Einstein correlations provide a unique opportunity for detailed understanding of the space-time geometry of the hadronization region, for determining the size and shape of the source from which particles are emitted and for interpreting of quark confinement effects. The ATLAS collaboration has performed a measurement of Bose-Einstein correlations of the pairs of charged particles in p-p collisions at 900 GeV and 7 TeV up to very high charged-particle multiplicities.

**Underlying Event / 12****Measurements of forward neutron and neutral pion productions with the LHCf detector**Gaku Mitsuka<sup>1</sup><sup>1</sup> *Universita e INFN (IT)***Corresponding Author(s):** gaku.mitsuka@cern.ch

The LHC forward (LHCf) experiment has measured neutral particles production in proton-proton and proton-lead collisions at the LHC. The main purposes of the LHCf experiment are first to measure the hadronic production cross sections of neutral particles emitted in very forward angles (pseudorapidity  $> 8.4$ ), and then to test hadronic interaction models widely used in various cosmic-ray experiments for an air-shower simulation.

In this talk, recent physics results in p-p collisions will be discussed. Especially the inclusive energy and transverse momentum spectra of neutrons and neutral pions for different rapidity ranges will be shown.

**MPI and small x and diffraction / 18****New results on Jets within High Energy Factorization**Piotr Kotko<sup>None</sup>

We discuss new results for forward-central and forward-forward dijet production at LHC obtained within the High Energy Factorization approach. For the first jet configuration we make a comparison with the new CMS data and discuss the importance of Sudakov-type resummation.

**MPI and small  $x$  and diffraction / 44**

## On multiple scattering effects in J/psi hadroproduction

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**Co-author(s):** Mariusz Sadzikowski<sup>1</sup>

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We consider a contribution to J/psi hadroproduction in which the meson production is mediated by three initial state gluons. This is a higher twist contribution, but the power suppression is partially compensated by a small- $x$  enhancement in gluon densities. The three-gluon contribution to J/psi hadroproduction is calculated within perturbative QCD in the  $k_T$  factorization framework, and it is found to provide a significant correction to the standard leading twist cross-section at the energies of the Tevatron or the LHC. The results are given as differential  $p_T$ -dependent cross-sections for J/psi polarization components.

**Double Parton Scattering / 29**

## On the transverse structure of double parton distributions

Federico Alberto Ceccopieri<sup>1</sup>

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We extend the recently proposed formalism for the QCD evolution of single-parton transverse-momentum-dependent (TMD) distributions to double parton distributions (DPS). We show, within a DPS simplified model in which no correlations are assumed at the starting scale, the effects of TMD evolution on quantities relevant for double parton scattering at higher scales.

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## Opening

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## Registration

**MPI and small  $x$  and diffraction / 26**

## Report from the LHC Forward Physics Working Group

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In this status report from the LPCC Forward Physics working group, studies looking towards future forward diffractive and low-x physics at the LHC will be reported. These cover a range of different beam optics, luminosity requirements and specialized forward detector simulations and will give specific focus to areas strongly affected by MPI effects. Topics covered shall include soft and hard diffractive physics, double Pomeron exchange - including CEP vector mesons, di-jet and gamma+jet and searches for anomalous quartic coupling using proton tagging.

**MPI in collisions with nuclei / 50**

### Rope hadronization

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The Lund string model has provided a solid framework for hadronization since the LEP era. In the busy environment of pp minimum bias events at LHC, or heavy ion collisions, strings will overlap, and corrections from interference effects will have large effects on the hadro-chemistry of events. We present a model for rope hadronisation, and its implementation in the DIPSY event generator, which corrects the ordinary Lund string model hadronization for interference effects. The inclusion of rope effects is seen to greatly improve the description of baryon/meson ratios and strange content in pp as well as AA collisions.

**MPI and small x and diffraction / 47**

### Studies of azimuthal decorrelation of dijets with a jet veto with ATLAS

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Measurements of di-jet systems with a veto on additional jets, probe QCD radiation effects. The two jets in each event with the highest transverse momentum are taken as the dijet system and a rapidity interval is defined as the region in rapidity between the centroids of these two jets. The fraction of dijet events without an additional jet in this rapidity interval and the mean jet multiplicity in the interval are presented as a function of the mean transverse momentum of the dijets and of the rapidity interval size. Correlations between the azimuthal angles of the dijets are studied both with and without a veto on additional jet activity in the rapidity interval between the jets. This study probes different approaches to the resummation of large logarithms when performing QCD calculations.

**Underlying Event / 17**

## **Studies of the underlying event and event shapes with ATLAS**

Oldrich Kepka<sup>1</sup>

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Studies of the underlying event and event shapes with ATLAS

Particle distributions sensitive to the underlying event and multi-parton interactions in proton-proton collisions have been measured with the ATLAS detector at the LHC at 7 TeV centre-of-mass energy. Various complementary measurements are presented, e.g. charged particle multiplicity, charged and inclusive sum transverse momentum densities and mean charged-particle transverse momentum in the regions of each event azimuthally transverse to the hardest jet or Z boson directions. Evolution of the event shape variables, such as the transverse thrust, thrust minor and transverse sphericity have been studied for minimum bias events as a function of momentum scale. In addition the high-energy pp collisions at the LHC provide unique opportunity to study particle flow and event shapes of the hadronic final state particles. When compared to the predictions of different Monte Carlo models, the data show sensitivity to the modelling of the underlying event.

**MPI and small x and diffraction / 22**

## **The heavy quark impact factor and double b production separated by rapidity**

German Rodrigo<sup>1</sup> ; Grigorios Chachamis<sup>2</sup> ; Michal Deak<sup>3</sup>

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We present the calculation of the finite part of the heavy quark impact factor at next-to-leading logarithmic accuracy in a form suitable for phenomenological studies at the LHC within the kT-factorization scheme. We apply our result in the calculation of the production of bb/ bbbar/ bbarbbar pair separated in rapidity. We compare our results with the collinear factorisation approach.

**MPI and small x and diffraction / 34**

## **Three-Dimensional Parton Densities in the Small-X Regime: Theoretical Aspects of Evolution and Factorization**

Igor Cherednikov<sup>1</sup>

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We address some unresolved issues in the field-theoretic description of the three-dimensional intrinsic structure of the nucleon accessible in the current and planned high-energy experiments. The emphasis is placed on the comparative analysis of the BFKL-, CCFM- and DGLAP-type resummation approaches and corresponding evolution equations for unintegrated and transverse-momentum dependent parton distributions.

## Double Parton Scattering / 4

### Towards correlations in double parton distributions (remote talk)

**Author(s):** Alexander Snigirev<sup>1</sup>

**Co-author(s):** Gennady Zinovjev<sup>2</sup>; Nina Snigireva<sup>3</sup>

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<sup>2</sup> *Bogolyubov Institute for Theoretical Physics, National Academy of Sciences of Ukraine*

<sup>3</sup> *School of Mathematical Sciences, University College Dublin*

Using the explicit form of the solutions of evolution equations in the Mellin representation we conclude that the double parton distribution functions “forget” the initial correlation conditions (unknown a priori) at not parametrically small longitudinal momentum fractions and the correlations perturbatively calculated survive only in the limit of large enough hard scales.

## MPI in collisions with nuclei / 21

### Transverse momentum dependent gluon density at low $x$

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We present new results on the unintegrated TMD (transverse momentum dependent) gluon density (u.g.d.) at low  $x$ , which is based on our previous study [1]. We match this u.g.d. at low transverse momenta  $|k_T|$  and starting scale  $Q_0^2 = 1 - 3 \text{ GeV}^2$  to the exact solution of the BFKL equation for the u.g.d. outside of the saturation region at large  $|k_T|$  obtained in [2], which includes all multiple Pomeron exchanges. Then, to extend this u.g.d. at higher  $Q^2$  we use the Catani-Ciafoloni-Fiorani-Marchesini (CCFM) evolution equation. The inclusion of the CCFM evolution results in a large increase of the u.g.d. magnitude at low  $x$  and large  $|k_T|$  above a few GeV/c. The application of the obtained gluon distribution to the analysis of the  $ep$  deep inelastic scattering allows us to get the results, which describe reasonably well the H1 and ZEUS data on the longitudinal proton structure function  $F_L(x, Q^2)$ ,  $F_{2c}(x, Q^2)$  and  $F_{2b}(x, Q^2)$ . In addition to this the use of new u.g.d. allows us to describe satisfactorily the LHC data on heavy meson production and especially the correlation between two B-mesons produced in  $pp$  collisions. The comparison of our new TMD unintegrated gluon density to the another ones is presented.

References

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#### MPI in collisions with nuclei / 39

### Transverse momentum spectra of light-flavor hadrons measured with ALICE in pp, p-Pb and Pb-Pb collisions at the LHC

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The transverse momentum spectra ( $p_T$ ) of light-flavor hadrons measured with ALICE in pp, p-Pb and Pb-Pb collisions at the LHC will be presented. Distributions in  $p_T$  and mean  $p_T$  as a function of particle multiplicity and/or collision centrality will be shown in the broad kinematical range, which varies depending on hadron species. Details of multiplicity and centrality selection, with emphasis on possible biases on the  $p_T$  spectra, will be provided. The obtained results in pp, p-Pb and Pb-Pb collisions will be compared, and will be confronted with theoretical models.

#### Underlying Event / 54

### UE and minimum bias tunes from CMS

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We will report on recent development on underlying events and minimum bias MC tunes

#### Underlying Event / 24

### Underlying events in EPOS 3

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Underlying event studies are very important for the reconstruction of all jets based high energy physics measurements. For Monte Carlo generator it is a very difficult test since it is probing the soft QCD physics in correlation with hard scale events. As a consequence it is challenging for both HEP type models like PYTHIA which are optimized to reproduce mainly hard scale processes and for

event generators like EPOS which are optimized for soft scale processes (heavy ion and air shower simulations). For instance EPOS LHC could reproduce nicely the data up to a transverse momentum of a few GeV where PYTHIA was actually starting to give better results. Using the new EPOS 3 hadronic interaction model, we will show how the two approaches can be reconcile using a variable saturation scale and if the data can be correctly reproduced.

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## Welcome

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