Long-Range Correlation Between Event Average Transverse Momenta and multiplicities of Charged Particles

Vladimir Vechernin, Rodion Kolevatov

St-Petersburg State University

Based on

Long range rapidity correlations in string fusion model in heavy ion collisions

- *V.V. Vechernin, R.S. Kolevatov* “On multiplicity and p_t Correlations in Relativistic Heavy Ion Collisions”, Phys. At. Nucl. Vol. 70, Iss. 10. P. 1797.
- “Long-Range Correlaions Between Transverse Momenta of Charged Particles in Relativistic Ion Collsions” Phys. At. Nucl. Vol. 70, Iss. 10. P. 1809.

String percolation (string fusion) in heavy nuclei collisions proposed by M.A. Braun and C. Pajares, Phys.Lett.B **287**, 154 (1992);
Nucl. Phys. B **390** 542, 549, (1993).

Introduction

A knowlege of only inclusive quantities is not sufficient to judge on the physics involved in pp or AA inelastic interaction (see also talk by A. Asryan).

Arguments for LRC study:

- Correlations between observables in well-separated rapidity windows
- Soft particles produced at separated rapidities come from spatially separated areas.
- Thus via LRC we can measure correlations between spatially separated parts of particle emitting sources.

$\Rightarrow$ Long-range rapidity correlations could give us information on the spatial structure of emitting sources and on applicability of models.

Long-Range Correlations, definitions, observables

Separated rapidity windows Δy_B, Δy_F, $\Delta y_{sep} \geq 1.5$.

<u>In each event:</u> definite number of particles n_B, n_F

with transverse momenta $p_{tB}^{(1)}, \ldots, p_{tB}^{(n_B)}$ and $p_{tF}^{(1)}, \ldots, p_{tF}^{(n_F)}$

Event average transverse momenta $p_{tB/F} = \frac{p_{tB/F}^{(1)} + \ldots + p_{tB/F}^{(n_{B/F})}}{n_{B/F}}$

- Correlation functions: $\langle p_{tB} \rangle|_{n_F} = f(n_F)$
  $\langle p_{tB} \rangle|_{p_{tF}} = g(p_{tF})$ – average of p_{tB} over all events where p_{tF} (n_F) takes on a fixed value as a function of p_{tF} (n_F).
- Correlation coefficients $b_{p_t-p_t} \equiv \frac{\langle p_{tF} \rangle}{\langle p_{tB} \rangle} \left. \frac{d\langle p_{tB} \rangle_{p_{tF}}}{dp_{tF}} \right|_{p_{tF}=\langle p_{tF} \rangle}$
  $b_{p_t-n} \equiv \frac{\langle n_F \rangle}{\langle p_{tB} \rangle} \left. \frac{d\langle p_{tB} \rangle_{n_F}}{dn_F} \right|_{p_{tF}=\langle p_{tF} \rangle}$

Choice of observables

Observables can be also number of jets, number of strange particles, etc.
Correlations involving p_t:

- Intensive dynamical variables, thus sensitive to the internal characteristics of the particle emitting source, not to the size or number of sources.
- Event average transverse momenta is much stronger coupled to the source features compared to p_t of a single particle.

$\Rightarrow$ Correlations involving event average p_t promise to be a sensitive tool.

Correlations in 2-stage scenario, general

First stage A set of sources is formed

Second stage Sources decay producing particles in soft part of the spectrum.

Assume

- Sources give rise to particle production at all rapidities considered;
- There are no LRC in fragmentation of a singe source;
- Inclusive 1-particle p_t distribution is determined uniquely by the source type;
- Multiplicity distribution in a given rapidity interval does not depend on the total number of particles produced in event.

Long-range correlations enter through the fluctuations of the number and type of particle emitting sources (configurations $\{C\}$).

Correlation functions:

$p_t n$, nn: $$\langle B\rangle_{n_F} = \frac{\sum\limits_{\{C\}} \langle B\rangle_{\{C\}} W(\{C\}) P_{\{C\}}(n_F)}{\sum\limits_{\{C\}} W(\{C\}) P_{\{C\}}(n_F)},$$

Main components: probabilities of confi gurations $W(C)$ multiplicity distributions $P_{\{C\}}(n_F)$

$p_t p_t$: $$\langle p_{tB}\rangle_{p_{tF}} = \frac{\sum\limits_{\{C\}} \langle p_{tB}\rangle_C W(C) P_C(p_{tF})}{\sum\limits_{\{C\}} W(C) P_C(p_{tF})}$$

Main components: $W(C)$, event-average p_t distribution: $P_{\{C\}}(p_{tF})$

Specific for $p_t - p_t$

$P_{\{C\}}(p_{tF})$ can not be computed analytically in general case.
Due to Central Limit Theorem, for $n_{\text{cluster } i} \gg 1$,
distribution $P_{\{\text{source}\}}(p_t)$ is Gaussian,

$$P_{\{C,n_{iF}\}}(p_{tF}) = \sqrt{\frac{(\sum n_{iF})^2}{2\pi \sum n_{iF} D_i}} \exp\left[-\frac{((p_{tF}\sum n_{iF} - \sum n_{iF}\alpha_i))^2}{2\sum n_{iF} D_i}\right]$$

with $\{\alpha_i\}$ and $\{D_i\}$ – average and dispersions for the sources.

Correlation functions (final)

$$\langle B\rangle_{n_F} = \frac{\sum\limits_{\{C\}} \langle B\rangle_{\{C\}} W(\{C\}) P_{\{C\}}(n_F)}{\sum\limits_{\{C\}} W(\{C\}) P_{\{C\}}(n_F)},$$

$$\langle p_{tB}\rangle_{p_{tF}} = \frac{\sum\limits_{\{C,n_{iF}\}} \langle p_{tB}\rangle_C P_{\{C,n_{iF}\}}(p_{tF}) W(C) \prod\limits_{i=1}^{M(C)} P_C^{(i)}(n_{iF})}{\sum\limits_{\{C,n_{iF}\}} P_C(p_{tF}) W(C) \prod\limits_{i=1}^{M(C)} P_C^{(i)}(n_{iF})},$$

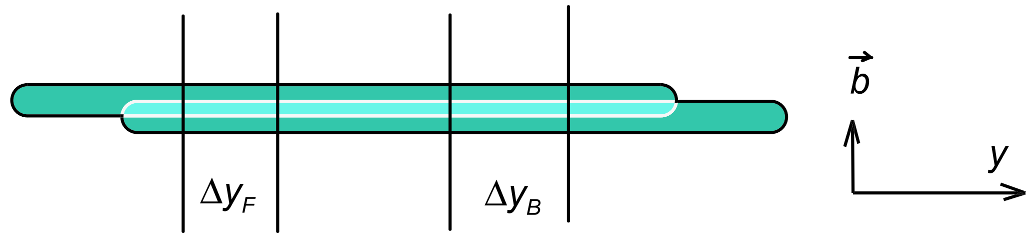
Monte-Carlo computations require modelling of $W(C)$ and $P_C^{(i)}(n_i)$).

String fusion model (SFM)

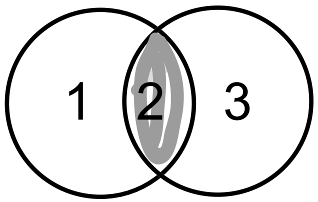
- Two-stage scenario. (*A. Capella et al* Phys. Lett. **B81** 68 (1979); Phys. Rep. **236** 225 (1994); *A.B. Kaidalov* Phys. Lett. **116B** 459 (1982))
- At large string densities flux tubes overlap in the impact parameter plane.
- Fusion scenarios are based on
  - pair productions in constant electric fi eld in QED *J. Schwinger* Phys. Rev. **82** (1951) 664. (Generalization for QCD – G. C. Nayak, P. van Nieuwehuizen, hep-ph/0504070.)
  - Idea of color charges summation: *T.S. Biro* et al, Nucl. Phys. **B245** (1984) 449; *A. Bialas, W. Czyz* Nucl. Phys. **B267** (1986) 242.

Fusion scenarios

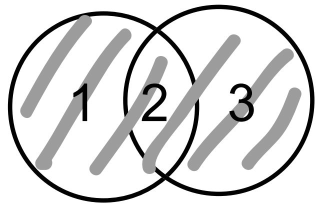
Braun M.A., Pajares C. Phys. Lett.**B287** (1992) 154; Nucl. Phys.**B390** (1993) 542, 549
Braun M.A., del Moral F., Pajares C. Eur. Phys. J. **C21** (2001) 557.



Overlaps



Clusters



$$\langle n\rangle_1 = \langle n\rangle_3 = \mu_0 \frac{S_1}{\sigma_0}, \quad \langle n\rangle_2 = \mu_0 \frac{S_1}{\sigma_0}\sqrt{2}$$

$$\langle p_t^2\rangle_1 = \langle p_t^2\rangle_3 = \overline{p^2}, \quad \langle p_t^2\rangle_2 = \overline{p^2}\sqrt{2}$$

$$\langle n\rangle_{cl} = \mu_0 \sqrt{2\frac{S_1+S_2+S_3}{\sigma_0}},$$

$$\langle p_t^2\rangle_{cl} = \overline{p^2}\sqrt{\frac{N_{cl}^{str}\sigma_0}{S_{cl}}}$$

General case

$$\langle n\rangle_k = \mu_0 \frac{S_k}{\sigma_0}\sqrt{k} \quad \langle p_t^2\rangle_k = \overline{p^2}\sqrt{k}$$

$$\langle n\rangle_{cl} = \mu_0 \frac{S_{cl}}{\sigma_0}\sqrt{k_{cl}} \quad \langle p_t^2\rangle_{cl} = \overline{p^2}\sqrt{k_{cl}}$$

$$k_{cl} = \frac{N_{cl}^{str}\sigma_0}{S_{cl}}$$

Fusion takes place in the whole rapidity interval covered by strings.
Result of fusion – new “string” with shifted multiplicity, $\bar{p}_t$, $\bar{p}_t^2$

Parameters

- Initial conditions
  - Number of strings for a given impact parameter $\mathbf{b}$

$$N_{str} = (1-x)N_{part}(\mathbf{b}) + x n_{str}^{pp} N_{coll}(\mathbf{b})$$

  - Distibution of strings in $\mathbf{b}$-plane $P(\mathbf{s}) \propto \frac{d^2 N_{\rm coll}}{d^2\mathbf{s}}$
    or
    $P(\mathbf{s}) \propto (1-x)\frac{d^2 N_{\rm part}}{d^2\mathbf{s}} + x N_{\rm str}^{NN}(E)\frac{d^2 N_{\rm coll}}{d^2\mathbf{s}}$
- String characteristics
  - string radius r_{str},
  - average multiplicity per unit rapidity μ_0,
  - p_0 – average p_t of produces particles,
  - γ – ratio average over sqrt of dispersion for p_t.

Fitted parameters – x, r_{str}, p_0.

Parameters

- Initial conditions
  - Number of strings for a given impact parameter $\mathbf{b}$

$$N_{str} = (1 - x)N_{part}(\mathbf{b}) + x n_{str}^{pp} N_{coll}(\mathbf{b})$$

  - Distibution of strings in $\mathbf{b}$-plane $P(\mathbf{s}) \propto \frac{d^2 N_{\rm coll}}{d^2\mathbf{s}}$
    or
    $P(\mathbf{s}) \propto (1 - x)\frac{d^2 N_{\rm part}}{d^2\mathbf{s}} + x N_{\rm str}^{NN}(E)\frac{d^2 N_{\rm coll}}{d^2\mathbf{s}}$

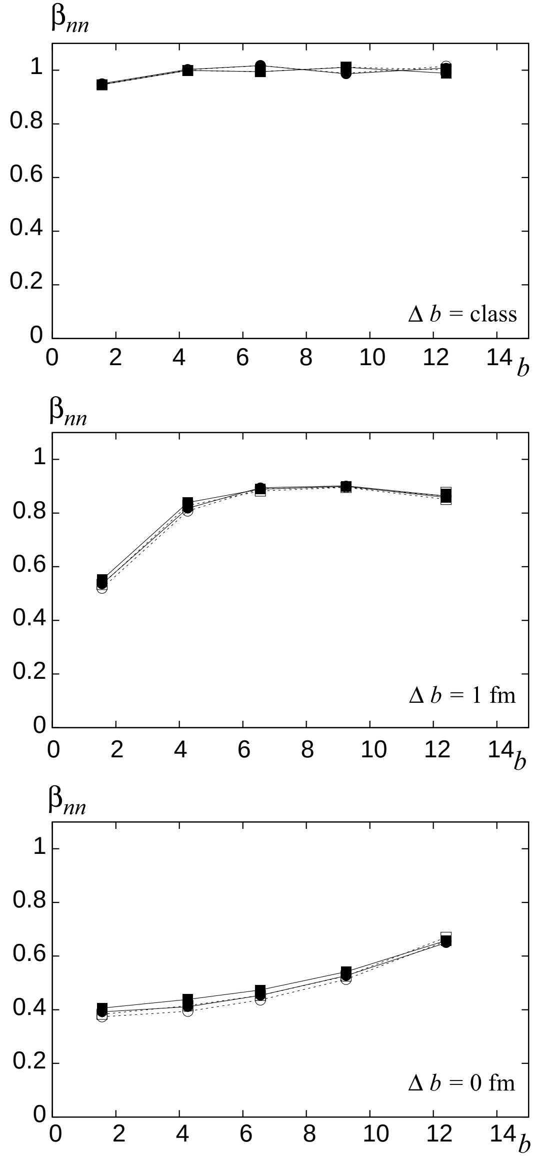
-

Parameter	Experiment		
	SPS	RHIC	LHC
x	0.18	0.45	1
$r_{\rm str}$	0.28	0.28	0.28
μ_0	1.1	1.1	1.1
p_0	0.305	0.345	–
γ	0.61	0.61	0.61

SFM results (inclusive quantities)

Class	AuAu, 130 GeV$\cdot A$			
	experiment		model	
	$dN/dy\|_{y=0}$	$\langle p_t \rangle$,MeV/c	$dN/dy\|_{y=0}$	$\langle p_t \rangle$,MeV/c
1	682	444.02	649	452
2	516.8	443.8	497	443
3	330.1	435.2	321	426
4	133.4	413.5	136	393
5	21.35	352.6	22.4	355
%σ_{tot}/ Class	PbPb, 17.3 GeV$\cdot A$			
	experiment		model	
0–5 / 1	478	361	474	359,5
5–10 / 2	388	354	370	355,0
10–25 / 3	269	348	258	347,6
25–35 / 4	165	338	155	337,7
35–45 / 5	106	329	93	329,0

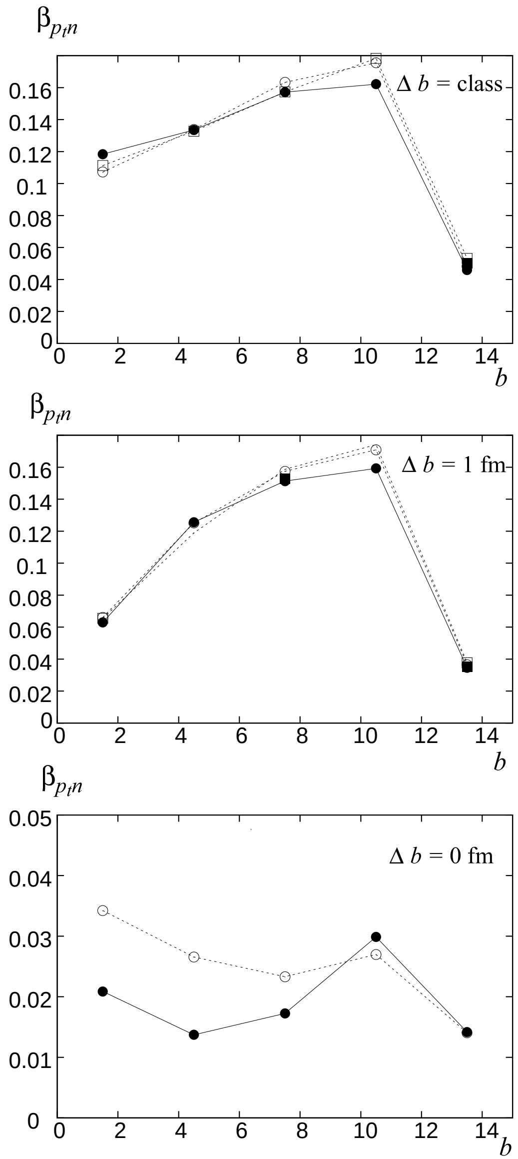
SFM results, nn correlations



130 GeV$\cdot A$, AuAu. Correlation coefficient dependence on the impact parameter fluctuations. $\Delta y_F = 2$ taken for illustrative purposes.

○ – “overlaps”; ● – “clusters”.

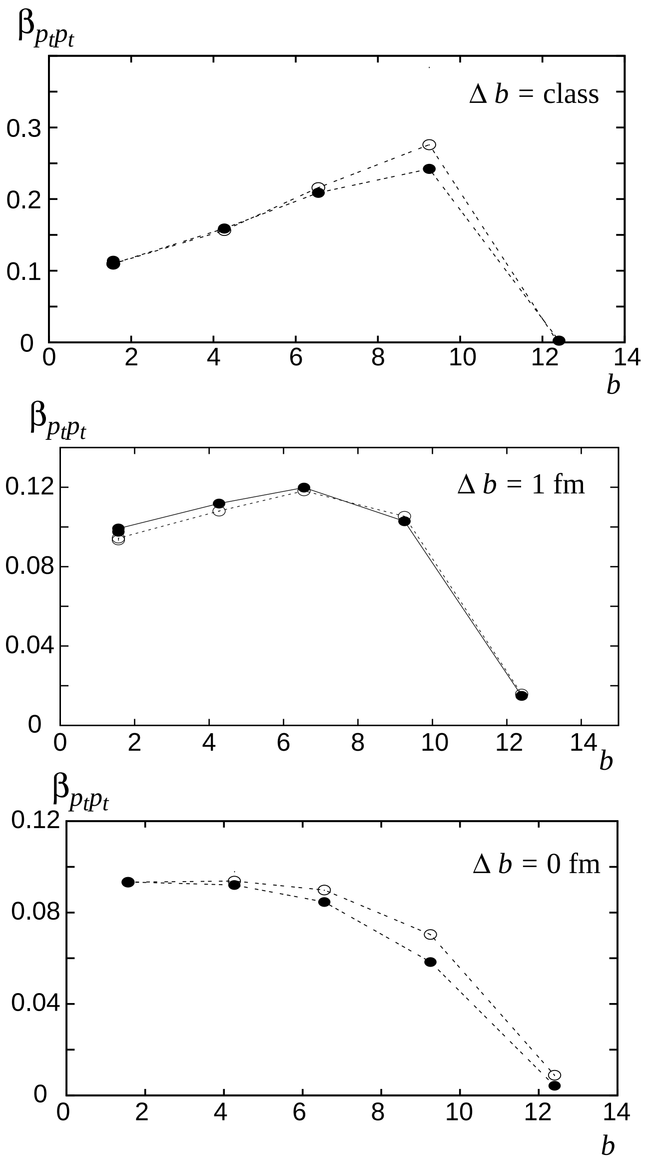
SFM, $p_t n$, Δb-dependence.



PbPb, 5500 GeV$\cdot A$. Correlation coefficient dependence on the impact parameter fluctuations. $\Delta y_F = 2$ taken for illustrative purposes.

○ – "overlaps"; ● – "clusters".

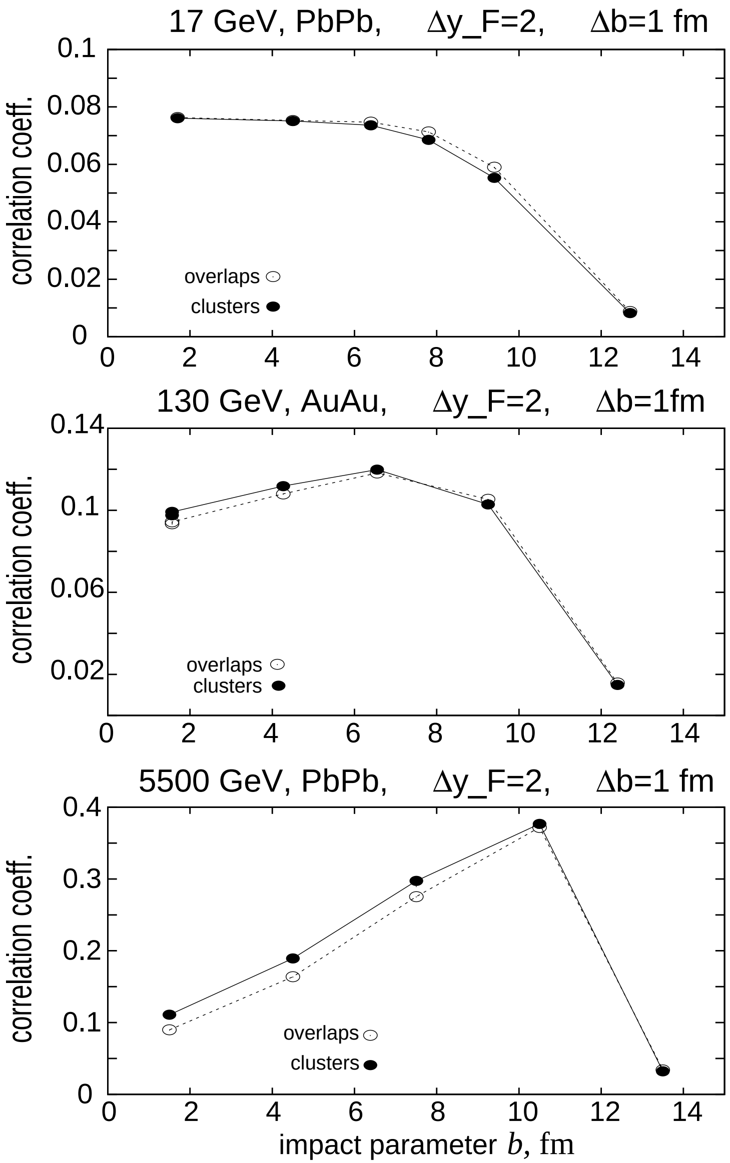
$p_t p_t$, Δb-dependence.



130 GeV$\cdot A$, AuAu. Correlation coefficient dependence on the impact parameter fluctuations. $\Delta y_F = 2$ taken for illustrative purposes.

○ – "overlaps"; ● – "clusters".

$p_t p_t$ energy dependence



For illustrative purposes $\Delta y_F = 2$ taken.
○ – "overlaps"; ● – "clusters".

$p_t - p_t$, $p_t - n$, $n - n$ in comparison

Correlation coefficients for full widths of centrality classes (also taken realistic width of rapidity intervals).

Class	$n-n$	p_t-n	p_t-p_t
PbPb, 17.3 GeV$\cdot A$, $\Delta y_F = 0.5$			
1	0.63	0.038	0.022
2	0.73	0.046	0.023
3	0.91	0.055	0.027
4	0.86	0.047	0.020
5	0.60	0.029	–
AuAu, 130 GeV$\cdot A$, $\Delta y_F = 1$			
1	0.83	0.061	0.058
2	0.98	0.082	0.087
3	1.0	0.090	0.12
4	0.98	0.080	0.17
5	1.0	0.031	–

Class	$n-n$	p_t-n	p_t-p_t
PbPb, 5500 GeV$\cdot A$, $\Delta y_F = 2$			
1	0.98	0.115	0.17
2	1.0	0.138	0.55
3	1.0	0.16	0.82
4	1.0	0.18	0.91
5	0.99	0.045	–

Centrality classes according to:
NA49 collab. & SPb group Proc. of the XVII International Baldin Seminar, vol.1, JINR, Dubna, 2005, 222-231;
Adcox et al. Phys. Rev. **c** 69 (2004) 024904;
For LHC $\Delta b_{\text{class}} = 3$ fm.

Conclusions

- Long range rapidity correlations are part of ALICE physical program.
- Model predictions: $p_t n$ correlations
  - Signifi cant value provided by SFM (several percent even at fi xed b)
  - have a moderate growth with energy and impact parameter fluctuations.

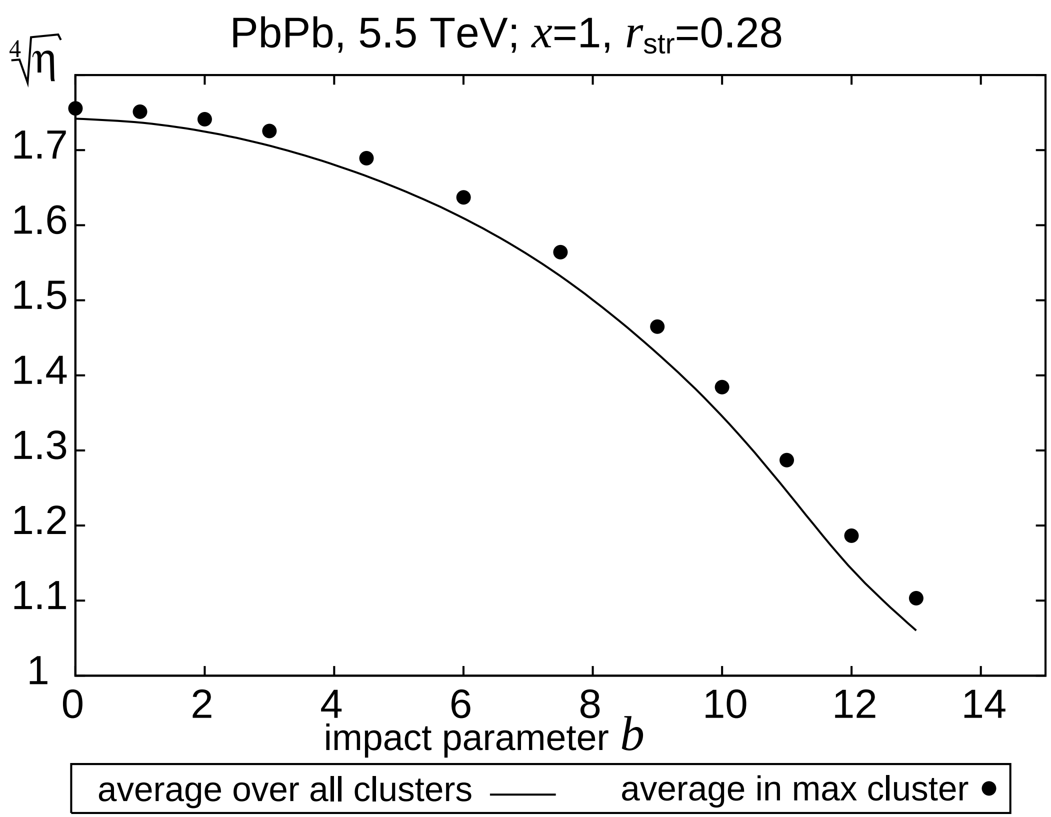
  $p_t p_t$ correlations

  - even more pronounced compared to $p_t n$ in heavy ion collisions
  - show an interesting trend of growth with collision energy which is straightforward to check.
- While waiting for LHC, comparison with SPS and RHIC results on long-range correlations is highly desirable.

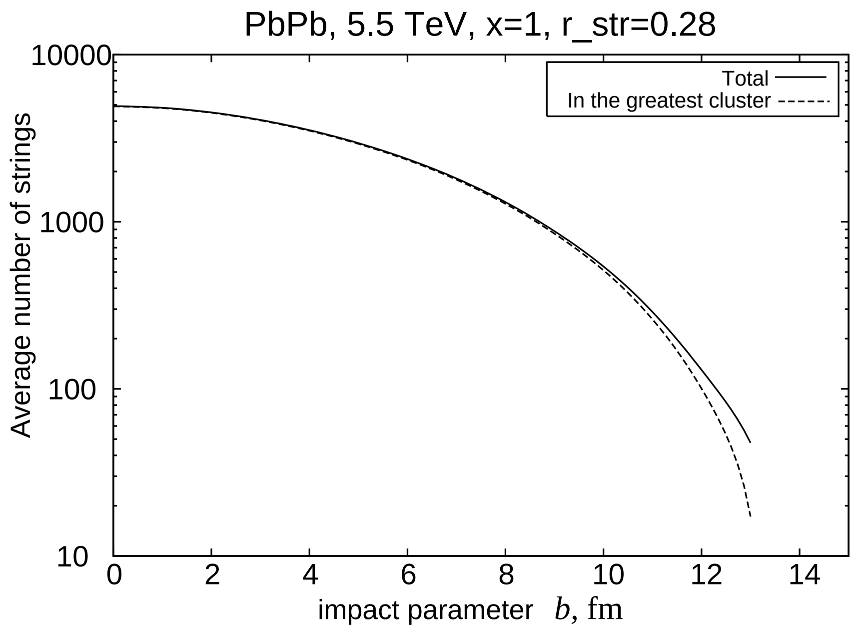
BACKUP SLIDES

On growth of $p_t p_t$ correlations

Assumption of the model: $\bar{p}_t \sim \sqrt[4]{\eta} \equiv \frac{N_{str} S_0}{S_{cluster}}$. Correlations are largest in the domain of the largest values of $\frac{d\sqrt[4]{\eta}}{db}$.



Backup slide $p_t p_t$, applicability of "$n \gg 1$"



- *Clusters*:

  Almost in each event a single cluster with high multiplicity.

- *Overlaps*: all areas with *k*-times overlap can be considered as a single cluster with high multiplicity.

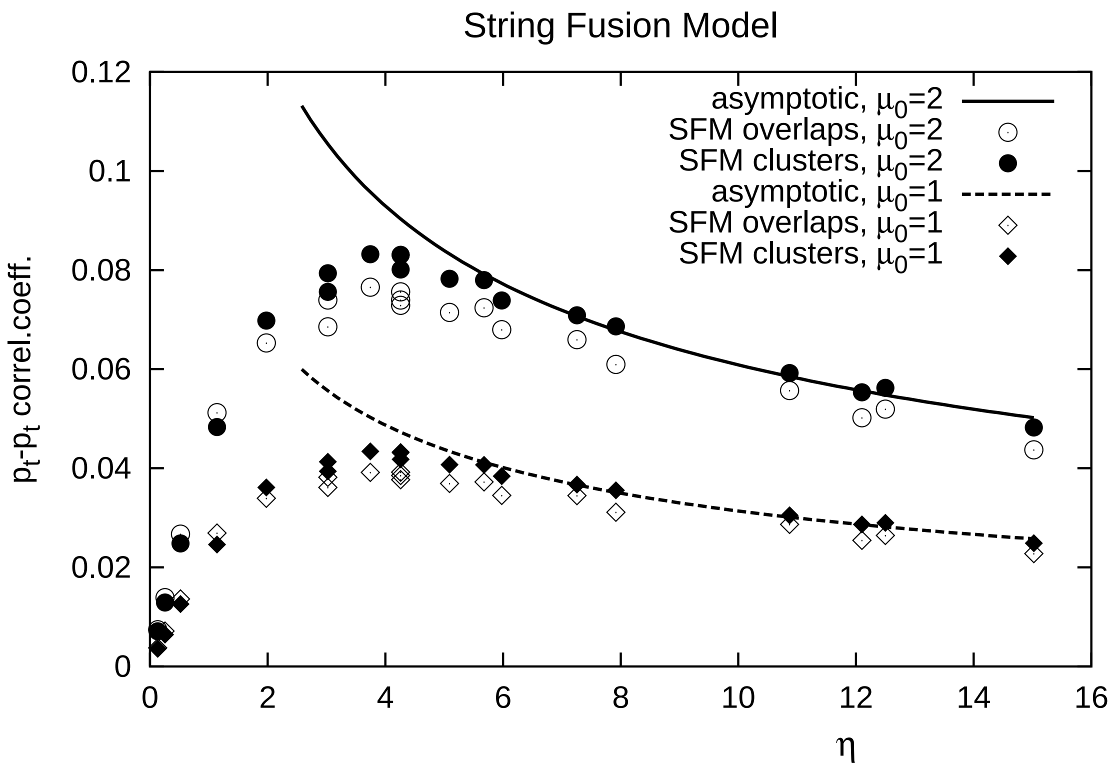
Backup slide – centrality

Centrality class	NA49 PbPb, 17.3 GeV$\cdot A$		AuAu, 130 GeV$\cdot A$	
	% σ_{tot}	(b_{min}, b_{max}), fm (model)	%σ_{tot}	(b_{min}, b_{max}), fm (model)
1	0–5	$(0, 3.4)$	0–5	$(0, 3.13)$
2	5–12.5	$(3.4, 5.3)$	5–15	$(3.13, 5.4)$
3	12.5–23.5	$(5.3, 7.4)$	15–30	$(5.4, 7.7)$
4	23.5–33.5	$(7.4, 9.1)$	30–60	$(7.7, 10.8)$
5	33.5–43.5	$(9.1, 10.2)$	60–92	$(10.8, 13)$
6	> 43.5	$(10.2, 15)$		–

Backup slide – parameters

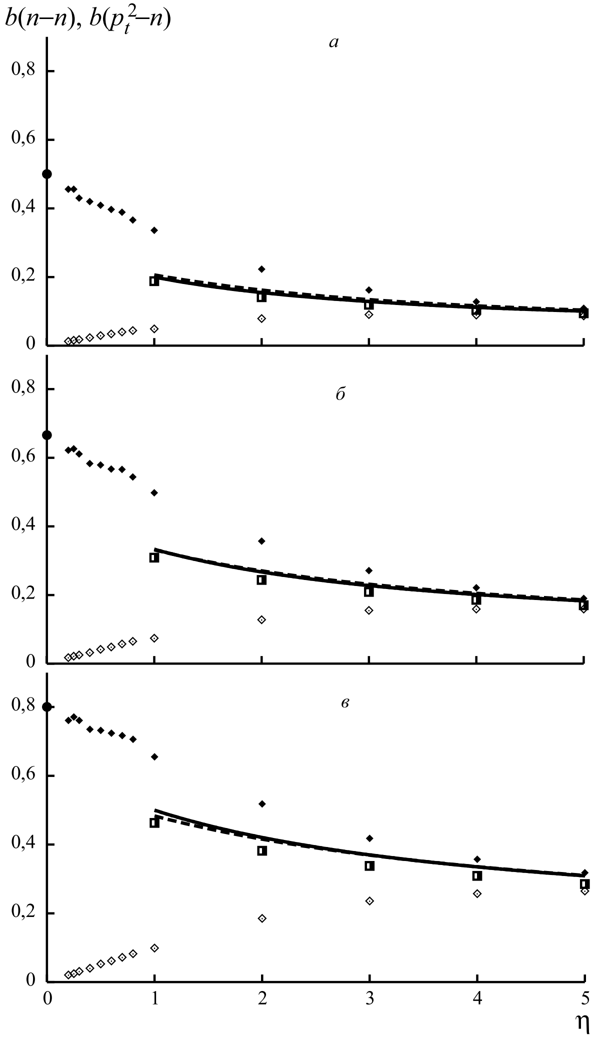
Parameter	Experiment		
	SPS	RHIC	LHC
x	0.18	0.45	1
r_{str}, fm	0.28	0.28	0.28
p_0, GeV	0.305	0.345	–
γ	0.61	0.61	0.61

Asymptotics - 1.



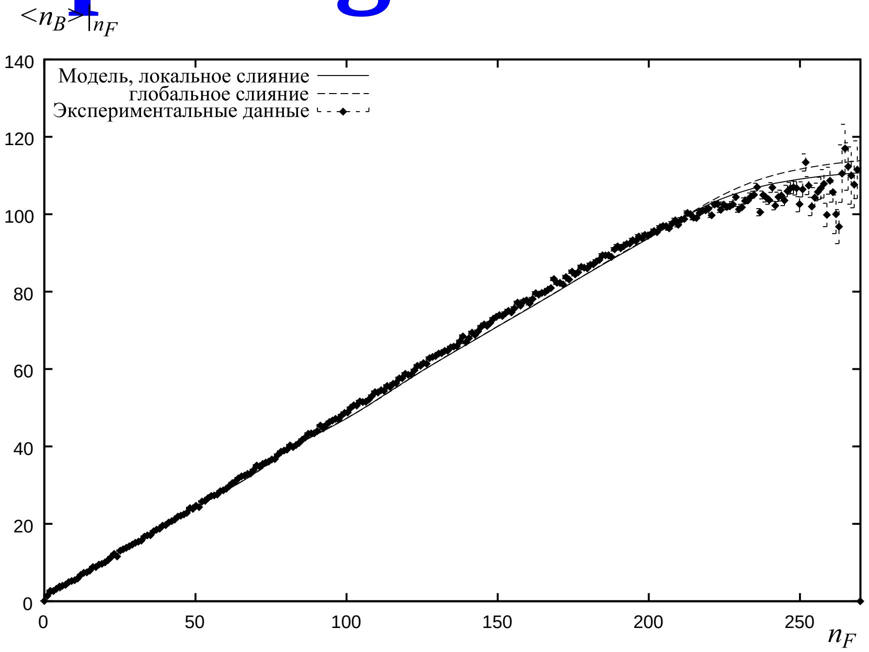
$$\beta_{p_t - p_t} = \frac{\mu_{0F}}{\mu_{0F} + 16\gamma^2 \sqrt{\eta}}$$

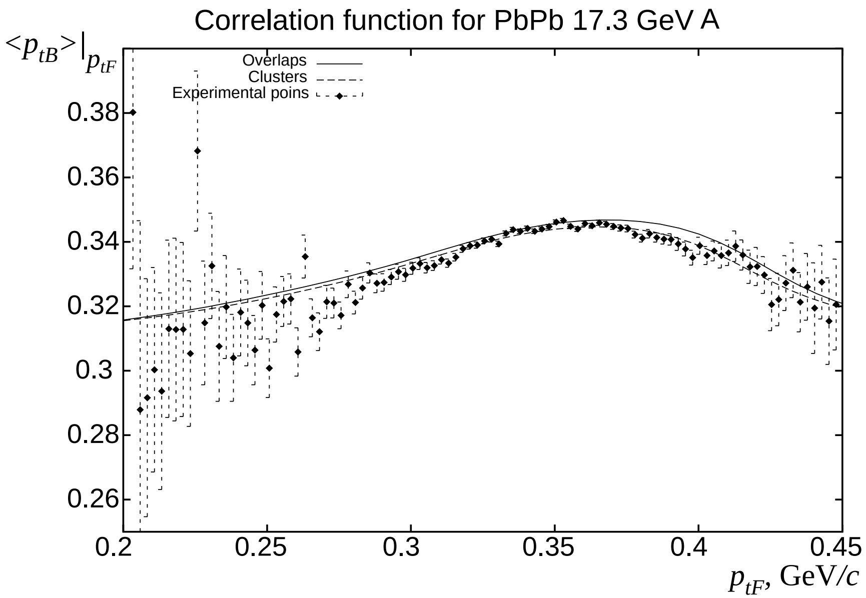
Asymptotics - 2

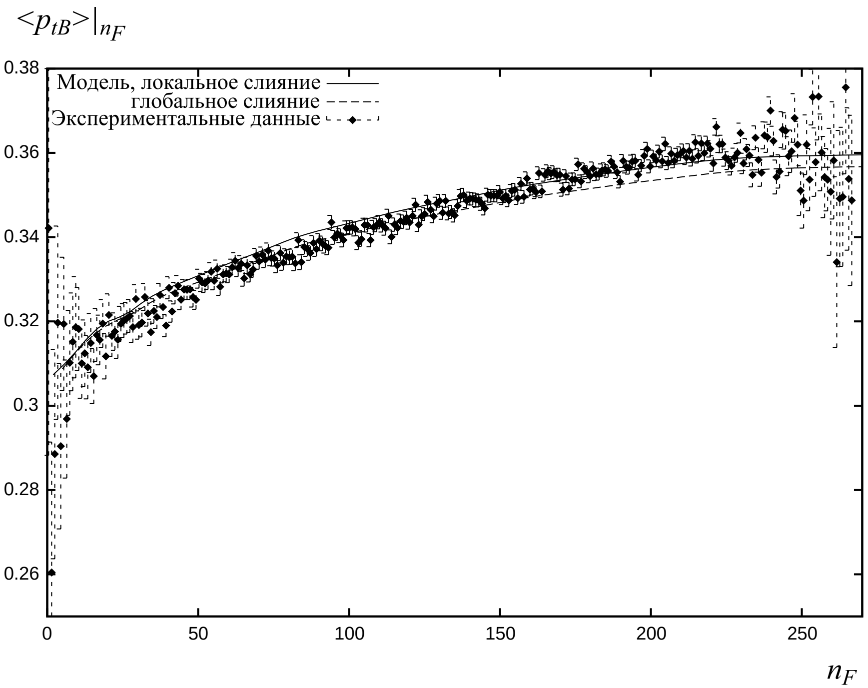


$$\beta_{nn} = b_{p_t^2 n} = \frac{\mu_0}{\mu_0 + 4\sqrt{\eta}}$$

Comparing with SPS data, minimum bias







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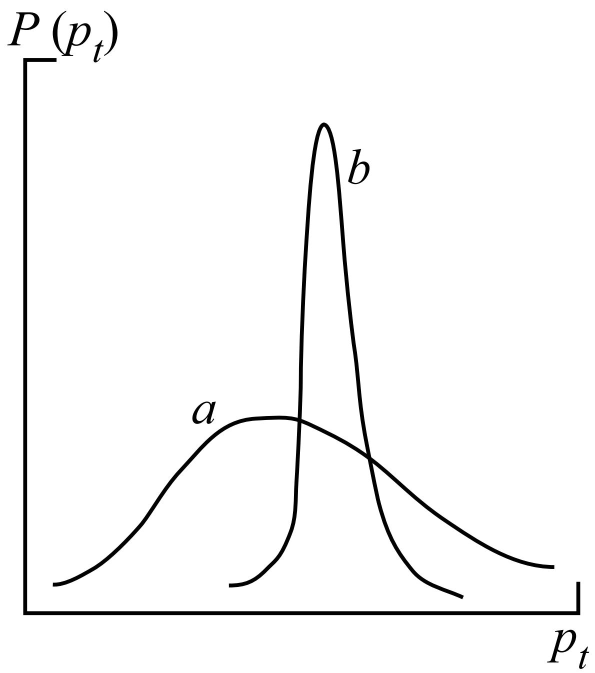
Minimum bias, comments



a – peripheral

b – central