Perspectives and remarks on MPI related studies at the (HL)-LHC

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A personal view at the moment.

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Multi-Parton interactions



MPI = Multi-Parton interactions

MPI: basis of underlying event and minimum bias physics in *pp* event generators (and in our heads)

strongly relying on parameterisation of data and heavy modelling: different pictures can often provide description of data

relevant for basically all measurements in inelastic collisions

at the LHC: higher probability to have multiple "hard" interactions in one collision than at lower collision energy

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Motivations for MPI studies



ALICE MB event display, CMS Higgs $\rightarrow \gamma\gamma$

- 1. modest: improve simulations of whole event for better inclusive measurement: dominating attitude in HEP \rightarrow "underlying event"
- 2. ambitious: "learn" something about more exclusive observables:
 - \rightarrow correlation between soft and hard particle production
 - \rightarrow role of geometry, other fluctuations, correlations between partons
- Connection to heavy-ion physics: → correlation between geometry and soft/hard particle production used for classification in heavy-ion collisions many observables insensitive to microscopic modelling for typical large dynamic ranges of multiplicities in semi-central /central nucleus-nucleus collisions
 - \rightarrow Better understanding might be needed to map calculations to measurements in the context of "collectivity"

MPI-sensitive observable classes



- correlation of hard particle production with overall/soft production underlying event analysis, hard production/property studies as function of event multiplicity
- 2. multiple "hard" production measurements

First class mostly interpreted in terms of event-generator models

A view on the current situation

- underlying event studies: mostly early results for generator tuning → new ideas/observables wit complementary information that are also beneficial for HEP colleagues?
- studies of hard probes as function of multiplicity via minimum bias and high-multiplicity triggers:

 \rightarrow large data samples not yet analysed, following slides some comments: statistics often not the main limitation

- ▶ Double/Multiple "hard" parton scattering studies: straightforward by-product of trigger menus of ATLAS/CMS (W,Z,jets and high-p_T objects in general), LHCb bulk bottom/charm → measurement opportunities automatically promoted towards rarer channels with larger luminosities
- in general: effort needed, what could bring conceptual progress independent of specific ansatz

Remarks on studies as function of event multiplicity



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- multiplicity distribution steep
- ▶ fight at some point impurity for extremely rare events: pile-up → put constraints on data taking conditions
- ▶ to be seen what are the experimental limits also in terms of resolution

Remarks on studies as function of event multiplicity: example ALICE





- qualitatively reproduced by all event generators
- \blacktriangleright difficult to conclude by now: probably room for retuning in generators, effects at most 2.x σ
- seems statistically limited
 - \rightarrow possible with open charm: more statistics
 - \rightarrow for quantitative comparisons care needed

Remarks on studies as function of event multiplicity



Left: multiplicity estimator distribution pp vs pPb from Phys. Rev. C 91, 064905; Right: Correlation between another estimator and multiplicity in pPb 2013 from , CERN-THESIS-2016-031.

 need proper comparisons for model falsification beyond qualitative findings

0) interface with models should be well-defined measureable quantities in model and in data $% \left({{\left[{{{\rm{c}}} \right]}_{{\rm{c}}}}_{{\rm{c}}}} \right)$

 \rightarrow avoid model assumption in observable itself, or, at least, provide particle (not detector)-level input of observables

 $1)\ \text{correction}\ \text{to}\ \text{particle}\ \text{level}\ \text{or}\ \text{correlation}\ \text{matrix}\ \text{between}\ \text{particle}\ \text{and}\ \text{detector}\ \text{level}$

2) analysis available in rivet

Example for Double-Parton scattering probe in pp/pPb: LHCb



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- ▶ about σ_{cc} 10% of $\sigma_{c\bar{c}}$ in LHCb acceptance → at low scales DPS already significant for quite inclusive observables
- for this example and for similar measurements, extension from pp to pPb possible

 \rightarrow variation of geometry without reliance on modelling by interchange of one of the projectiles

generators/models used for soft-hard correlation: to be applied also here to check for overall consistency of picture

New directions?

- 1. event-shape differential analysis: sphericity, event-shape engineering in pp
- 2. an idea: publish fully efficiency corrected MB events or underlying event in fiducial phase space with high efficiency
 - \rightarrow data start to be public anyhow

 \rightarrow allow model-builders to play with new, potentially higher dimensional projections for model validation with proper systematic uncertainties and no need of completely new analysis just for one new projection of data \rightarrow possible at all (S/B good enough)? worth the effort?

Conclusions

- minimum bias and underlying event measurements: further studies with current data certainly possible, comparison of different triggers, more differential
- multiple hard probe production: natural extension to rarer processes with larger luminosities
- multiplicity dependent studies: extensions under way
- personal view on limitations and progress:

 \rightarrow better standardised synchronous comparisons of already existing/new soft data to fully exploit data: under way

 \rightarrow big improvements for parameterisation of data possible, not clear for conceptual part

 \rightarrow if attempt to falsify part of the implemented event-generator/model pictures: rather new ideas than more data needed