Multiparticle correlations in *pp*-interactions at 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, number 3-4, p. 703-718.

- Method consists in building the dependence of normalized factorial moments of the multiplicity distribution in the pseudorapidity interval $\Delta\eta$ on the bin size (number of bins):

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

- The factorial moment method allows one to suppress the statistical fluctuations related to finite particle multiplicities in the events.

- By analogy with the theory of turbulence the intermittency phenomenon was introduced. When applied to the process of multiparticle production, intermittency is defined as the power law $F_q^h(M) \sim M^{\varphi_q}$ and is a sign of dynamical fluctuations of particle multiplicities in the events.

Mathematical model

- For simplicity we consider a mathematical model which can be related to the clan model of multiparticle production proposed by Giovanni & Van Hove.

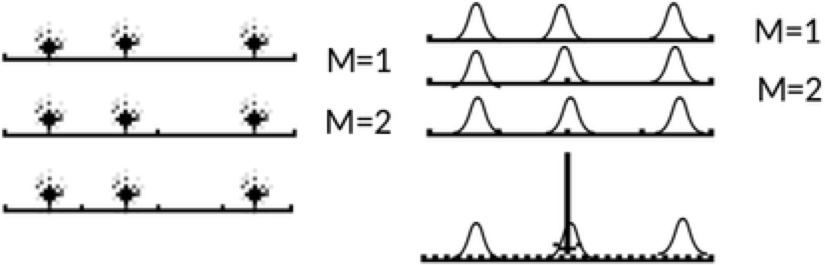
- *A. Giovanni, L. Van Hove*. Negative binomial properties and clan structure in multiplicity distributions // Acta Phys. Pol. B. 1988. vol. 19, p. 495-510.

- The considered mathematical model is based on the following assumptions:
  1. particles in event are produced in groups, moreover each group contains at least one particle;
  2. number of produced groups cannot be greater than the number of produced particles;
  3. number of groups produced in the event follows the Poisson distribution;
  4. number of particles in a group follows the Geometric distribution.

- Let m be the number of groups produced in event and α be the probability that a particle is produced in a group. Thus the multiplicity probability density to produce k particles on the $\Delta\eta$ interval is given by the next equation:

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

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.

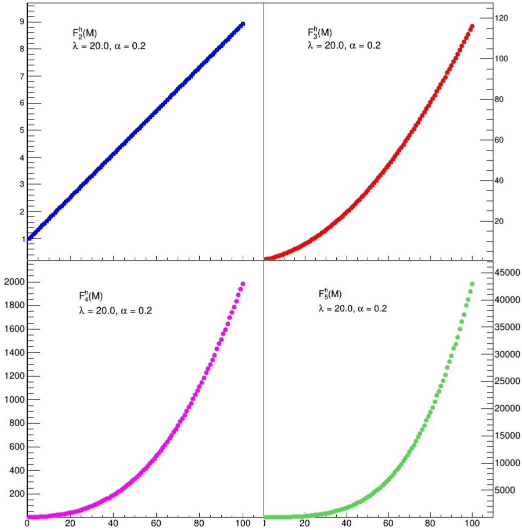


Point-like groups

- *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 $q-1$:

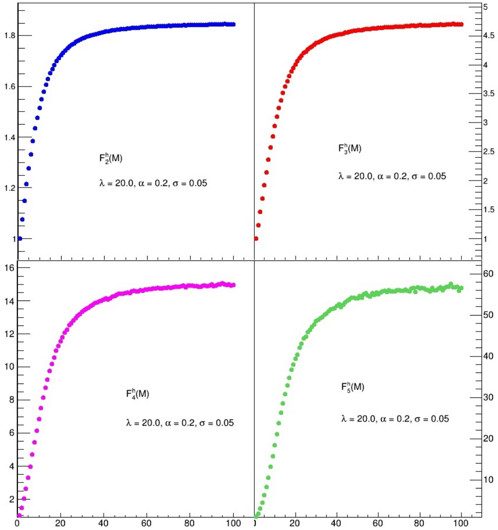
$$F_q^h(M) = \sum_{k=0}^{q-1} A_k^h M^k.$$



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 ($\delta\eta \ll \sigma$).



Drell-Yan process $q\bar{q} \rightarrow Z \rightarrow \mu^+\mu^-$ in pp-collisions at $\sqrt{s} = 13$ TeV:

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)
DY01234jets_13TeV-sherpa	6077 (NNLO)

Used data and framework

Background processes:

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 data and framework

Sample	Size
aMC@NLO+Py8	$\sim$ 196 M events
MadGraph+Py8 01234 jets	$\sim$ 228 M events
MadGraph+Py8 inclusive	$\sim$ 103 M events
MadGraph+H7 inclusive	$\sim$ 30 M events
POWHEG+Py8	$\sim$ 6 M events
Sherpa	$\sim$ 103 M events
Background	$\sim$ 323 M events

Used data and framework

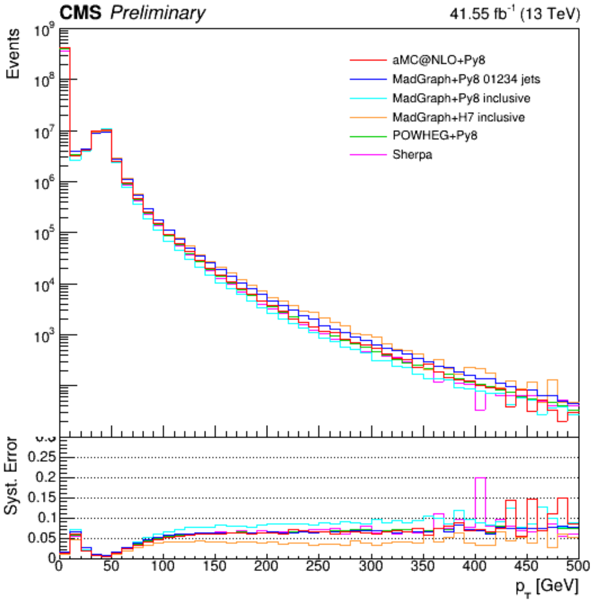
Particle selection
particle is charged
$p_T > 0.5$ GeV
$\|\eta\| \leq 1$

Muon selection
$\|\eta\| \leq 2.4$

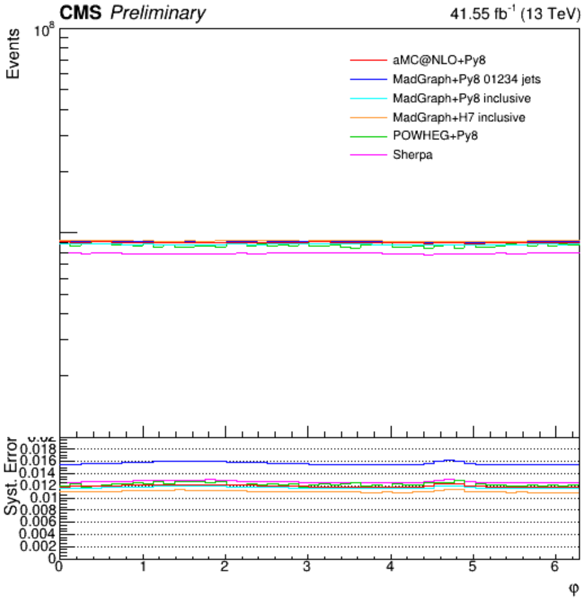
Event selection
$70 \leq m_{\mu\mu} \leq 110$ GeV

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

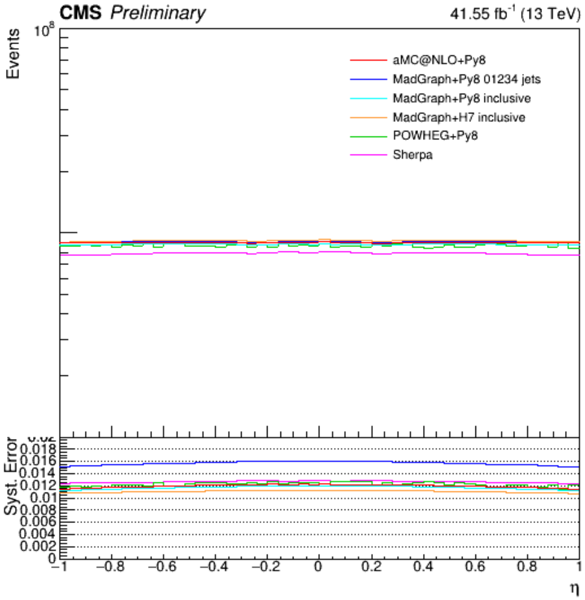
Generator level p_T distributions after event selection



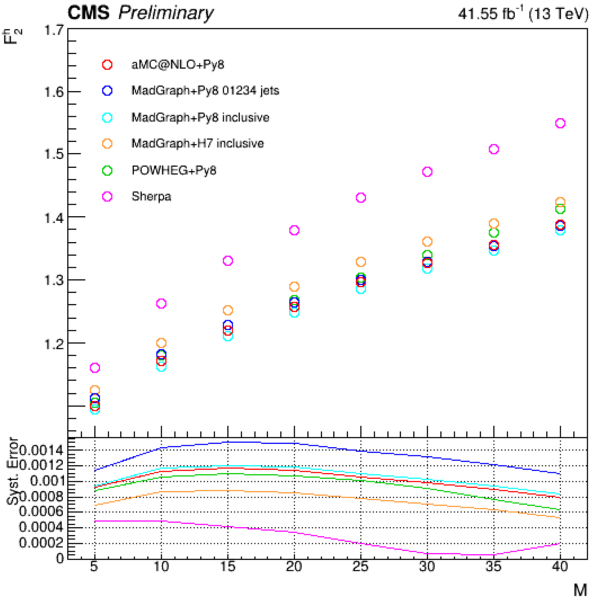
Generator level φ distributions after event selection



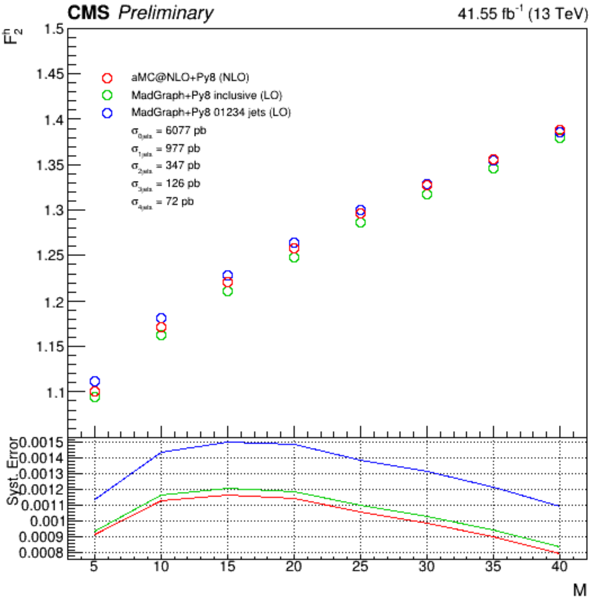
Generator level η distributions after event selection



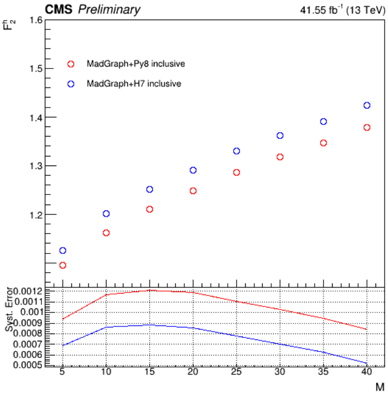
Generator level $F_2^h(M)$ dependencies after event selection



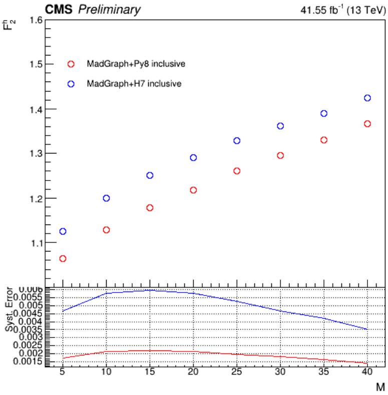
Generator level $F_2^h(M)$ dependencies after event selection: LO vs NLO



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

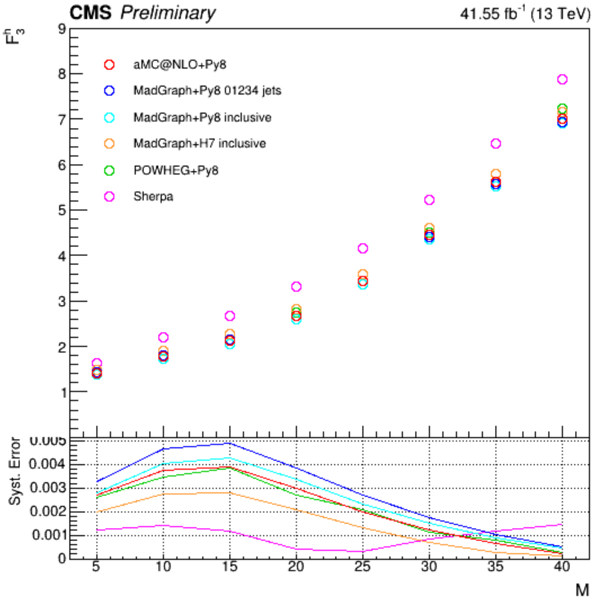


$N_{partons} = \text{all}$

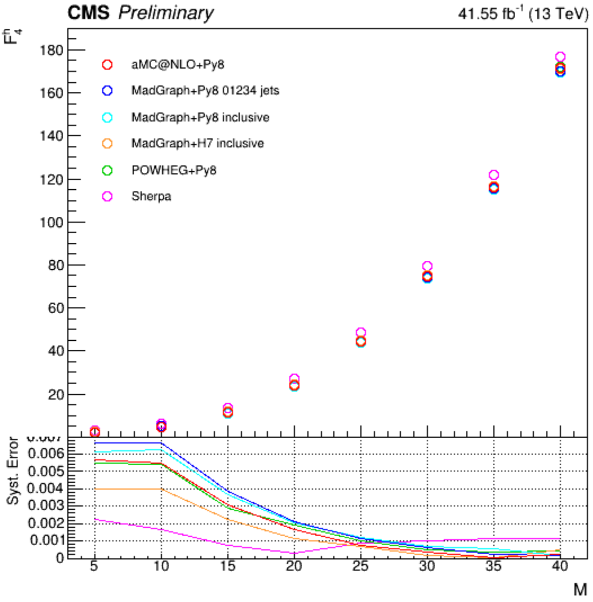


$N_{partons} = 0$

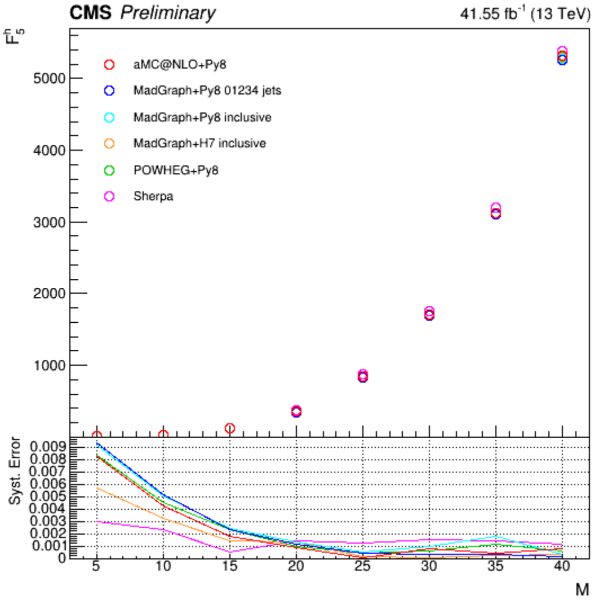
Generator level $F_3^h(M)$ dependencies after event selection



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



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



- We observe dependencies of normalized factorial moments of the multiplicity distribution on the details of theoretical calculations:

  1. the small dependence of normalized factorial moments of the multiplicity distribution on the strong coupling order;
  2. the strong dependence of normalized factorial moments of the multiplicity distribution on the parton shower and hadronization (PYTHIA 8 vs Herwig 7);
  3. decrease in the number of partons just slightly changes the values of factorial moments, but the behaviour of the $F_q^h(M)$ dependencies does not change;
  4. normalized factorial moments of the multiplicity distribution evaluated using Sherpa sample exceedes those evaluated using all other samples.

Conclusions

- Since the values of normalized factorial moments of the 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.

- In summary, the method of normalized factorial moments of the multiplicity distribution to study multiparticle correlations can be used as an additional measure for the underlying events activity.

THANK YOU FOR YOUR ATTENTION!