Extraction of multiple parton interactions from forward-backward multiplicity correlations

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E. Cuautle, E.Dominguez, I. Maldonado, Eur. Phys. J.C.79 (2019) 626

Main goal of the talk

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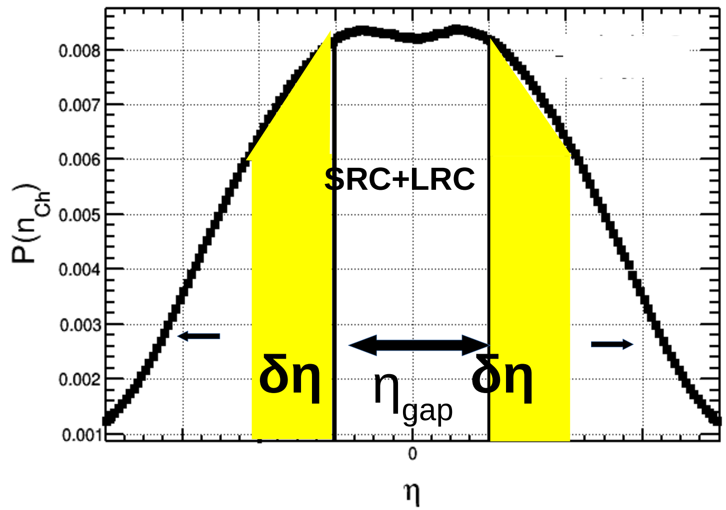
Pseudorapidity Distribution

Backward Multiplicity (n_B)



Forward Multiplicity (n_F)

Theoretical deduction
PRD 29, 2512 (1984)
PRD18, 4120 (1978)

$$b_{corr} = \frac{\langle n_F n_B \rangle - \langle n_F \rangle \langle n_B \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2}$$

$$b_{Corr} = b_{Corr}(\delta\,\eta)$$
$$b_{Corr} = b_{Corr}(\eta_{gap})$$

- ✔ Models of the number of Multiple Parton Interaction (<nMPI>) and Color Reconection (CR) could be used to extract information of pp collisions.
- ✔ Direct measurements of CR and <nMPI> is not possible.
- ✔ Measuring b_{corr} one can get CR and using it is possible to extract the < nMPI > for different energies.
- ✔

Talk based on Eur. Phys. J. C, 79, (2019) 626

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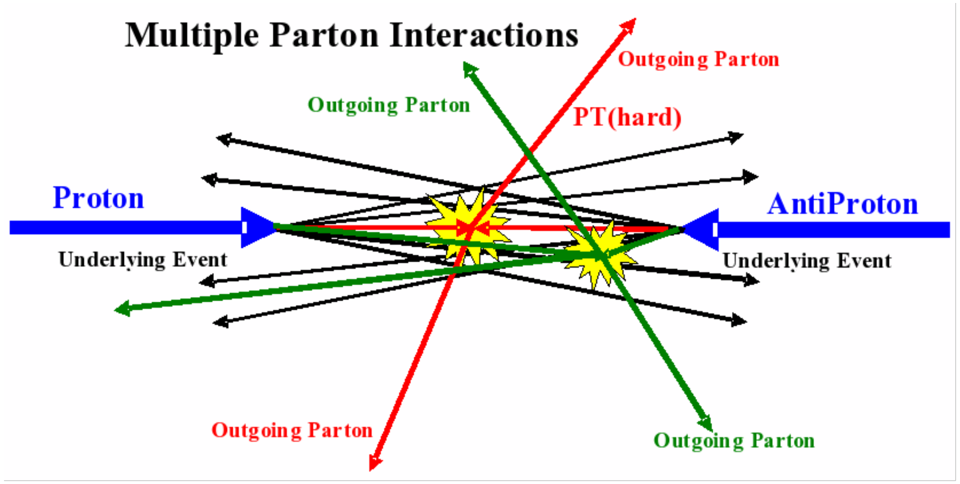
Outline

- **Relationship between data and models**
  - Multiple Parton Interactions and multiplicity
  - Color reconnection and average p_T
- **Simulation of proton-proton collisions**
  - Relationship between Multiple parton interactions vs multiplicity, energy,...
- **Forward-Backward multiplicity correlations**
  - As a function of color reconnection, vs data
  - As a function of multiple parton interactions, vs data
- **Conclusions**

Multiple parton interactions and multiplicity



$$\frac{d\sigma}{dp_T{}^2} = \sum_{i,j,k} \int \int \int dx_1 dx_2 d\hat{t}\, \hat{\sigma}_{ij}^{k}(\hat{s},\hat{t},\hat{u}) f_i^1(x_1,Q^2) f_j^2(x_2,Q^2)\, \delta\left[p_T{}^2 - \frac{\hat{t}\,\hat{u}}{\hat{s}}\right]$$

Hard cross section above $p_{Tmin\,;}$ is:

$$\sigma_{\rm hard}(p_{T\rm min}) = \int_{p_{T\rm min}{}^2}^{s/4} \frac{d\sigma}{dp_T{}^2}\, dp_T{}^2 \,.$$

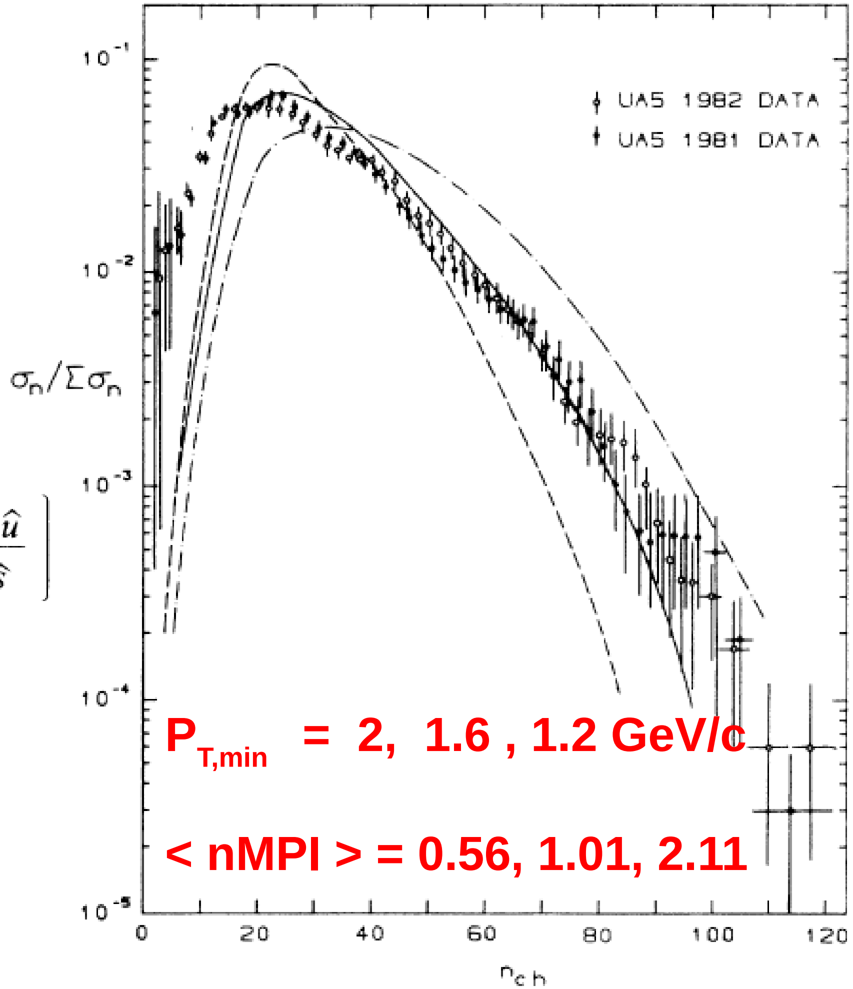


FIG. 5. Charged-multiplicity distribution at 540 GeV, UA5 results (Ref. 32) vs impact-parameter-independent multiple-interaction model: dashed line, $p_{T\rm min}=2.0$ GeV; solid line, $p_{T\rm min}=1.6$ GeV; dashed-dotted line, $p_{T\rm min}=1.2$ GeV.

Sjöstrand, et. al
Phys. Rev. D36, 2019 (1987)

Color reconnection effects on <p_T>

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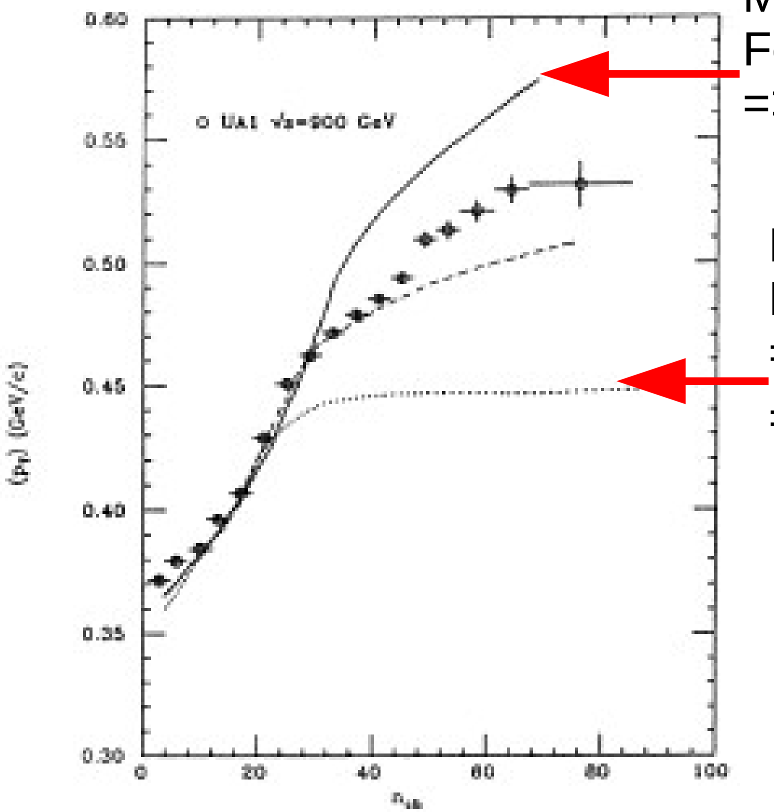
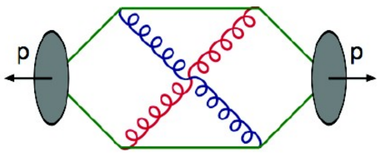
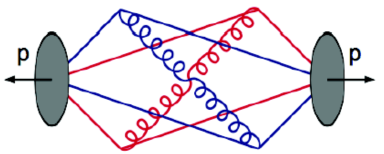


Minimal string length:
For each consecutive interaction
=> <p_T> (n_{ch}) ~ rising.



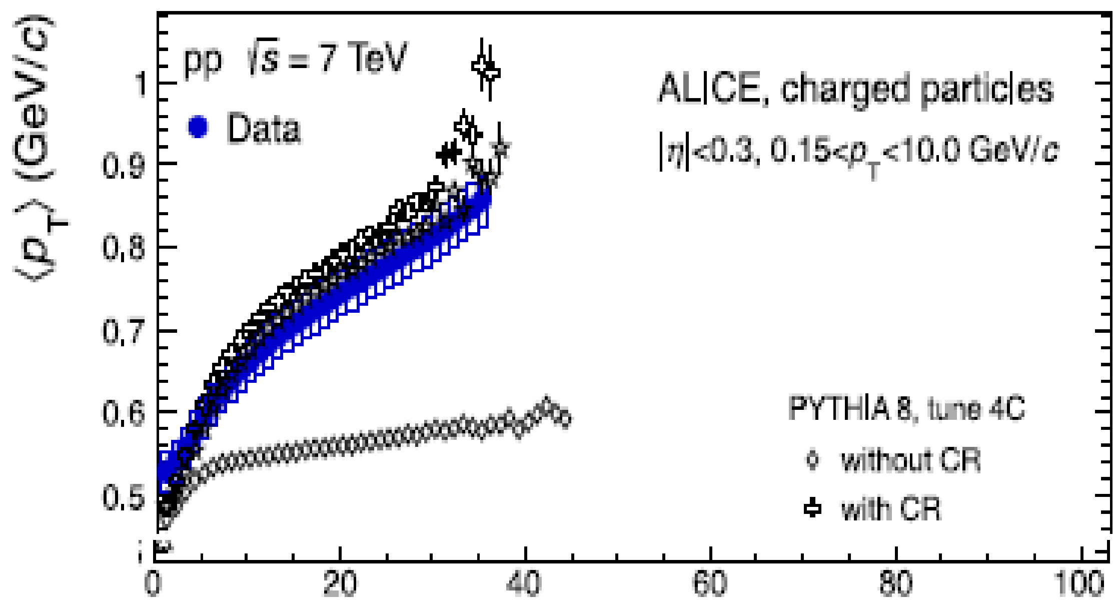
Maximal string length:
Long strings to remnants
=> comparable n_{ch}/interaction
=> <p_T> (n_{ch}) ~ Flat.



Phy.Rev.Lett.111,042001(2013)

Average transverse momentum of charged particles in |η| < 2.5 as a function of the multiplicity. UA1 data points at 900GeV

Sjöstrand, et. al
Phys. Rev. D36, 2019 (1987)



ALICE: Phys. Lett. B 727 (2013),371

Simulation of nMPI vs N_{ch} in p-p collisions

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PYTHIA 8.2, EVENT GENERATOR

- ✔ Is a standard tool for the generation of events in high-energy collisions,
- ✔ Comprising a coherent set of physics models for pp collisions
- ✔ It contains a library of hard processes,
- ✔ models for initial and final state parton showers, matching and merging methods between hard processes and parton showers,
- ✔ **multiparton interactions, beam remnants, string fragmentation and particle decays**.
- ✔ notably for LHC physics studies. The many new features should allow an improved description of data.

T. Sjöstrand, et al., Comput. Phys.Commun. 191 (2015) 159. arXiv:1410.3012

<nMPI> vs Multiplicity

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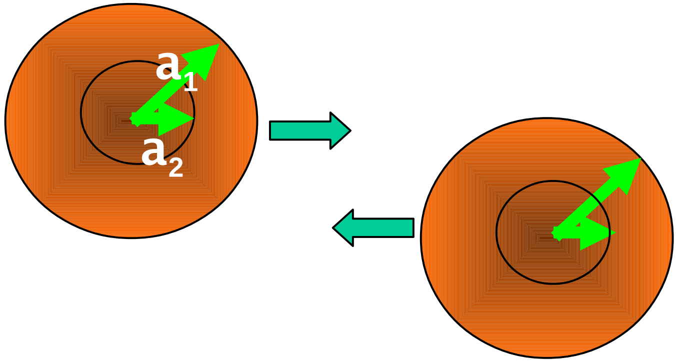
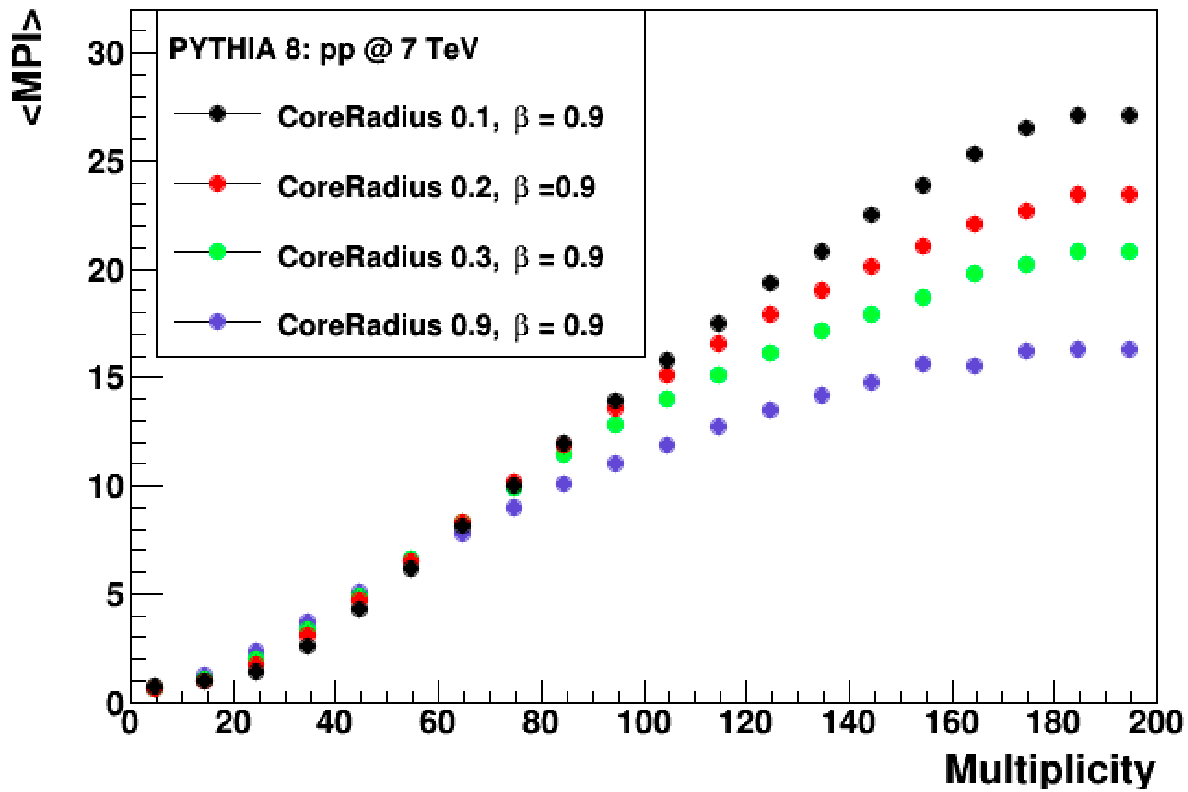
Nondiffractive topologies present impact parameter dependence regulated by several parameters:

$$\rho(r) \propto \frac{1-\beta}{a_1^3} Exp\left(-\frac{r^2}{a_1^2}\right) + \frac{\beta}{a_2^3} Exp\left(-\frac{r^2}{a_2^2}\right)$$



CoreRadio = a_2 = core radius

CoreFraction = β = fraction of hadronic matter inside the core



<nMPI> =kO(b)

k = related to parton-parton interactions, function of the √s

O(b) = Overlap between hadronic matter distributions of protons

Sjóstrand et al. PRD36, 2019 (1987)

The highest multiplicity events could have almost twice of the nMPI according to the proton matter density

Multiplicity vs <nMPI>

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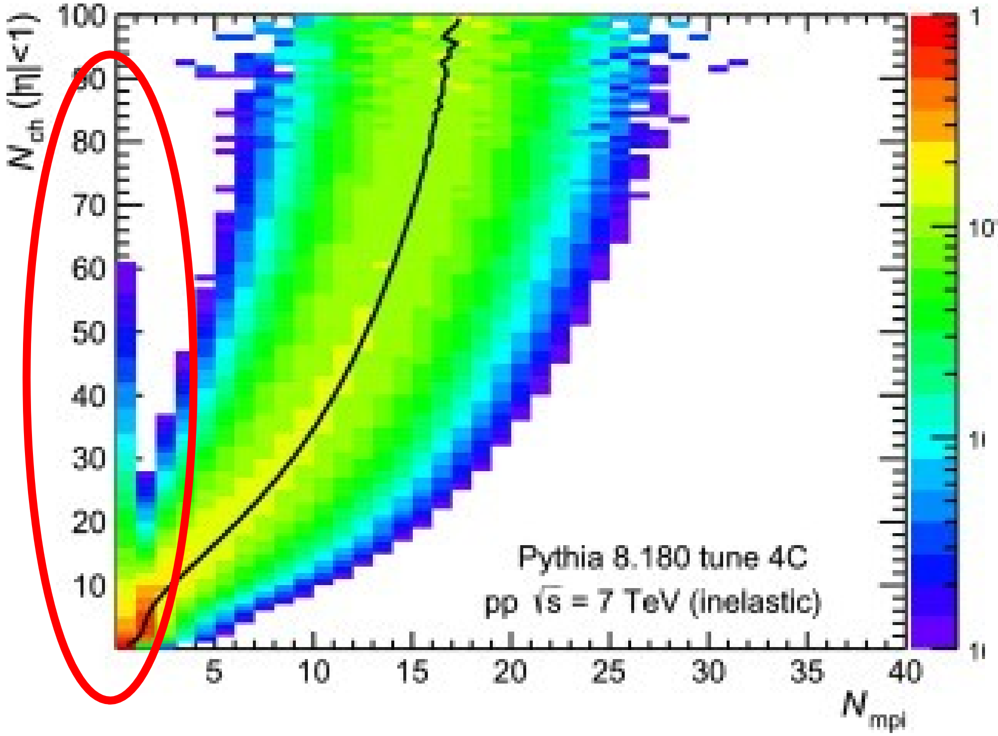
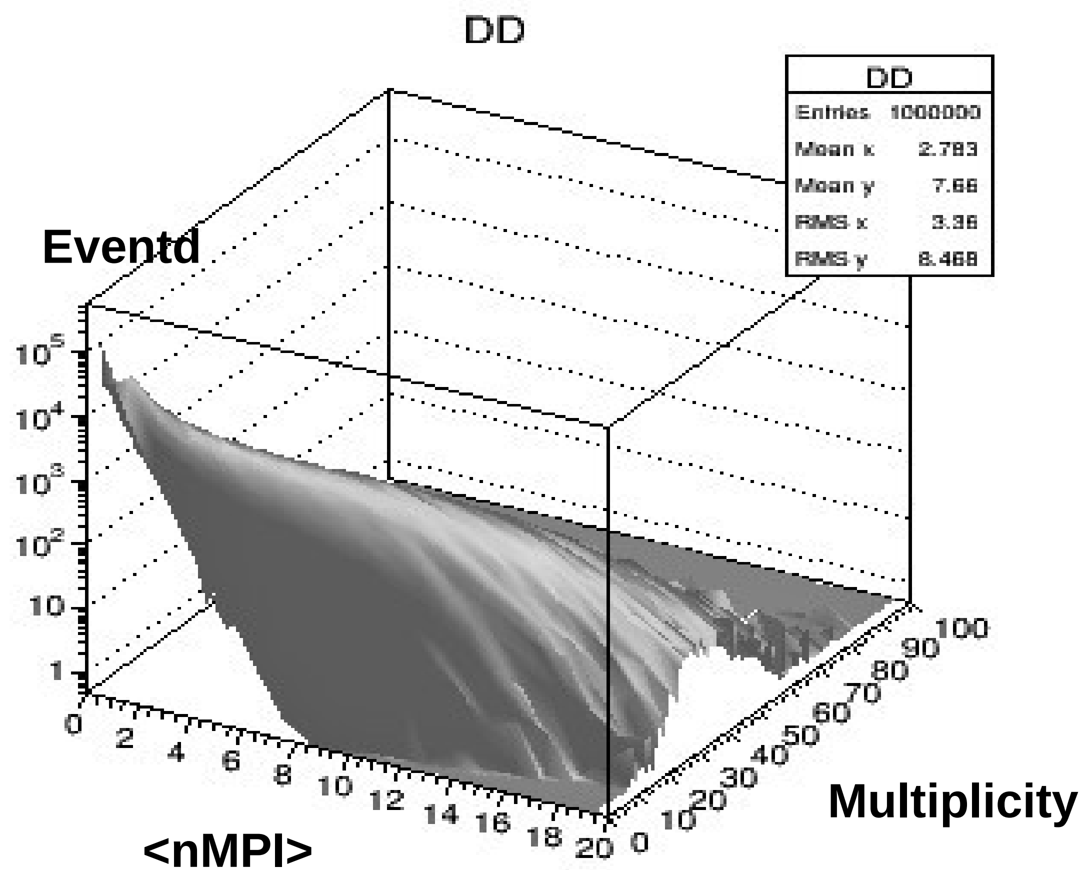


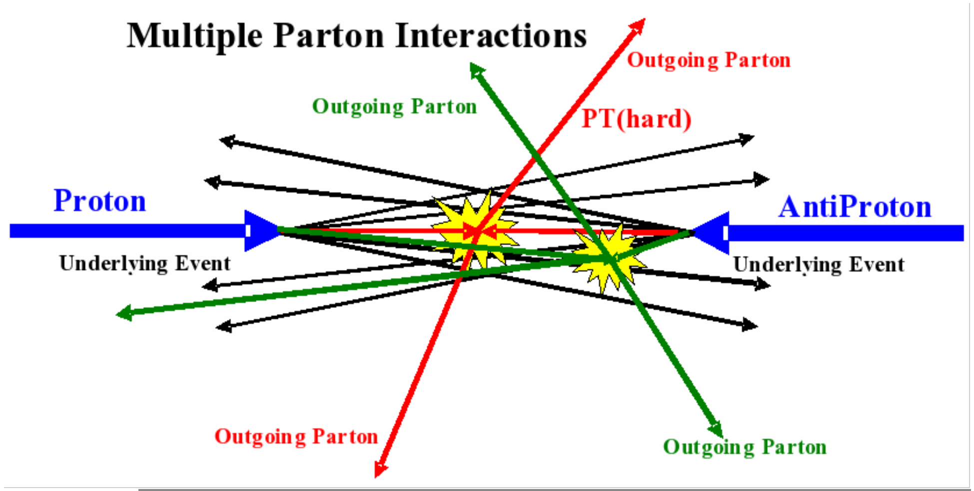
- The relationship between nMPI and multiplicity indicate that nMPI saturate. This results will brings consequences in F-B multiplicity correlation
-

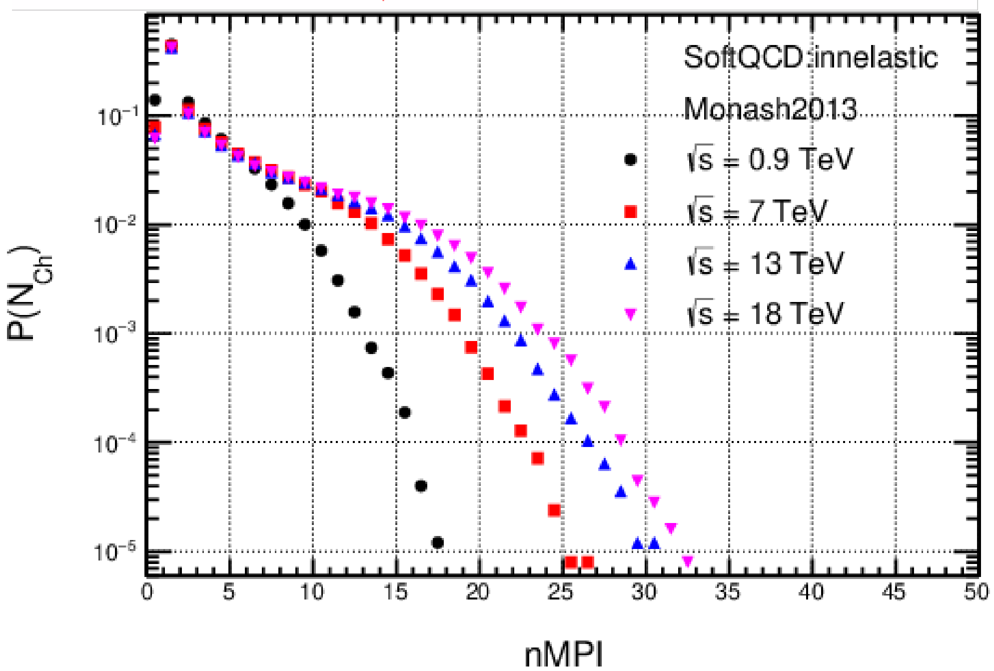
The inelastic process produce and enhancement of multiplicity at lower nMPI

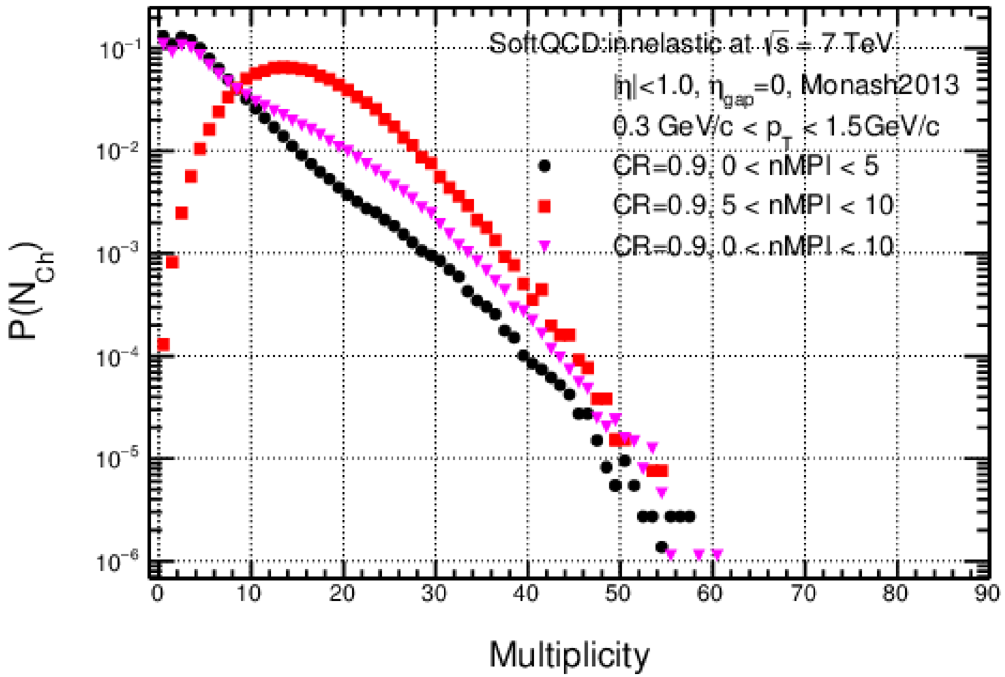
Nucl. Phys. A941 (2015) 78



Multiplicity and nMPI distributions at different energies







The multiplicity distributions depends of various factors, one of them is the nMPI

The increase of energy => nMPI => enhancement of multiplicity => increase of b_{corr}

b_{corr} vs event multiplicity

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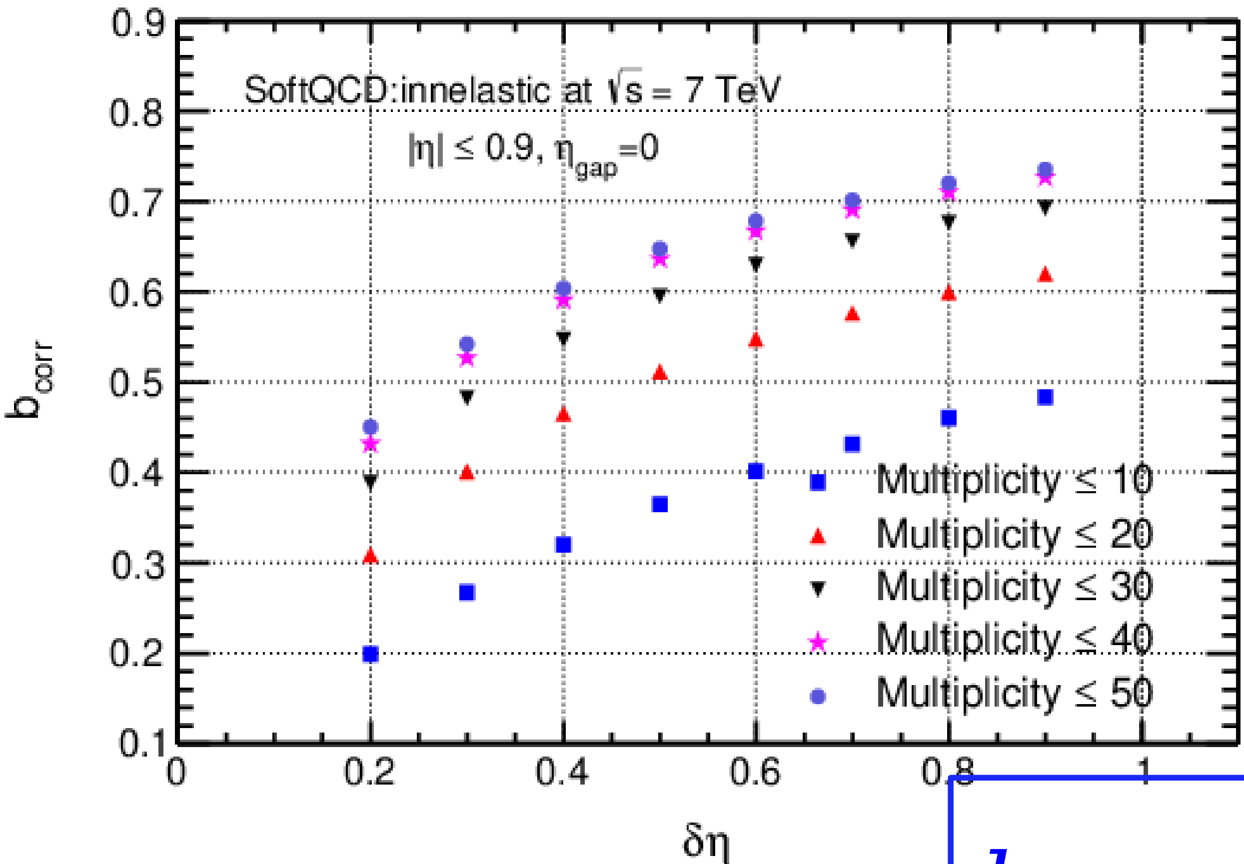

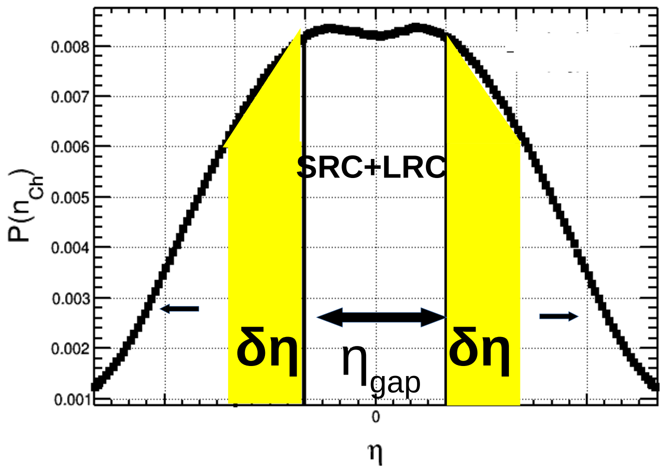

$$b_{Corr} = \frac{\langle n_F n_B \rangle - \langle n_F \rangle \langle n_B \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2}$$

Computing b_{corr} multiplicity event classes:

Increase of multiplicity distribution produce and enhancement of the b_{corr}.

Resonances effects on b_{corr}

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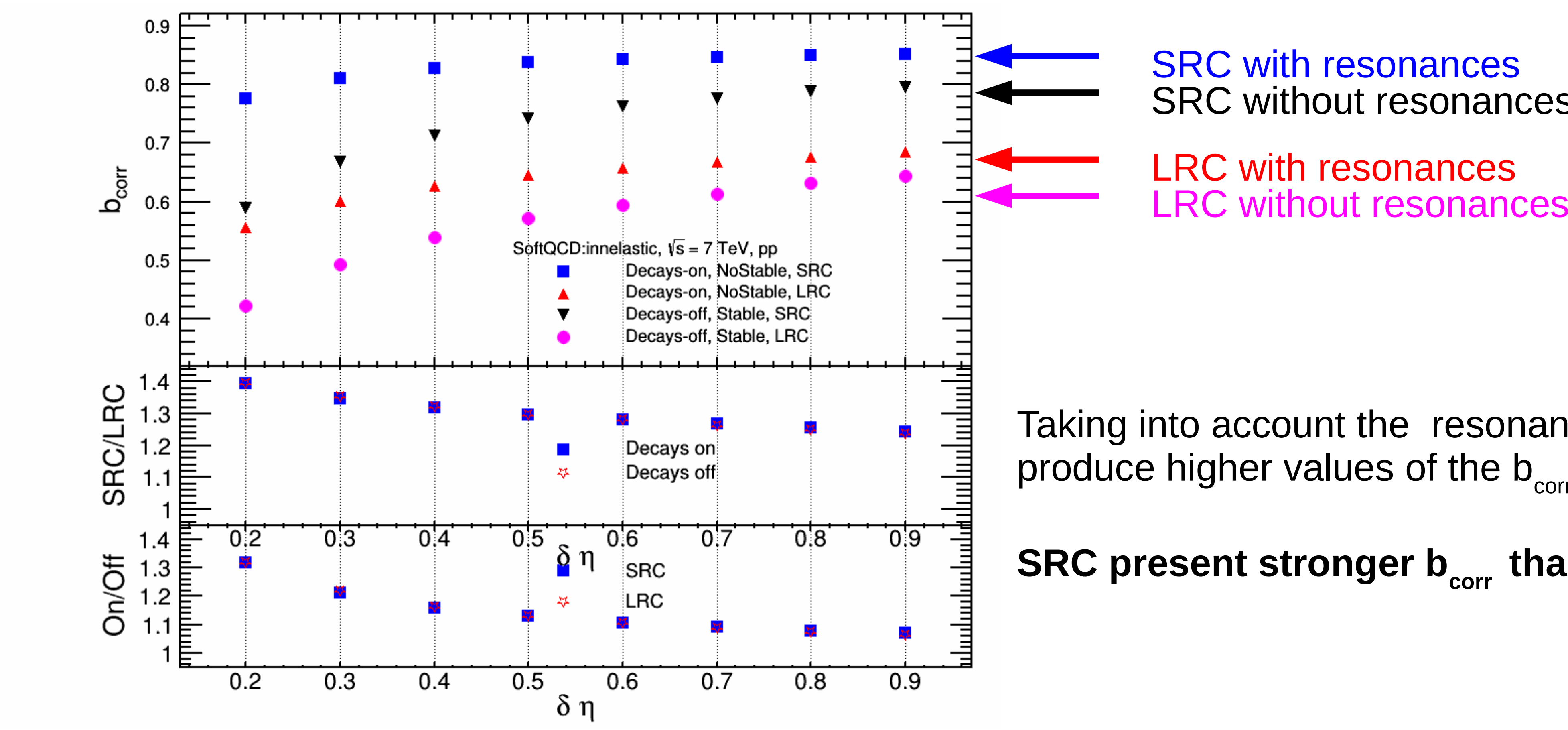
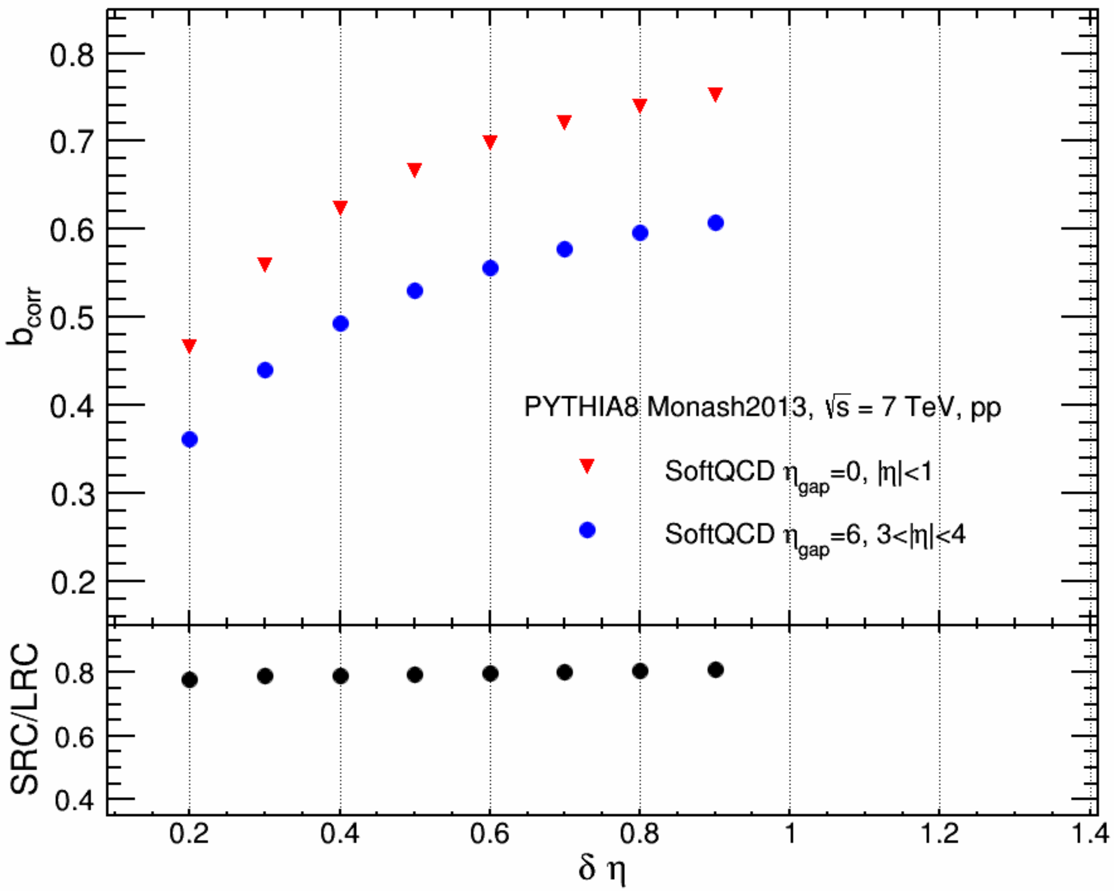


Taking into account the resonances, produce higher values of the b_{corr}

SRC present stronger b_{corr} than LRC

Resonances introduce and enhancement on the SRC and LRC .

b_{corr} for soft QCD processes



pp collisions at 7 TeV.
b_{corr} for short and long range correlations.

Strength of the correlations is larger for central ($|\eta|<1$) pseudo-rapidity regions w.r.t. forward ($3<|\eta|<4$) region.

Hardness of the events also contribute to an increase of the correlation.

b_{corr} vs soft (low p_T) hard (high p_T)

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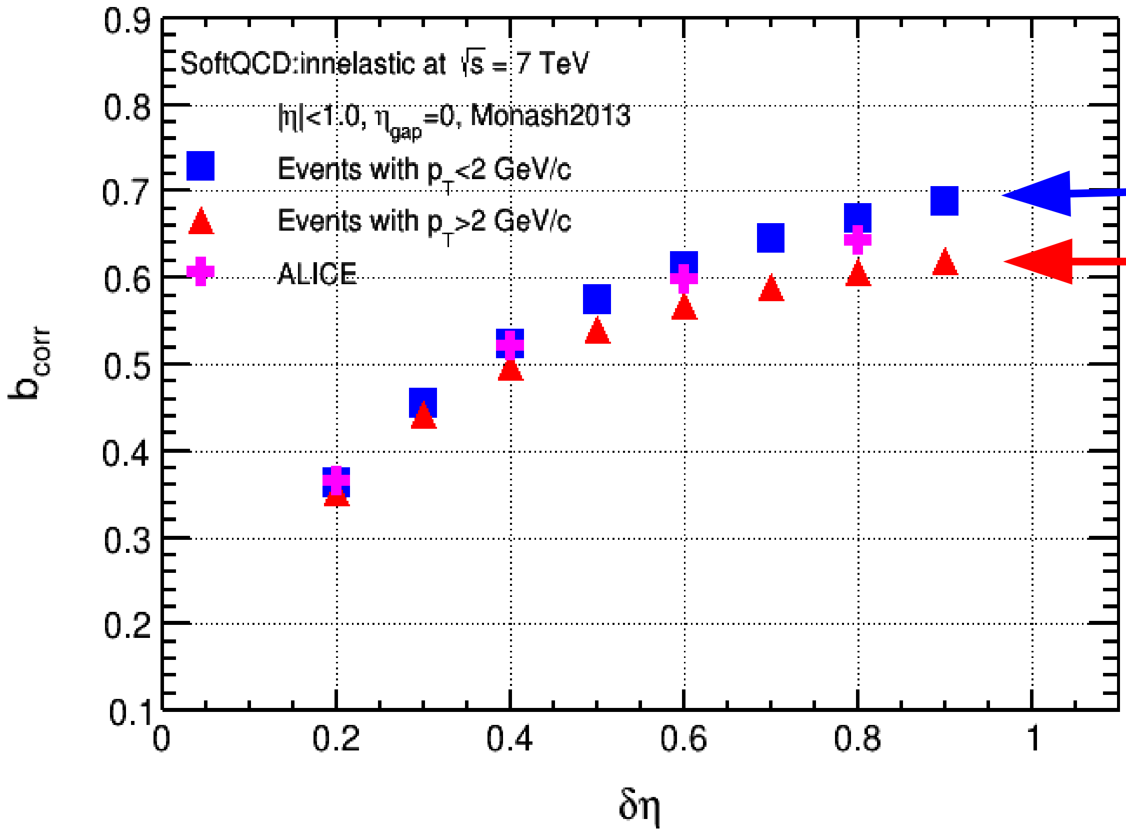
Experimentally we can make event classes by,

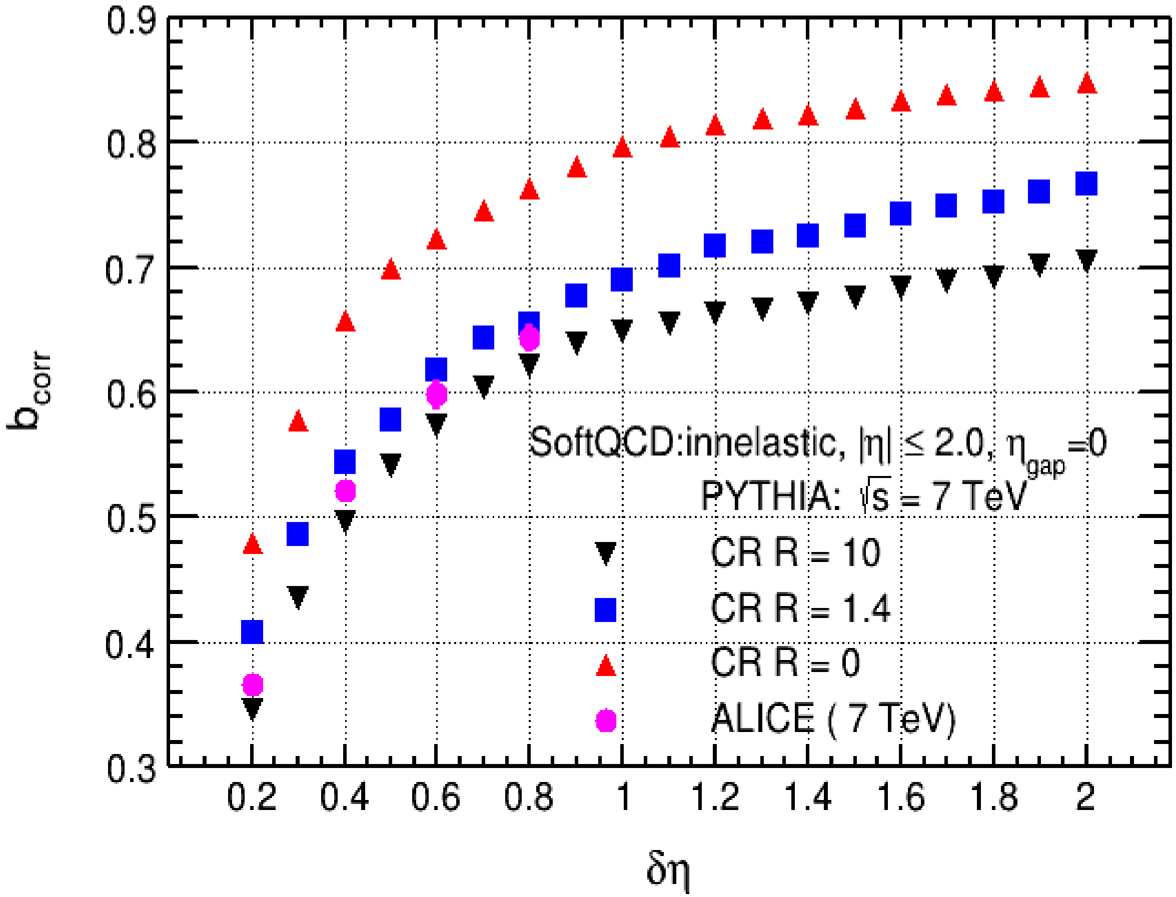
- multiplicity,
- particle species,
- Soft and hard events



Selecting event with pT < 2 GeV/c

Selecting event with pT > 2 GeV/c

Color reconnection effects on b_{corr}



pp at 7 TeV
Soft processes |η| < 2

Color reconnection parameter
10, 1.4, 0.0

Results for 3 values of CR and their comparison to experimental data.

Simulation of b_{corr} with CR and nMPI vs data

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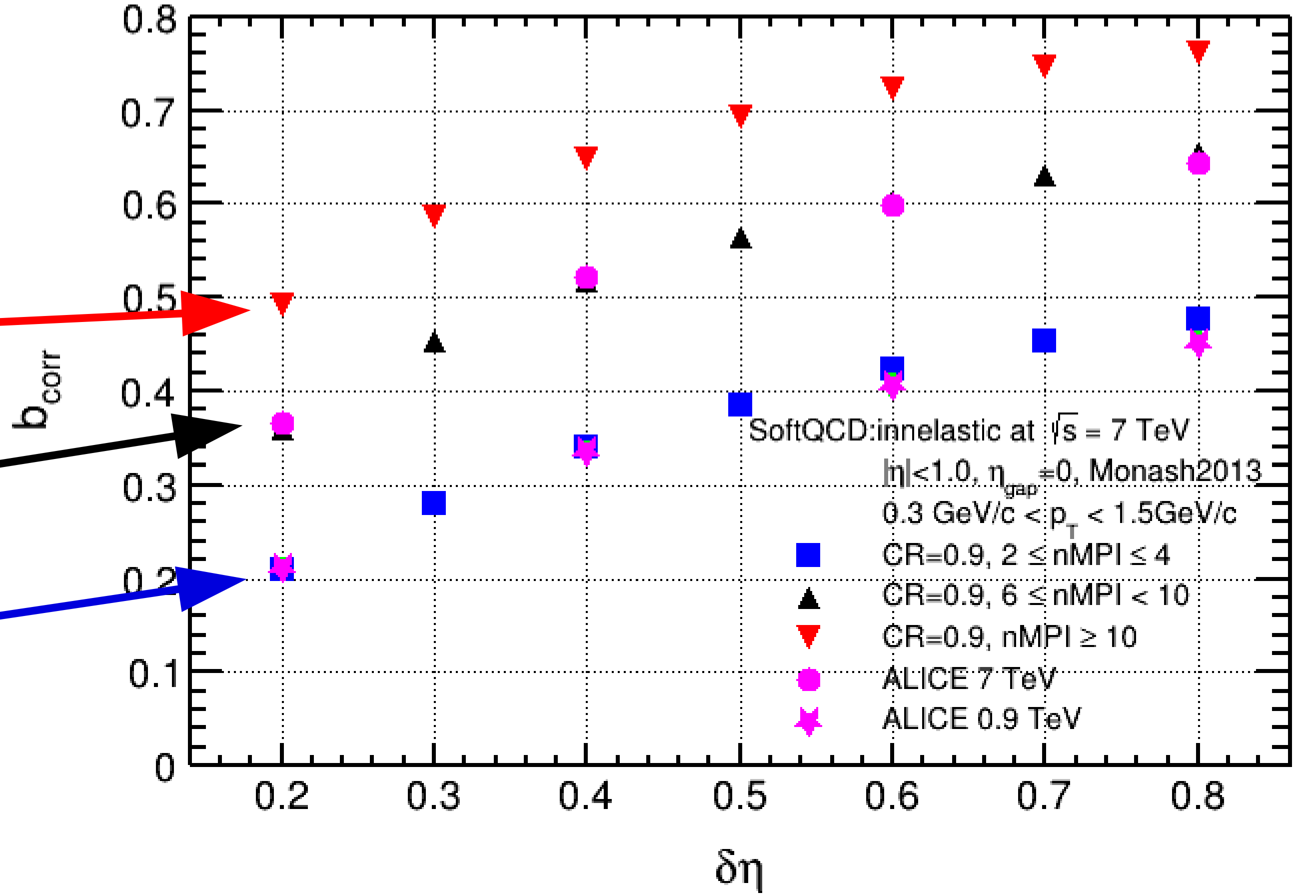
pp at 7 TeV, different ranges on nMPI:

Prediction at 13 TeV

Data at 7 TeV
Simulation (6 < nMPI < 10)

Data at 0.9 TeV
Simulation (2 < nMPI < 4)

pp at determined energy and with nMPI selections can reproduce data at different energy!



Simulation of b_{corr} at NICA energies

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pp at 4, 11 GeV:

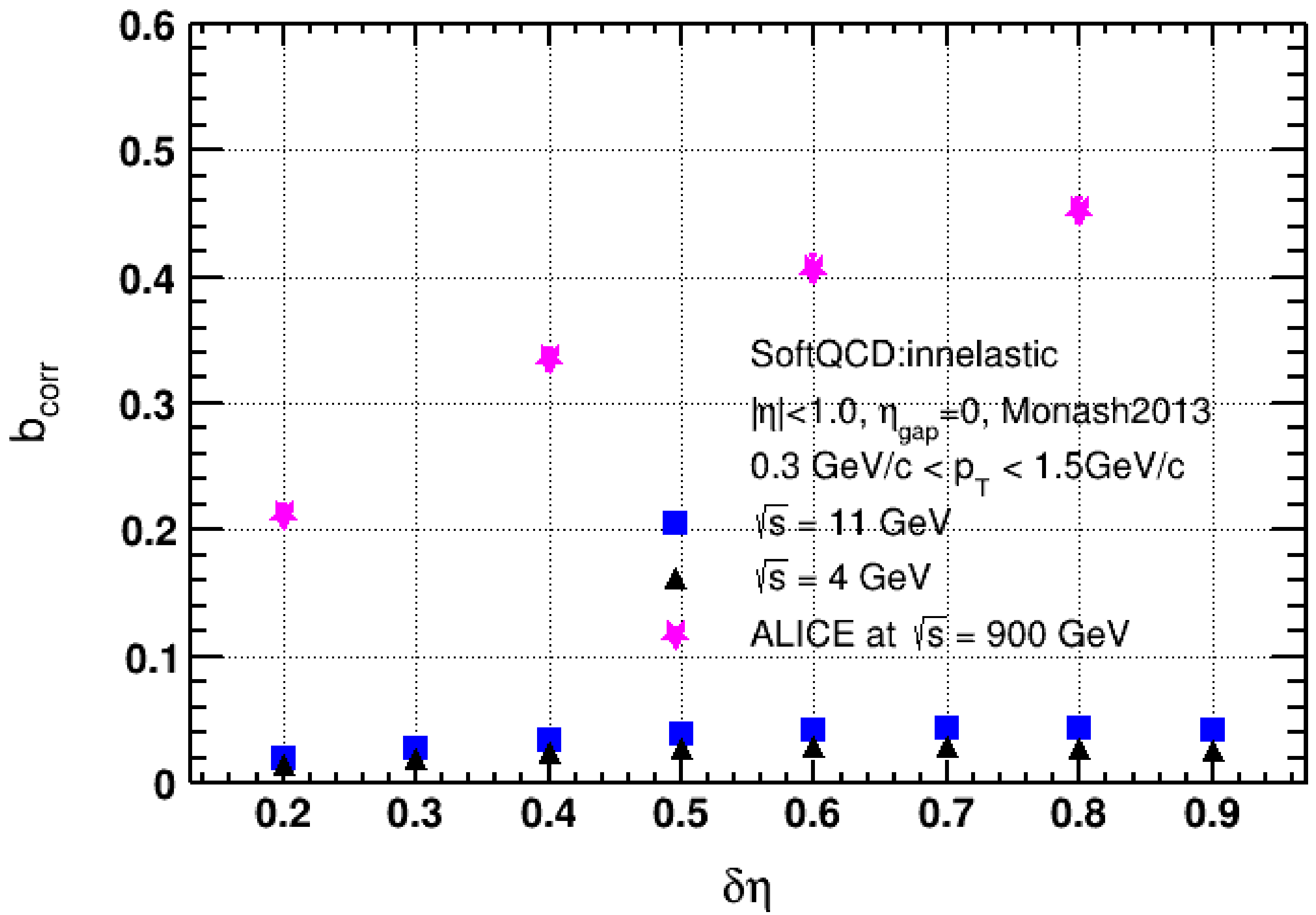
There is not cut on nMPI

Data at 0.9 TeV (from ALICE)

pp at low energy seems to not scale to LHC energies

But

May be we need to explore high multiplicity events, ...



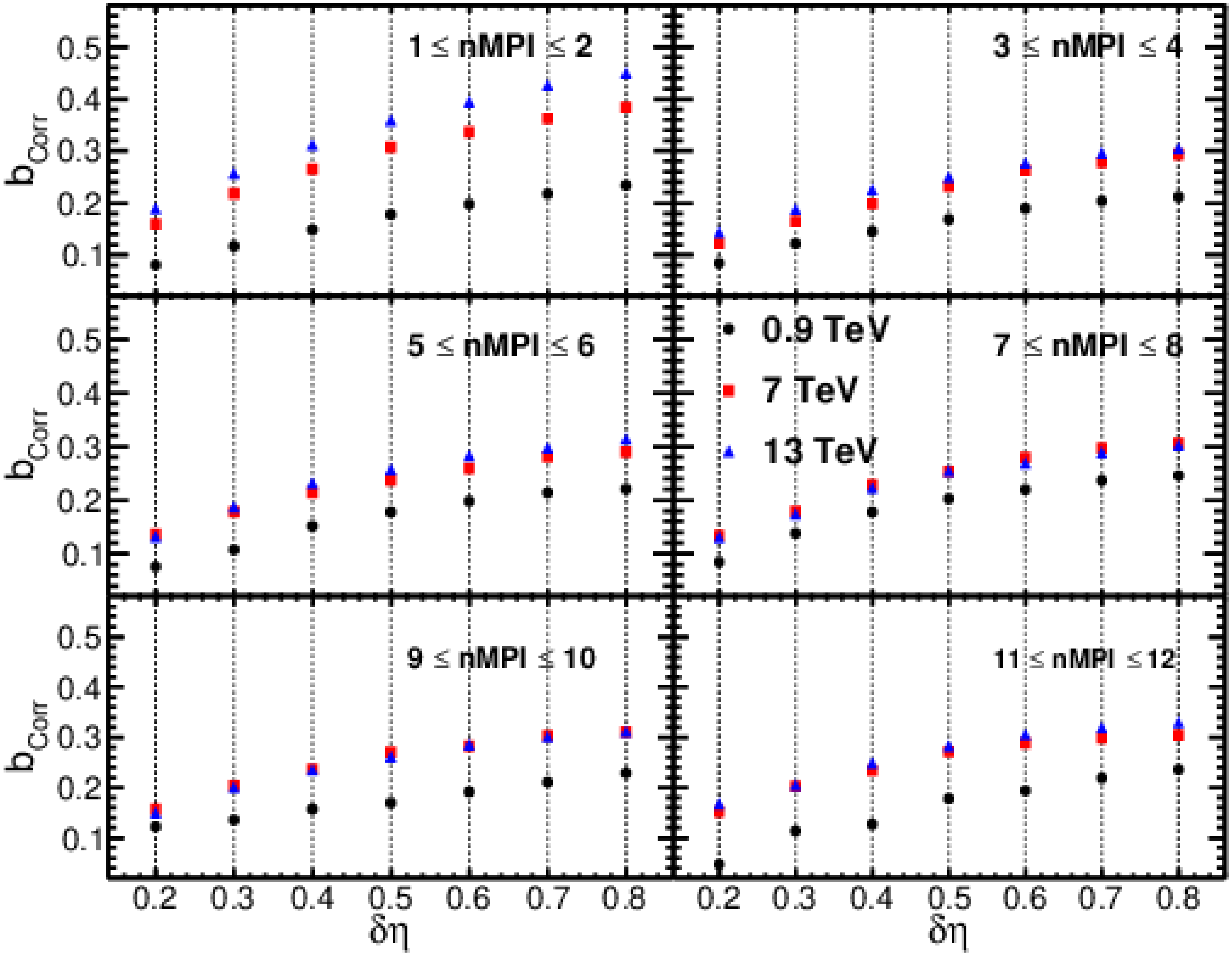
At RHIC (200 GeV) b_{corr} 0.1

At ISR (pp a 56 GeV) very samll b_{corr}

Conclusions

- **Using PYTHIA event generator, we have analyzed the effects of CR and <nMPI> for QCD processes (Soft and Hard) on calculation of forward-backward multiplicity correlations.**
  - Soft QCD process are more correlated than the Hard ones.
  - Correlation decrease as CR increase
  - Higher <nMPI> produce a higher mean multiplicity, however the correlation produce a small change on the shape of it .
  - The correlation increase as the energy does, **It just not at scaled.**
- **There is a relationship between <nMPI> and CR. May be, measuring one of them, could be able to extract the second one. Still we are working on it.**
- **There is possible to predict the b_{corr} for some energies just defining the <nMPI>. Still we working on it to find the relationship among Energy, nMPI,CR,..**
- **Extracting <nMPI> indirectly. It would be useful to understand soft QCD processes (Underlying events)**

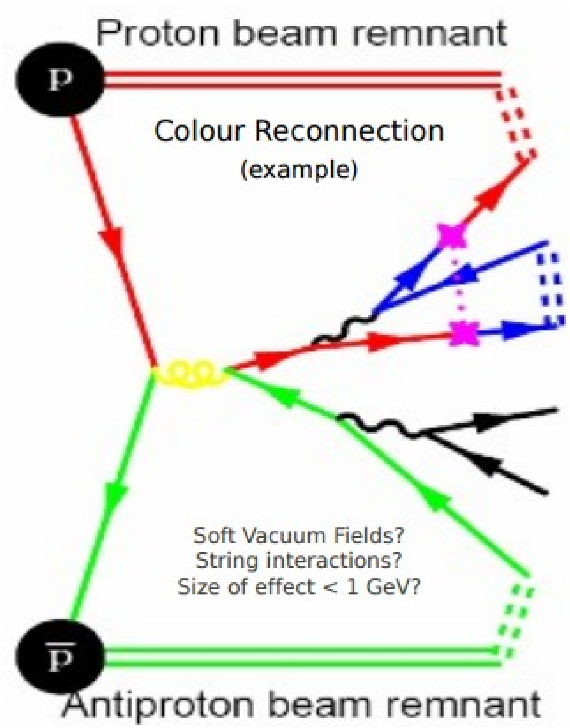
nMPI and b_{corr} for pp at 0.9, 7 and 13 TeV



0.9 TeV
7 TeV
13 TeV

There are two more CR models that we use. One is based in QCD and the other in Gluon-move, the idea from this two models is to reduce the string length (λ).

$$\lambda \langle n_h \rangle$$

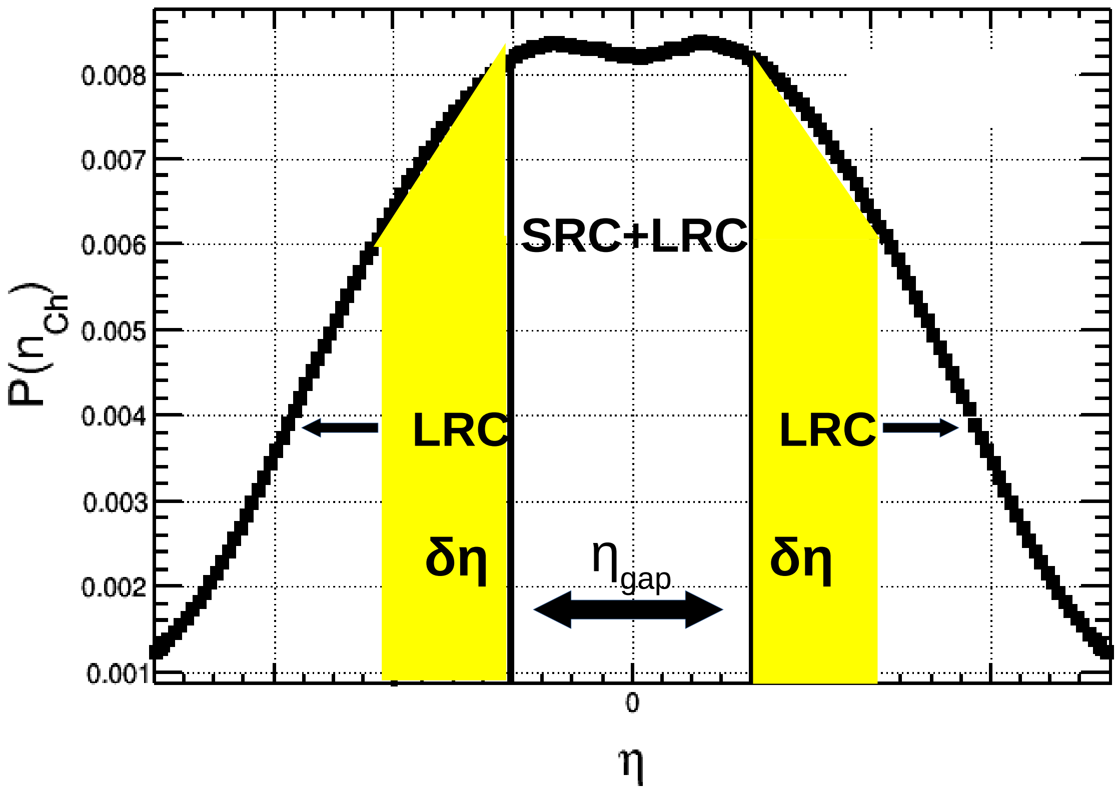


CR-QCD model takes into account the hadronization based in the colour rules of SU(3) to determine if two strings are colour compatible using a junction structure.

arXiv1507.02091

Gluon-move is a Toy Model, in which it is tried to reduce λ by moving a gluon between a pair.

SRC and LRC correlations



n_B **Backward (η < 0)** n_F **Forward (η >0)**

$$b_{Corr} = b_{Corr}(\delta\,\eta)$$
$$b_{Corr} = b_{Corr}(\delta\,\eta_{gap})$$

$$b_{Corr} = \frac{\langle n_F n_B \rangle - \langle n_F \rangle \langle n_B \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2}$$

SRC: Short Range Correlations
Mainly at central rapidty |η|< 1

LRC: Long Range Correlations
Mainly for |η|>1

$$\eta = \frac{1}{2}\ln\left(\frac{P+P_Z}{P-P_Z}\right) = -\ln\left(\tan\frac{\theta}{2}\right)$$

- Collisions in ISR, PETRA (Phys.Rev. D34 (1986) 3304), “suggests the direct and independent production of hadrons.”
- Collisions *pp* in ISR (Nucl.Phys. B132 (1978) 15), “In the framework of the cluster model we interpret the observed correlations as correlations between the clusters.”
- Collisions in (Phys.Lett. B123 (1983) 361), “We find that the bulk of the charged particles are produced from clusters with the same average size independent of observed multiplicity”.
- Collisions *Au*-*Au* in RIHC (Phys.Rev.Lett. 103 (2009)172301), “ A large long-range correlation is observed in central Au-Au collisions that vanishes for 40–50% centrality ”.
- Collisions *pp* in ALICE and ATLAS at CERN (JHEP 05 (2015) 097, JHEP 07, 019 (2012))

b_{corr} for hard QCD processes

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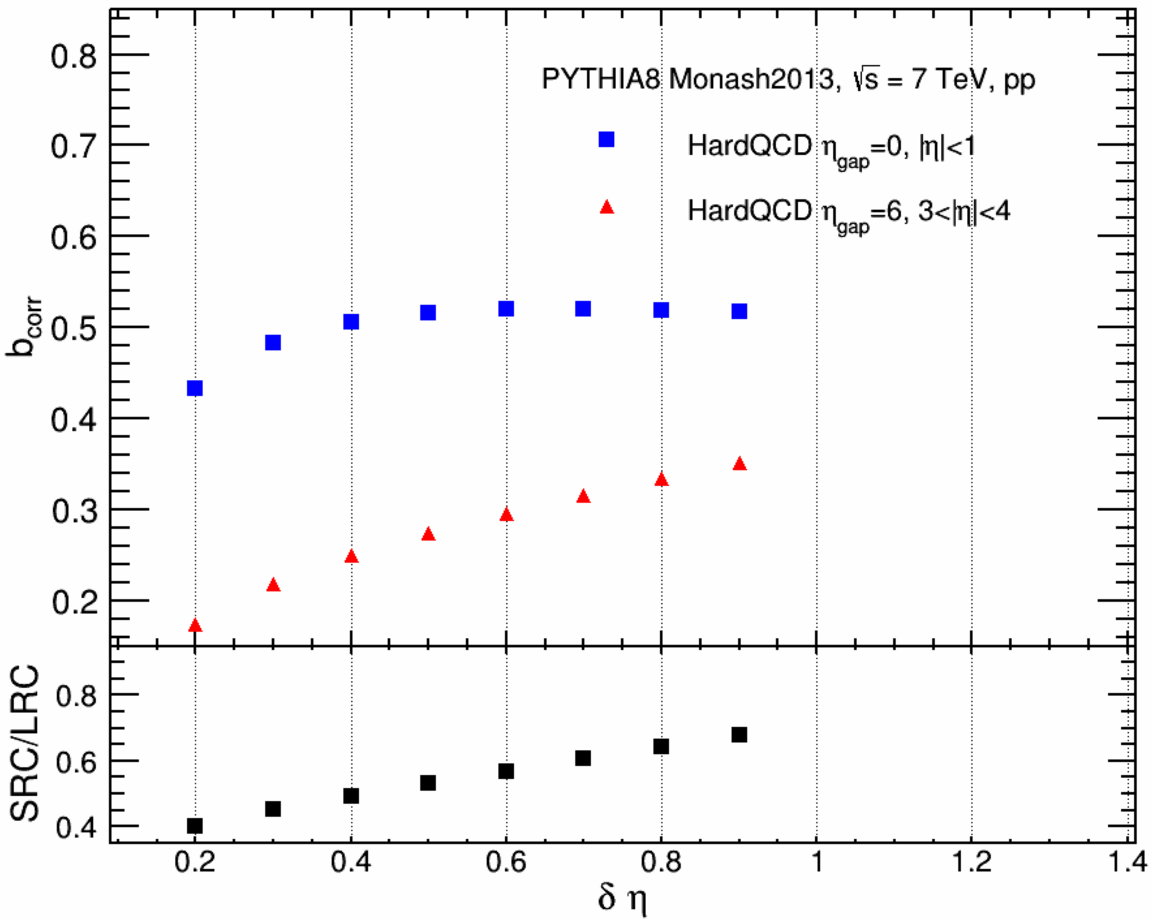


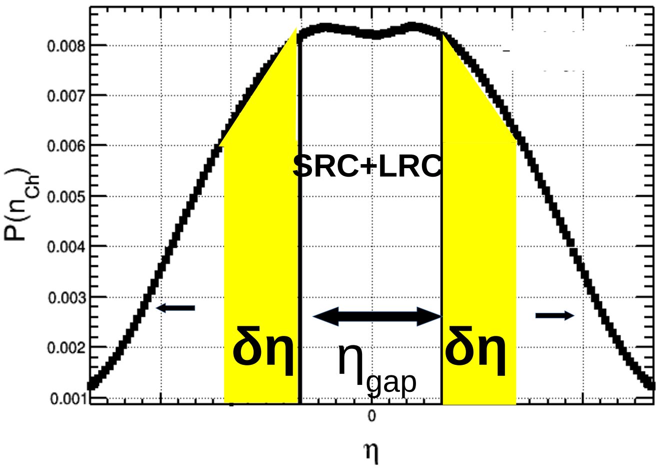
pp collisions at 7 TeV.
b_{corr} for short and long range correlations.

Strength of the correlations is larger for central ($|\eta|<1$) pseudo-rapidity regions w.r.t. forward ($3<|\eta|<4$) region.

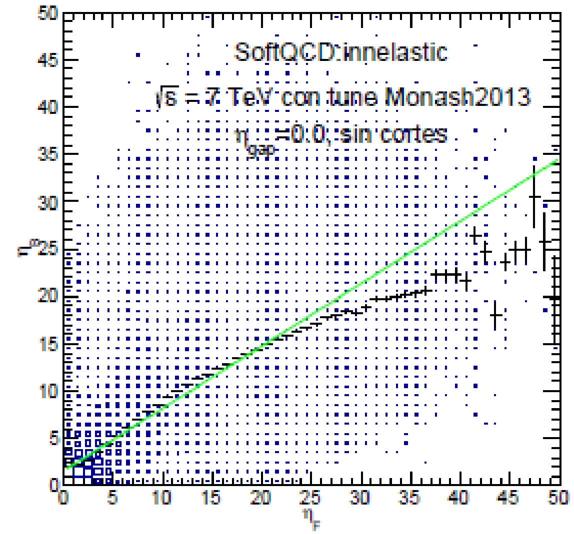
Hardness of the events also contribute to an increase of the correlation.

F-B multiplicity correlations

Experimentally the average multiplicity of particles in the backward pseudorapidity region can be related to the multiplicity in the forward region



$$\langle N_B \rangle (N_F) = a + b N_F$$

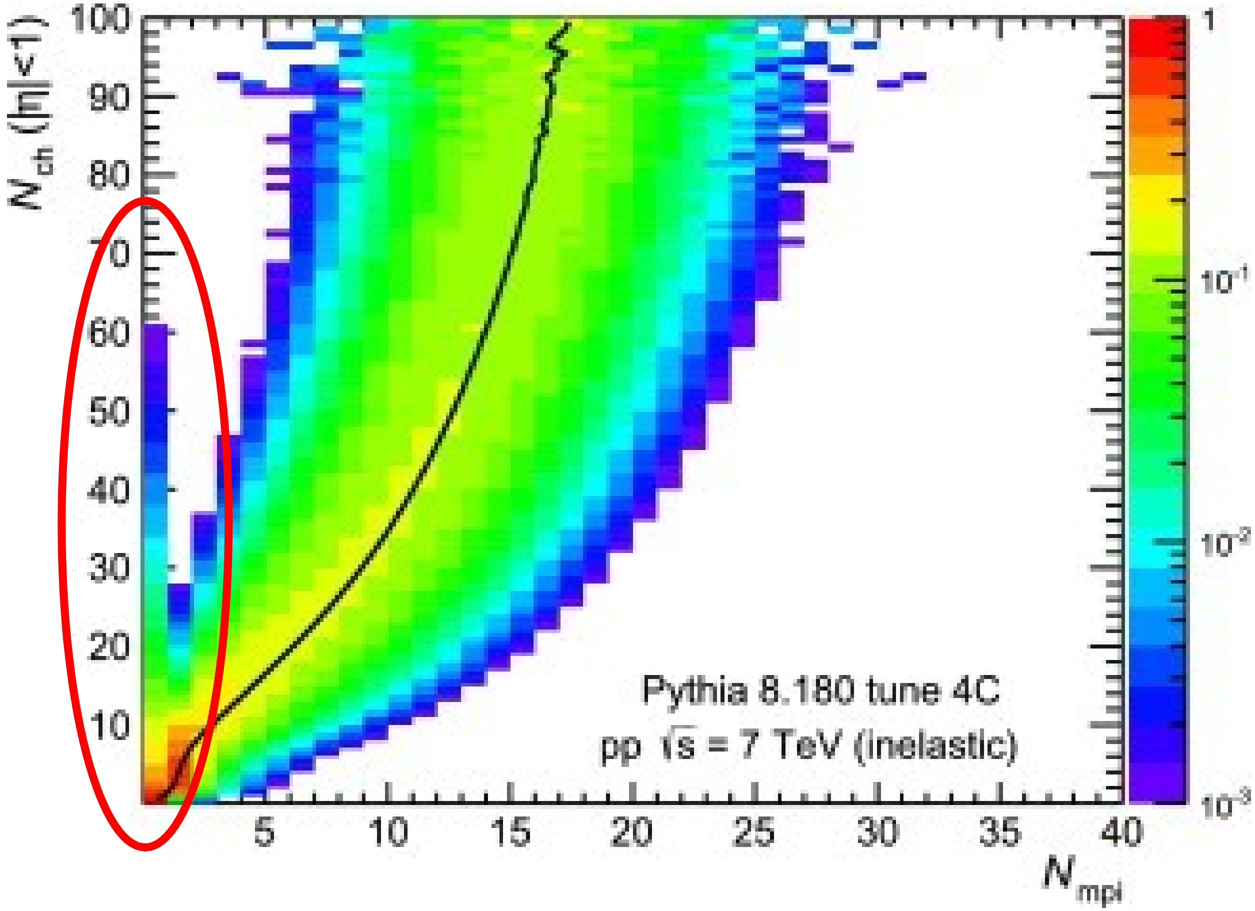


The Correlation is theoretically defined event by event, comparing the integrated density of particles produced in different ranges of pseudorapidity.

Applying a linear regression one can obtain the correlation strength b_{corr}:

$$b_{Corr} = \frac{\langle n_F n_B \rangle - \langle n_F \rangle \langle n_B \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2}$$

Multiplicity vs nMPI



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- There is a relationship between nMPI and multiplicity, this indicate that the number of nMPI saturate. This results will brings consequences in F-B multiplicity correlation
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