JOINT INSTITUTE FOR NUCLEAR RESEARCH
XXII INTERNATIONAL BALDIN SEMINAR ON HIGH ENERGY PHYSICS PROBLEMS
RELATIVISTIC NUCLEAR PHYSICS & QUANTUM CHROMODYNAMICS
Dubna, Russia, September 15-20, 2014

Long-range rapidity correlations between the transverse momentum and the multiplicities in light-nuclei collisions

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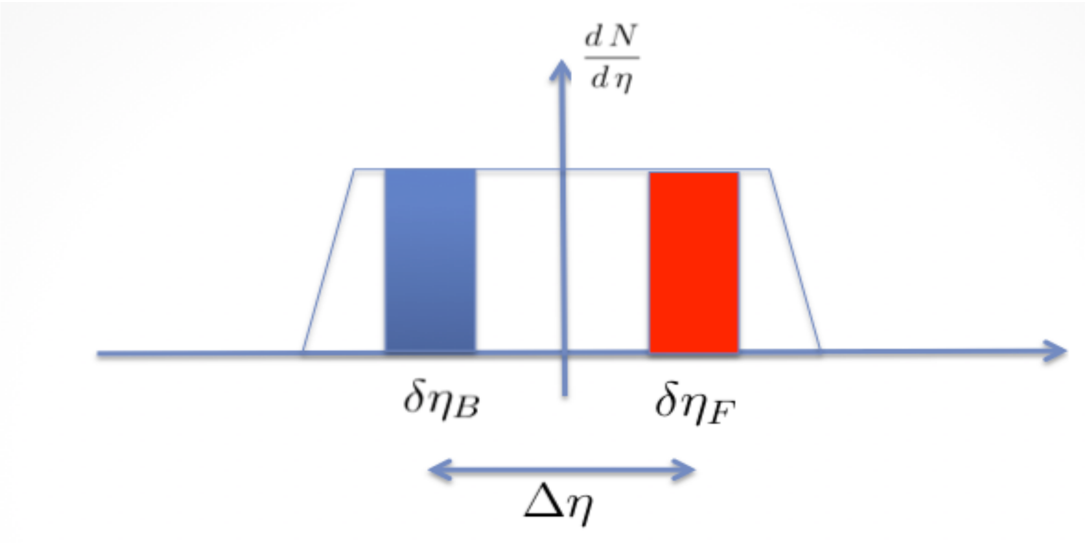
Dubna, 17/09/14

Outline

- Introduction
- Model with two types of strings
- Results for the n-n and pT-n correlation parameters
- Summary

Long-range pseudorapidity correlations



Two definitions of the correlation parameter for two observables B and F

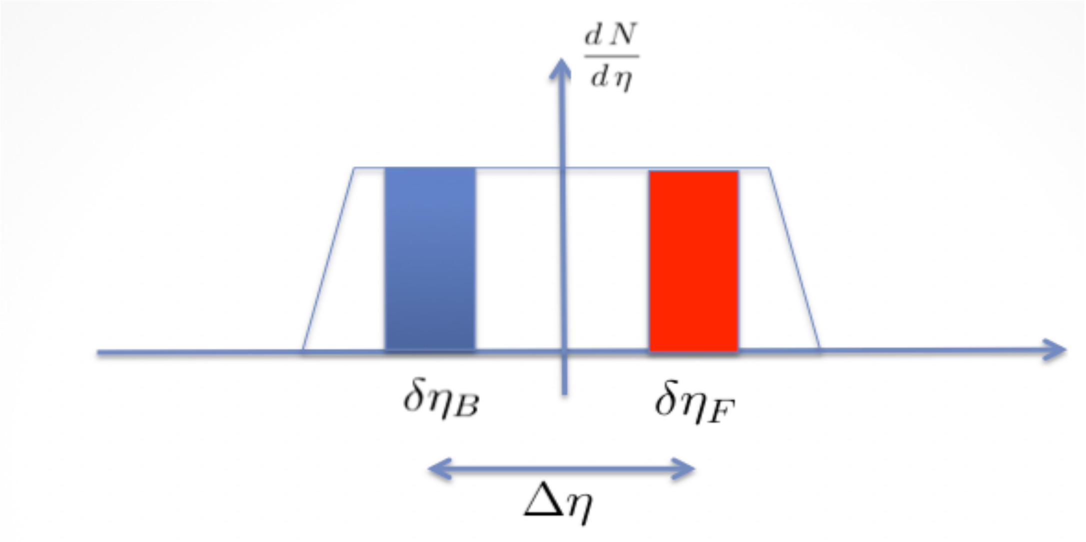
1) Linear regression

$$\langle B \rangle_F = a + b \cdot F$$

2) Correlator formula

$$b = \frac{\langle B \cdot F \rangle - \langle B \rangle \cdot \langle F \rangle}{\langle F^2 \rangle - \langle F \rangle^2}$$

Long-range pseudorapidity correlations



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Long-range pseudorapidity correlations

Observable types

n – charged particles multiplicity

$$p_t = \frac{1}{n}\sum_{i=1}^{n} p_t^{(i)}$$ - event mean value of transverse momentum

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Correlation types

- n-n
- pT-n
- pT-pT

Long-range pseudorapidity correlations

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Correlation types

- n-n
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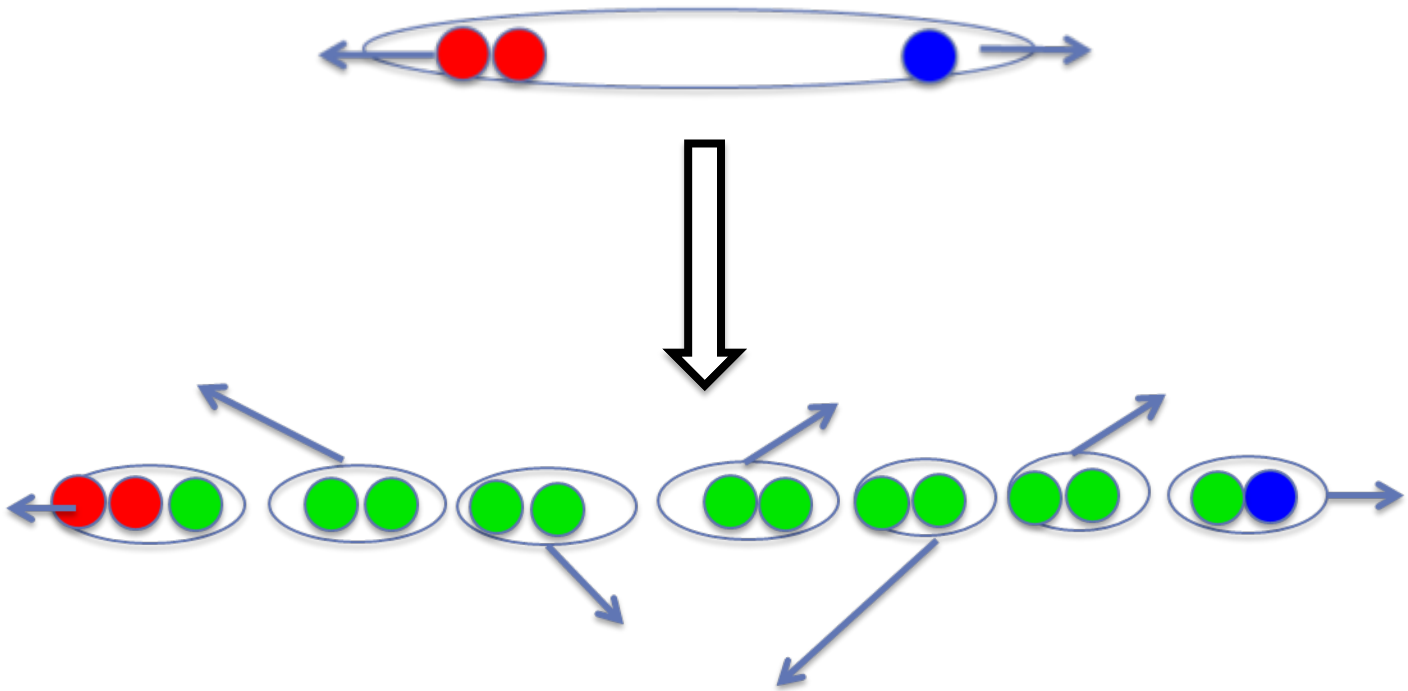
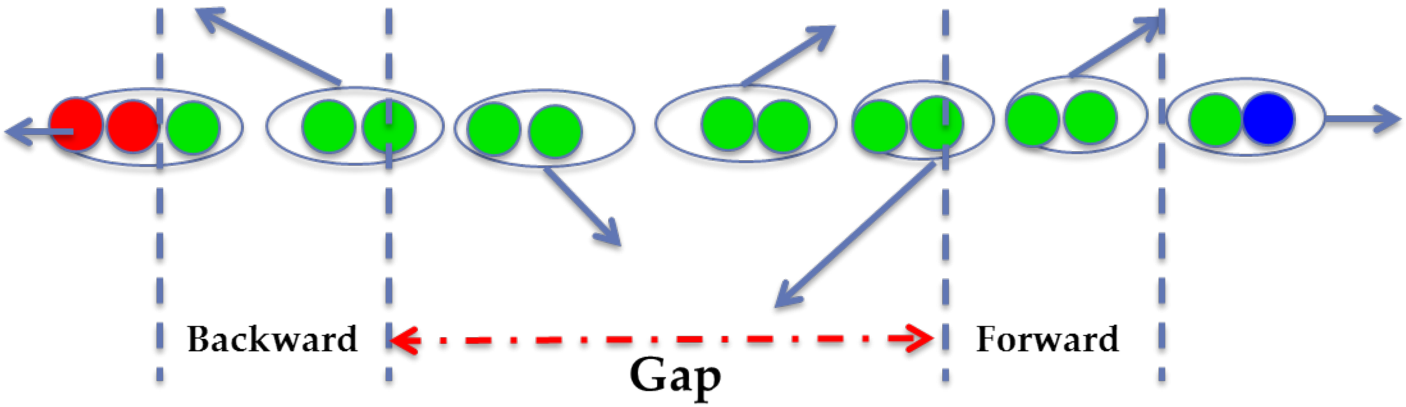
- ~~pT-pT~~

Mechanism of particle production in the model with independent strings



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, Phys. Lett., 116B(1982)459

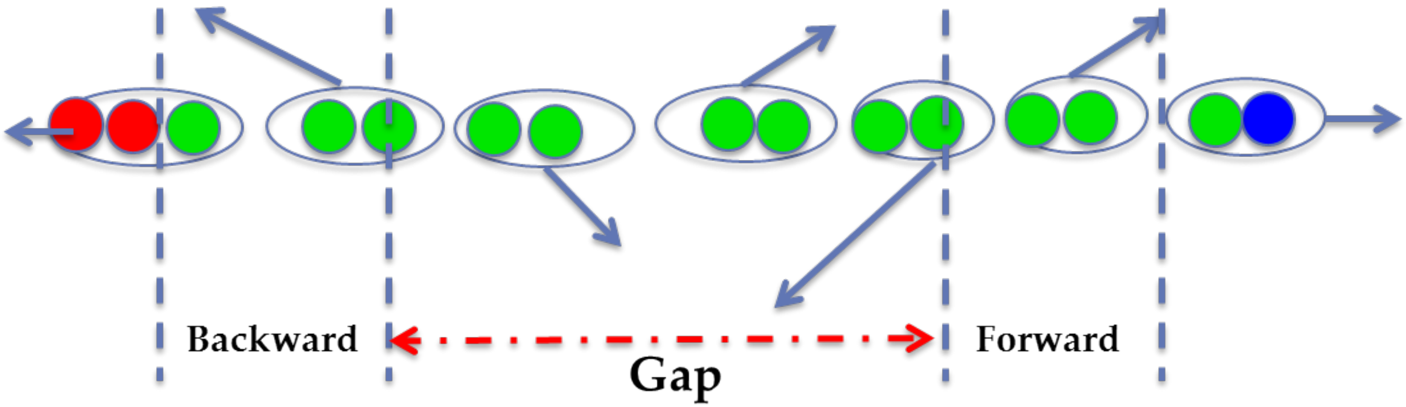
Single string case



$$\langle n_B \rangle = \sum_B B \cdot P(B) = \langle n_B \rangle_{one}$$

$$\langle n_F \rangle = \sum_F F \cdot P(F) = \langle n_F \rangle_{one}$$

Single string case



$$\langle n_B \rangle = \sum_B B \cdot P(B) = \langle n_B \rangle_{one}$$

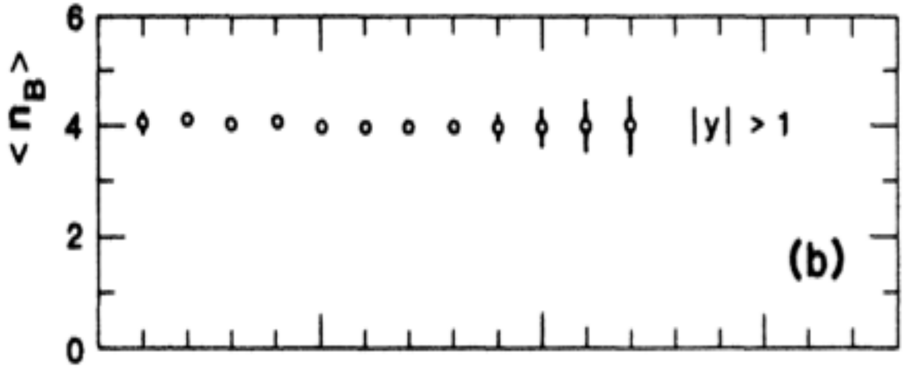
$$\langle n_F \rangle = \sum_F F \cdot P(F) = \langle n_F \rangle_{one}$$

In case of sufficiently large gap between windows one string produces particles in both windows independently!

$$\left(P(F,B) = P(B) \cdot P(F)\right)$$

$$\langle n_B n_F \rangle = \sum_{F,B} F \cdot B \cdot P(F,B) = \langle n_B \rangle \cdot \langle n_F \rangle \longrightarrow b_{n-n} = 0$$

Single string case



e+ e- at 29 GeV

$$\langle n_B \rangle = \sum_B B \cdot P(B) = \langle n_B \rangle_{one}$$

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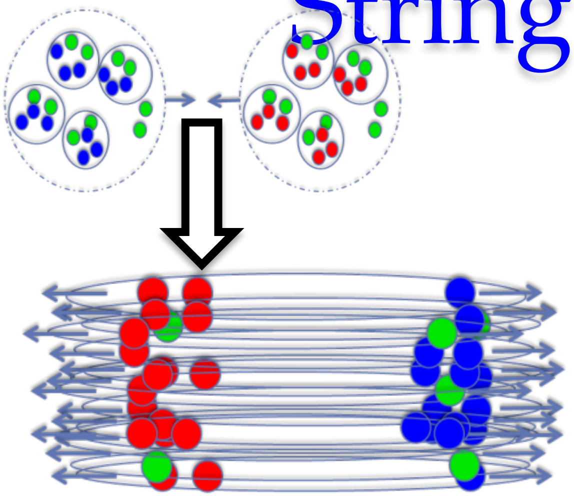
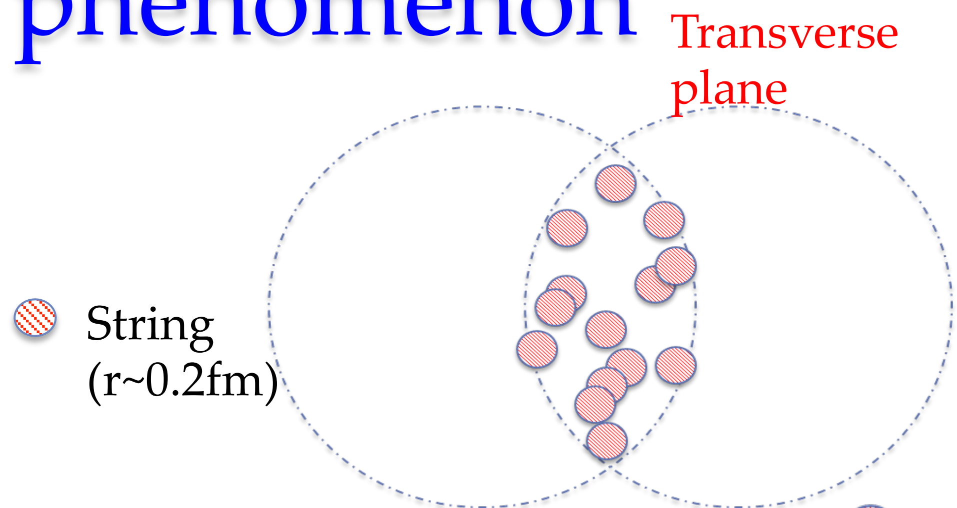
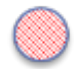
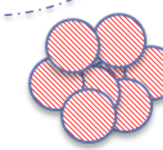
Experiment: $b = 0.002 \pm 0.006$ Phys.Rev.D vol.34, num.11(1986)

String fusion phenomenon





	Single string 	**Overlapping strings** 
Multiplicity	$\langle n \rangle_{one}$	$\langle n \rangle_{new} = \sqrt{N_{str}}\,\langle n \rangle_{one}$
Transverse momentum	$\langle p_t \rangle_{one}$	$\langle p_t^{\,2} \rangle_{new} = \sqrt{N_{str}}\,\langle p_t^{\,2} \rangle_{one}$

M.A.Braun and C.Pajares, Phys. Rev. Lett. **85** (2000) 4864;
M.A.Braun and C.Pajares, Phys. Lett. **B287** (1992) 154; Nucl. Phys. **B390** (1993) 542, 549;
N.S.Amelin, M.A.Braun and C.Pajares, Phys. Lett. **B306** (1993) 312;
M.A.Braun, C.Pajares and V.V.Vechernin, Internal Note/FMD ALICE---INT---2001---16

Long-range correlations. General remarks.

- LRC are governed by the fluctuations in number of strings and by the string fusion effects
- n-n correlation coefficient is zero without these fluctuations and fusion effects
- pT-n correlation coefficient is zero without fusion effects.

Also at the seminar: 1) 16/09/14 talk by V.Vechernin
2) 16/09/14 talk by D. Neverov
3) 17/09/14 talk by G. Feofilov
4) 17/09/14 talk by V. Kovalenko

Model with two types of strings

N primary strings (N – even)

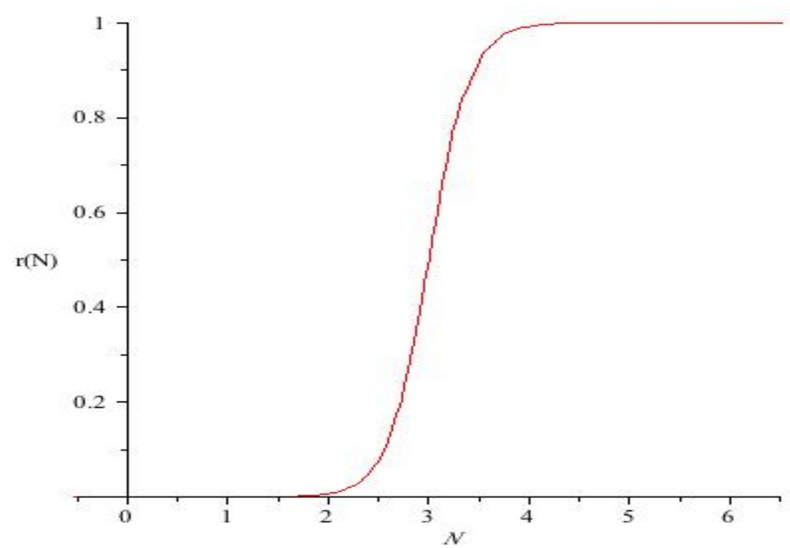
$$P_N(N_2) = C_{N/2}^{N_2} r^{N_2} (1-r)^{N/2-N_2}$$

$$N_2 \; ; \; N_1 = N - 2N_2$$

Analytical results for n-n correlation coefficient
Only negative pT-n correlations!
E. A., V. Vechernin, PoS(QFTHEP2013), 054 (2014).

$$r(N) = \frac{1}{1 + e^{-\frac{N - shift}{slope}}}$$

Only MC simulations



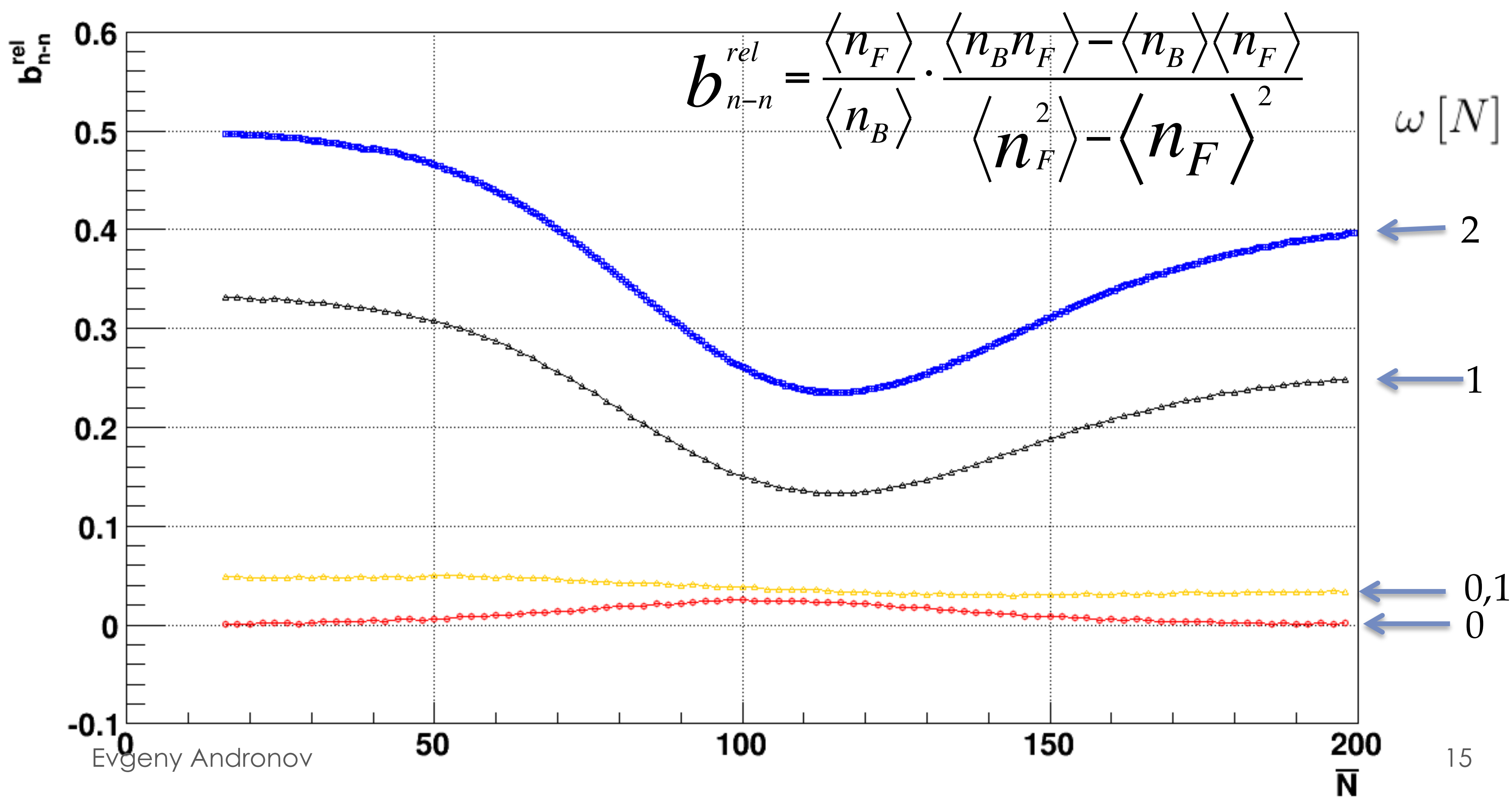
Long-range n-n correlation parameter. Monte-Carlo simulations.

$\overline{N}$ - mean value of the number of primary strings

$\omega[N] = \frac{D_N}{\overline{N}}$ - scaled variance of the number of primary strings

$\overline{\mu} = D_\mu = 0.5$ - parameters of string decay

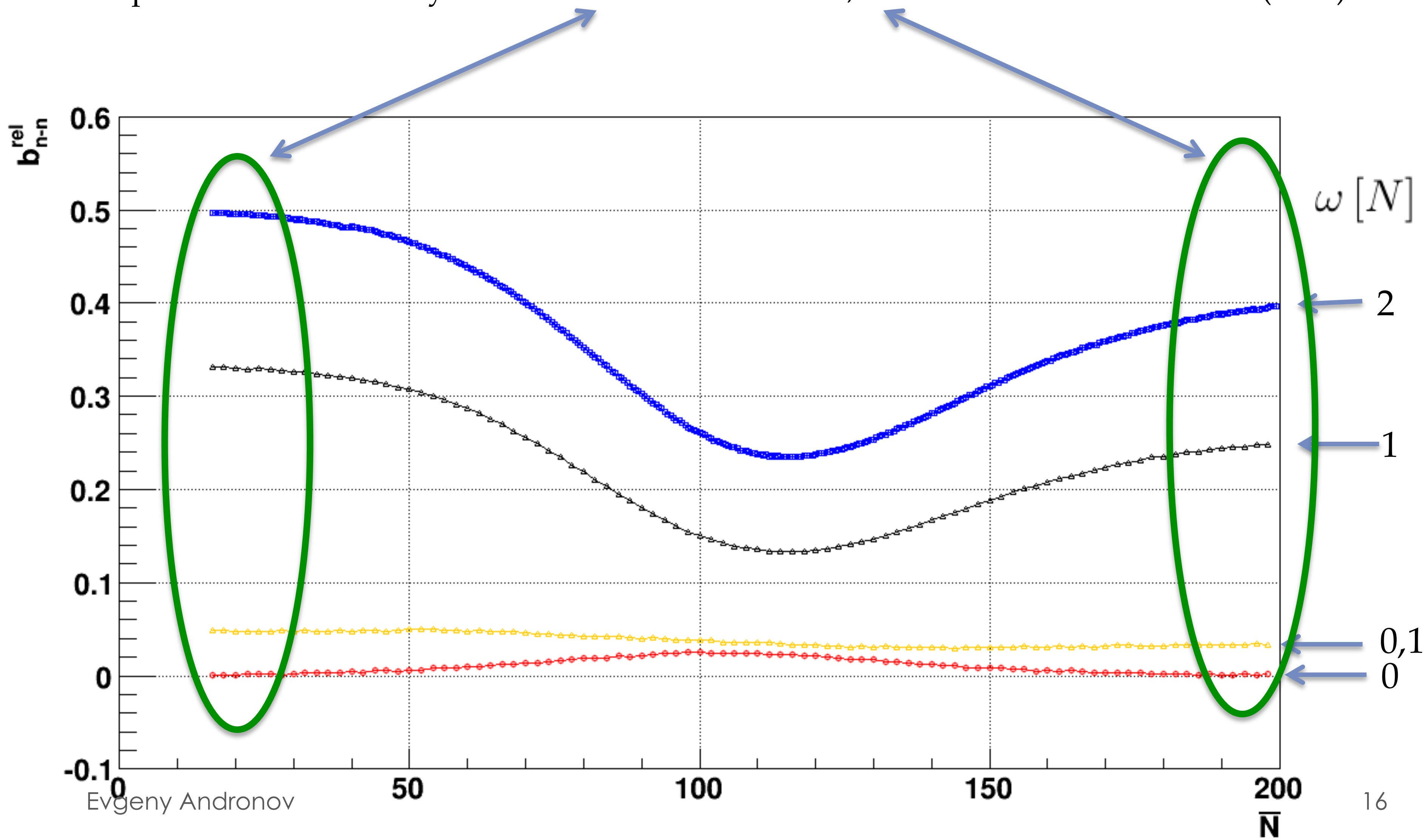
Shift=100
Slope=20



Long-range n-n correlation parameter. Monte-Carlo simulations.

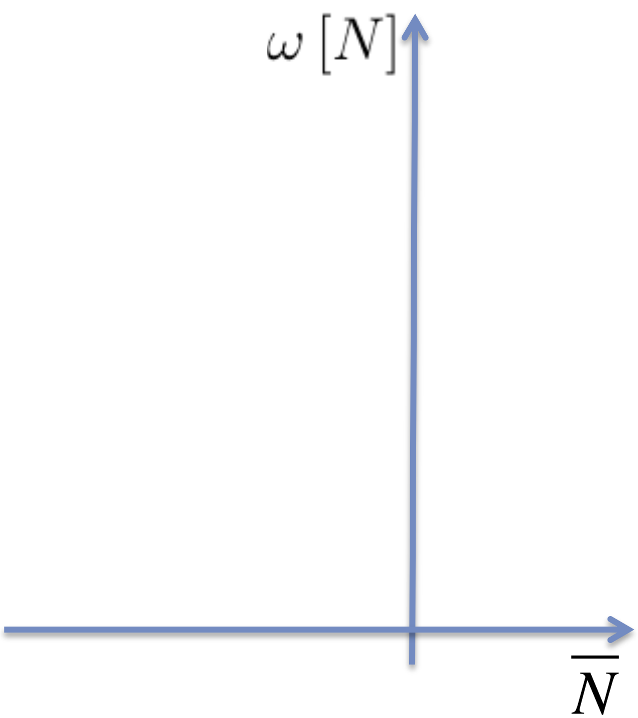
Single type of the string limits (r=0 or r=1)

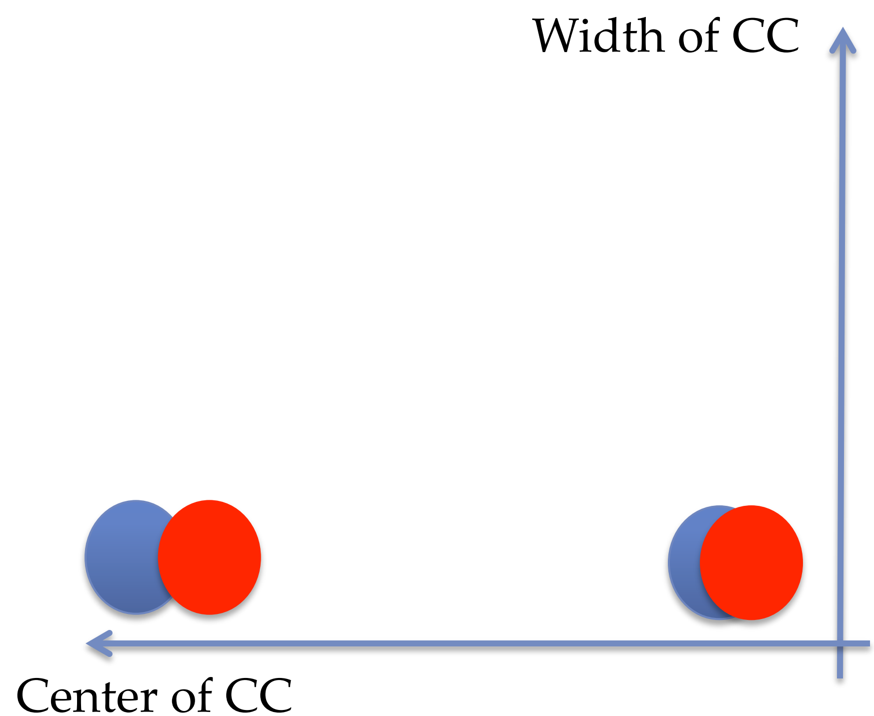
Correspondence to the analytical results – V.V. Vechernin, Proc. Of XX Baldin ISHEPP (2011)



Long-range n-n correlation parameter. Connection with experiment.

By varying the width and the position of the centrality class one can scan our plot in two directions and search for the predicted effects





CC=centrality class

Long-range pT-n correlation parameter. Monte-Carlo simulations.

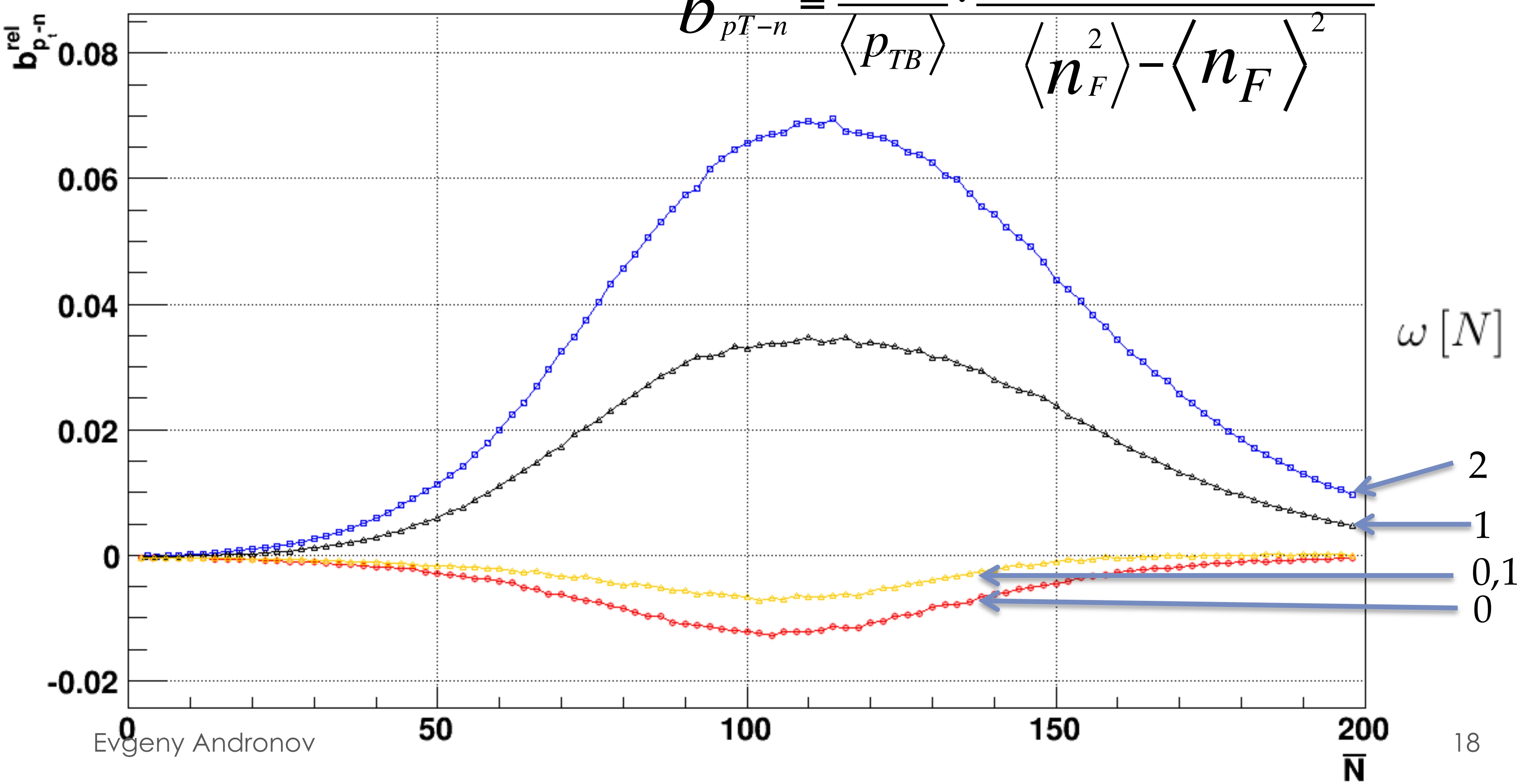
$\overline{N}$ - mean value of the number of primary strings

$\omega[N] = \frac{D_N}{\overline{N}}$ - the scaled variance of the number of primary strings

$\overline{\mu} = D_\mu = 0.5$ - parameters of string decay

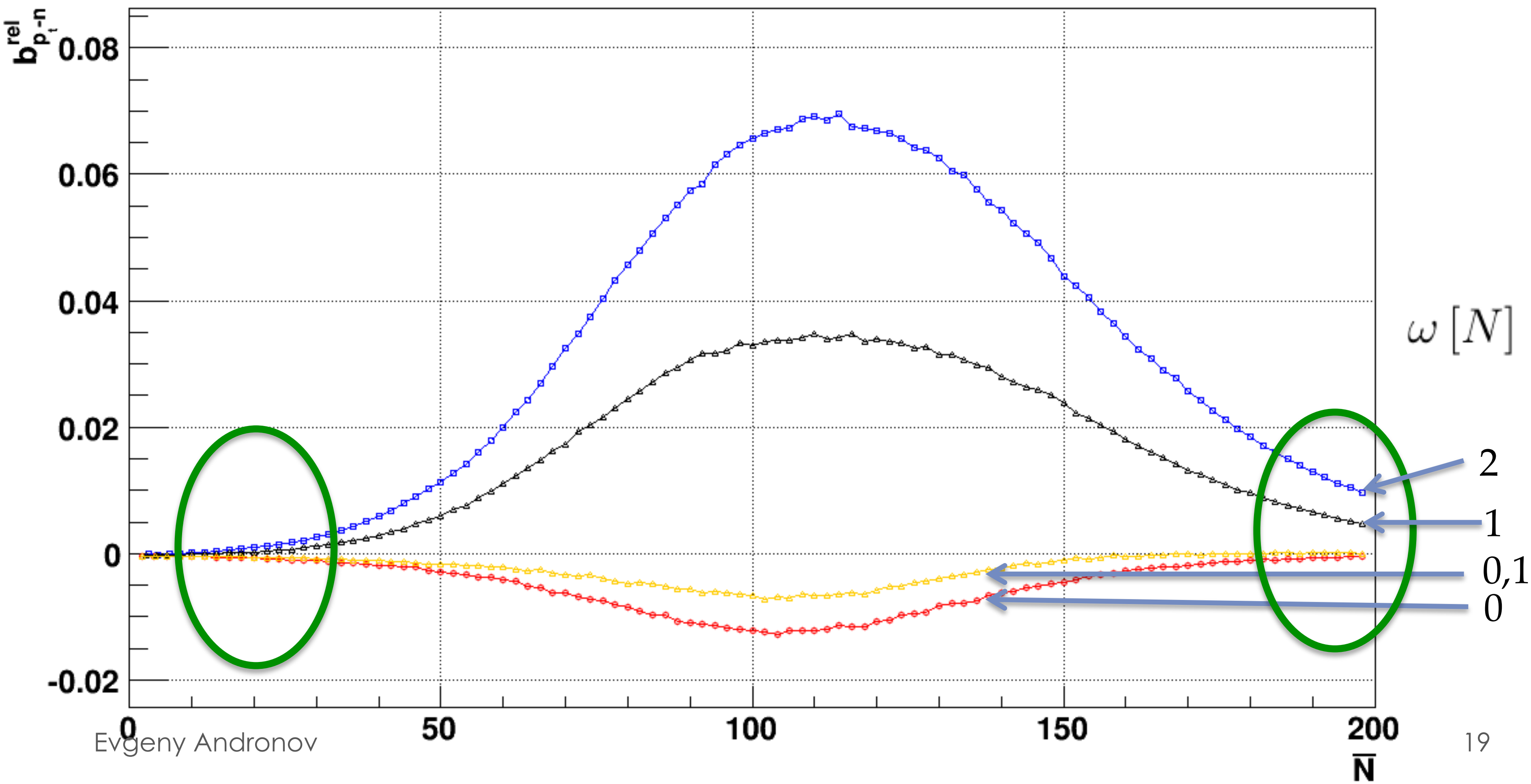
Shift=100
Slope=20

$$b^{rel}_{pT-n} = \frac{\langle n_F \rangle}{\langle p_{TB} \rangle} \cdot \frac{\langle p_{TB} n_F \rangle - \langle p_{TB} \rangle \langle n_F \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2}$$

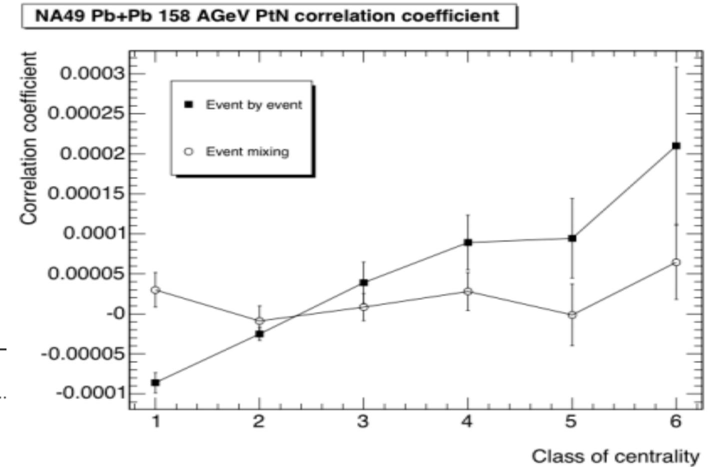


Long-range pT-n correlation parameter. Monte-Carlo simulations.

Absence of correlations without fusion effects!

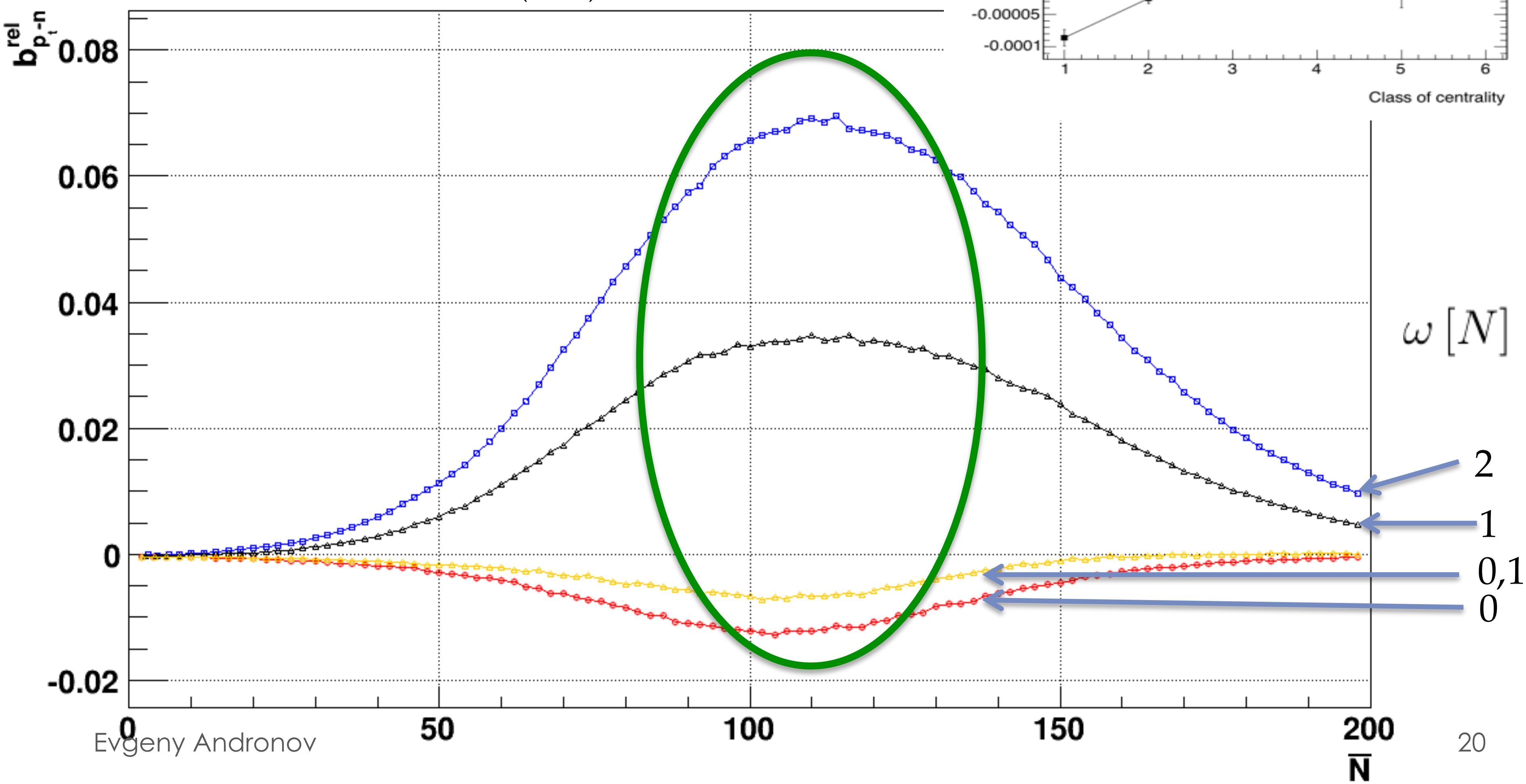


Long-range pT-n correlation parameter. Monte-Carlo simulations.



Transition from the negative values to positive.

G. Feofilov et al. (NA49 Collaboration), Proc. of Baldin ISHEPP XVII, Volume I, 222 (2005)



Summary

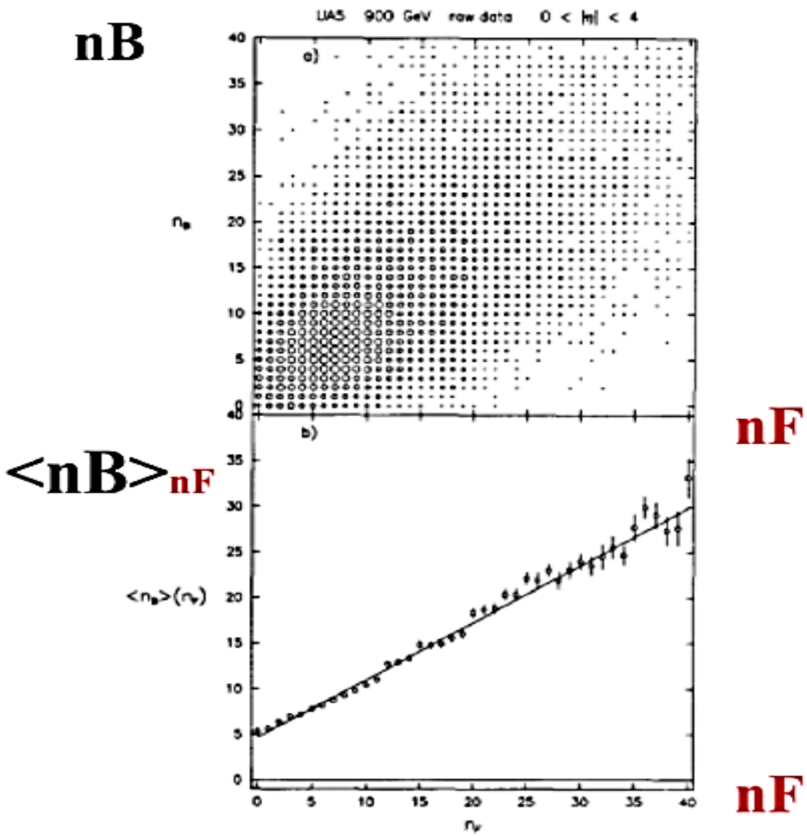
- Development of the model with 2 types of strings. Predictions for the n-n and pT-n correlation parameters with Monte-Carlo simulations.
- The calculation results predict the non-monotonic behavior of the correlation parameters with the growth of the mean number of primary strings, i.e. with the increase of the collision centrality.
- Taking into account that fusion parameter depends on the number of primary emitters in the event enables to describe transition from the negative values of the pT-n correlation parameters to the positive ones.

Thank you for your attention!

Back-up

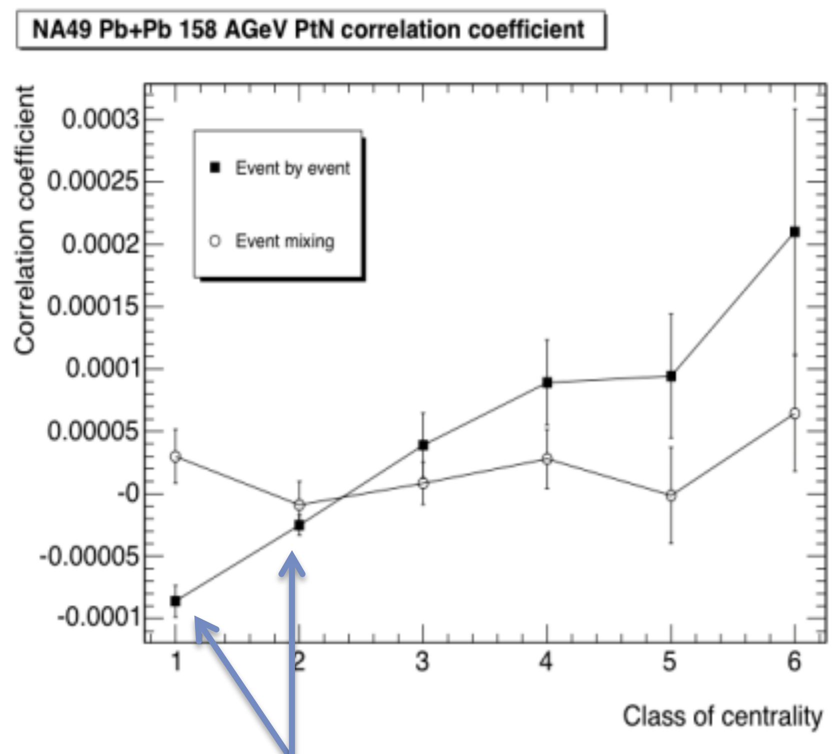
Experimental studies on LRC

p+(anti-)p, 900 GeV (1988)
Linear regression



Pb+Pb, 158 AGeV/c (2005)

pT-n



Negative pT-n correlations

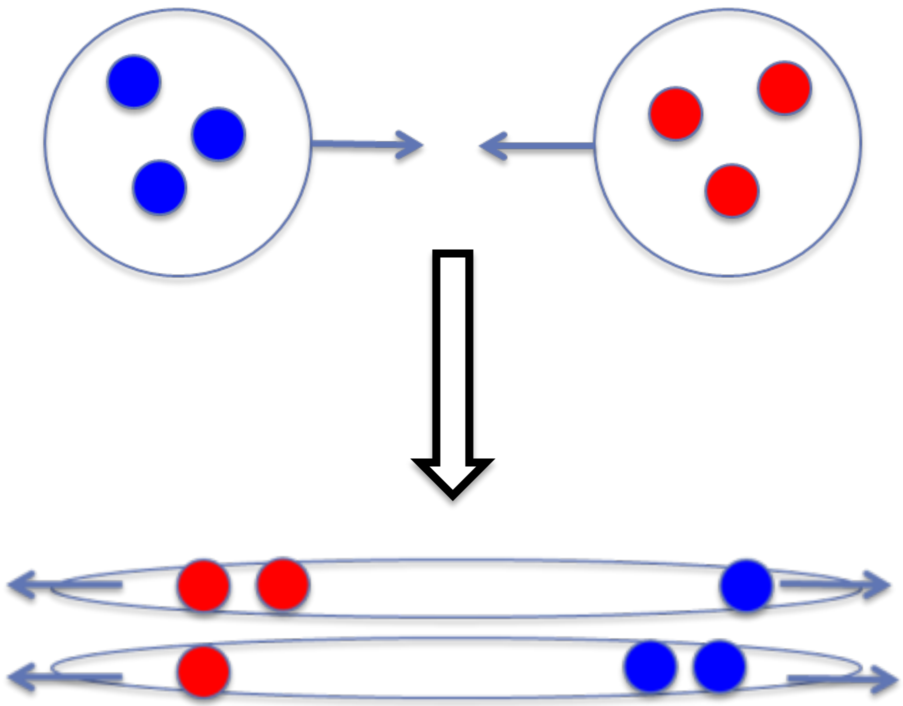
[1] R.E. Ansorge et al. (UA5 Collaboration), Z. Phys., C37-191, (1988).

[2] G. Feofilov et al. (NA49 Collaboration), Proc. of Baldin ISHEPP XVII, Volume I, 222 (2005)

Two-stage scenario of particles production.

I stage: strings creation.

p-p, low energies



[1]A.Capella, U.P.Sukhatme, C.I.Tan and J.Tran Thanh Van, Phys. Lett. B81 (1979) 68; Phys. Rep. **236** (1994) 225.
[2]A.B.Kaidalov, Phys. Lett., 116B(1982)459

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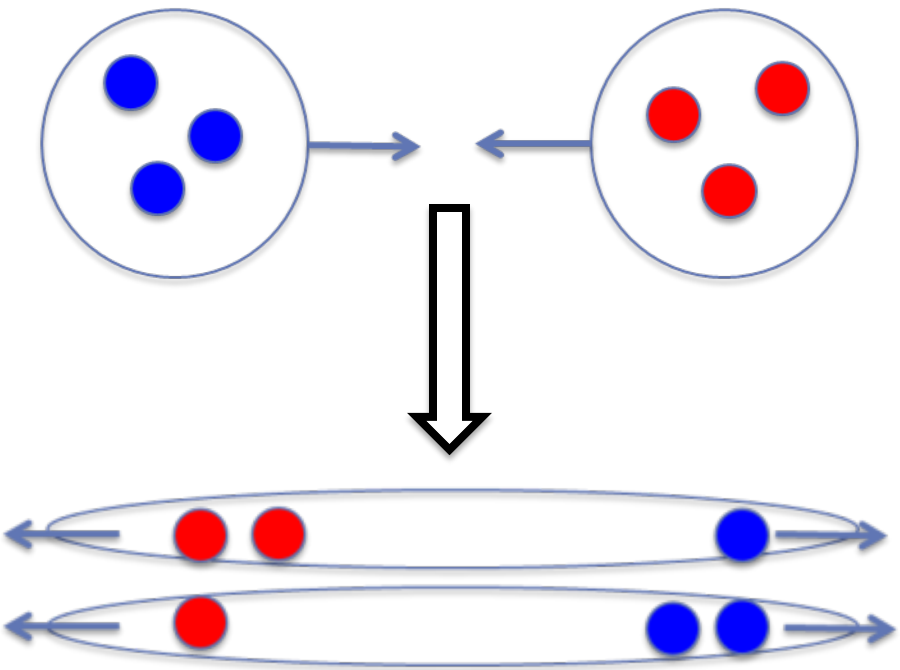
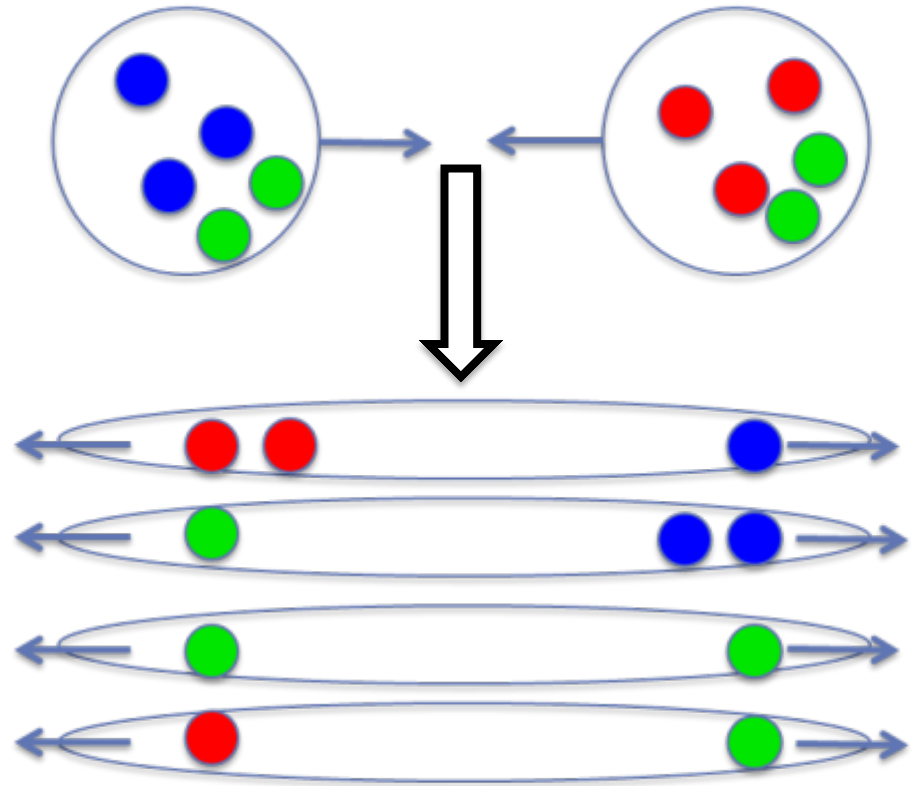
q_{sea}

p-p, low energies



p-p, high energies



[1]A.Capella, U.P.Sukhatme, C.I.Tan and J.Tran Thanh Van, Phys. Lett. B81 (1979) 68; Phys. Rep. **236** (1994) 225.
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Model with two types of emitters.

Non-fused	Fused
N_1	N_2
$\overline{\mu_{F1}} = \overline{\mu_{B1}} = \overline{\mu}$	$\overline{\mu_{F2}} = \overline{\mu_{B2}} = \sqrt{2}\,\overline{\mu}$
$D_{\mu F1} = D_{\mu B1} = D_{\mu}$	$D_{\mu F2} = D_{\mu B2} = \sqrt{2} D_{\mu}$
$\langle p_{tB1} \rangle_{1-string} = \overline{k_1}$	$\langle p_{tB2} \rangle_{1-string} = \overline{k_2} = 2^{1/4}\,\overline{k_1}$

E.Andronov, V.Vechernin PoS(QFTHEP 2013)054

Model with two types of emitters.

$$b_{n-n} = \frac{D_{N_1}\overline{\mu} + 2D_{N_2}\overline{\mu} + 2\sqrt{2}\operatorname{cov}(N_1, N_2)}{\overline{N_1}\omega[\mu] + \overline{N_2}\omega[\mu] + D_{N_1}\overline{\mu} + 2D_{N_2}\overline{\mu} + 2\sqrt{2}\operatorname{cov}(N_1, N_2)}$$

↓ Transition to one-type case

$$b_{n-n} = \frac{D_N\overline{\mu}}{\overline{N}\omega[\mu] + D_N\overline{\mu}}$$

Model with two types of emitters.

$$\langle p_{tB} \rangle = \bar{k} \sum_{B^{(1)},B^{(2)}} \frac{B^{(1)} + 2^{1/4} B^{(2)}}{B^{(1)} + B^{(2)}} \sum_{N_1,N_2} \omega(N_1, N_2) P_{N_1}(B^{(1)}) P_{N_2}(B^{(2)})$$

$$\langle p_{tB} n_F \rangle = \bar{\mu}\bar{k} \sum_{B^{(1)},B^{(2)}} \frac{B^{(1)} + 2^{1/4} B^{(2)}}{B^{(1)} + B^{(2)}} \sum_{N_1,N_2} (N_1 + \sqrt{2} N_2) \omega(N_1, N_2) P_{N_1}(B^{(1)}) P_{N_2}(B^{(2)})$$

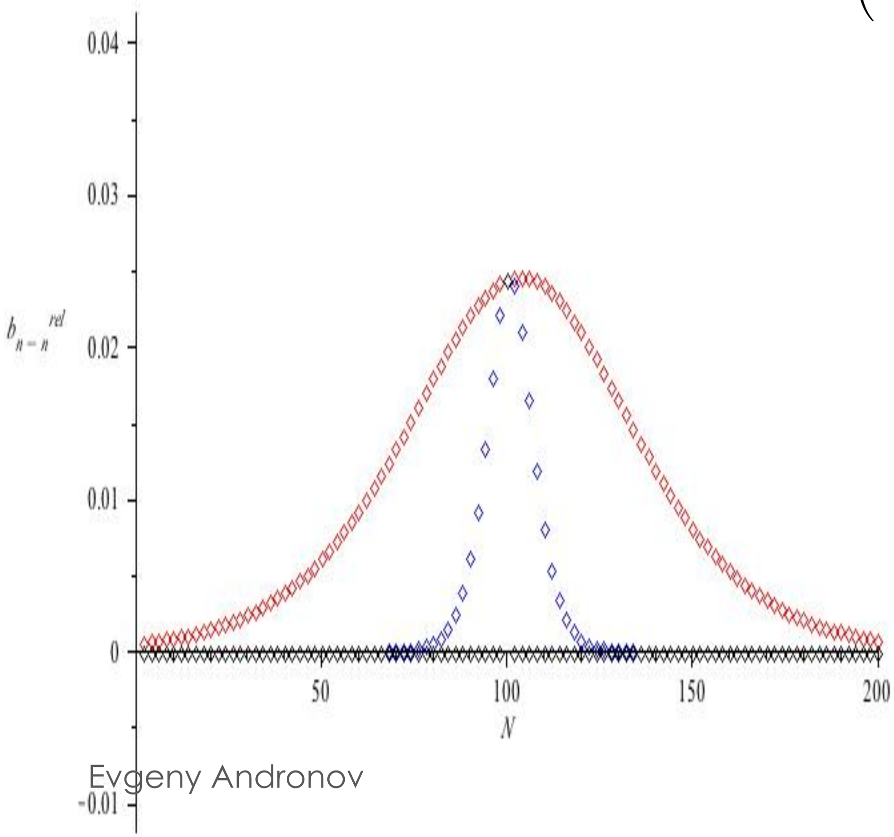
Model with two types of emitters.

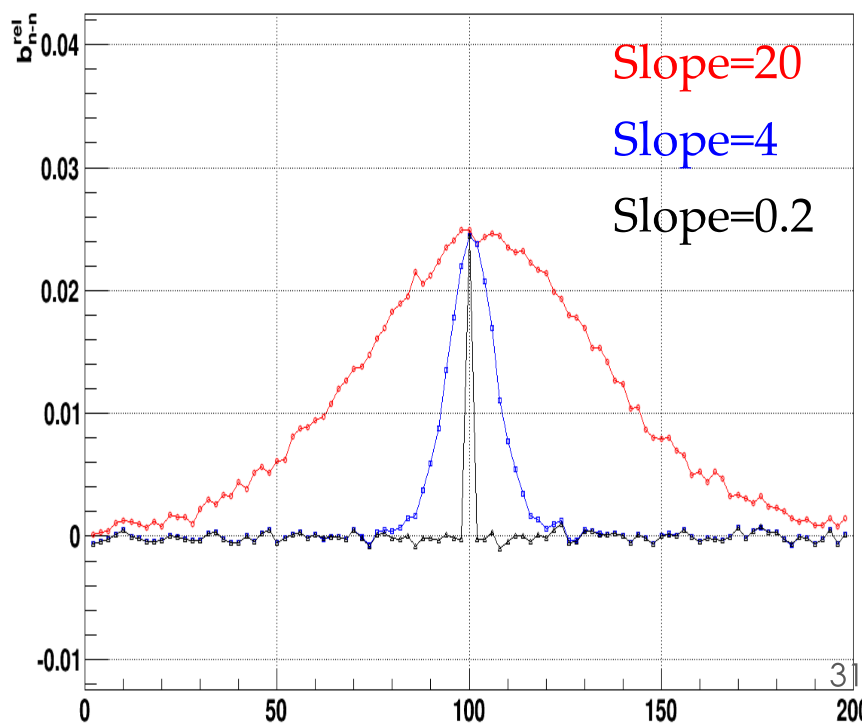
N primary strings in all events

$$b_{n-n} = \frac{\bar{\mu} * N * r(N) * (1 - r(N)) * (3 - 2\sqrt{2})}{D_{\mu} * N * (1 - r(N) + \sqrt{2}/_{2}\, r(N)) + \bar{\mu} * N * r(N) * (1 - r(N)) * (3 - 2\sqrt{2})}$$

Comparison of the n-n correlation coefficients without fluctuations in the number of primary strings.

$$b_{n-n}^{rel} = \frac{0.25 \cdot N \cdot r(N) \cdot (1 - r(N)) \cdot (3 - 2\sqrt{2})}{0.25 \cdot N \cdot r(N) \cdot (1 - r(N)) \cdot (3 - 2\sqrt{2}) + 0.5 \cdot N \cdot \left(1 - r(N) + \frac{\sqrt{2}}{2} r(N)\right)}.$$





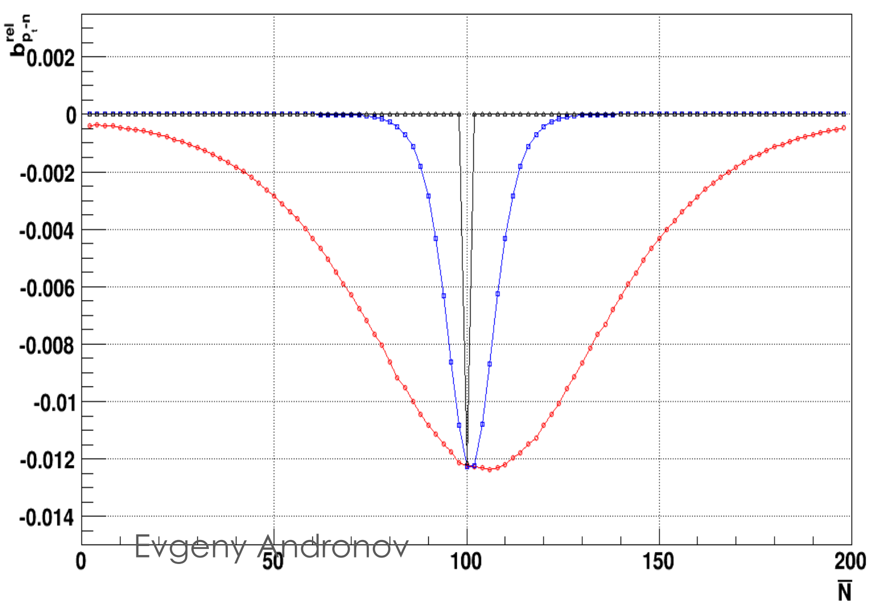
Comparison of the pT-n correlation coefficients.

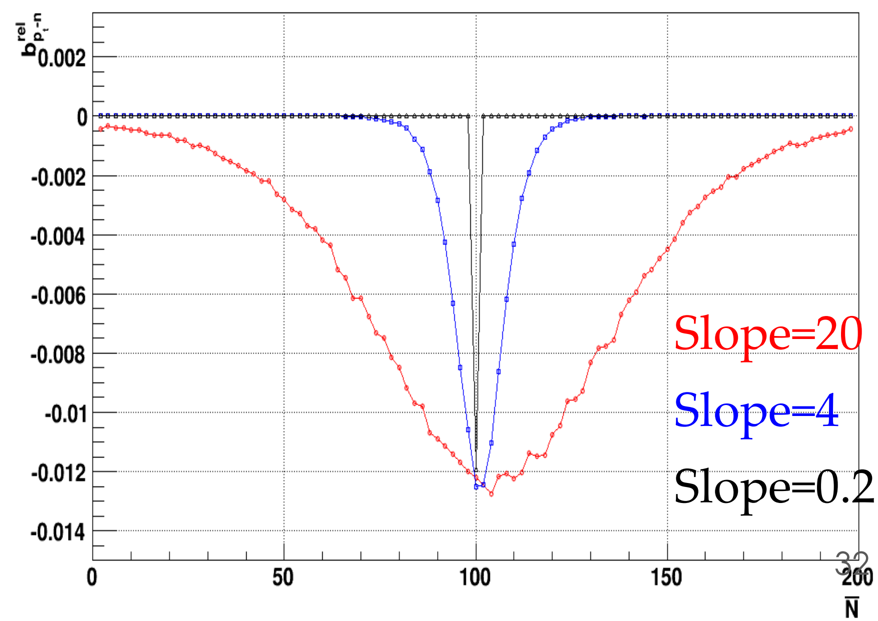
$$\langle p_{TB} \rangle = \sum_{B^{(1)},B^{(2)}} \frac{\overline{k_1} B^{(1)} + \overline{k_2} B^{(2)}}{B^{(1)} + B^{(2)}} \sum_{N_1,N_2} q\left(N_1, N_2\right) P_{N_1}\left(B^{(1)}\right) P_{N_2}\left(B^{(2)}\right);$$

$$\langle p_{TB}\, n_F \rangle = \sum_{B^{(1)},B^{(2)}} \frac{\overline{k_1} B^{(1)} + \overline{k_2} B^{(2)}}{B^{(1)} + B^{(2)}} \sum_{N_1,N_2} q\left(N_1, N_2\right) \left(N_1 \overline{\mu}_{F^{(1)}} + N_2 \overline{\mu}_{F^{(2)}}\right) P_{N_1}\left(B^{(1)}\right) P_{N_2}\left(B^{(2)}\right).$$

Approximation: $B^{(1)} + B^{(2)} \approx N_1 \overline{\mu}_{B1} + N_2 \overline{\mu}_{B2}$

Without approximation





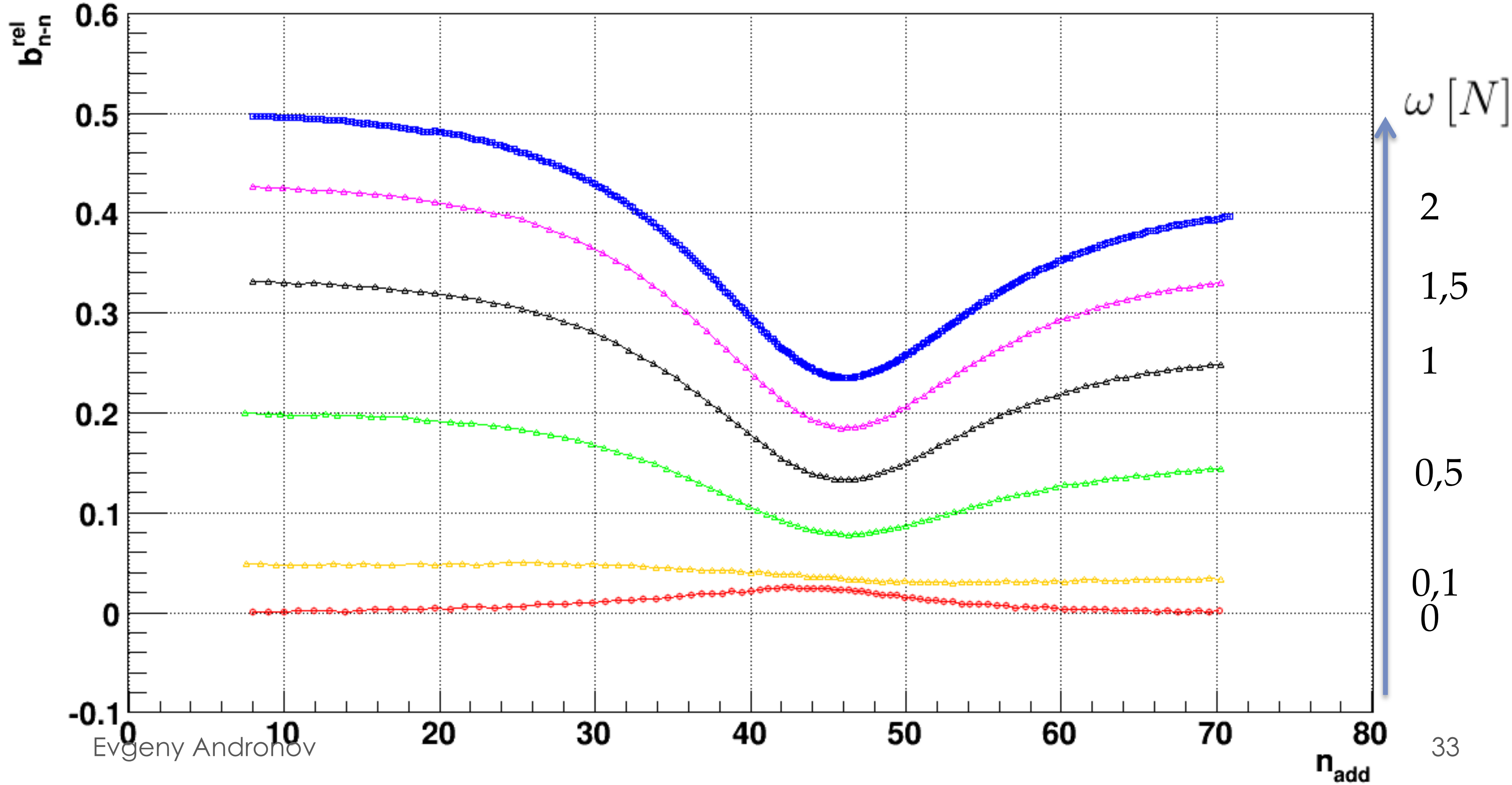
$\overline{\mu} = D_\mu = 0.5$

Long-range n-n correlations

$$r(N) = \frac{1}{1 + e^{-\frac{N - shift}{slope}}}$$

Shift=100
Slope=20

$\omega[N] = \frac{D_N}{\overline{N}}$ - the scaled variance of the number of primary strings



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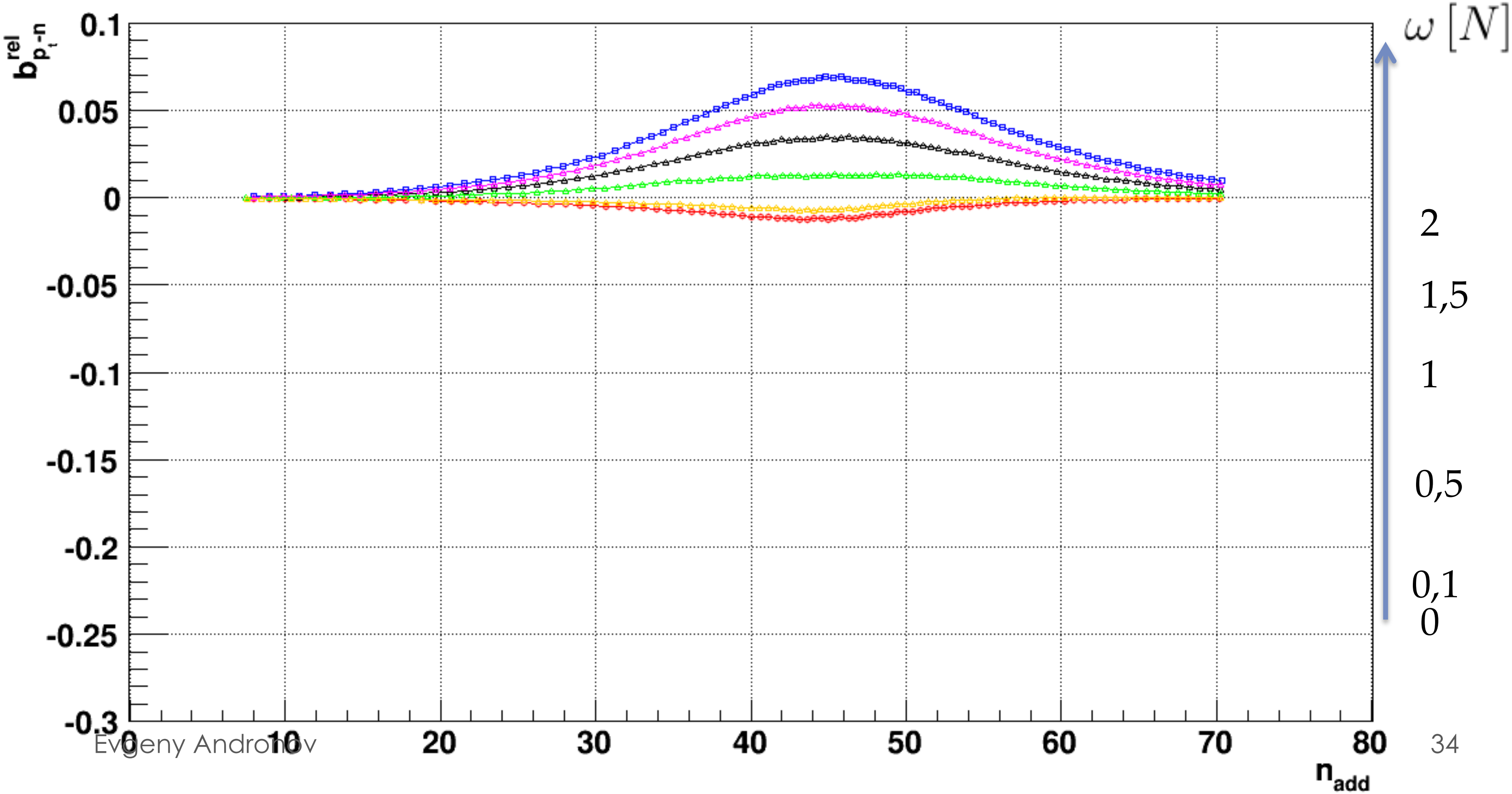


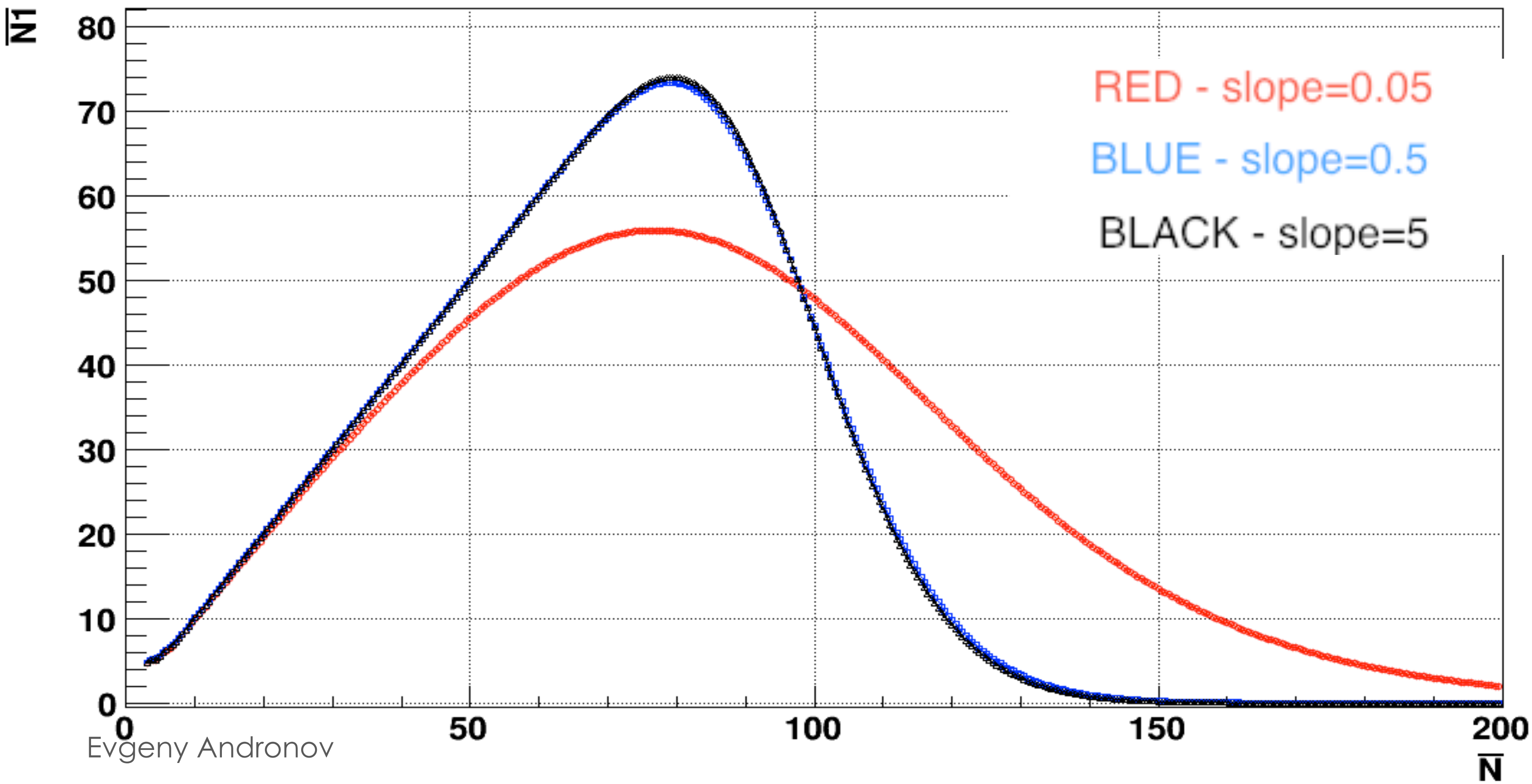
$\overline{\mu} = D_\mu = 0.5$

Monte-Carlo generator

Fluctuating number of strings N, w[N]=2

Shift=100

MC



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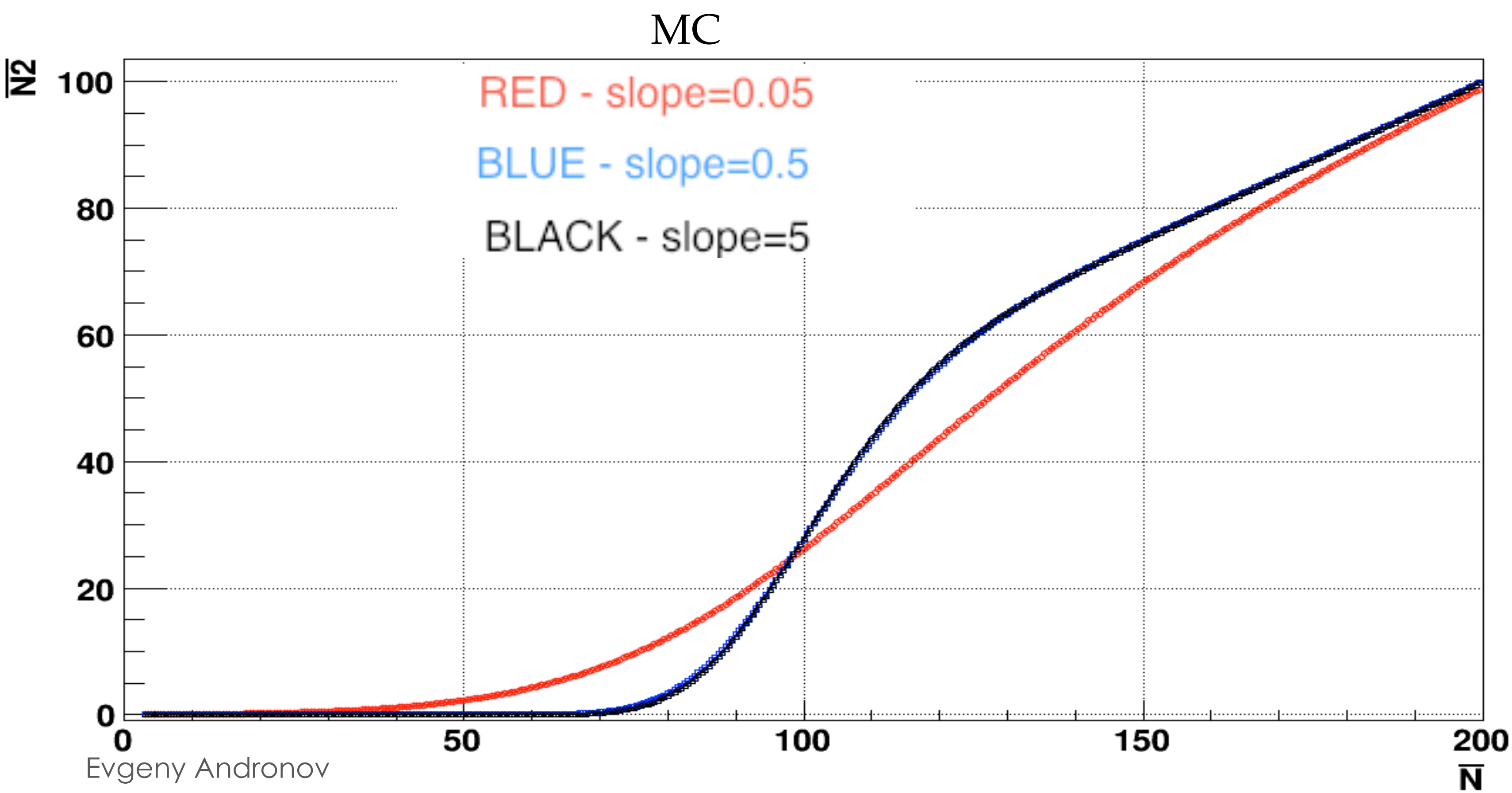

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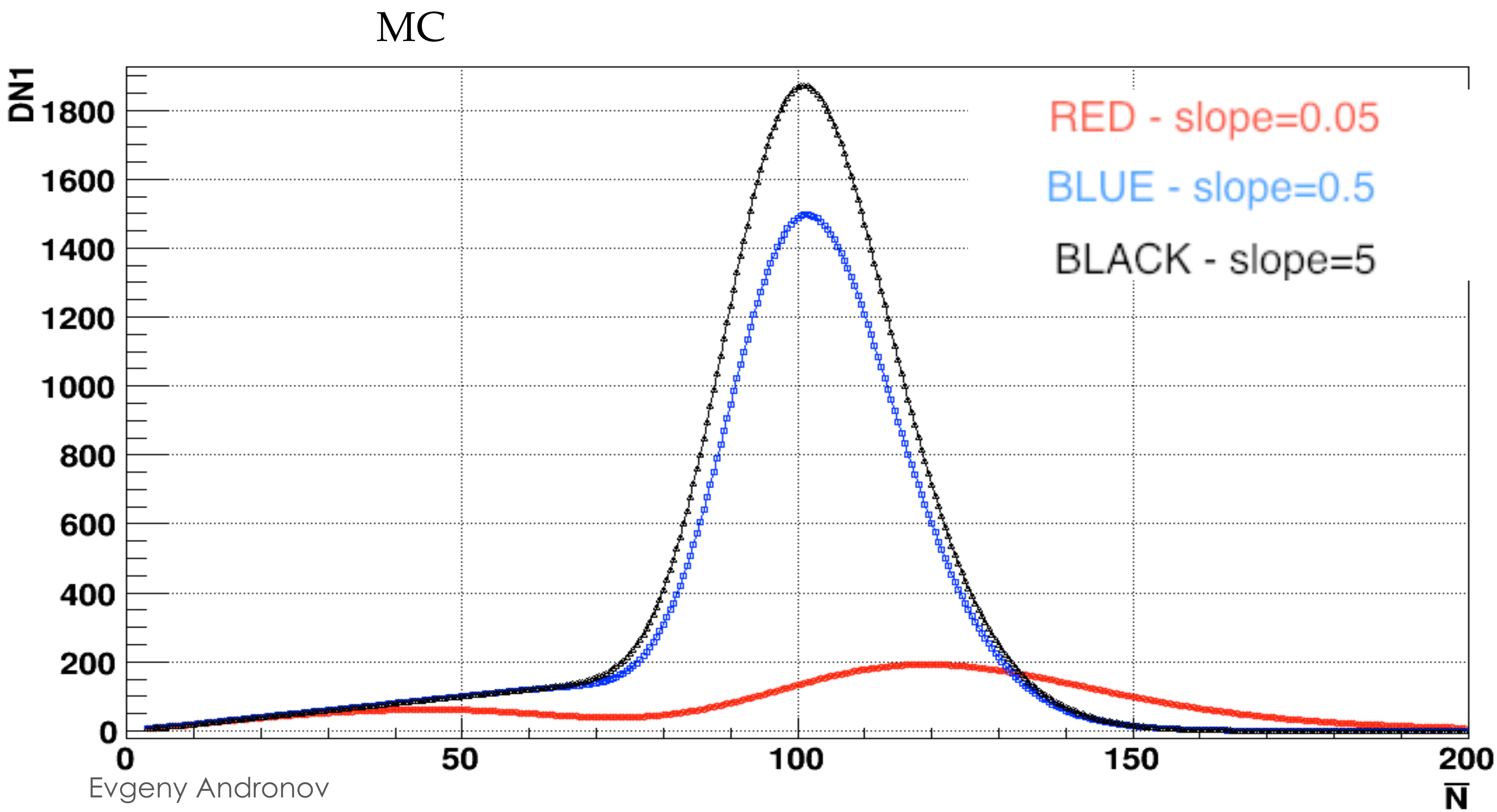

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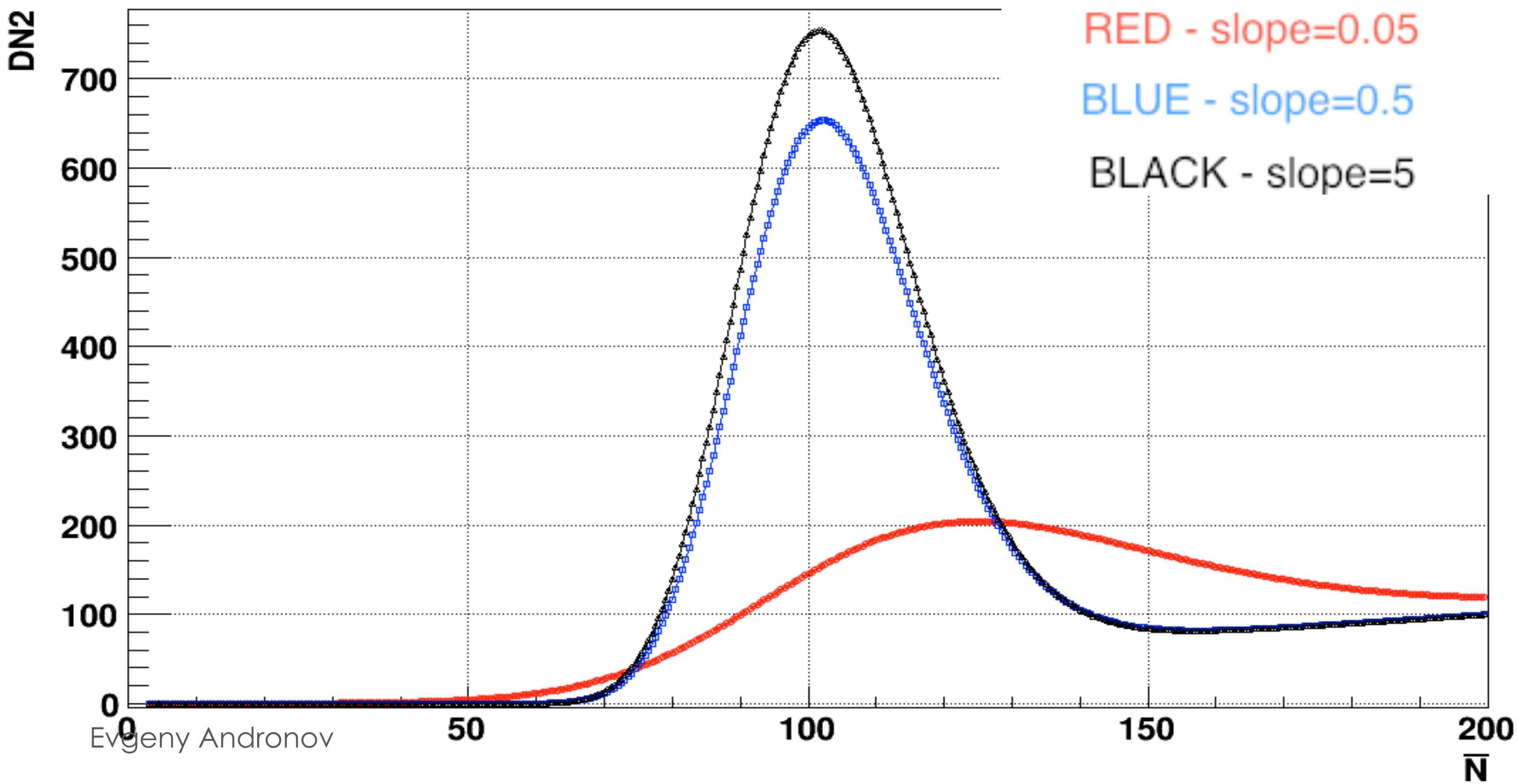

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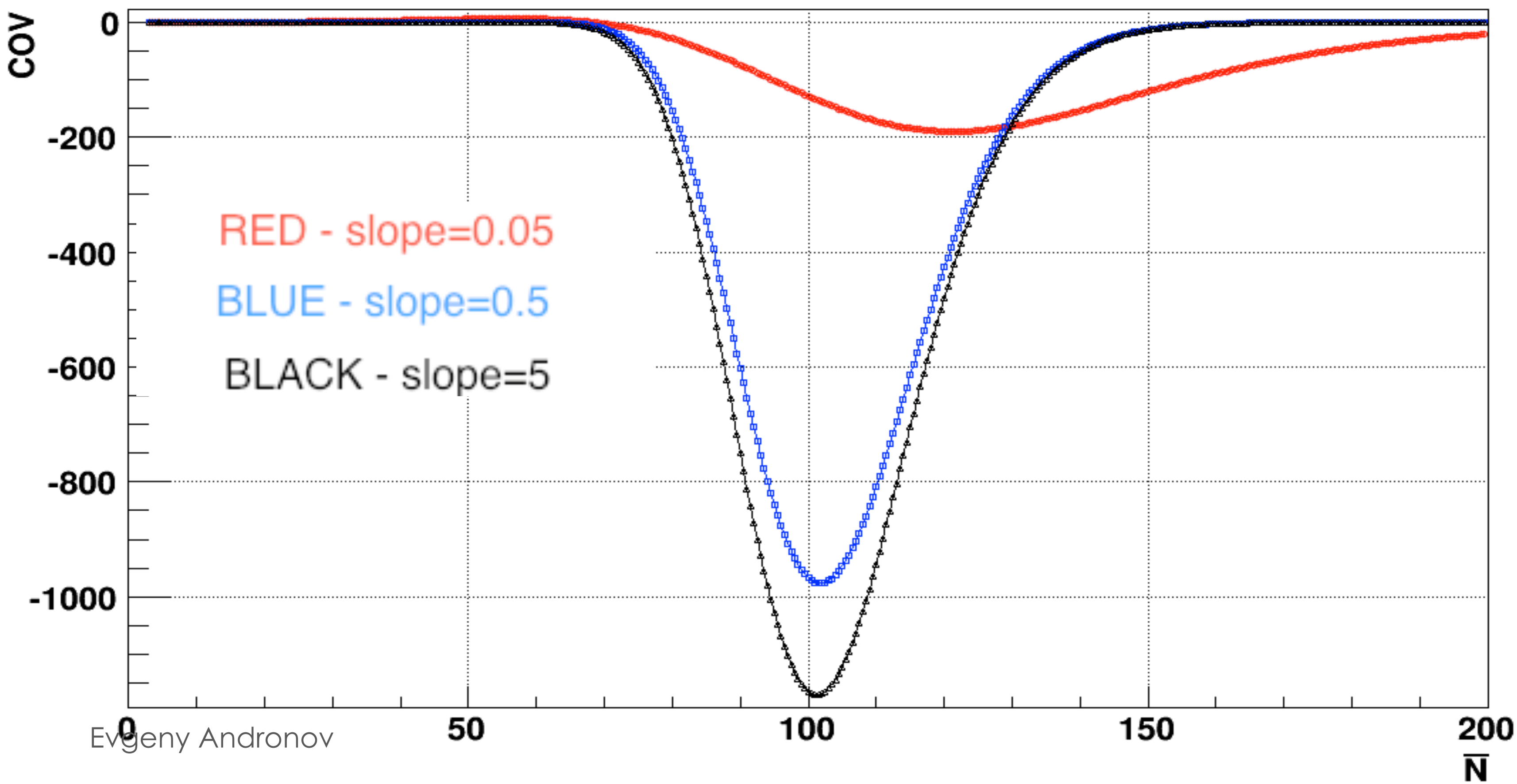

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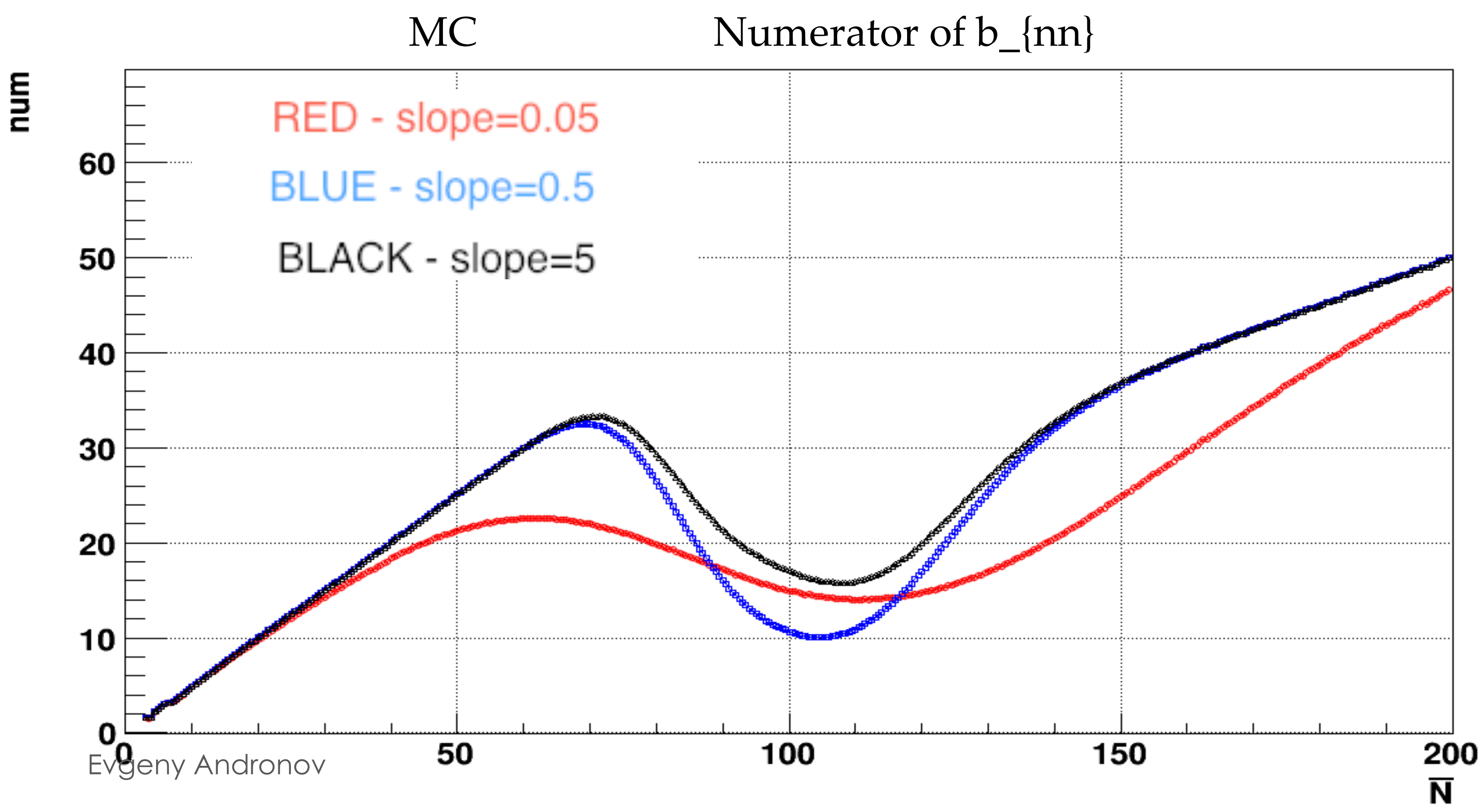


$\overline{\mu} = D_{\mu} = 0.5$

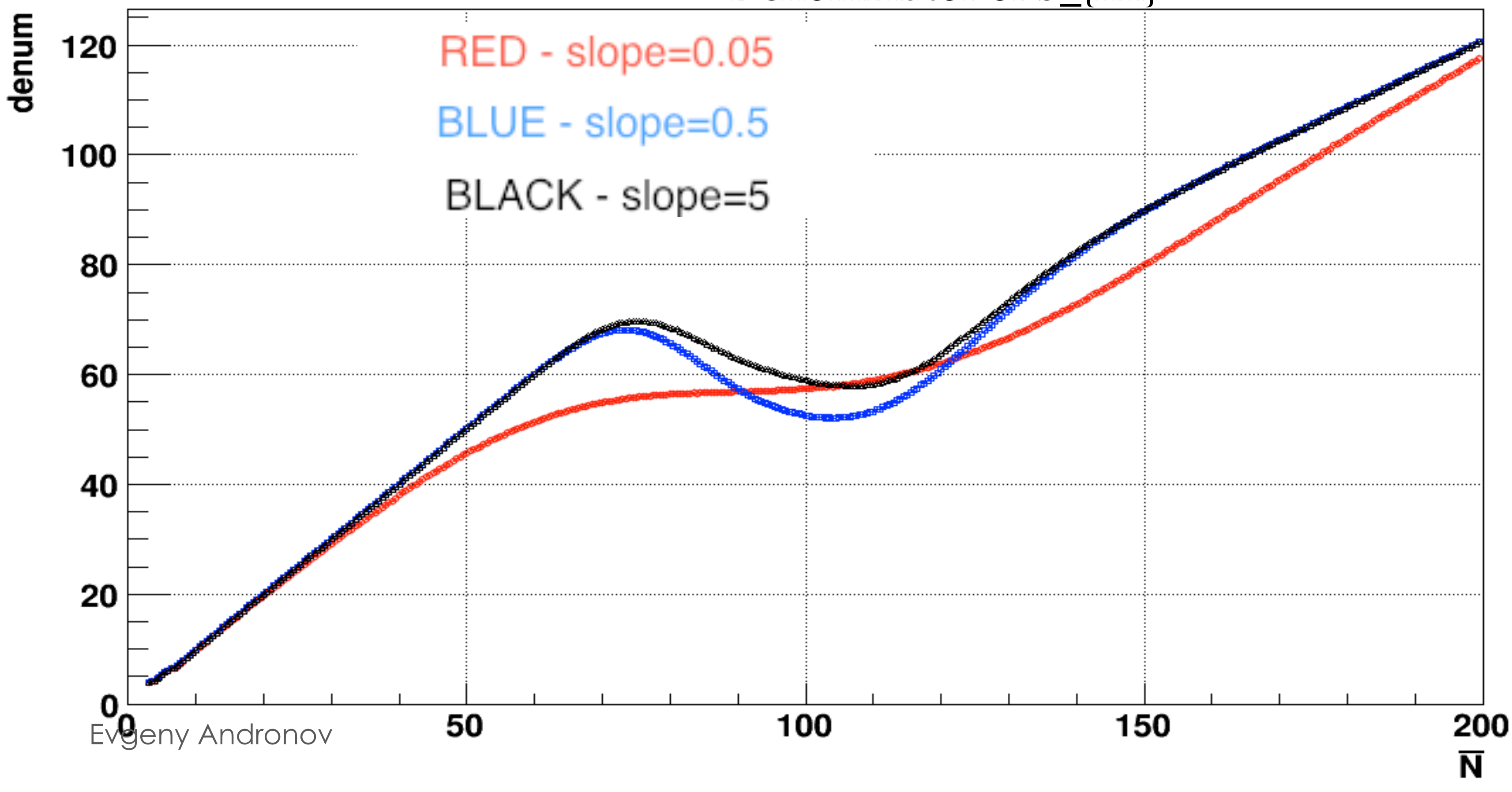
Monte-Carlo generator

Fluctuating number of strings N, w[N]=2

Shift=100

MC

Denominator of b_{nn}



RED - slope=0.05

BLUE - slope=0.5

BLACK - slope=5

MC

$$\overline{\mu} = D_{\mu} = 0.5$$

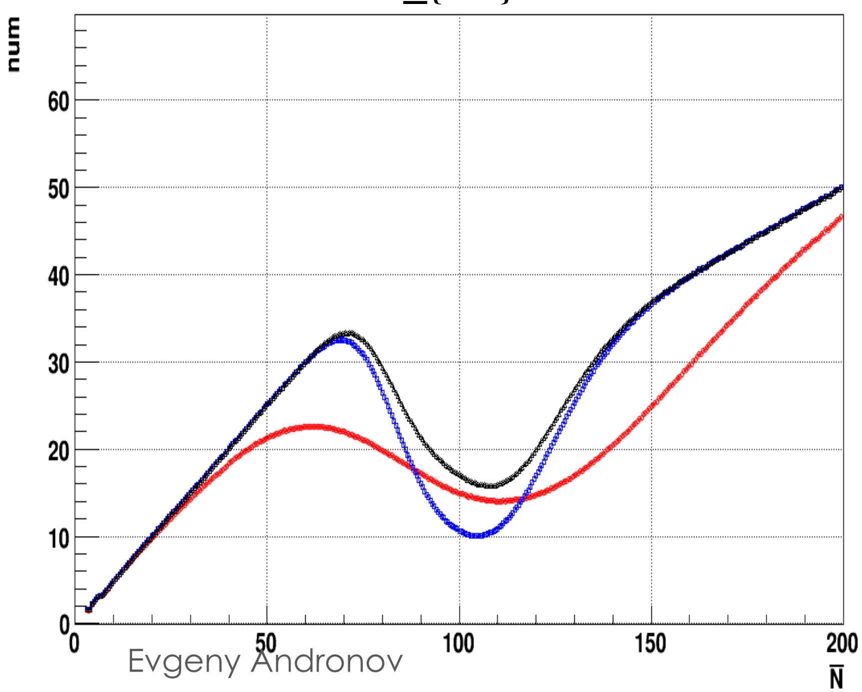
Monte-Carlo generator

Fluctuating number of strings N, w[N]=2

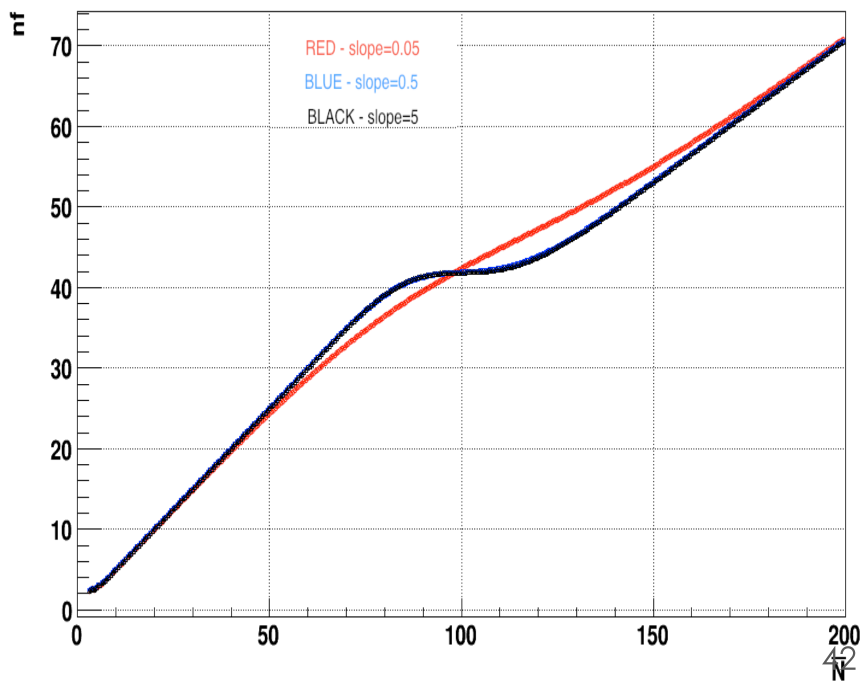
Shift=100

$$b_{n-n} = \frac{num}{num + \langle n_F \rangle}$$

Numerator of b_{nn}



<nF>



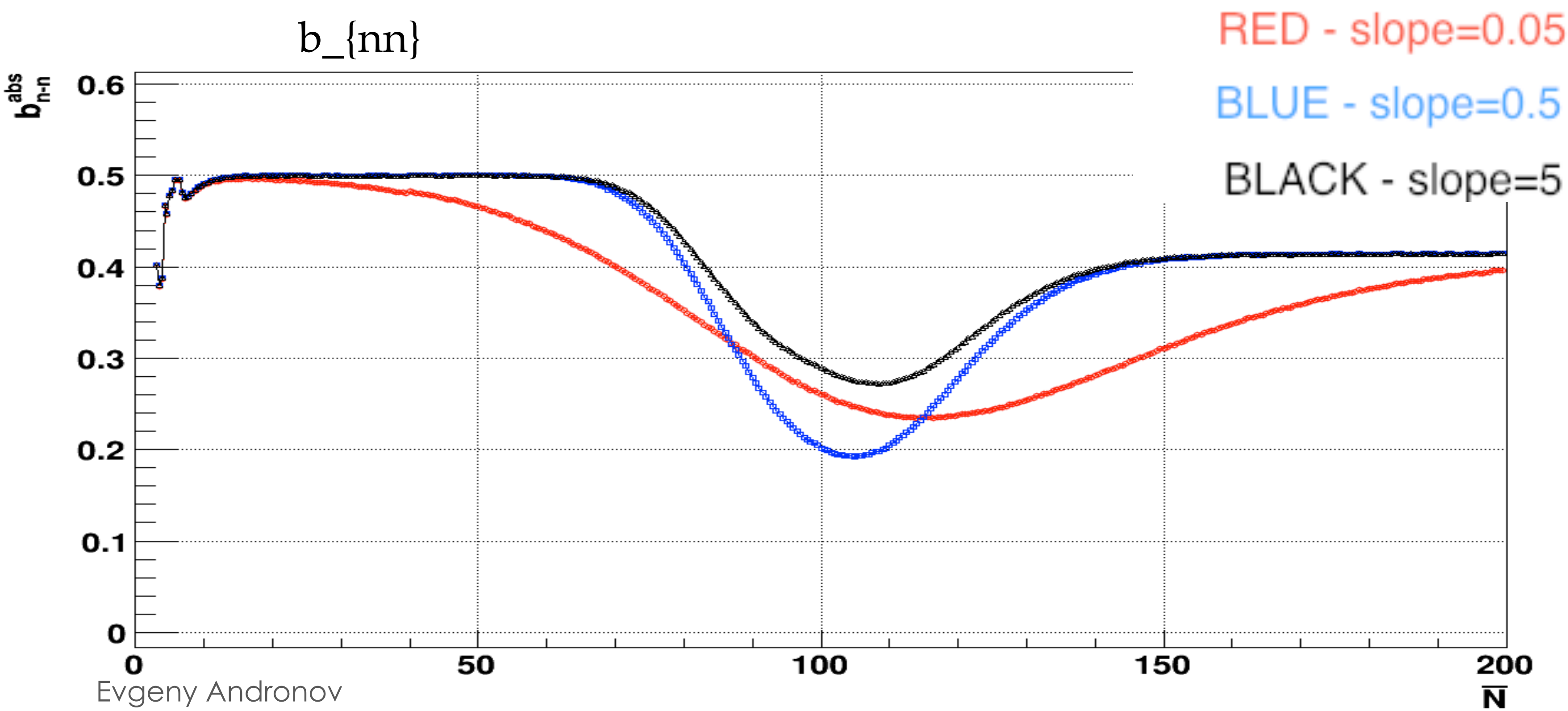
$\overline{\mu} = D_{\mu} = 0.5$

Monte-Carlo generator

Fluctuating number of strings N, w[N]=2

Shift=100

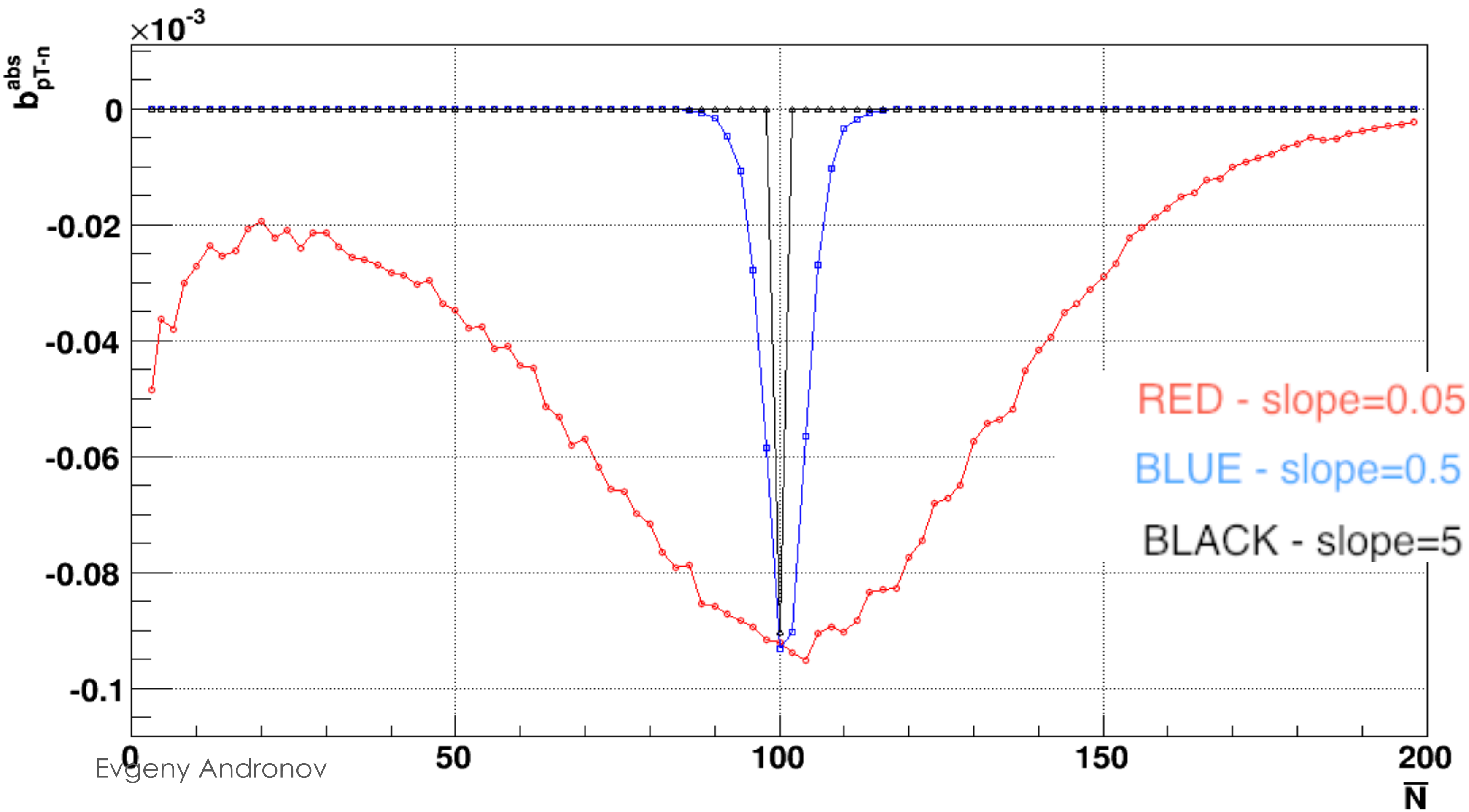
$$b_{n-n} = \frac{num}{num + \langle n_F \rangle}$$



MC $\overline{\mu} = D_{\mu} = 0.5$

Monte-Carlo generator

Nonfluctuating number of strings N Shift=100



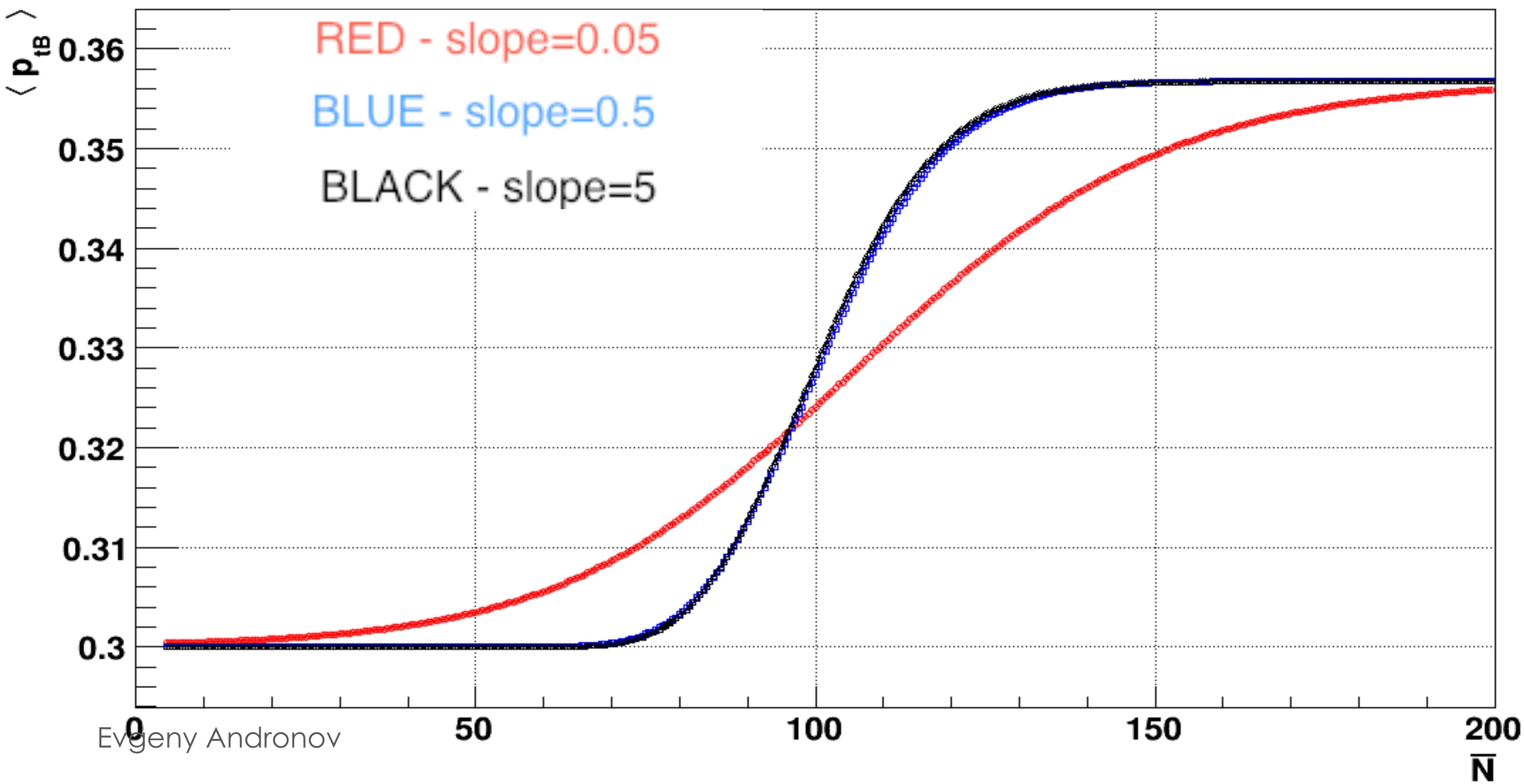
MC

$\overline{\mu} = D_{\mu} = 0.5$

Monte-Carlo generator

Fluctuating number of strings N, w[N]=2

Shift=100



MC

$\overline{\mu} = D_{\mu} = 0.5$

Monte-Carlo generator

Fluctuating number of strings N, w[N]=2

Shift=100