Multiparticle correlations in pp-collisions at $\sqrt{s} = 13$ TeV

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The factorial moment method

- *A. Bialas, R. Peschanski.* Moments of rapidity distributions as a measure of short-range fluctuations in high-energy collisions // Nuclear Physics B. 1986. vol. 273, p. 703-718.

- Method consists in analyzing the dependence of normalized factorial moments of multiplicity distribution in the intervals of a kinematic variable on the size of these intervals and allows one to exclude statistical effects associated with the finite number of particles produced in events.

- Let $\Delta\eta$ be the pseudorapidity interval which is divided into M bins of the size $\delta\eta = \Delta\eta/M$. Let n_i be the particle multiplicity in the i-th bin and let N be the total particle multiplicity in the whole $\Delta\eta$ interval. Then the normalized factorial moment of multiplicity distribution of the q-th order is defined as follows:

$$F_q^h(\delta\eta) = M^{q-1} \left\langle \sum_{i=1}^{M} \frac{n_i(n_i-1)(n_i-2)...(n_i-q+1)}{N(N-1)(N-2)...(N-q+1)} \right\rangle_{events}.$$

- For statistically independent particle production with a uniform distribution factorial moments of any order are constant and equal to 1. Any deviation from unity, particularly a dependence on the bin width $\delta\eta$, signals the presence of correlations among produced particles.

Mathematical model

- We consider a simple mathematical model inspired by the clan model of multiparticle production proposed by Giovannini and Van Hove.

- *A. Giovaninni, L. Van Hove*. Negative binomial properties and clan structure in multiplicity distributions // Acta Phys. Pol. B. 1988. vol. 19, p. 495-510.

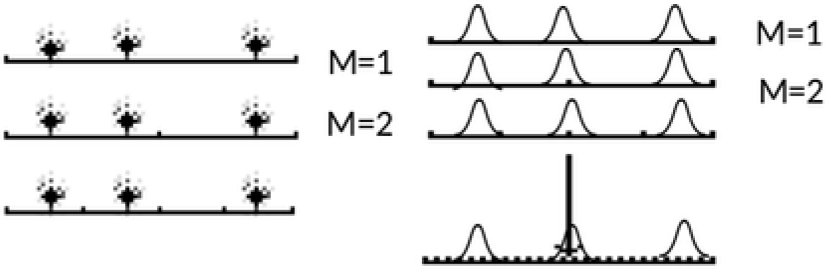
1. Particles in events are produced in groups.
2. Each group contains at least one particle.
3. The number of groups can't be greater than the number of particles.
4. The number of groups follows the Poisson distribution with the mean λ.
5. The number of particles in a group follows the Geometric distribution.

- Let m be the number of groups and α be the probability that a particle belongs to a group. The probability of producing k particles in the interval $\Delta\eta$ is then given by:

$$P(k) = \sum_{m=0}^{k} \frac{e^{-\lambda}\lambda^m}{m!} \binom{k-1}{m-1} \alpha^{k-m}(1-\alpha)^m.$$

Cases of particle clustering

1. Non-point-like groups: if the particle position fluctuates with respect to the group center η_c by a Gaussian distribution (with σ) in the vicinity of the group center.
2. Point-like groups: the extreme case of $\sigma = 0$, all particles have the η value equal to η_c.

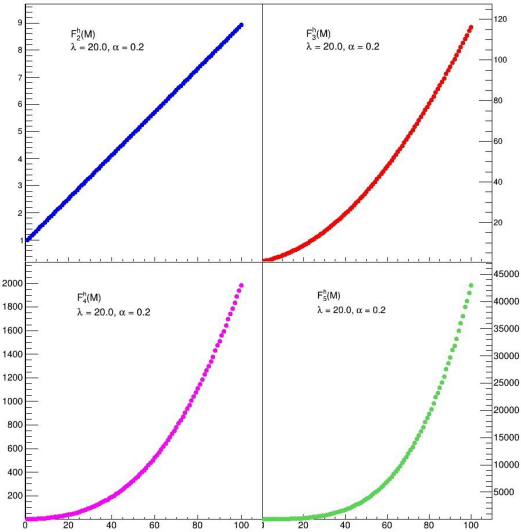


Point-like groups

- *Bogolyubskii M. Y. et al.* Clan model and factorial moments of the multiplicity distribution in intervals // Physics of Atomic Nuclei. 1994. vol. 57, number 12.

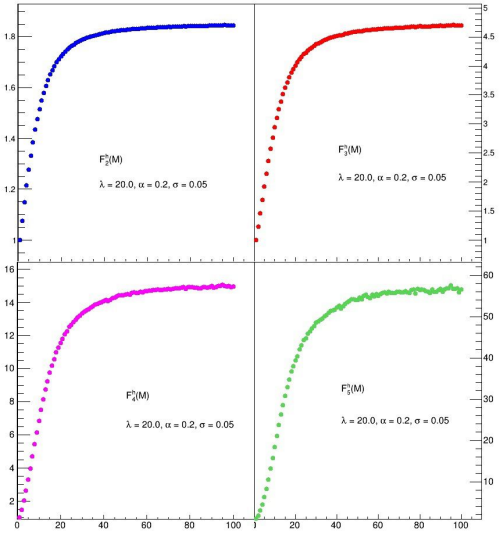
- In case of point-like groups the $F_q^h(M)$ dependence can be evaluated analytically and is a polynomial function with a degree of a polynomial $q-1$:

$$F_q^h(M) = \sum_{k=0}^{q-1} A_k^h M^k.$$



Non-point-like groups

- *Bogolyubskii M. Y. et al.* Clan model and factorial moments of the multiplicity distribution in intervals // Physics of Atomic Nuclei. 1994. vol. 57, number 12.
- In case of non-point-like groups the $F_q^h(M)$ dependence tends to a constant with the bin size becoming much less than a characteristic group width ($\delta\eta \ll \sigma$).



Used MC datasets: DY+jets

Dataset name	Cross-section [pb]
DYJetsToLL_M-50_TuneCH3_13TeV-madgraphMLM-herwig7	6077 (NNLO)
DYJetsToLL_M-50_TuneCP5_13TeV-madgraphMLM-pythia8	6077 (NNLO)
DY1JetsToLL_M-50_MatchEWPDG20_TuneCP5_13TeV-madgraphMLM-pythia8	977 (NNLO)
DY2JetsToLL_M-50_MatchEWPDG20_TuneCP5_13TeV-madgraphMLM-pythia8	347 (NNLO)
DY3JetsToLL_M-50_MatchEWPDG20_TuneCP5_13TeV-madgraphMLM-pythia8	126 (NNLO)
DY4JetsToLL_M-50_MatchEWPDG20_TuneCP5_13TeV-madgraphMLM-pythia8	72 (NNLO)
DYJetsToLL_M-50_TuneCP5_13TeV-amcatnloFXFX-pythia8	6077 (NNLO)
DYJetsToMuMu_M-50_TuneCP5_ZptWeighted_13TeV-powhegMiNNLO-pythia8-photos	6077/3 (NNLO)
Sherpa private generation	6077/3 (NNLO)

ME calculation: aMC@NLO / MadGraph / POWHEG / Sherpa
Parton shower and hadronization: Herwig7 / PYTHIA8 / Sherpa

Used MC datasets: background

Dataset name	Cross-section [pb]
TTTo2L2Nu_TuneCP5_13TeV-powheg-pythia8	88.3 (NNLO)
WWTo2L2Nu_TuneCP5_13TeV-powheg-pythia8	12.2 (NNLO)
WZTo2Q2L_mllmin4p0_TuneCP5_13TeV-amcatnloFXFX-pythia8	6.4 (NLO)
WZTo3LNu_TuneCP5_13TeV-amcatnloFXFX-pythia8	5.2 (NLO)
ZZTo2L2Nu_TuneCP5_13TeV_powheg_pythia8	0.97 (NLO)
ZZTo2Q2L_mllmin4p0_TuneCP5_13TeV-amcatnloFXFX-pythia8	3.7 (NLO)
ZZTo4L_TuneCP5_13TeV_powheg_pythia8	1.3 (NLO)

Used samples

Sample	Size [events]
aMC@NLO+Py8 (inc. NLO)	196329377
MadGraph+H7 (inc. LO)	29578468
MadGraph+Py8 (inc. LO)	103344974
MadGraph+Py8 ($\geq$ 4j LO)	227989474
POWHEG+Py8 (inc. NLO)	5989403
Sherpa (inc. NLO)	6000000

Used kinematic and event cuts

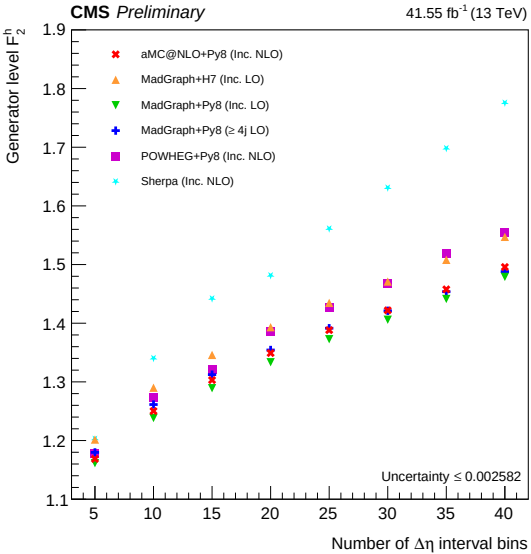
Particle selection
particle is charged
$p_T > 0.5$ GeV
$\lvert\eta\rvert \leq 1$

Muon selection
$\lvert\eta\rvert \leq 2.4$

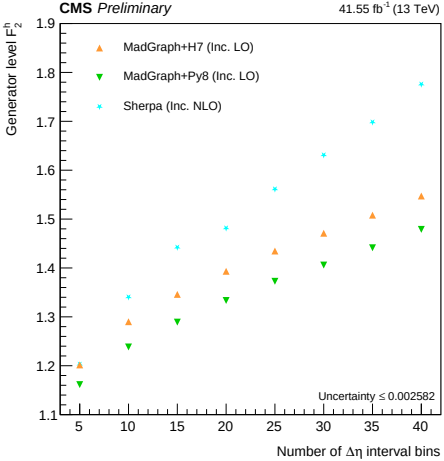
Event selection
$p_T(\mu_1) \geq 25$ GeV & $p_T(\mu_2) \geq 10$ GeV
$70 \leq m_{\mu\mu} \leq 110$ GeV

Every distribution or dependence is normalized to the integrated luminosity of 41.55 fb^{-1}, which corresponds to the 2017 data taking year.

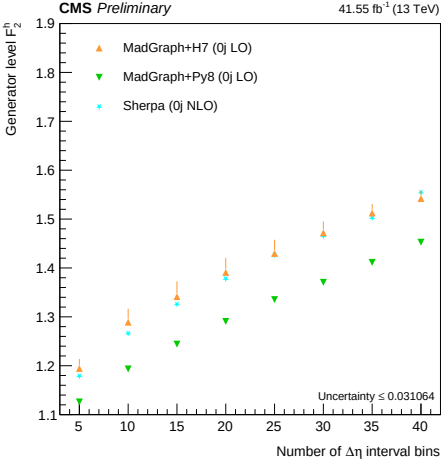
Generator level $F_2^h(M)$ dependencies after event cuts



Generator level $F_2^h(M)$ dependencies after event cuts: H7 vs Py8 vs Sherpa

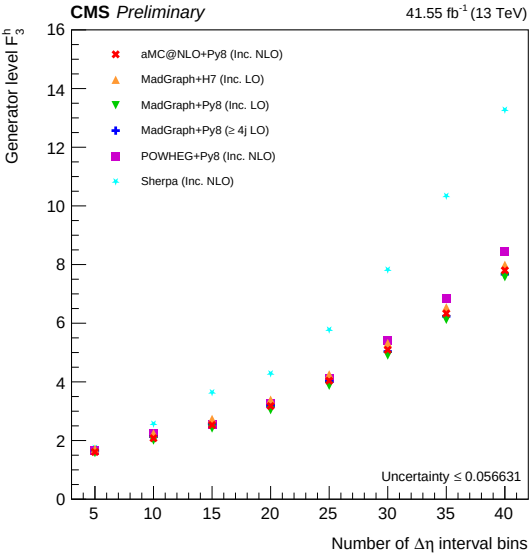


$N_{partons} = \text{all}$

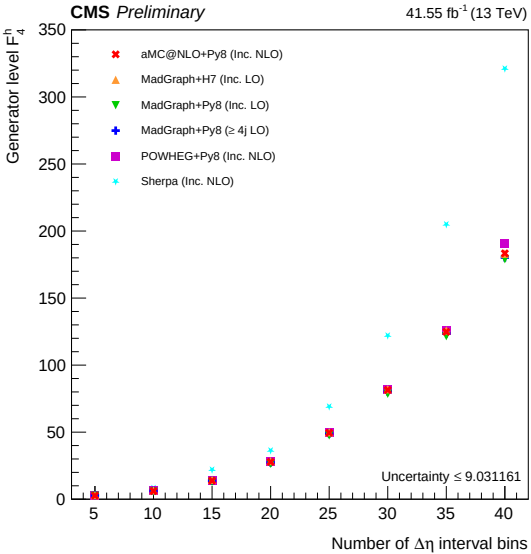


$N_{partons} = 0$

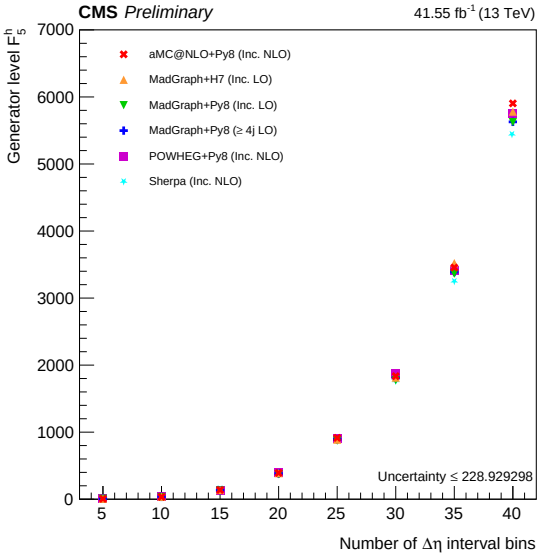
Generator level $F_3^h(M)$ dependencies after event cuts



Generator level $F_4^h(M)$ dependencies after event cuts



Generator level $F_5^h(M)$ dependencies after event cuts



Conclusions

1. We observe the small dependence of normalized factorial moments of multiplicity distribution on the strong coupling order.

2. We observe the strong dependence of normalized factorial moments of multiplicity distribution on the parton shower and hadronization (PYTHIA8 vs Herwig7 vs Sherpa).

3. The decrease in the number of partons just slightly changes the values of factorial moments for PYTHIA8 and Herwig7, but the behaviour of the $F_q^h(M)$ dependencies does not change.

4. The decrease in the number of partons changes both the values of factorial moments and the behaviour of the $F_q^h(M)$ dependencies for Sherpa.

Conclusions

- Since the values of normalized factorial moments of multiplicity distribution may be directly related to the number of produced particles and to the number of produced groups of particles in events, the assumption about differences in clusterization processes in different generators makes sense. In particular, group widths and probabilities of particles to be clustered in a group may vary in different theory approaches.

- To summarize, the method of normalized factorial moments of multiplicity distribution to study multiparticle correlations can be used for tuning Monte-Carlo generators and testing their performance via comparison with experimental data.

THANK YOU FOR YOUR ATTENTION!