Long-range correlations in *pp* and *A-A* collisions

Grigori Feofilov (St. Petersburg State University)
for the ALICE collaboration

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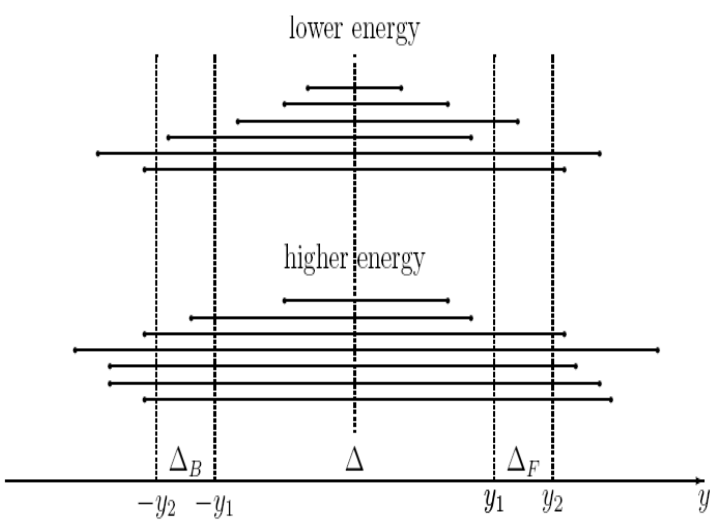
http://igfae.usc.es/is2013/

Motivation: Long range forward-backward correlations

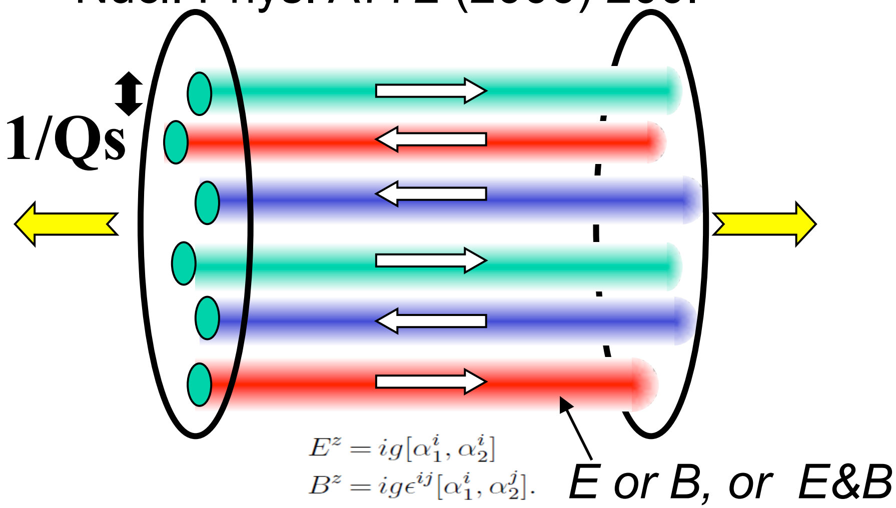
The initial conditions for the QGP formation in A-A collisions:

Color string fusion phenomenon (SFM) **vs.** **Color Glass Condensate (CGC) and Glasma flux tubes,** L.McLerran, Nucl.Phys.A699,73(2002); T. Lappi and L. McLerran, Nucl. Phys. A772 (2006) 200.

M.A.Braun and C.Pajares
Phys. Lett. B287 (1992) 154;
Nucl. Phys. B390 (1993) 542.



Schematics of strings formed just after the collision in cases of lower and of higher energy.



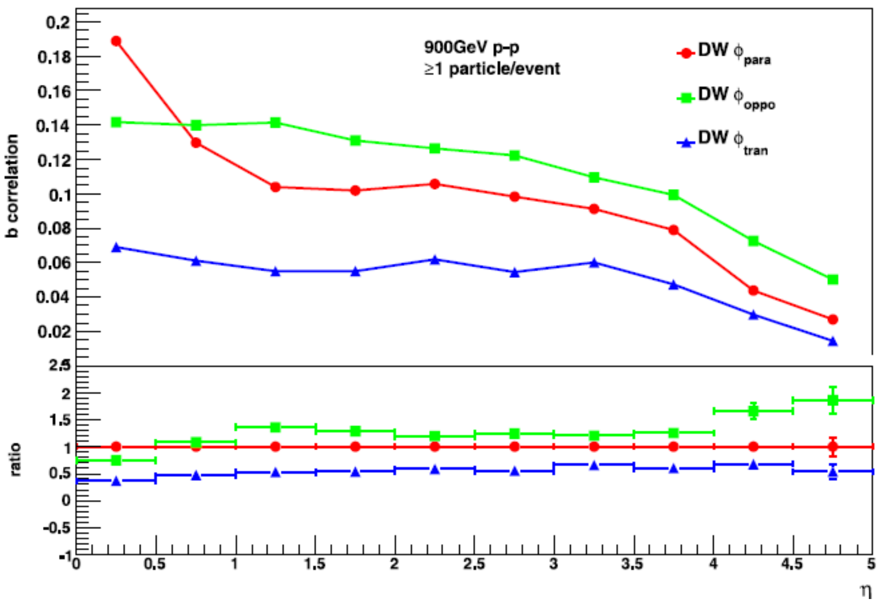
The color electric and magnetic flux tubes just after the collision (see arXiv:0803. 0410)

Different predictions for correlation strength behaviour with centrality in Pb-Pb collisions at the LHC.

⟶ ***pp*** **collisions as a benchmark for Pb-Pb analysis**

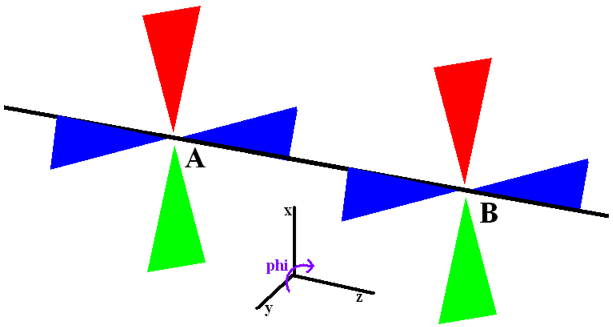
Additional motivation: Forward–backward correlations and event shapes as a tool to tune color reconnection and MPI in PYTHIA

Extension into *azimuthal* dimension



Three φ regions in F-B η slices

para: $-\pi/3 < \Phi < \pi/3$
oppo: $\pm 2\pi/3 < \Phi < \pm \pi$
tran: $\pm \pi/3 < \Phi < \pm 2\pi/3$



$$b_{twist} = (\langle n^{\Phi}_{f} n\uparrow_{b} \rangle - \langle n\uparrow_{f} \rangle^{2}) / (\langle n\uparrow_{f}^{2} \rangle - \langle n\uparrow_{f} \rangle^{2})$$

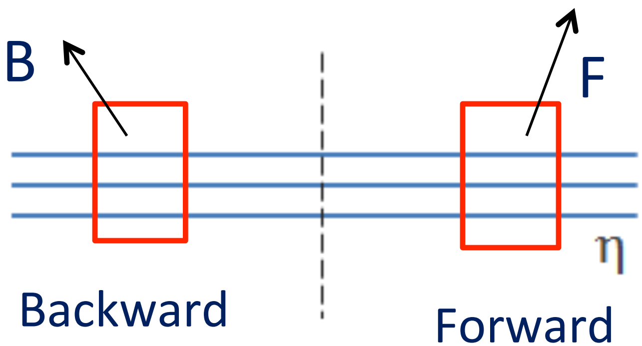
→ Clear separation of correlation distributions

Correlation strength distributions for charged particles for the DW tune for the three different combinations of φ regions, defined with respect to the lead particle trajectory.

"Twisted correlations": K. Wraight and P. Skands, Eur. Phys. J., C 71 (2011) 1628.

Forward-Backward (Long-Range) correlations

Charged particles produced in pp, p-A or A-A collisions are detected in two separated pseudorapidity intervals (windows) called Forward(F) and Backward(B).



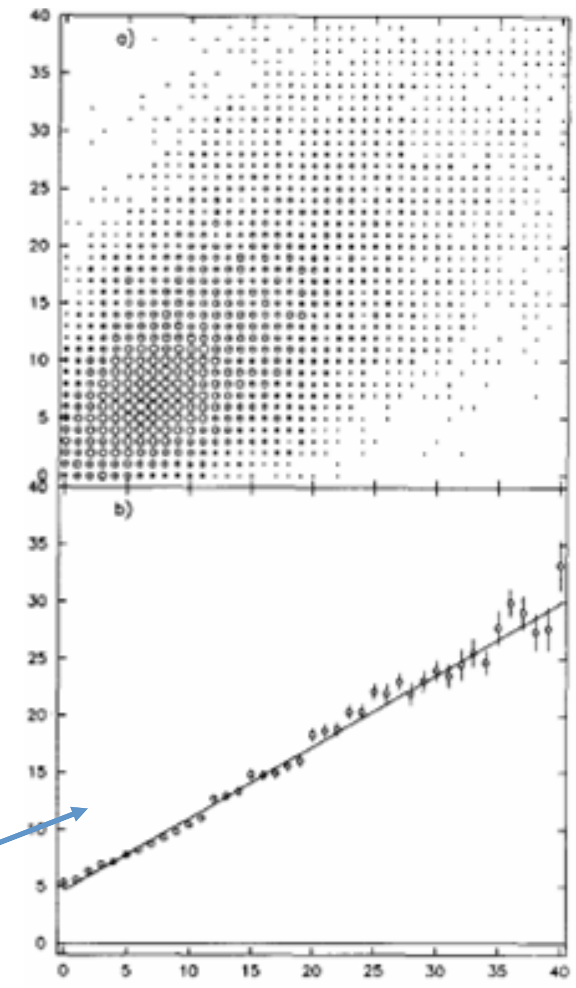
Some observables are measured event-by-event in these F and B η windows:

Types of correlations:

- n_B-n_F - the correlation between charged particle multiplicities in backward (B) and forward (F) rapidity windows (n-n correlation)

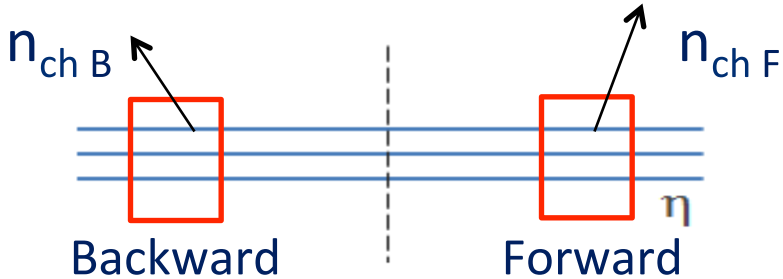
UA5 Collaboration,900 GeV

Z. Phys. C – Particles and Fields 37, 191–213 (1988)



$$\langle n_B \rangle_{n_F} = a + b_{corr} \cdot n_F$$

Definition of the FB multiplicity correlation coefficient



Extract correlation strength by:

1) linear regression [1]

$$\langle n_B \rangle_{n_F} = a + b_{corr} \cdot n_F$$

2) correlator [2]

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

(is used by RHIC and ATLAS)

Relative variables

$$\nu_F = n_F / \langle n_F \rangle$$
$$\nu_B = n_B / \langle n_B \rangle$$

$$\langle \nu_B \rangle_{\nu_F} = a_{rel} + b_{corr}^{rel} \nu_F$$

$$b_{corr}^{rel} = \frac{\langle \nu_F \nu_B \rangle - 1}{\langle \nu_F^2 \rangle - 1} = \frac{\langle n_F \rangle}{\langle n_B \rangle} b_{corr}$$

For symmetrical windows $b_{corr}^{rel} = b_{corr}$

Relative variables are being used in our present study.

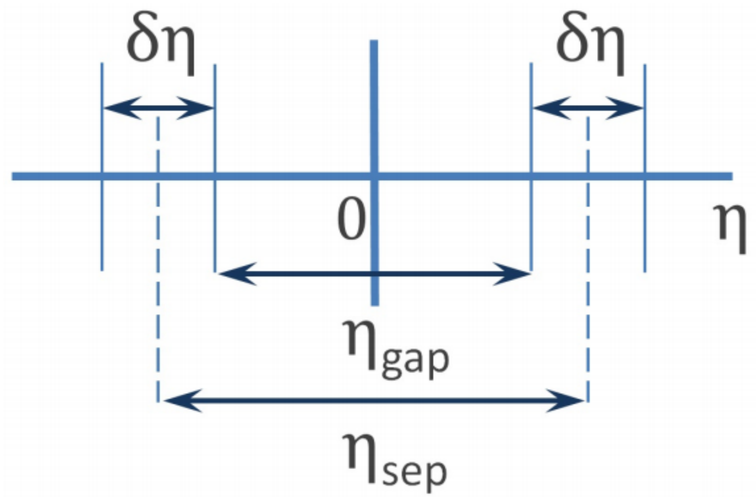
[1] UA5 Collaboration, Z.Phys,C-Particles and Fields 37,191-213 (1988)
[2] A.Capella et al.,Phys.Rep. 236,225(1994)

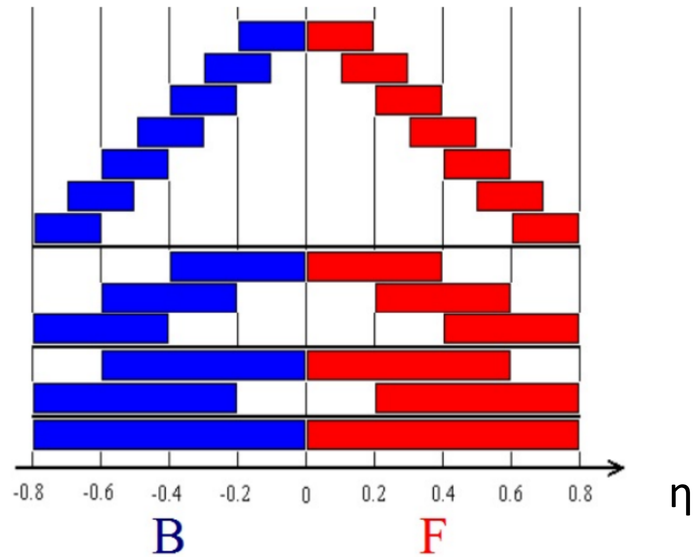
Data Analysis

Long-range correlations in pp collisions at LHC energies (0.9, 2.76 and 7 TeV)

pp collisions data at 0.9, 2.76 and 7 TeV: Selection of η-window pairs in ALICE

ALICE





η_{gap} – distance between windows (η_{sep} – between the centers)

$\delta\eta$ – windows width

Correlation coefficient b_{corr} is calculated for every configuration of η-windows pair.

<u>Data collected:</u>
900 GeV (2 Mln events)
2.76 TeV (10 Mln events)
7 TeV (6.5 Mln events)

p_T range: 0.3-1.5 GeV/c
"soft" physics domain!

Calculation of b_{corr} and correction procedures

- Calculation:

1) by linear regression

2) using correlator formula

- Corrections (three alternative procedures):

1) by correcting b_{corr} *raw* values

2) by correcting

3) by extrapolation of b_{corr}

to corrected <nF> values

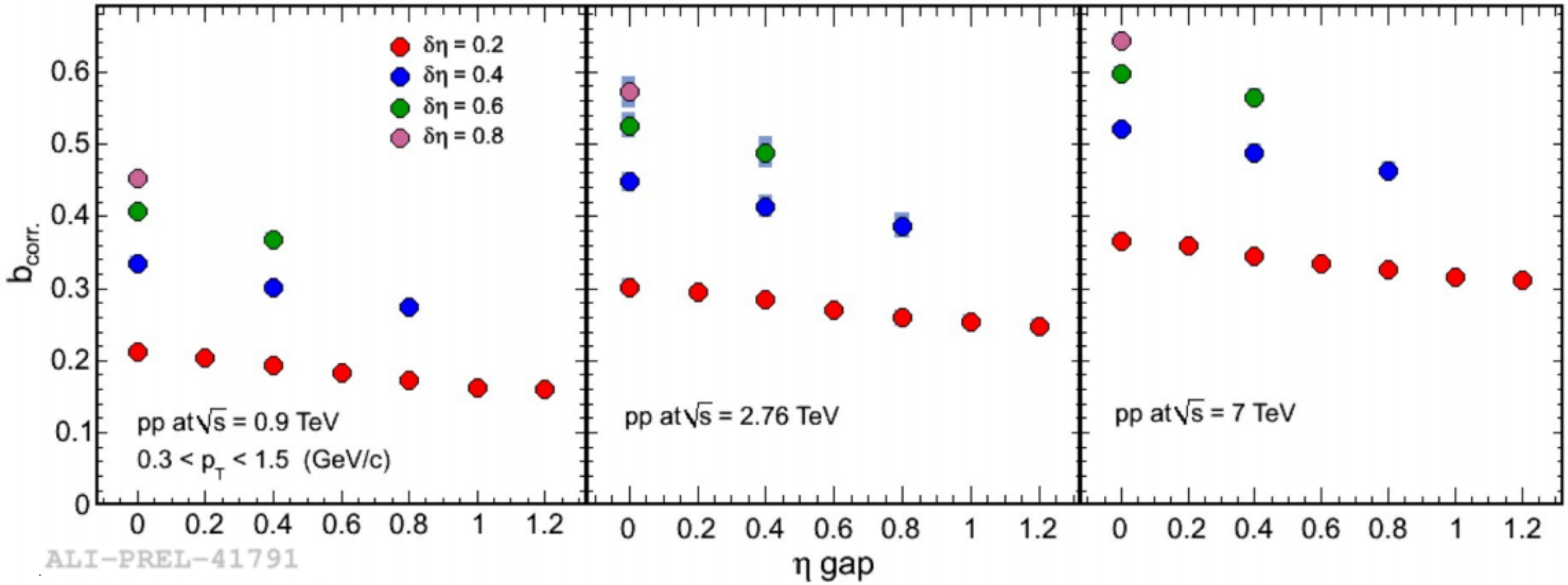
$\langle n_B n_F \rangle$, $\langle n_B \rangle$, $\langle n_F \rangle$ and $\langle n_F^2 \rangle$

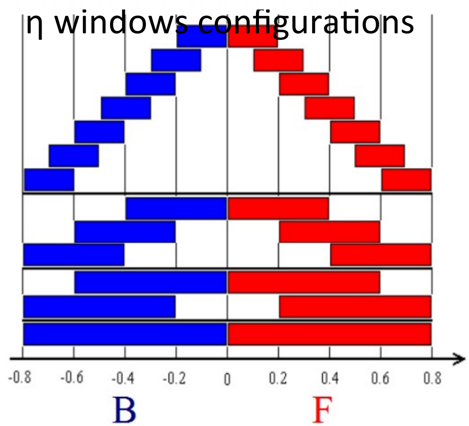
Correction factors are found to be of the order of *5-10%*
Systematic uncertainties are of the order *2-5%*

Sources	0.9 TeV	2.76 TeV	7 teV
TPC clusters	0.5-3.0%	0.01-0.13%	0.2-0.7%
ITS clusters	0.6-1.9%	–	0.15-1.4%
DCA	3.0-4.0%	0.98-1.8%	0.1-0.98%
VertexZ	0.2-1.1%	0.016-1%	0.015-0.7%
Method	2.5-4%	2.2-4.2%	1.6-2.8%
Pile Up	< 1%	< 1%	<1%
Total	3.4-4.5%	2.8-4.2%	2.0-3.0%

List of the sources of systematic uncertainty

1) FB multiplicity correlations in separated η windows

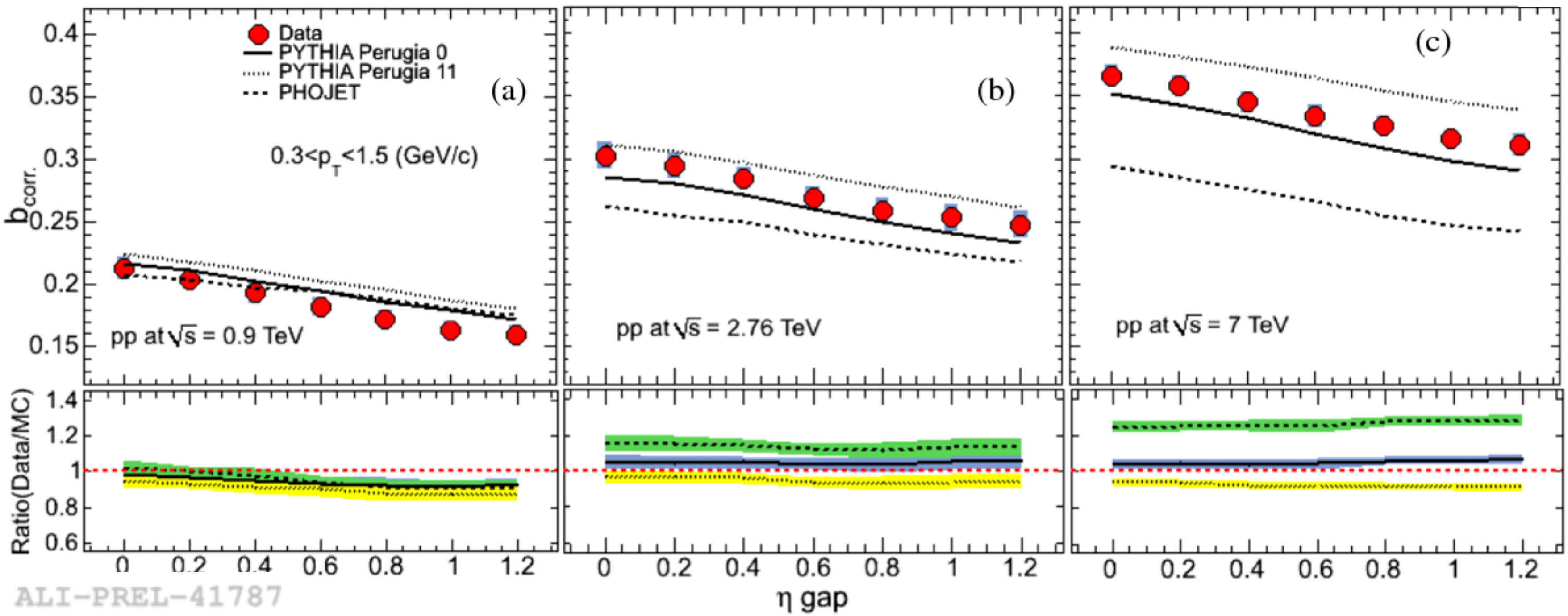


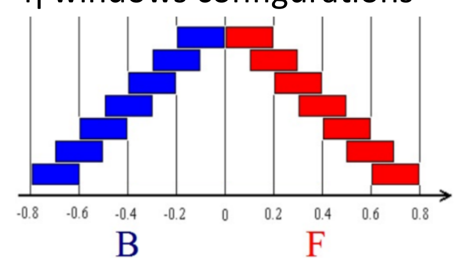


- correlation coefficient b_{corr} drops with η gap
- the slope is constant with the collision energy
- wider windows give higher b_{corr} values
- values of b_{corr} increase with the collision energy

2) Comparison with event generators:

FB multiplicity correlations in separated η windows

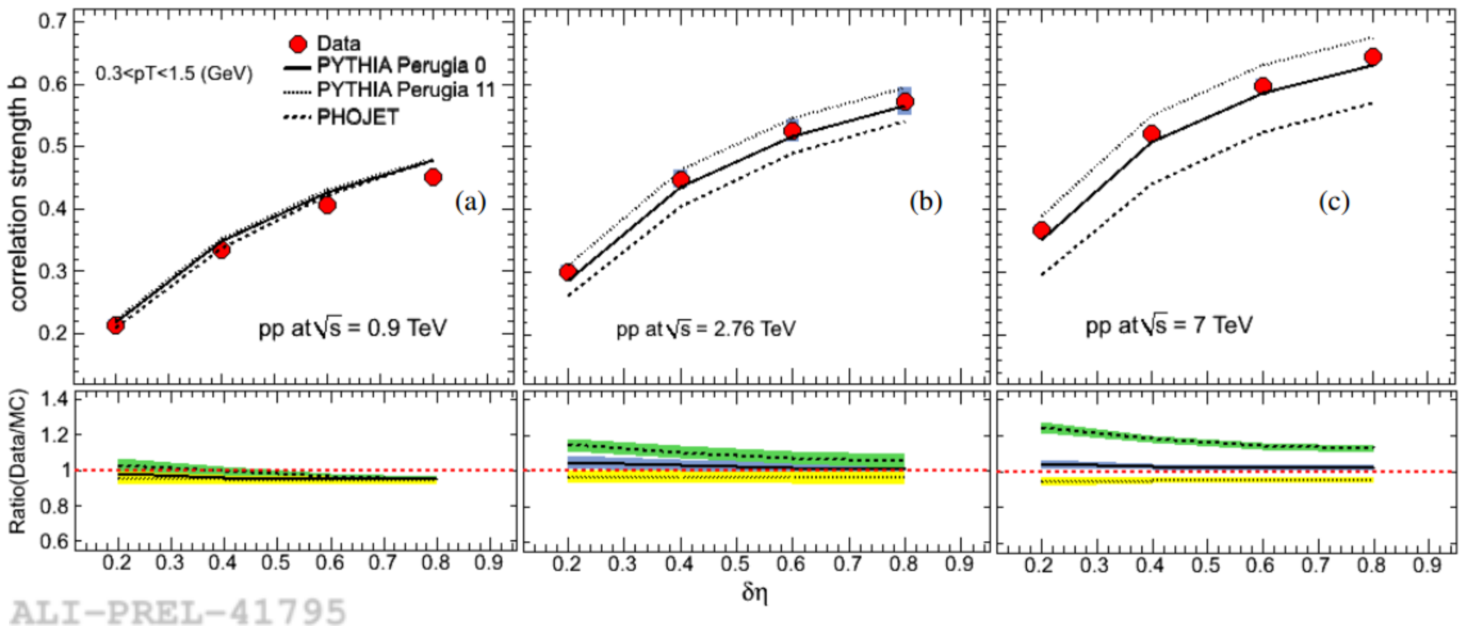




Comparison with generators:

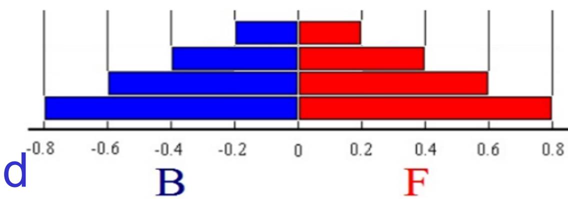
- trends are reproduced
- PYTHIA reproduces the numbers better than PHOJET
- generators give similar estimations at 900 GeV but different at higher energies.

3) FB multiplicity correlations in separated η windows as function of windows width (+comparison to the generators). **Example for η gap =0**



- Correlations grow with windows η-width for all energies
- Generators give similar estimations at 900 GeV but different at higher energies

η windows configurations

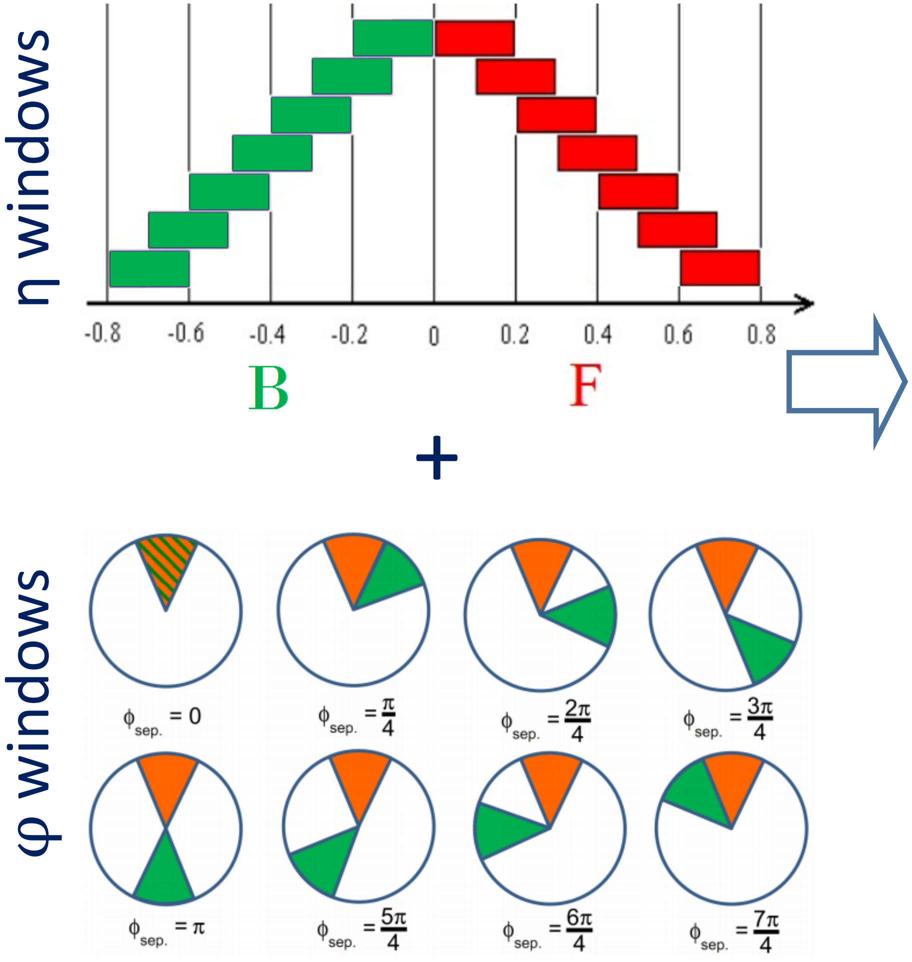


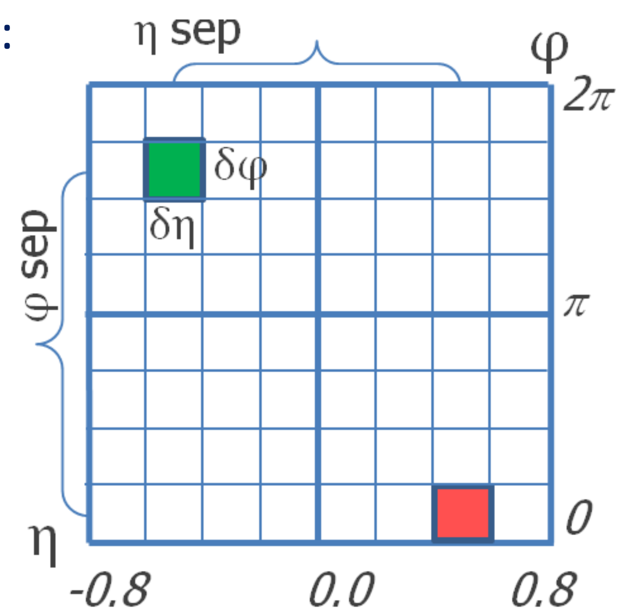
Different tunes give both different multiplicity distributions and b_{corr} values: on the origin of FB correlations and relation to multiplicity fluctuations see A. Capella et.al in Phys. Rep. 236, 225(1994))

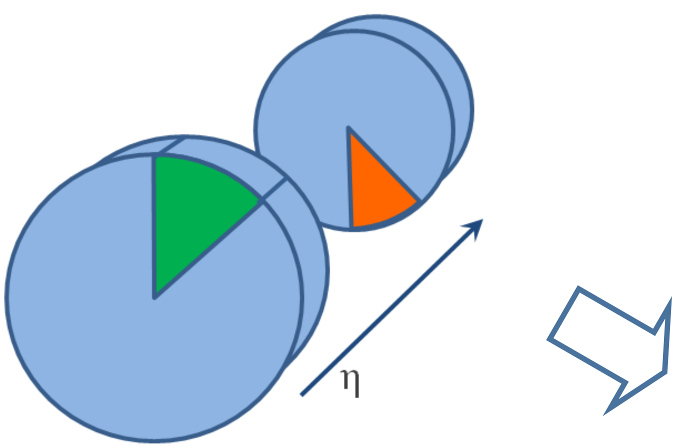
Extension into *azimuthal* dimension: study n-n correlations in η and ϕ separated window pairs

ALICE

η and φ windows pairs chosen for the analysis:



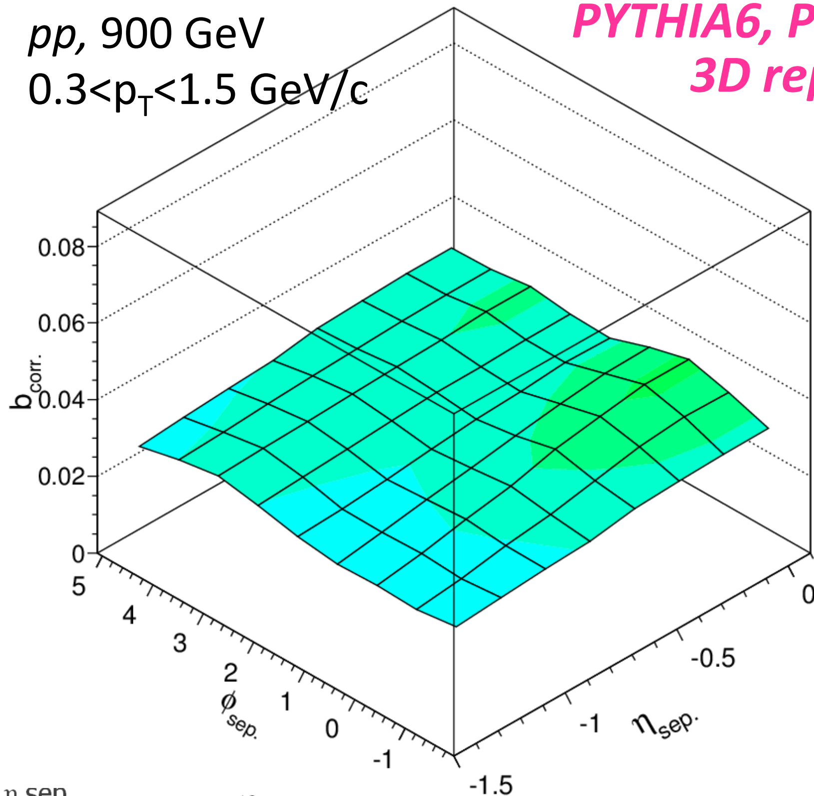




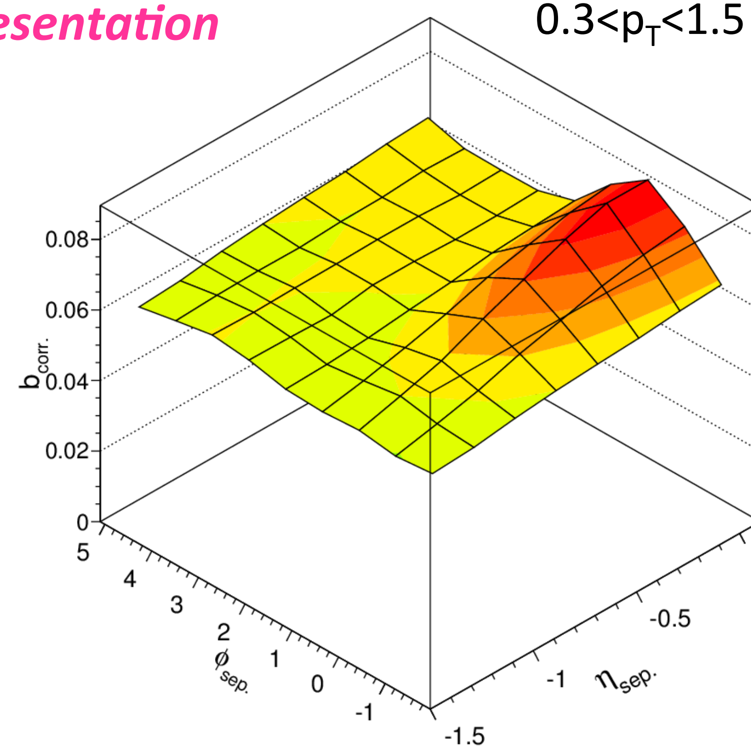
FB multiplicity correlations in separated η and ϕ windows (...so far in PYTHIA...the experimental data are in progress)

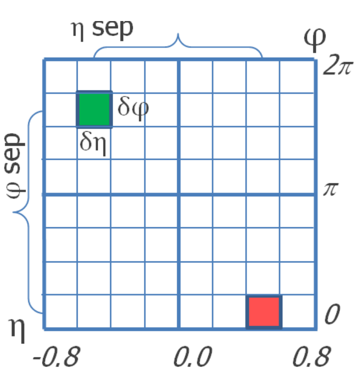
PYTHIA6, Perugia-2011
3D representation

pp, 900 GeV
$0.3 < p_T < 1.5$ GeV/c



pp, 7 TeV
$0.3 < p_T < 1.5$ GeV/c



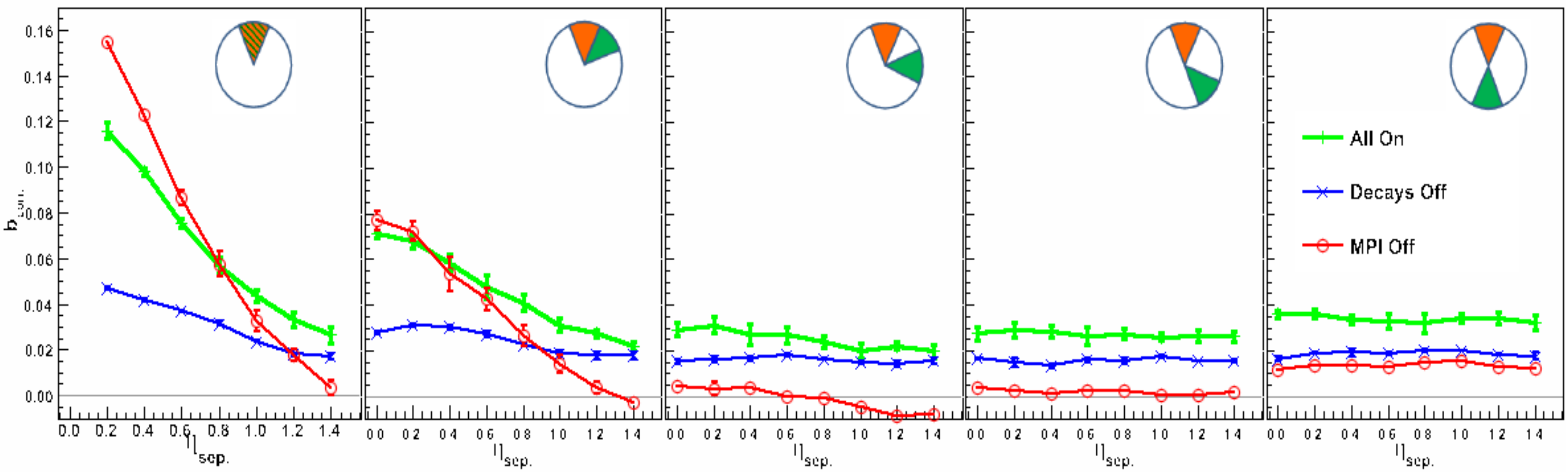


→ short-range and long-range contributions are distinguishable

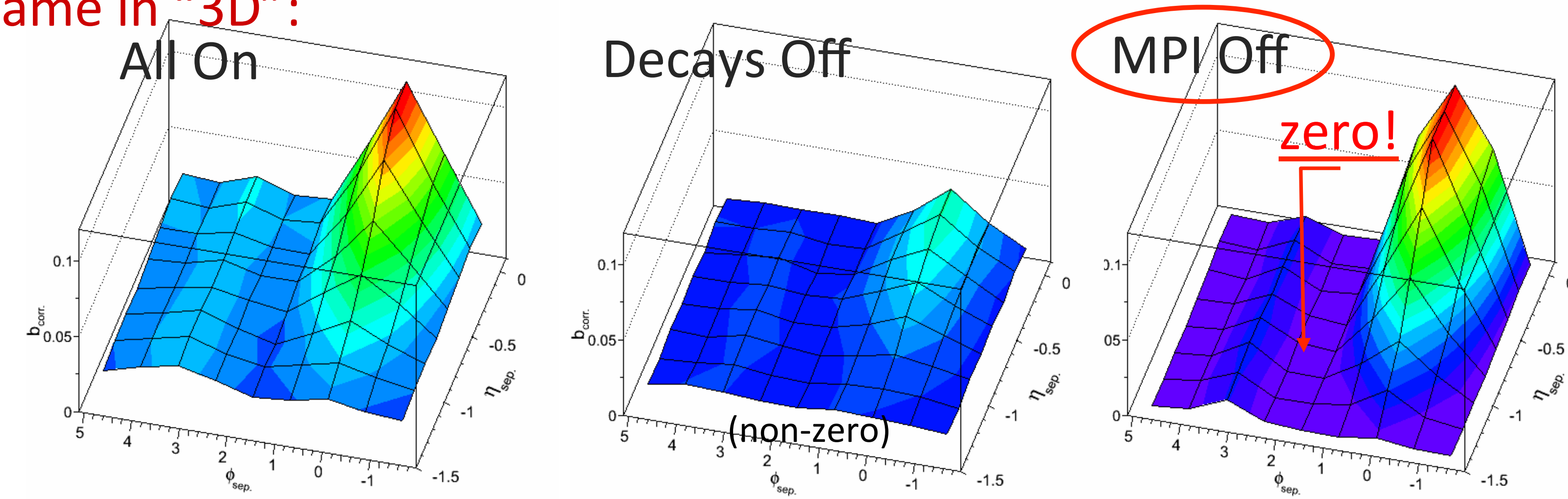
→ non-zero plateau is observed and increases with the energy

FB multiplicity correlations : *pp*, 7 TeV, look at Pythia8

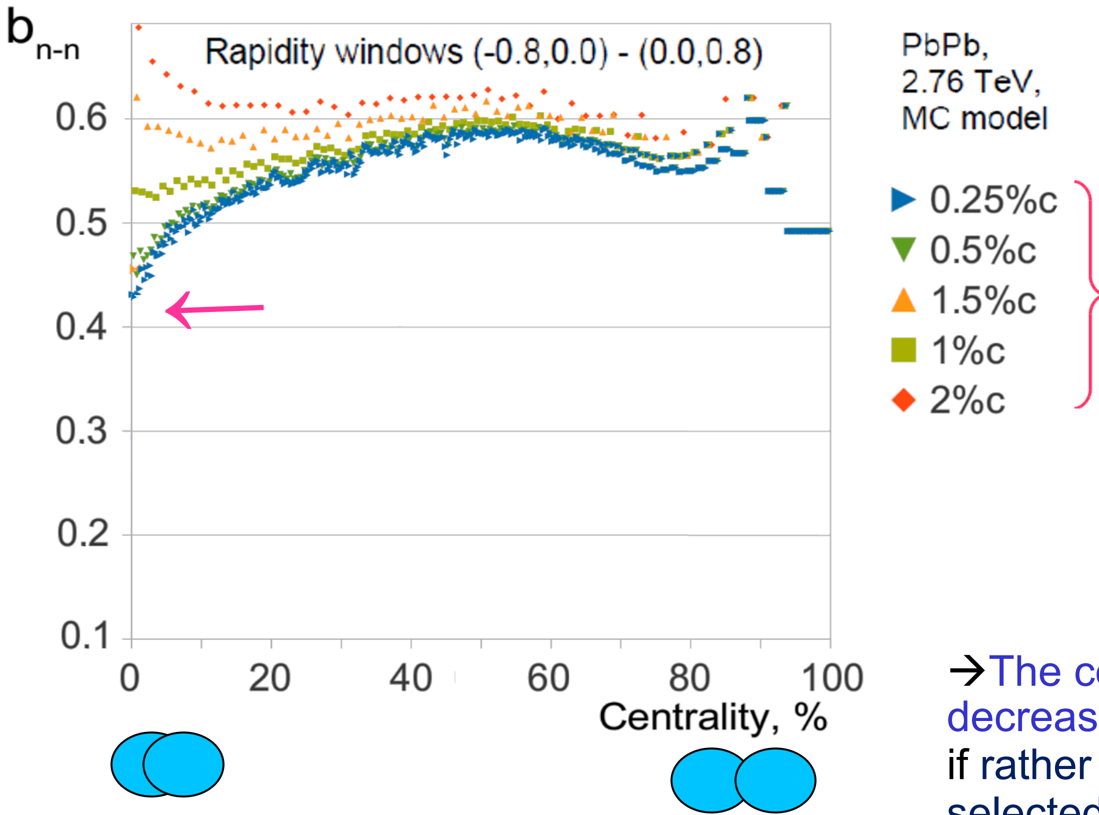
Windows are separated in both in η and in ϕ:



Same in "3D":



PbPb@LHC : example of SFM MC predictions[1] for b_{corr} for different centrality selection conditions



Strong dependence of b_{corr} (b_{nn}) on centrality determination (!): Npart

Bins of different centrality class width are shown here in %

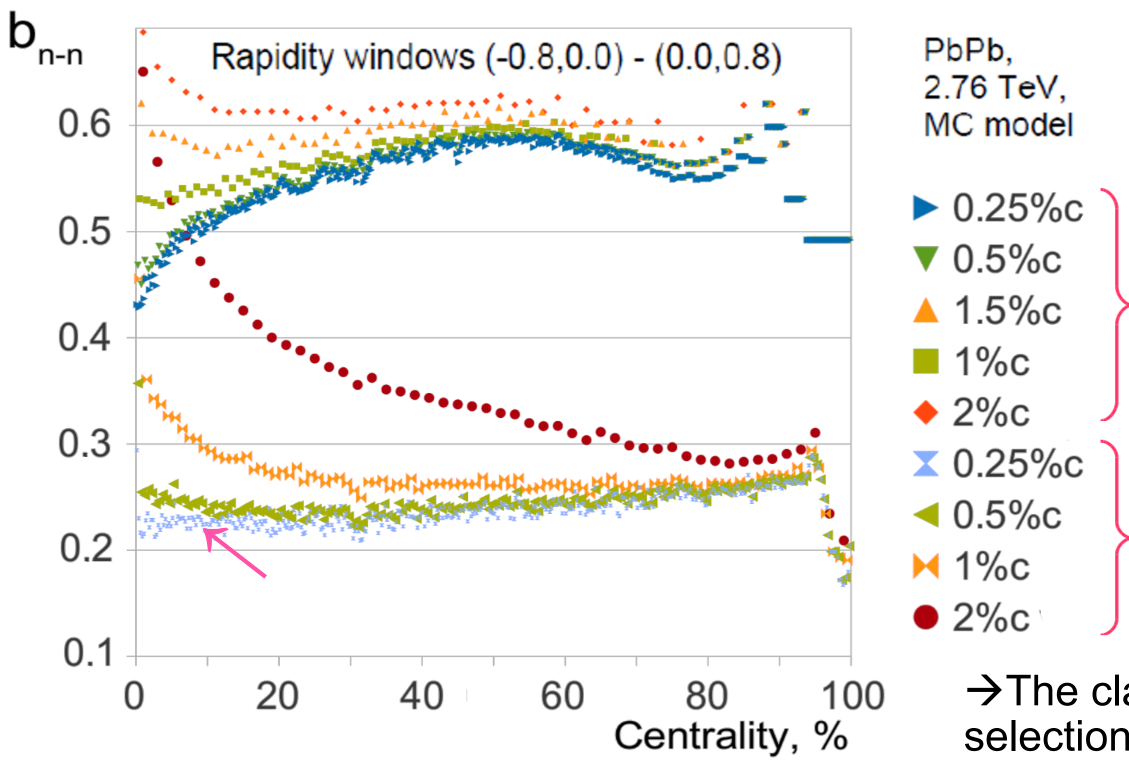
→The correlation strength in SFM decreases for very central events in case if rather narrow centrality classes are selected (< 0.5% in Npart selection)

→The "volume fluctuations" are obviously playing the role in case of wider centrality classes

[1] V. Kovalenko, V. Vechernin, report HD 043 at INPC 2013, arXiv:1308.6618 [nucl-th], to be published

PbPb@LHC : example of SFM MC predictions[1] for b_{corr} for different centrality selection conditions

ALICE



Strong dependence of b_{corr} (b_{nn}) on centrality determination (!): Npart vs. multiplicty (M)

(M is in the forward region)

→The classes defined by multiplicity selection differ from those selected via Npart.

→Decrease of correlation coefficient with centrality can be also demonstrated in sufficiently narrow centrality bins

→ This will be taken into account in the ongoing analysis of Pb-Pb data

[1] V. Kovalenko, V. Vechernin, report HD 043 at INPC 2013, arXiv:1308.6618 [nucl-th], to be published

Summary -1: Experimental results

ALICE

- Forward-backward multiplicity correlations were measured in separated η windows for minimum bias *pp* events in pp@LHC at 0.9, 2.76 and 7 TeV for charged particles with transverse momenta 0.3-1.5 GeV/c.
- A considerable general increase of b_{corr} with the growth of the collision energy is observed.
- b_{corr} increases with the width of η windows but
- b_{corr} only slightly decreases with the growth of the gap between the η windows

Experimental results for separated η-φ windows are coming.

Summary -2: Model analysis

- Model analysis of b_{corr} in pp collisions@LHC for various configurations of azimuthal sectors enables to separate the short-range (SR) and the long-range (LR) effects:
  - the LR part arises due to event-by-event fluctuation of the number of emitters,
  - the SR part is due to pair correlation between particles produced by the same emitter.
- PYTHIA and PHOJET indicate that the behavior of b_{corr} *with* azimuth and rapidity is compatible in *pp* collisions with the multiparticle production by independent string emitters.

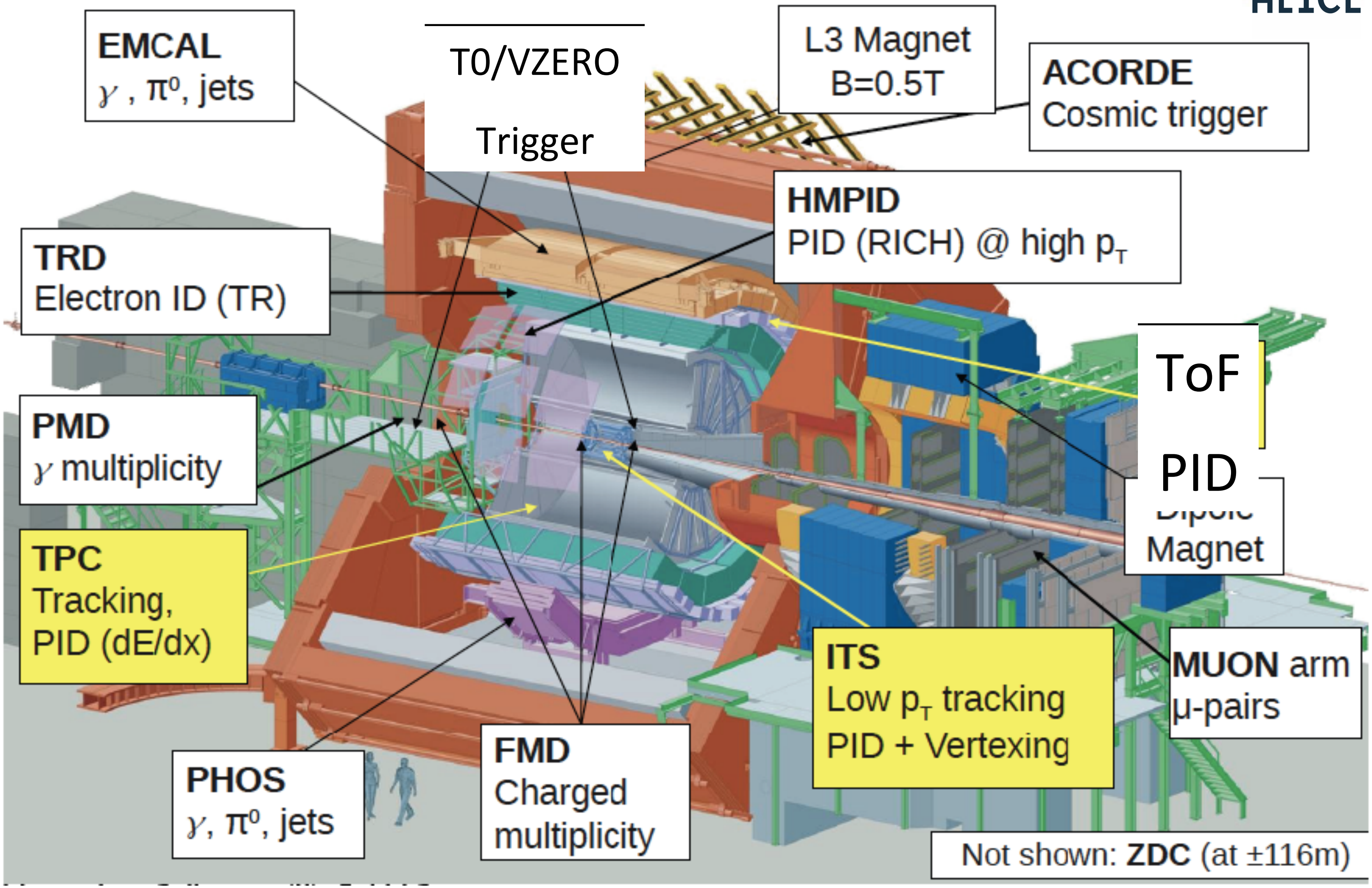
SFM vs CGC model: correlation strength behaviour with centrality in Pb-Pb collisions at the LHC

–> will be investigated

Thank you!

Back-up slides

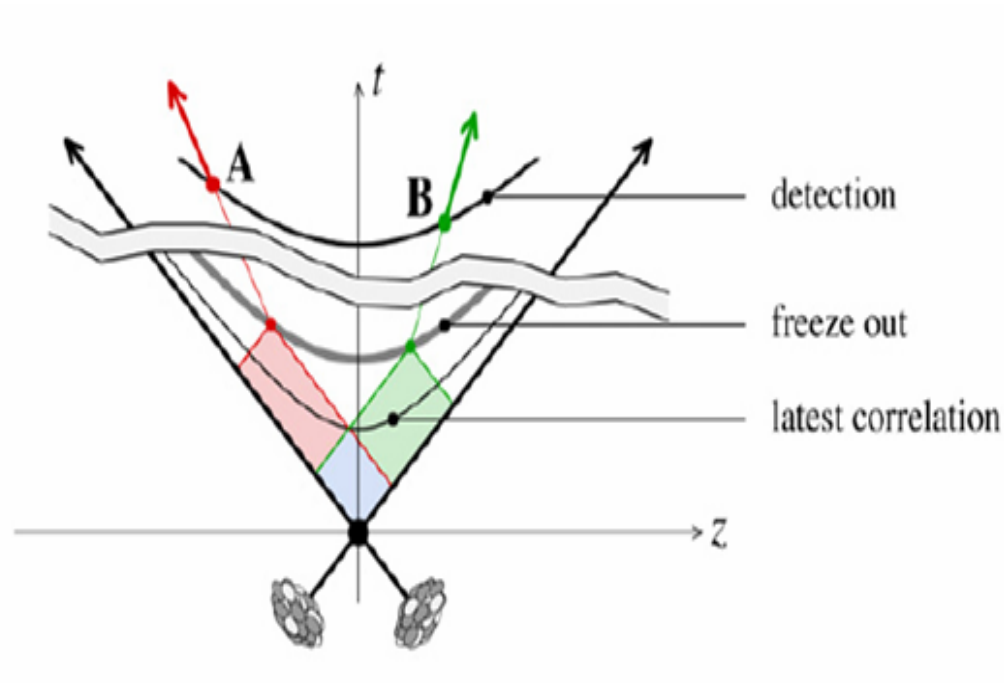
A Large Ion Collider Experiment

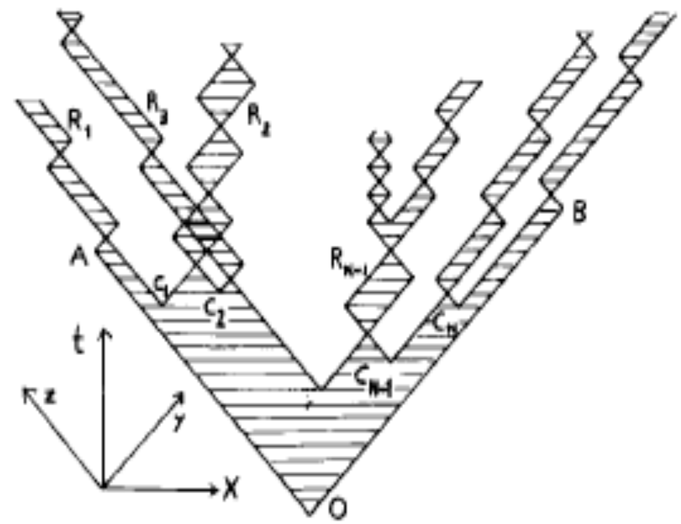


K. Aamodt et al. (ALICE), JINST, 3 , S08002 (2008)

Forward-Backward (Long-Range) correlations

Causality requires appearance of long-range correlations – if they exist – at the very early stages between particles detected in separated rapidity intervals in any type of collisions (pp, pA, AA):





A.Dumitru et al./ Nuclear Physics A 810 (2008) 91-108

X. ARTRU and G. MENNESSIER, Nuclear Physics B70 (1974) 93-115

Theoretical Motivation:
Color string formation and decay

2-stage scenario of color string formatic

and decay:

A.Capella, U.P.Sukhatme, C.--I.Tan

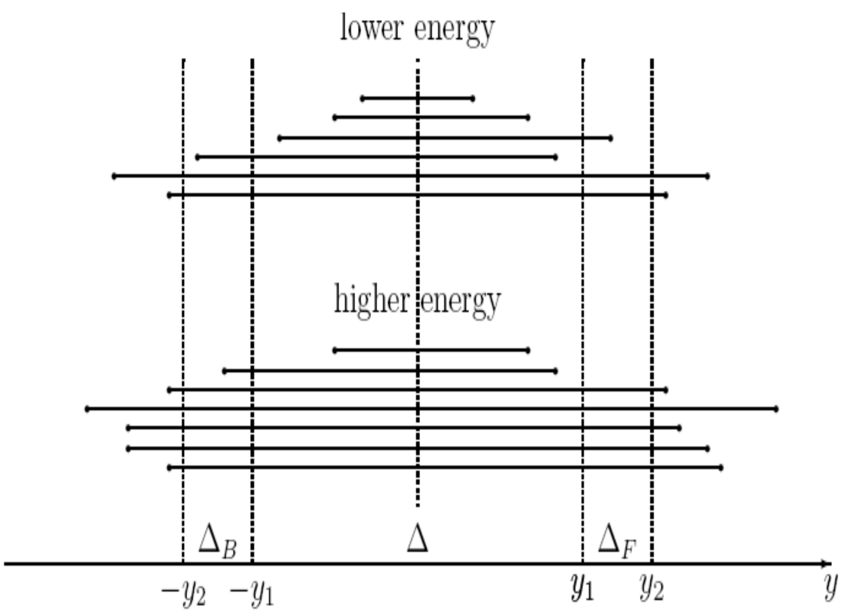
and J.Tran Thanh Van,

Phys. Lett. **B81** (1979) 68;

Phys. Rep.,236(1994) 225.

A.B.Kaidalov K.A.Ter-Martirosyan ,

Phys.Lett., **117B**(1982)247.



Do these color strings interact

and what is the signal?

Abramovskii V. A., Gedalin E. V., Gurvich E. G., Kancheli O. V. ,

JETP Lett., vol.47, 337-339 , 1988 .

Color string fusion phenomenon:

M.A.Braun and C.Pajares,

Phys. Lett. B287(1992) 154; Nucl. Phys. B390} (1993) 542, 549;

FB multiplicity correlations in *pp collisions:*

look at Pythia8

samples:

Pythia8 (8170)

Tune 4Cx

Beams:eCM = 7000 ! CM energy of collision

Can switch on/off the key event generation steps:

#PartonLevel:MPI = off ! no multiparton interactions

#PartonLevel:ISR = off ! no initial-state radiation

#PartonLevel:FSR = off ! no final-state radiation

#HadronLevel:Hadronize = off ! no hadronization

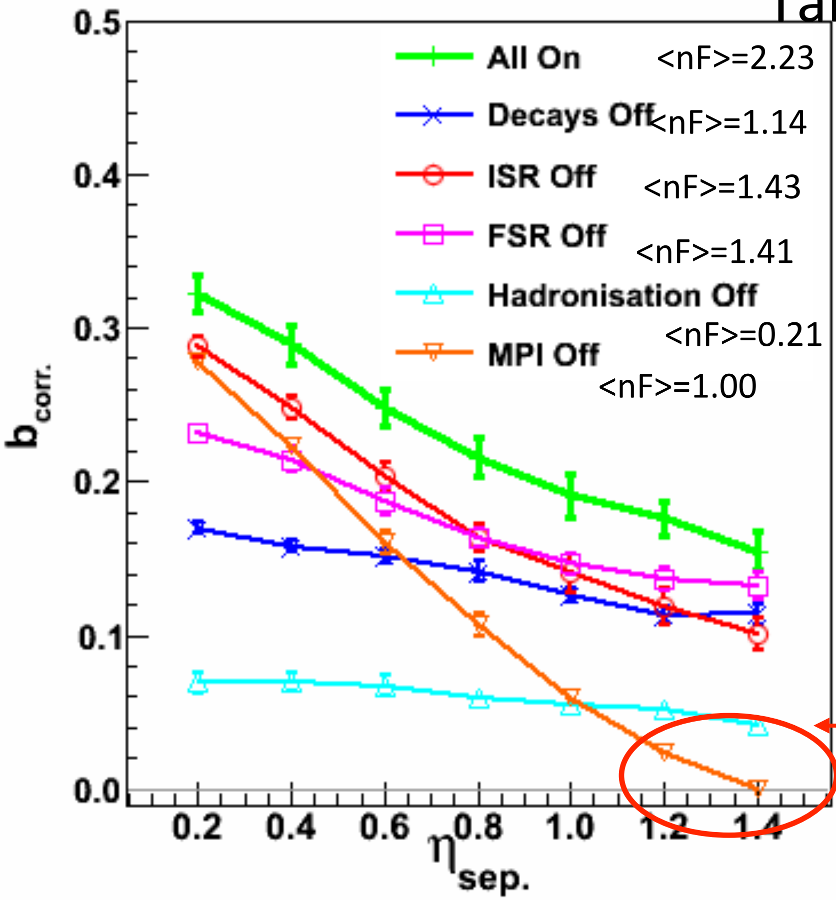
#HadronLevel:Decay = off ! no decays

⇨ 100k events were generated for each option set "off"

FB multiplicity correlations, *pp*, 7 TeV:

look at Pythia8

Take separated in η windows (φ size is 2π):



(<nF> is the mean multiplicity in Forward rapidity window)

MPI Off - removes fluctuations in number of emitting sources

That causes the absence of correlations for distant η windows (b_{corr}=0),

while switching off the other processes leads to reduction of mean multiplicity and of the correlation strength

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Model with strings as independent emitters [1,2]

$\delta a = \delta\eta\,\delta\phi/2\pi$ - *acceptance* of the forward and backward windows.

For windows with small acceptances in rapidity and azimuth situated in a mid rapidity region:

ω_N is the event-by-event **scaled variance of the number of strings.**

μ_0 is the average rapidity density of the charged particles produced by one string.

$\Lambda(\eta,\phi)$ is the pair correlation function of a single string

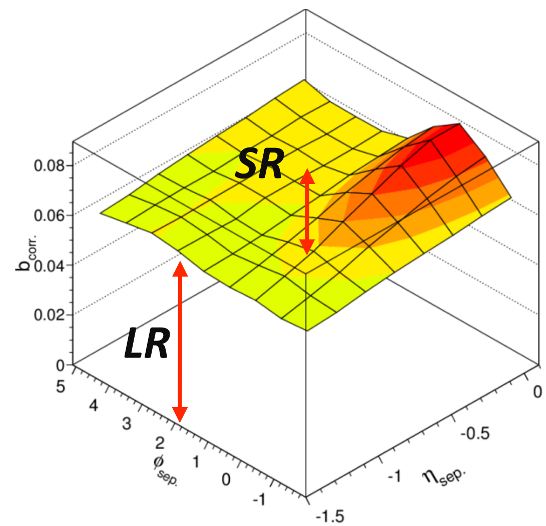
$$b_{corr} = b^{LR} + b^{SR}$$

$$b^{LR} = \frac{\omega_N \mu_0 \delta a}{1 + [\omega_N + \Lambda(0,0)]\mu_0 \delta a}$$

$$b^{SR} = \frac{\mu_0 \delta a}{1 + [\omega_N + \Lambda(0,0)]\mu_0 \delta a}\Lambda(\eta_{sep},\phi_{sep})$$

At $\Lambda(\eta,\phi) = 0$ we have

$$b^{SR}_{\Lambda=0} = 0, \text{ but } \; b^{LR}_{\Lambda=0} = \frac{\omega_N \mu_0 \delta a}{1 + \omega_N \mu_0 \delta a} \neq 0$$



b^{LR} (through the ω_N)

is sensible to fluctuations in the number of emitters

1) V.V. Vechernin, arXiv: 1305.0857, 2013
2) M.A. Braun, R.S. Kolevatov, C. Pajares, V.V. Vechernin, Eur. Phys. J. C32, 535 (2004).

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Connection of the FB correlation coefficient with two-particle correlation function - 1

By definition the two-particle correlation function C_2 is defined through the inclusive ρ_1 and double inclusive ρ_2 distributions:

$$C_2(\eta_F,\phi_F;\eta_B,\phi_B) = \frac{\rho_2(\eta_F,\phi_F;\eta_B,\phi_B)}{\rho_1(\eta_F,\phi_F)\rho_1(\eta_B,\phi_B)} - 1 \qquad (1)$$

$$\rho_1(\eta,\phi) = \frac{d^2N}{d\eta\, d\phi}\ , \qquad \rho_2(\eta_F,\phi_F;\eta_B,\phi_B) = \frac{d^4N}{d\eta_F\, d\phi_F\, d\eta_B\, d\phi_B} \qquad (2)$$

To measure the ρ_1 one has by definition to take a small window $\delta\eta\,\delta\phi$ around η, ϕ, then

$$\rho_1(\eta,\phi) \equiv \frac{\langle n\rangle}{\delta\eta\,\delta\phi}\ , \qquad (3)$$

here $\langle n\rangle$ is the mean multiplicity in the acceptance $\delta\eta\,\delta\phi$.
One has to reduce the acceptance until the ratio (3) becomes constant.

Connection of the FB correlation coefficient with two-particle correlation function - 2

To measure the ρ_2 one has by definition to take TWO small windows: $\delta\eta_F\,\delta\phi_F$ around η_F, ϕ_F and $\delta\eta_B\,\delta\phi_B$ around η_B, ϕ_B, then

$$\rho_2(\eta_F,\phi_F;\eta_B,\phi_B) \equiv \frac{\langle n_F n_B\rangle}{\delta\eta_F\,\delta\phi_F\,\delta\eta_B\,\delta\phi_B}\ . \tag{4}$$

One has to reduce the acceptances of the observation windows until the ratio (4) becomes constant.
So by (3) and (4) the definition (1) means the following experimental procedure of the determination of the correlation function C_2:

$$C_2(\eta_F,\phi_F;\eta_B,\phi_B) \equiv \frac{\langle n_F n_B\rangle - \langle n_F\rangle\langle n_B\rangle}{\langle n_F\rangle\langle n_B\rangle}\ , \tag{5}$$

where n_F and n_B are the event multiplicities in TWO small windows: $\delta\eta_F\,\delta\phi_F$ around η_F, ϕ_F and $\delta\eta_B\,\delta\phi_B$ around η_B, ϕ_B.

Connection of the FB correlation coefficient with two-particle correlation function - 3

Traditionally one uses the following definition of the FB correlation coefficient:

$$b_{abs} \equiv \frac{\langle n_F n_B \rangle - \langle n_F \rangle \langle n_B \rangle}{\langle {n_F}^2 \rangle - \langle n_F \rangle^2} \qquad \text{or} \qquad b_{rel} \equiv \frac{\langle n_F \rangle}{\langle n_B \rangle} b_{abs} \tag{6}$$

For small FB windows by (5) we have

$$b_{abs} = \frac{\langle n_F \rangle \langle n_B \rangle}{D_{n_F}} C_2(\eta_F, \phi_F; \eta_B, \phi_B) \ , \qquad b_{rel} = \frac{\langle n_F \rangle^2}{D_{n_F}} C_2(\eta_F, \phi_F; \eta_B, \phi_B) \tag{7}$$

Note that for small forward window: $D_{n_F} \to \langle n_F \rangle$.
So by (7) we see that the traditional definition of the FB correlation coefficient in the case of TWO small observation windows coincides with the standard definition of two-particle correlation function C_2 upto some common factor $\langle n_B \rangle$ or $\langle n_F \rangle$, which depends on the width of windows.

Connection of the FB correlation coefficient with two-particle correlation function - 4

Note that one can go in C_2 to the variables:

$$\Delta\eta = \eta_F - \eta_B \ , \qquad \eta_C = (\eta_F + \eta_B)/2 \tag{8}$$

$$\Delta\phi = \phi_F - \phi_B \ , \qquad \phi_C = (\phi_F + \phi_B)/2 \tag{9}$$

and EXPERIMENTALLY check up the dependence of the two-particle correlation function C_2 on η_C for the different configurations and separations between FB observation windows.
Summing up, we see that by the standard definition (1) the experimental determination of the two-particle correlation function $C_2(\eta_F, \phi_F; \eta_B, \phi_B)$ requires (5) the measurements of the event multiplicities n_F and n_B in TWO SMALL windows: $\delta\eta_F\,\delta\phi_F$ around η_F, ϕ_F, and $\delta\eta_B\,\delta\phi_B$ around η_B, ϕ_B, which is performed in our approach.

Connection of the FB correlation coefficient with two-particle correlation function - 5

Note that the so-called di-hadron correlation function

$$C(\Delta\eta, \Delta\phi) \equiv S/B - 1 \ , \tag{10}$$

which takes into account all possible pair combinations of particles produced in given event in some ONE LARGE pseudorapidity window, where

$$S = \frac{d^2 N}{d\Delta\eta \, d\Delta\phi} \tag{11}$$

and the B is the same but in the case of uncorrelated particle production, has only indirect connection with the standard definition (1) of the two-particle correlation function $C_2(\eta_F, \phi_F; \eta_B, \phi_B)$ and can coincide with it only in the case when the pseudorapidity translation invariance (the independence C_2 on η_C) takes place. This indirect method can also lead to the loss in $C(\Delta\eta, \Delta\phi)$ the common "pedestal", which takes place in $C_2(\Delta\eta, \Delta\phi)$ (see arXiv:1305.0857 for details).

Connection of the FB correlation coefficient with two-particle correlation function - 6

This common "pedestal" in $C_2(\Delta\eta, \Delta\phi)$ is physically important as, for example, in the model with fluctuating number N of the independent identical emitters (strings) one has the following expression for the $C_2(\Delta\eta, \Delta\phi)$:

$$C_2(\Delta\eta, \Delta\phi) = \frac{\omega_N + \Lambda(\Delta\eta, \Delta\phi)}{\langle N \rangle} \ , \tag{12}$$

where the $\Lambda(\Delta\eta, \Delta\phi)$ is the pair correlation function of a single string and the $\omega_N = D_N / \langle N \rangle$ is the scaled variance of the event-by-event fluctuation of the number N of strings.

Hence by (12) we see that from the height of the "pedestal" ($\omega_N / \langle N \rangle$) one can obtain the important physical information on the magnitude of the fluctuation of N at different energies and centrality fixation.