# Лабораторный семинар, вторник, 17 ноября 2020

- 17:00 - 17:40 Г.Феофилов, Percolation of strings in AA and pp collisions.
- 17:40 - 18:00 Г.Феофилов, Краткая информация по докладу Andrea Dubla "The KF Particle package for particle decay reconstruction"

# Percolation of strings in AA and pp collisions

Предполагается осудить доклад Brijesh Srivastava на сессии ALICE AIM: "Sudden increase in the degree of freedom in dense QCD matter"

https://indico.cern.ch/event/957574/

и сопоставить с результатами O. Kochebina, G. Feofilov,” Onset of 'ridge phenomenon' in AA and pp collisions and percolation string model” in Proc. XX Baldin ISHEPP, **PoS(Baldin ISHEPP XXII)069 ,** arXiv:1012.0173 (2010).

# Sudden increase in the degree of freedom in dense QCD matter

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**Department of Physics & Astronomy**
**Purdue University, USA**

*in collaboration with*

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**[2]Instituto de Ciencias Nucleaares, Mexico**
**[3]Universidale de Santiago de Compostela, Spain**
**[4] Purdue University, USA**

**AIM Session at ALICE week**
**November 9-13, 2020**
**CERN**

**Our results agree with LQCD results up to temperature of T~ 210 MeV.**

**Above 210 MeV CSPM $\frac{\varepsilon}{T^4}$ rises much faster and reaches the ideal gas value of 16.**

**It has been argued that QCD could lead to three –state phase structure as a function of temperature. In such a scenario, color deconfinement would result in a plasma of massive "dressed quarks". At still higher temperature this gluonic dressing of quarks would then " evaporate" , leading to a plasma of deconfined massless quarks and gluons : a "QGP".**

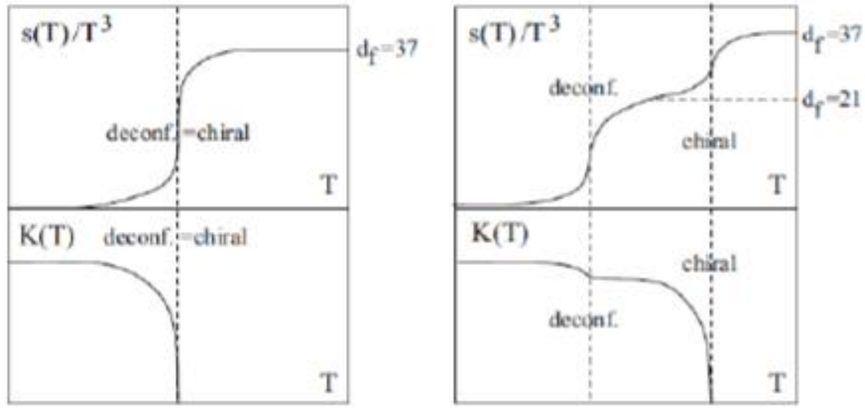
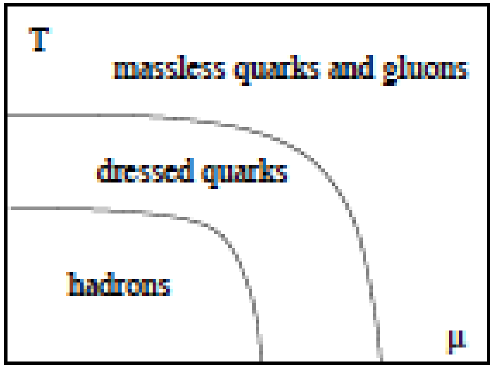



Fig. 6.6 Deconfinement and chiral symmetry restoration for one (left) and two (right) distinct transitions

**Castorina, Gavai, Satz, Eur, Phys. J C 69 (2010) 69.**

# Сегодня:

- Статью **P. Castorina**, **R. V. Gavai**, **H. Satz** **“The QCD Phase Structure at High Baryon Density”** Eur.Phys.J.C69:169-178,2010https://arxiv.org/abs/1003.6078




предлагаю обсудить потом отдельно

Figure 1: Three-state scenario of QCD matter [6]

- Пока сегодня отдельное внимание на предпосылках перколяционной модели
- Brijesh Srivastava "Sudden increase in the degree of freedom in dense QCD matter”

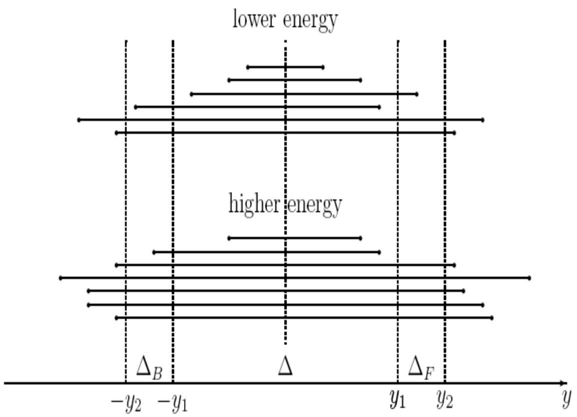
https://indico.cern.ch/event/957574/

- Ниже несколько слайдов из данного доклада для обсуждения

# Theoretical Motivations

- **2-stage scenario of color string formation 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. {\bf B287} (1992) 154;\\ Nucl. Phys. {\bf B390} (1993) 542, 549;
- **Color Glass Condensate and Glasma flux tubes see e.g. L.McLerran, Nucl.Phys.A699,73c(2002)**

**…both are defining the initial conditions before the QGP and predicting the LRC – but in a different way! (see N.S.Amelin, N.Armesto, M.A.Braun, E.G.Ferreiro and C.Pajares, Phys. Rev. Lett., 73 (1994) 2813)**

# Color Strings

Multiparticle production at high energies is currently described in terms of color strings stretched between the projectile and target.

These strings decay into new ones by $q-\bar{q}$ production and subsequently hadronize to produce the observed hadrons. Particles are produced by the Schwinger 2D mechanism.

As the no. of strings grow with energy and or no. of participating nuclei they start to interact and overlap in transverse space as it happens for disks in the 2-D percolation theory

In the case of a nuclear collisions, the density of disks –elementary strings

$$\xi = \frac{N^s S_1}{S_N}$$

$N^s$ = # of strings

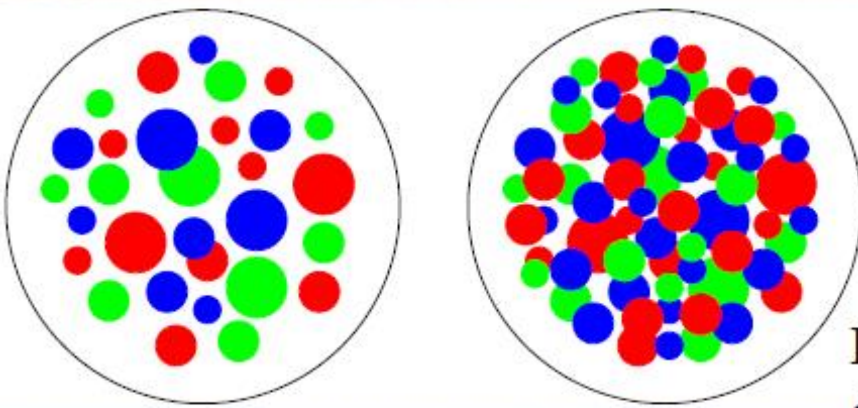
$S_1$ = Single string area

$S_N$ = total nuclear overlap area

# Clustering of Color Sources

**De-confinement is expected when the density of quarks and gluons becomes so high that it no longer makes sense to partition them into color-neutral hadrons, since these would overlap strongly.**

**We have clusters within which color is not confined : De-confinement is thus related to cluster formation very much similar to cluster formation in percolation theory and hence a connection between percolation and de-confinement seems very likely.**



Parton distributions in the transverse plane of nucleus-nucleu collisions

**In two dimensions, for uniform string density, the percolation threshold for overlapping discs is:** $\xi_c = 1.18$

**H. Satz, Rep. Prog. Phys. 63, 1511(2000).**
**H. Satz , hep-ph/0212046**

**Critical Percolation Density**

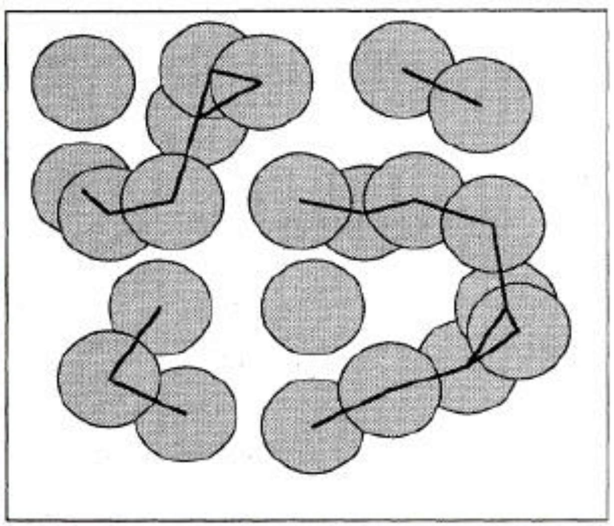
# Percolation : General

**Percolation, statistical topography, and transport in random media**

M. B. Isichenko

Reviews of Modern Physics, Vol. 64, No. 4, October 1992

$$\xi = \pi n r^2$$

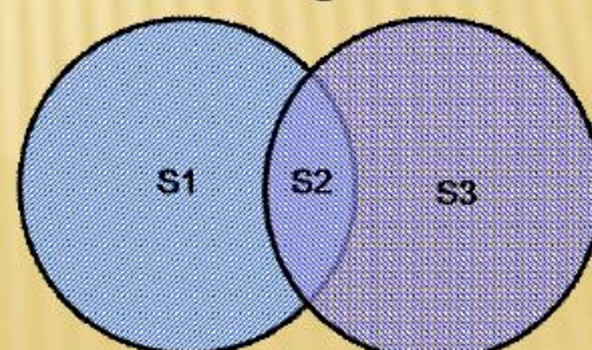


**$\xi$ is the percolation density parameter**
**n is the density and r the radius of the disc**

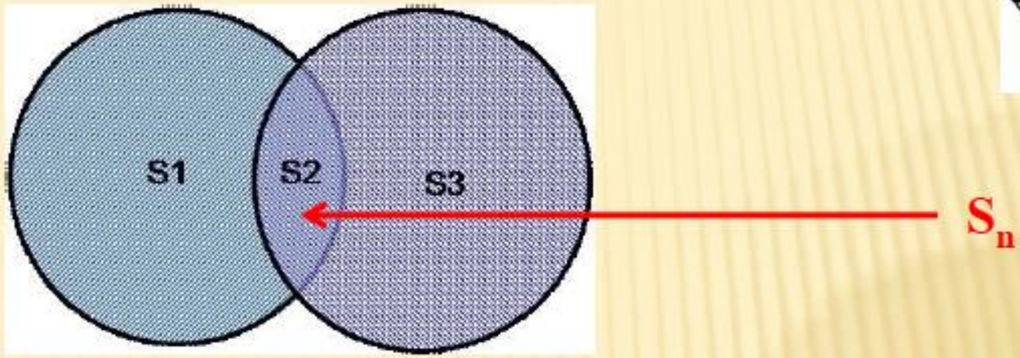
**$\phi$ is the fractional area covered by the cluster** $\phi = 1 - e^{-\xi}$

**$\xi_c$ is the critical value of the percolation density at which a communicating cluster appears**

**For example at $\xi_c$ =1.2 , $\phi \sim 2/3$**
**It means ~ 67% of the whole area is covered by the cluster**
**In the nuclear case it is the overlap area**



# Color Sources




**The transverse space occupied by a cluster of overlapping strings split into a number of areas in which different no of strings overlap, including areas where no overlapping takes place.**

**A cluster of *n* strings that occupies an area $S_n$ behaves as a single color source with a higher color field $\vec{Q}_n$ corresponding to vectorial sum of color charges of each individual string $\vec{Q}_1$**

$\vec{Q}_n^2 = n\vec{Q}_1^2$ **If strings are fully overlap**

$\vec{Q}_n^2 = n\frac{S_n}{S_1}\vec{Q}_1^2$ **Partially overlap**

# Schwinger mechanism for the Fragmentation

## Multiplicity and <$p_T^2$ > of particles produced by a cluster of *n* strings

**Multiplicity** ($\mu_n$)

$$\mu_n = F(\xi) N^s \mu_1$$

**Average Transverse Momentum**

$$< p_T^2 >_n = < p_T^2 >_1 / F(\xi)$$

$$\xi = \frac{N^s S_1}{S_N}$$

$$F(\xi) = \sqrt{\frac{1-e^{-\xi}}{\xi}}$$

= **Color suppression factor** (due to overlapping of discs).

$N^s$ = # of strings
$S_1$ = disc area
$S_N$ = total nuclear overlap area

**ξ is the string density parameter**

M. A. Braun and C. Pajares, Eur.Phys. J. C16,349 (2000)
M. A. Braun et al, Phys. Rev. C65, 024907 (2002)

# Color String Percolation Model for Nuclear Collisions from SPS-RHIC-LHC

Elementary partonic collisions

Formation of Color String

SU(3) random summation of charges

Reduction in color charge
Increase in the string tension

String breaking leads to formation of secondaries

Probability rate ->Schwinger
Fragmentation proceeds in an iterative way

1. Multiplicity
2. pt distribution
3. Particle ratios
4. Elliptic flow
5. Suppression of high pt particles $R_{AA}$
6. J/ψ production
7. Forward-Backward Multiplicity Correlations at RHIC

Braun, Dias de Deus, Hirsch, Pajares, Scharenberg, & Srivastava
Phys. Rep. 599 (2015) 1-50.

## Schwinger : $p_t$ distribution of the produced quarks

$$\frac{dn}{d^2p_\perp} \sim \exp(-\frac{\pi p_t^2}{k^2})$$

**Thermal Distribution**

$$\frac{dn}{d^2p_\perp} \sim \exp(-\frac{\pi p_t}{T})$$

**The Schwinger formula can be reconciled with the thermal distribution if the String tension undergoes fluctuations**

$$P(k)dk = \sqrt{\frac{2}{\pi\langle k^2\rangle}}\exp\left(-\frac{k^2}{2\langle k^2\rangle}\right)dk$$

which gives rise to thermal distribution

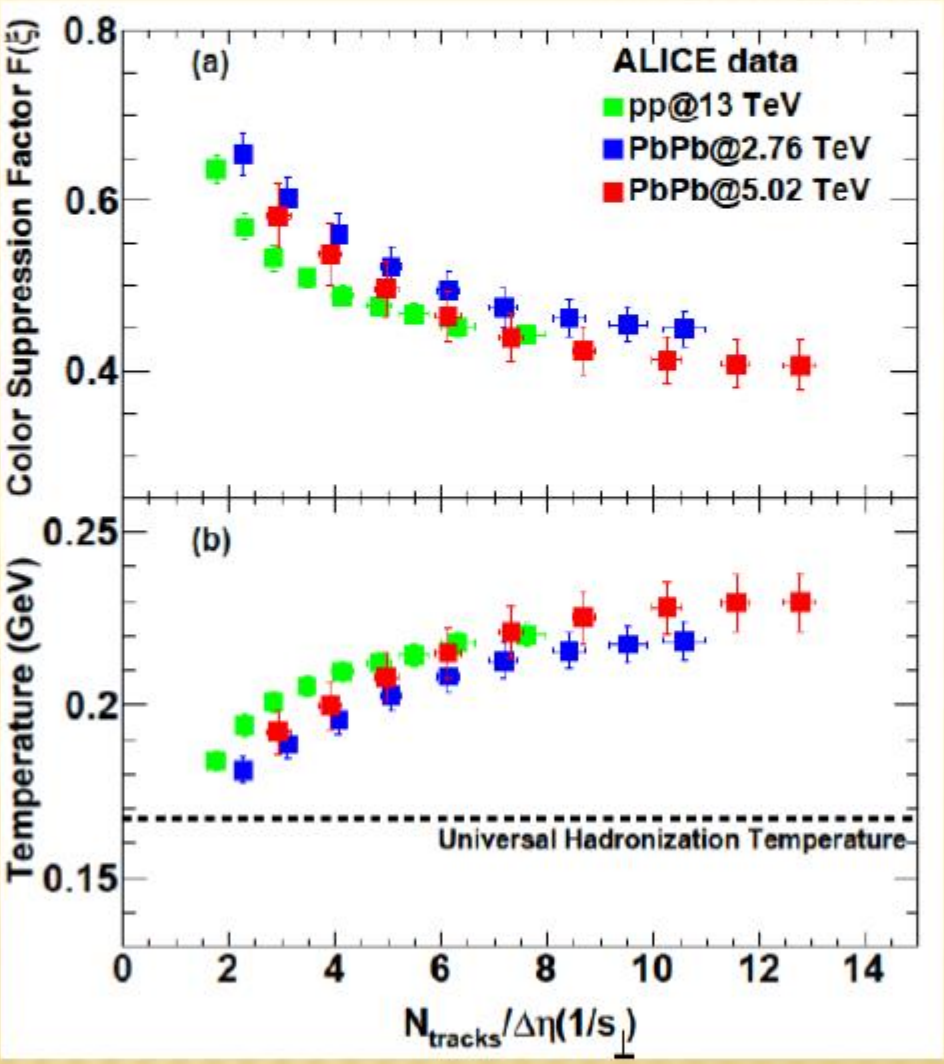
$$\frac{dn}{d^2p_\perp} \sim \exp\left(-p_\perp\sqrt{\frac{2\pi}{\langle k^2\rangle}}\right)$$

$$T = \sqrt{\frac{\langle k^2\rangle}{2\pi}}$$

$$\sqrt{<p_t^2>} = \sqrt{\frac{<k^2>}{\pi}} = \sqrt{\frac{<p_t^2>_1}{F(\xi)}}$$

$$T = \sqrt{\frac{\langle p_t^2\rangle_1}{2F(\xi)}}$$

# Results


(a)
ALICE data
pp@13 TeV
PbPb@2.76 TeV
PbPb@5.02 TeV
Color Suppression Factor F(ξ)
0.8
0.6
0.4
(b)
Temperature (GeV)
0.25
0.2
0.15
Universal Hadronization Temperature
0
2
4
6
8
10
12
14
N_tracks/Δη(1/s⊥)

Nucl. Phys. A 916 (2013) 210-218

# Transverse momentum of protons, pions and kaons in high multiplicity pp and pA collisions: Evidence for the color glass condensate?

Larry McLerran [a,b,c], Michal Praszalowicz [d], Björn Schenke [a,*]

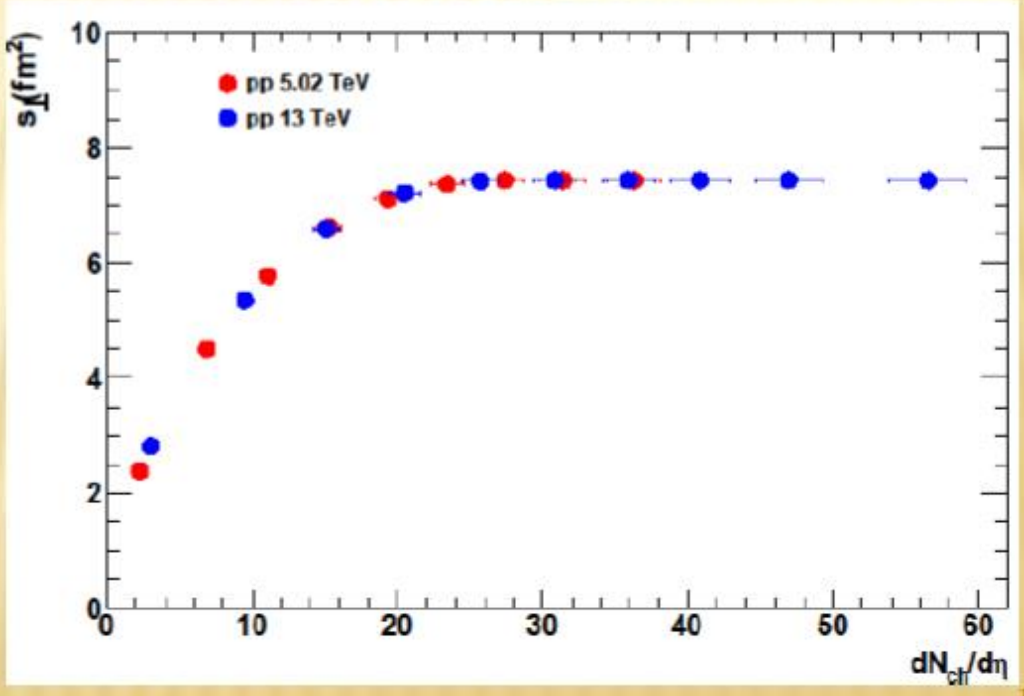
**Interaction area is computed: IP-Glasma model**

**The gluon multiplicity can be approx. related to the no of tracks**

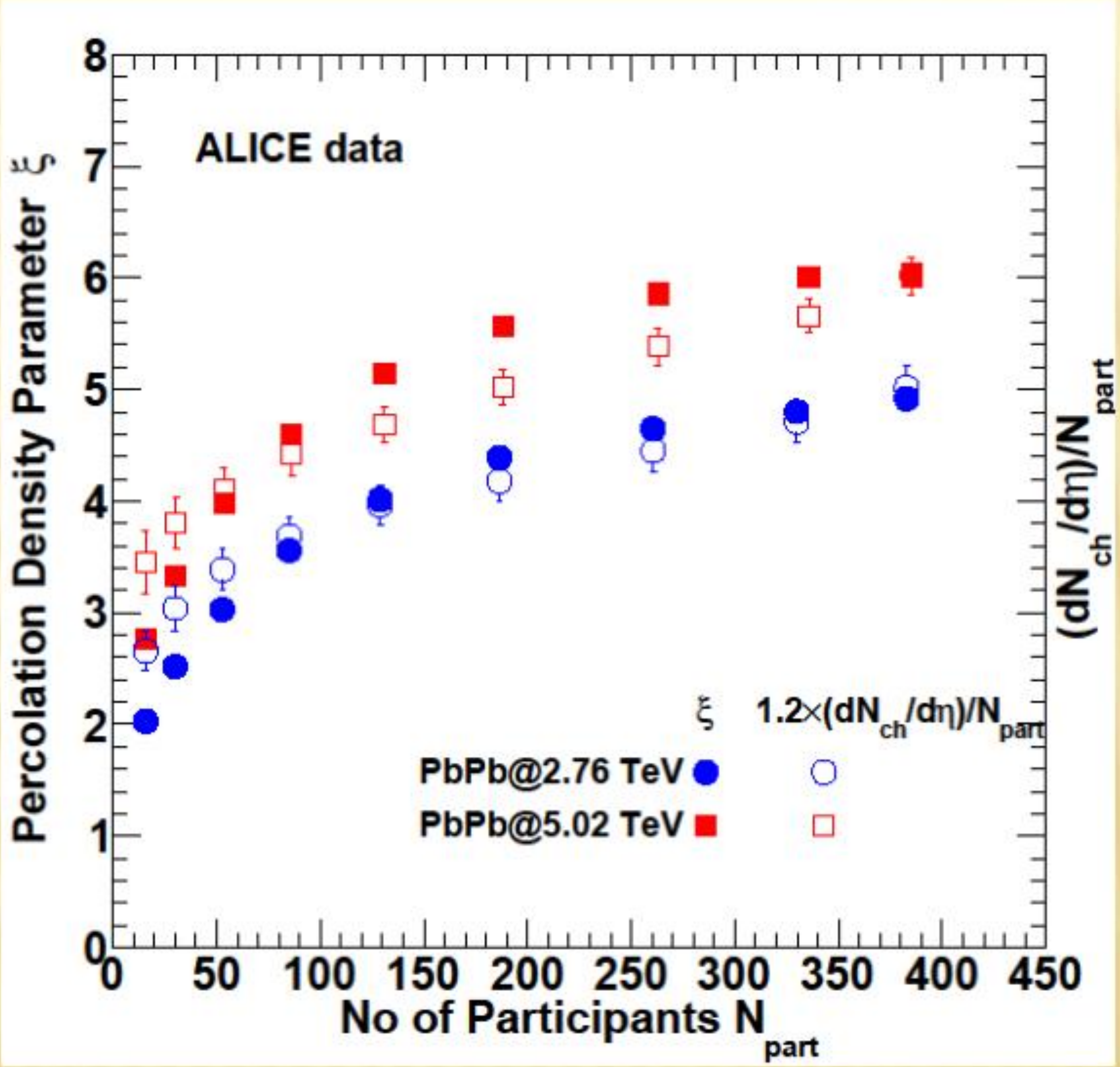
$$\frac{dN_g}{dy} \approx K \frac{3}{2} \frac{1}{\Delta\eta} N_{track}$$

**Transverse area :** $S_{pp} = \pi R_{pp}^2$

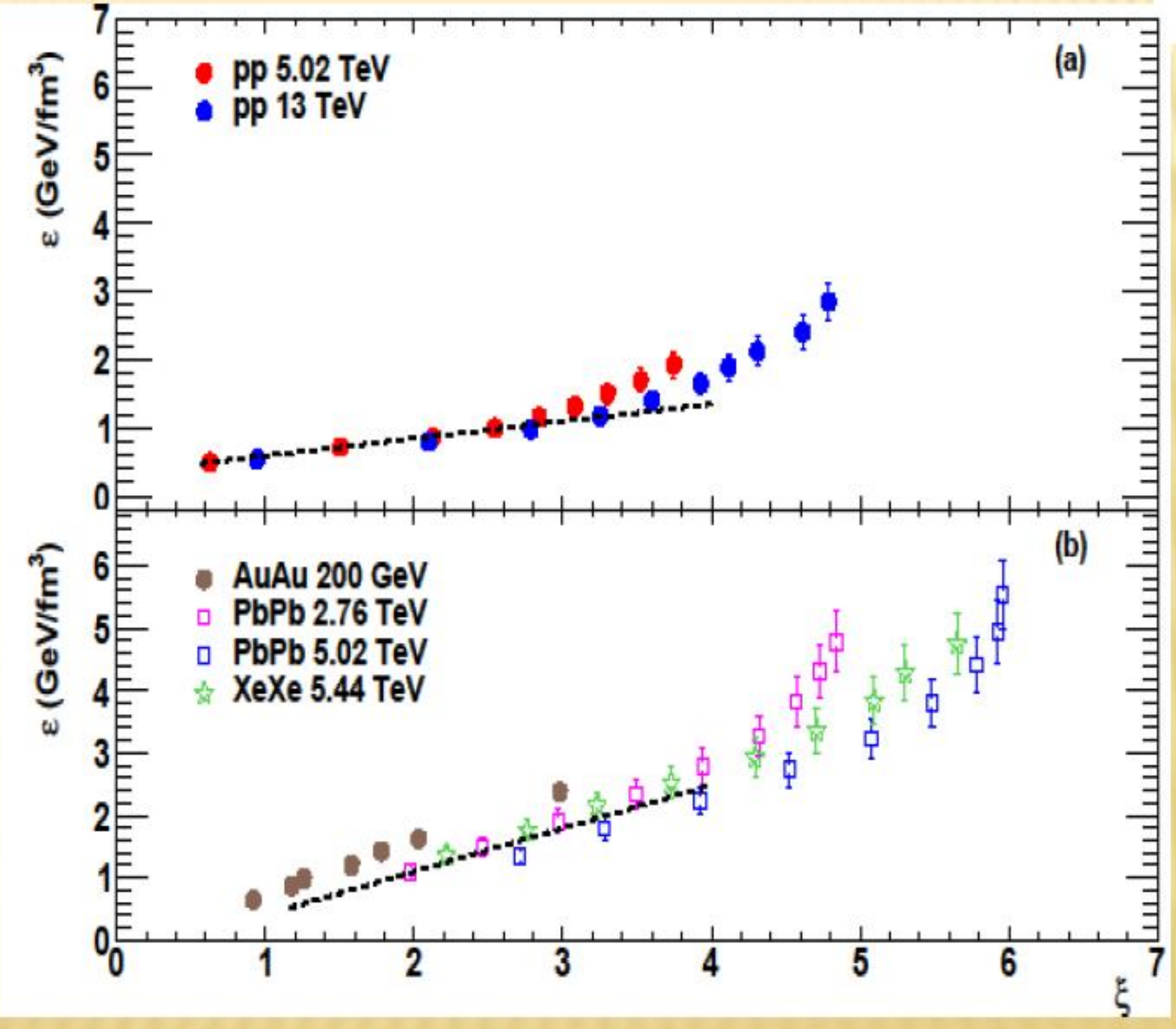
$$R_{pp} = 1\ \text{fm} \times f_{pp}\left(\sqrt[3]{dN_g/dy}\right)$$



# Percolation Density Parameter vs $N_{part}$



# Energy Density



# Summary by Brijesh

## Summary

- The Clustering of Color Sources produced by overlapping strings has been applied to both A-A and *pp* collisions.
- The most important quantity in this picture is the multiplicity dependent interaction area in the transverse plane $S_\perp$
- The temperature from AA and *pp* scales as $\frac{dN_c}{d\eta}\left(\frac{1}{S_\perp}\right)$
- Quantum tunneling through color confinement leads to thermal hadron production in the form of Hawking-Unruh radiation. In QCD we have string interaction instead of gravitation.
- We observe for the first time a two-step behavior in the increase of DOF.

# Onset of “low-p_t ridge” and percolation of strings in AA and pp collisions

O.A. Kochebina, G.A. Feofilov

*St. Petersburg State University*

**The XX International Baldin Seminar on High Energy Physics Problems**
**"*Relativistic Nuclear Physics and Quantum Chromodynamics*",**
**JINR,October 8, 2010 , Dubna, Russia**
**( http://relnp.jinr.ru/ishepp/)**

# Outline

1. Motivation
   - *Experimental threshold phenomena: onset of the "low-pt" ridge*
2. *Percolation string model and calculations*
3. Conclusions

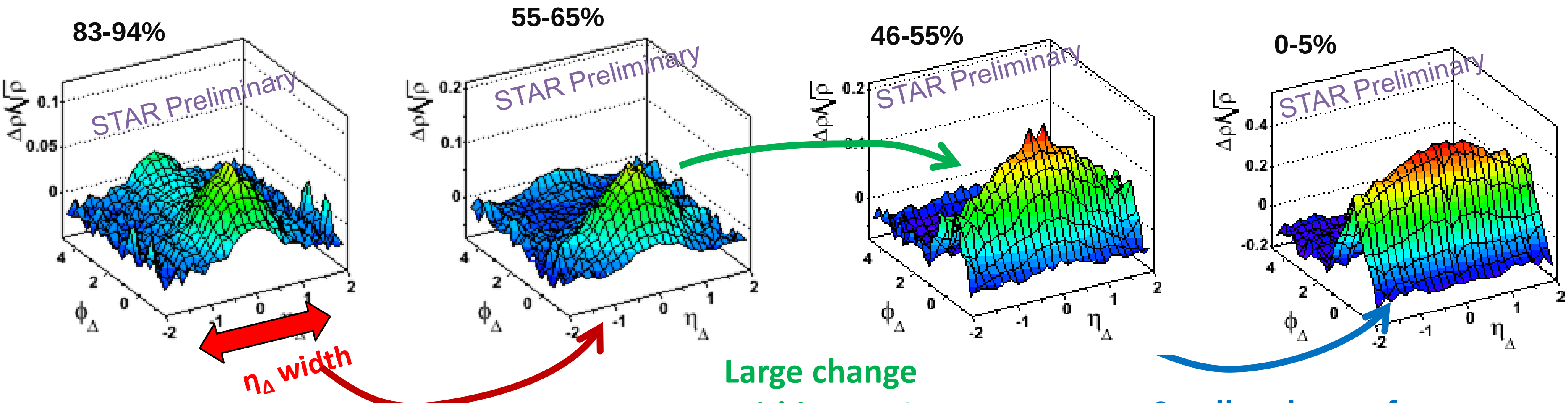


**See NA61. Physics goals. https://na61.web.cern.ch**

# New phenomena in AA collisions observed by STAR [1]

**Variation of low-$p_T$ "ridge" with centrality (Npart).**

***(pt> 0.15 GeV/c )***




**Shape changes little from peripheral to the transition**

**Large change within ~10% centrality**

**Smaller change from transition to most central**

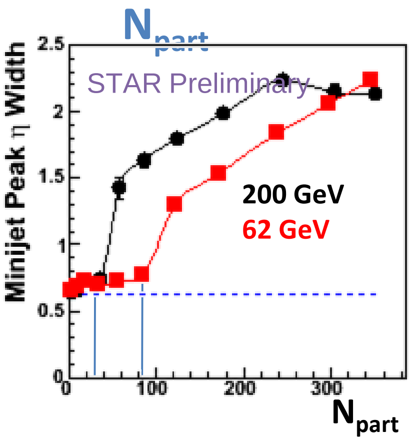
**Low-$p_T$ manifestation of the "ridge"**

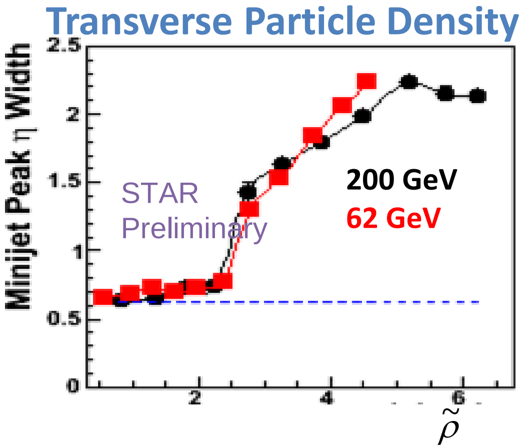
The data showed a <u>sharp transition</u> at some definite energy-dependent centrality: **growing of peak amplitude** and **stretching of width**.

[1]Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR. **M. Daugherity(QM2008), J.Phys.G35:104090,2008**

## Variation of low-$p_T$ “ridge” with centrality (Npart).

A sudden increase of the **peak amplitude** and **η width** of ***the near-side low p_t ridge*** were found at an *energy-dependent* centrality point ***marked by the definite number*** of participating nucleons **Npart**. **(M. Daugherity(QM2008), J.Phys.G35:104090,2008)**




$$\tilde{\rho} = \frac{3}{2}\frac{dN_{ch}}{d\eta}/S$$

**We estimate:**
**For 62 GeV**
**“Critical value” $N_{part}$≈90**

**For 200 GeV**
**“Critical value” $N_{part}$≈40**

$$\tilde{\rho}_{crit} = 2{,}6 \pm 0{,}2\ fm^{-2}$$

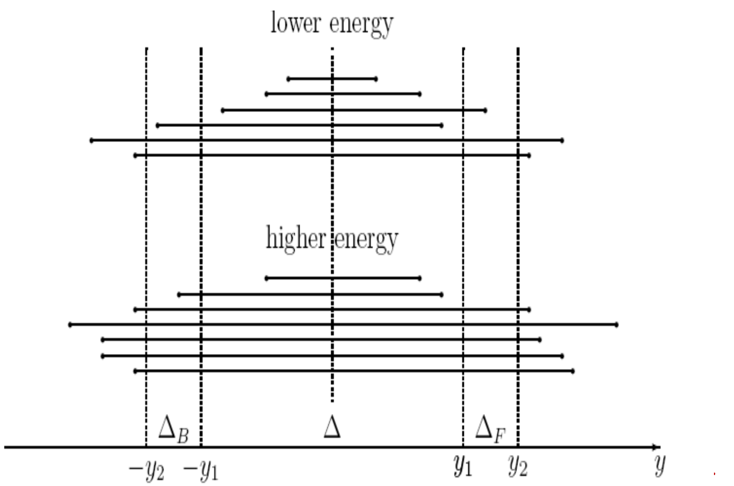
Same-side gaussian peak width. Points show eleven centrality bins for each energy (84-93%, 74-84%, 65-74%, 55-65%, 46-55%, 37-46%, 28-37%, 19-28%, 9-19%, 5-9%, and 0-5%) transformed to tranvserse density.

Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR. M. Daugherity. QM2008, J.Phys.G35:104090,2008

# Our hypothesis:

- The onset of this phenomena of ***the near-side low p_t ridge in AA collisions is relevant to the string percolation phase transition*** that happens at some definite ("critical") number of participating nucleons Npart.
- As a result of color string interaction the new kind of particle-emitting sources appear, the phenomenon could be characterized by the long-range correlations in the event-by-event studies
- The same may happen in pp collsions at some critical energy density reached

# Motivation: Theory




## Color string formation and decay

### “Founding Fathers”:

A two-stage scenario of color string formation and decay

- A.Capella, U.P.Sukhatme, C.--I.Tan and J.Tran Thanh Van, Phys. Lett. **B81** (1979) 68; Phys. Rep. {\bf 236} (1994) 225. A.B.Kaidalov, Phys. Lett., **116B**(1982)459; A.B.Kaidalov K.A.Ter-Martirosyan ,Phys.Lett., **117B**(1982)24

**Do these color strings interact and what is the si**

*<p_t>* *and* *elliptic flow* --- were predicted for AA and pp --- in 1988 (!):

- Abramovskii V. A., Gedalin E. V., Gurvich E. G., Kancheli O. V. , Long-range azimuthal correlations in multiple-production processes at high energies, JETP Lett., vol.47, 337-339 , 1988 (!)

**String Fusion Model** :

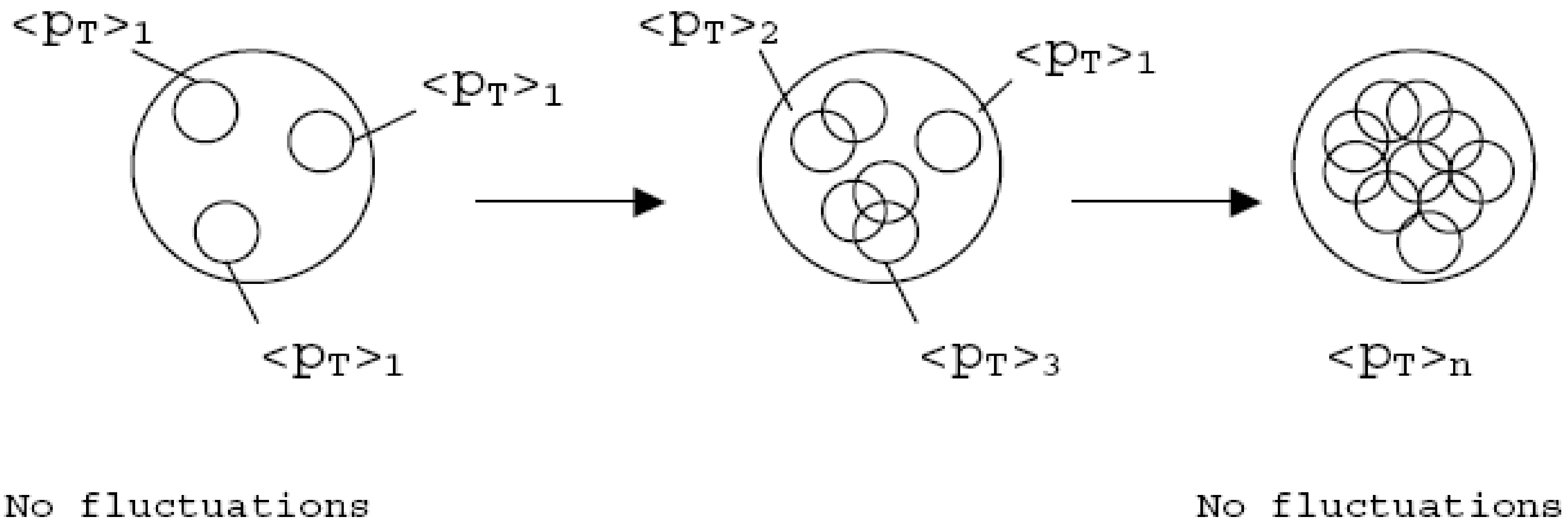
- M.A.Braun and C.Pajares, Phys. Rev. Lett. {\bf 85} (2000) 4864; M.A.Braun and C.Pajares, Phys. Lett. {\bf B287} (1992) 154;\\ Nucl. Phys. {\bf B390} (1993) 542, 549;\\
- N.S.Amelin, M.A.Braun and C.Pajares, Phys. Lett. {\bf B306} (1993) 312;\\ Z.Phys. {\bf C63} (1994) 507.
- **M.A.Braun, C.Pajares and V.V.Vechernin,** Low pT Distributions in the Central Region and the Fusion of Colour Strings, Internal Note/FMD ALICE-INT-2001-16

...more...

# "Percolating color strings approach".

**With growing energy and/or atomic number of colliding particles, the number of strings grows and they start to overlap, forming clusters [3-5].**

***Fluctuations are due to the mixture of different type sources !***

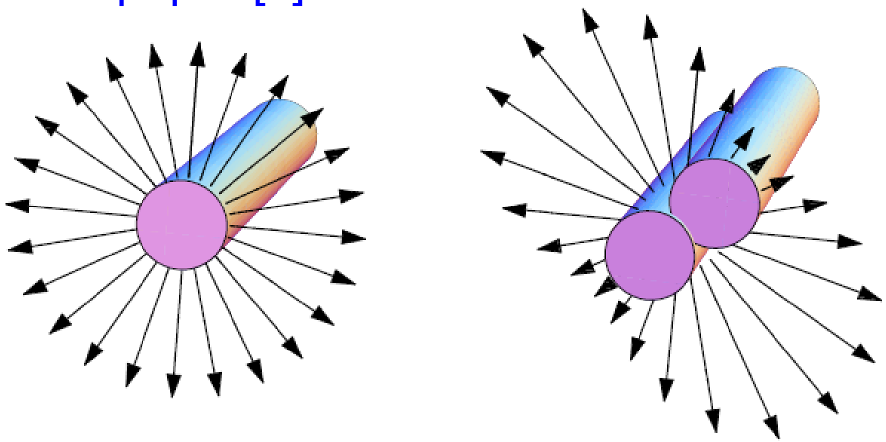




[3] **M.A.Braun and C.Pajares, Eur. Phys. J. {\bf C16} (2000) 349.**
**M.A.Braun,R.S.Kolevatov,C.Pajares.V.V.Vechernin, ''Correlations between multiplicities and everage transverse momentum in the percolating color strings approach'', Eur.Phys.J.C.32.535-546(2004)**
**[4] N/**Armesto, C/Saldago, U/Wiedemann// PRL94 (2005) 022002.
[5] C. Pajares // arXiv:hep-ph/0501125v1 14 Jan 2005

# Motivation: more of Theory

This old concept *of interacting chromoelectric tubes [1],* ***extended in rapidity,*** may be illustrated by some nice figure from the quite recent paper [2] :

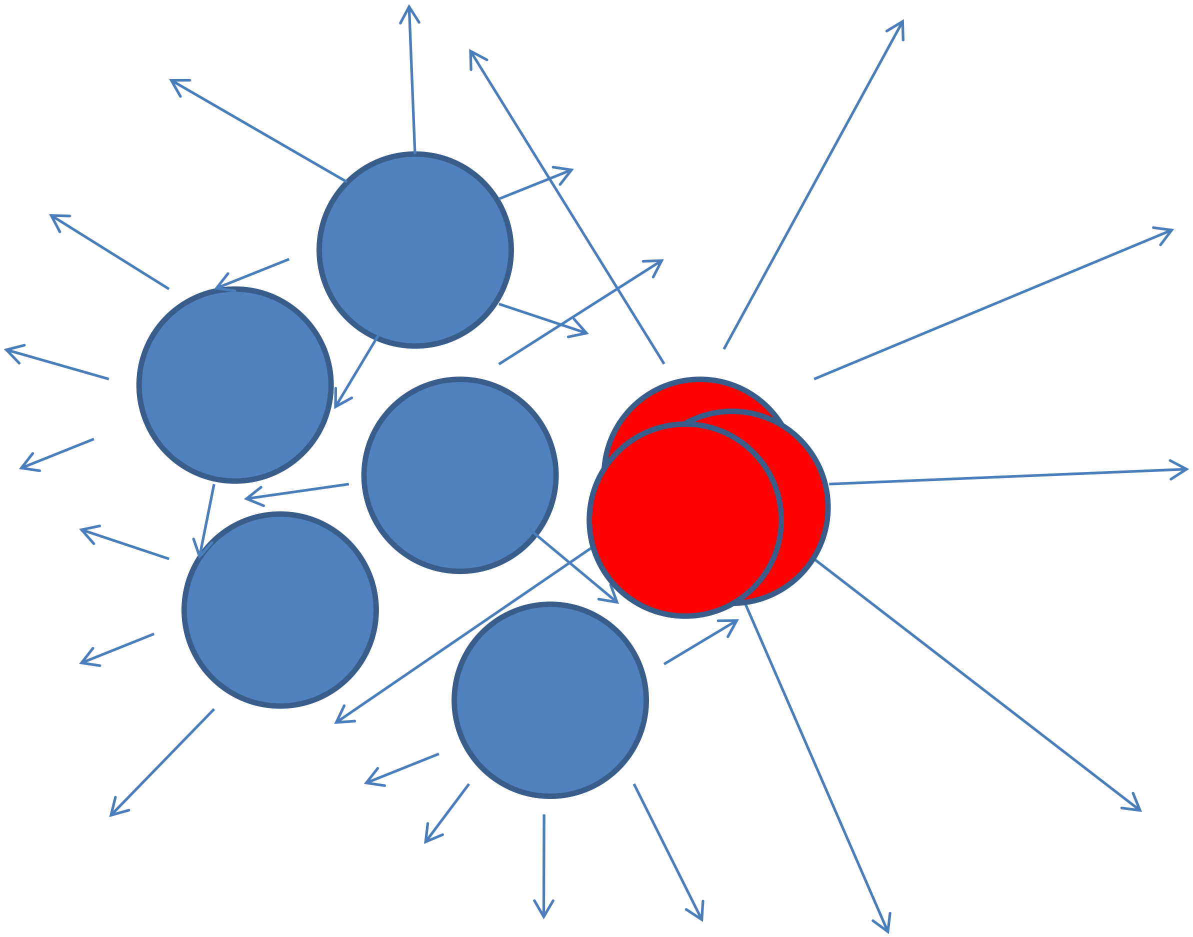


"Fig. 1. Sketch of the one and two flux tubes configurations considered. On the left a single flux tube elongated in space-time rapidity generates azimuthally symmetric flow. On the right a configuration with two strings leads to an **azimuthally asymmetric flow** in the transverse plane" [2].

[1] Abramovskii V. A., Gedalin E. V., Gurvich E. G., Kancheli O. V. , Long-range azimuthal correlations in multiple-production processes at high energies, JETP Lett., vol.47, 337-339 , 1988

[2] Piotr Bozek, "**Observation of the collective flow in proton-proton Collisions**", arXiv://0911.2392v2 [nucl-th] 22 Jan 2010

…more…



Transverse plane schematics of formation and decay of the "macroscopic" cluster composed of several overlapped strings - red, and the “ordinary strings - - - blue

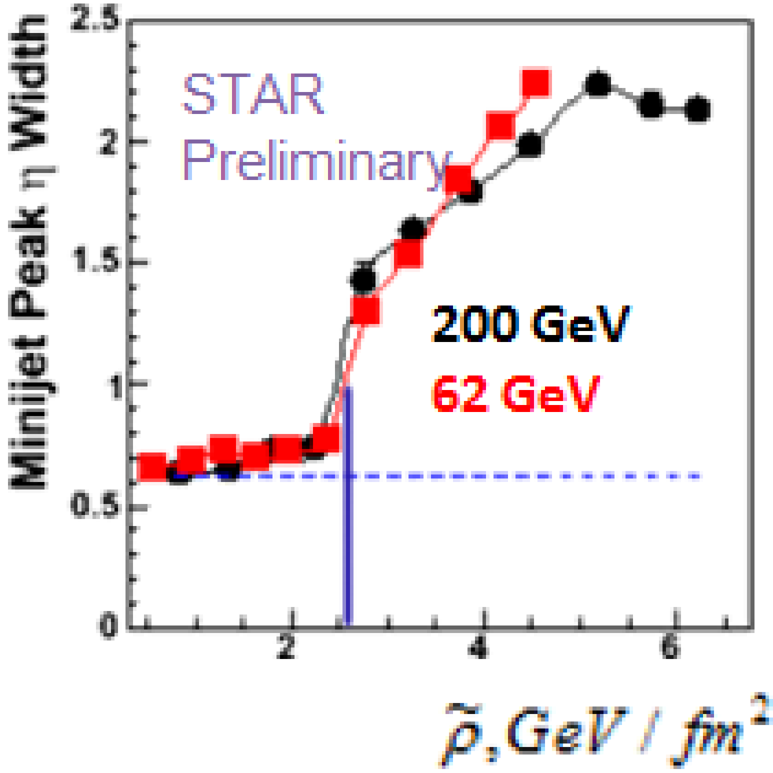
**Multiplicity density and mean p_t**

**in case of fusion of n strings(M.Braun, C.Pajares):**

$$\mu_n = \sqrt{\frac{nS_n}{S_1}}\mu_1 \; ; \; \langle p_T^2 \rangle_n = \sqrt{\frac{nS_1}{S_n}} \langle p_T^2 \rangle_1$$

- One may assume that the formation of rather large "macroscopic" clusters composed of several overlapped strings extended in rapidity and localized in azimuth could be one of the possible processes leading to the observed near-side ridge phenomenon.

# Transverse particle density

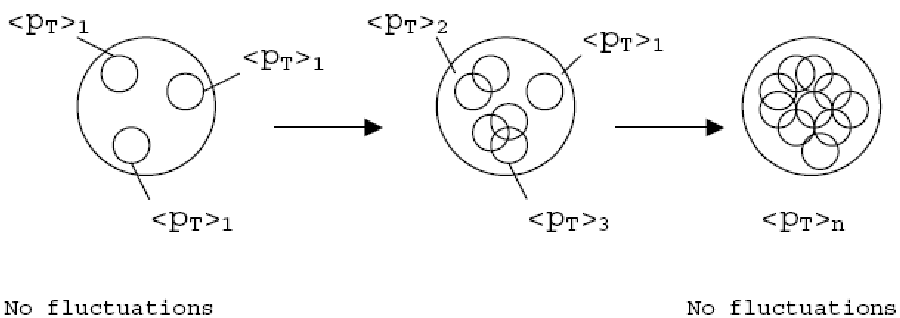



$$\tilde{\rho} = \frac{3}{2}\frac{dN_{ch}}{d\eta} / S$$

$$\tilde{\rho}_{crit} = 2{,}6 \pm 0{,}2\, fm^{-2}$$

Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR. M. Daugherity. QM2008, J.Phys.G35:104090,2008

# String model. Estimate of string percolation parameter.

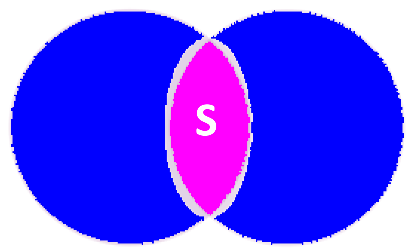



With growing energy and/or atomic number of colliding particles, the number of strings grows and they start to overlap, forming clusters, **new type of particle emitting source**.
At a critical density a macroscopic cluster appears that marks the percolation phase transition.[3]

Percolation parameter:

$$\eta(b) = \frac{N_{str}(b)\pi r_0^2}{S(b)}$$

**Nstr - ?**
**S - ?**




*$\eta_c$ = 1,12-1,175 ([4])*

$$N_{str} = N_{Sea} + N_{Valent}$$

$$\eta(N_{part}) = N_{str}(N_{part})\pi r_0^2 / S(N_{part})$$

$$N_{str} = N_V + N_S = N_{part} + aN_{coll}$$

$\mathbf{N_{Str}}$ - number of strings, $\boldsymbol{\pi r_0^2}$ string transverse area, ***S*** overlap area of two nucleons.

$\mathbf{r_0}$**=0,2-0,3 fm** – change of string radius value results in different percolation parameter


[3] C. Pajares // arXiv:hep-ph/0501125v1 14 Jan 2005
[4] N. Armesto, M.A, Braun, E.G. Ferreiro, C. Pajares// Phys. Rev. Lett. 77, 3736 (1996)
[6] Ncoll, see: G.Feofilov,A.Ivanov "Modified Glauber moel"//Journal of Physics: Conference Series 5 (2005) 230–237

$\tilde{\rho}$

$\tilde{\rho}$

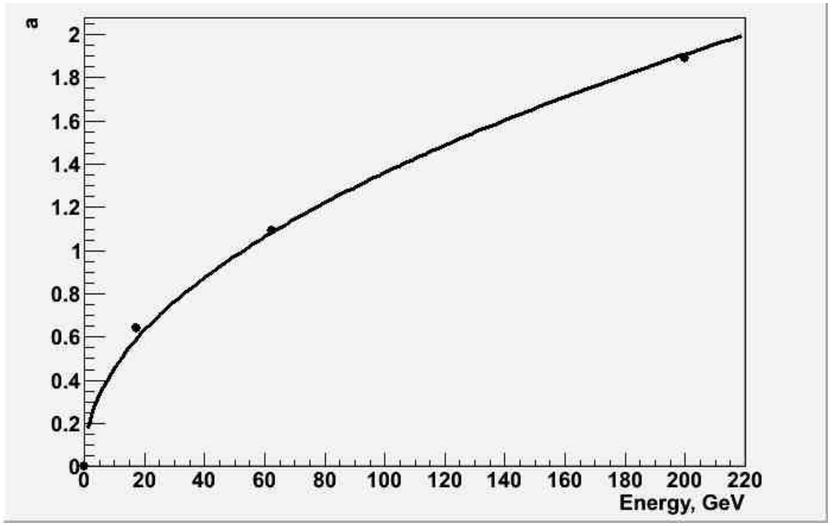
# Table 1. Our first estimates of number of particles emitting sources Nstr in case of $r_0=0.2fm$

| √s, GeV AA collisions | $Npart_{crit}(\sqrt{s})$ | S(b)= S( $Npart_{crit}(\sqrt{s})$, $fm^2$ | $\eta_{crit}$ | *Nstr* | *Nv* | *Ns* | $\tilde{\rho}_{crit}$ $fm^{-2}$ |
|---|---|---|---|---|---|---|---|
| 62 AuAu | 90 | 62,0 | 1,15 | 531 | 90 | 441 | 2,8 ±0,2 |
| 200 AuAu | 36 | 38,7 | 1,15 | 303 | 36 | 267 | 2,9±0,2 |

## Estimates of parameter $a$:

$$N_{str} = N_V + N_S = N_{part} + aN_{coll}$$

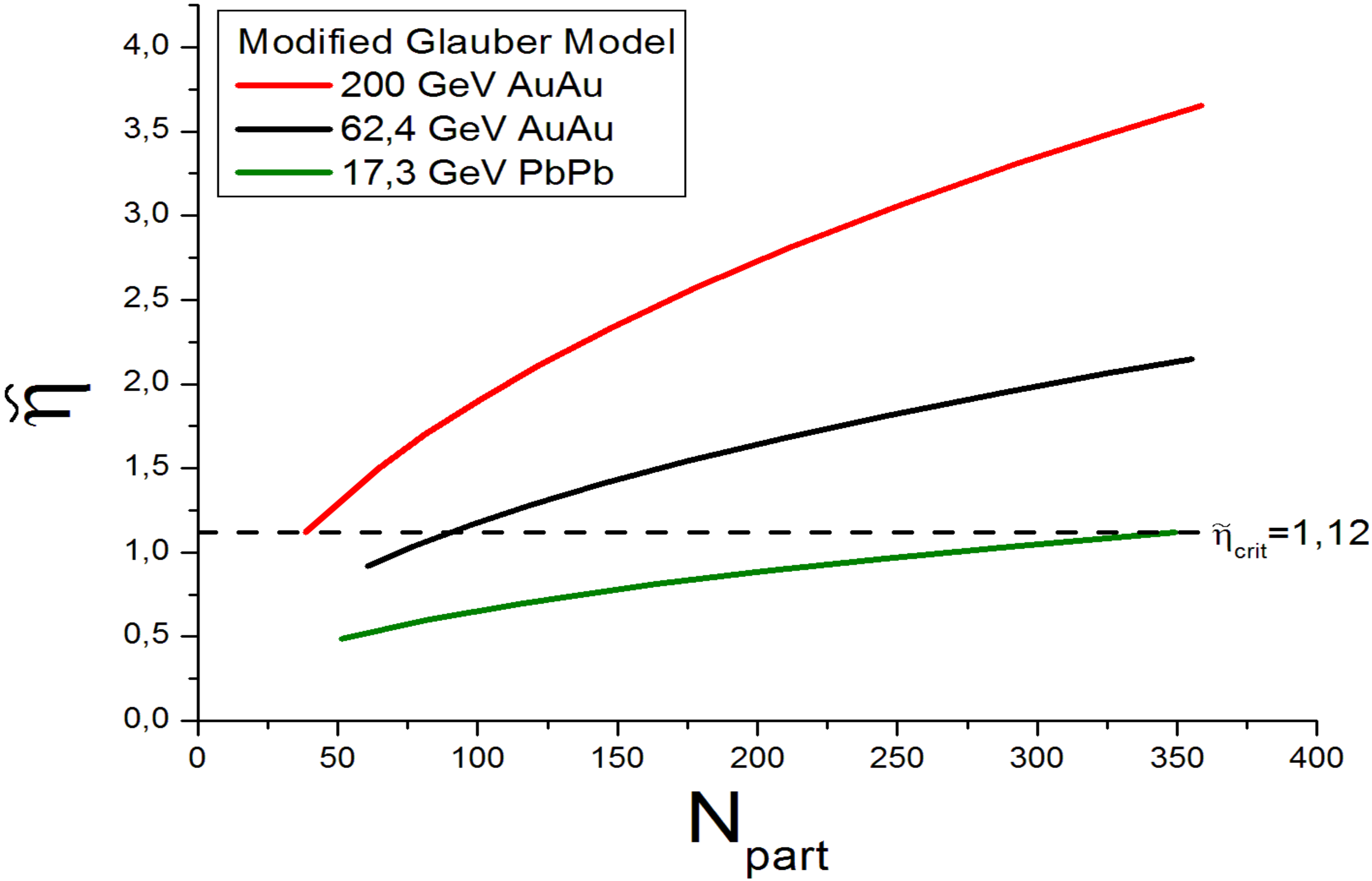
Nstr is defined basing on values of Npart form [1].
Ncoll is defined by using [2].
Uncertanties are at the level of 30% (preliminary estimate).




$$a = b + c \cdot e^{-\sqrt{s}/t}$$

[1]Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR. **M. Daugherity(QM2008), J.Phys.G35:104090,2008**

[2] G.Feofilov,A.Ivanov "Modified Glauber moel"//Journal of Physics: Conference Series 5 (2005) 230–237



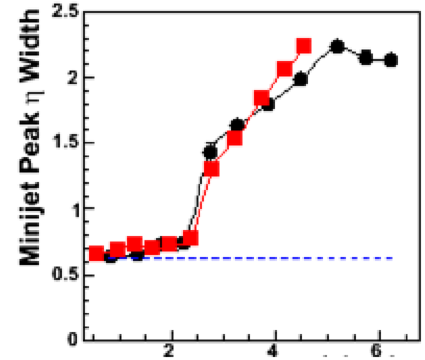

[6] G.Feofilov,A.Ivanov “Modified Glauber model”//Journal of Physics: Conference Series 5 (2005) 230–237

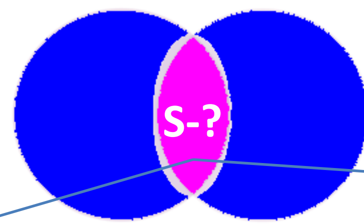
# New! **Our calculation**

Percolation model parameters at **the "critical" point**

Percolation sting theory[3-5]

Transverse particle density




$$\tilde{\eta} = N_{string} \pi r_0^2 / S$$

$$\tilde{\rho} = \frac{3}{2} \frac{dN_{ch}}{d\eta} / S$$

$$\frac{\tilde{\rho}_{crit}}{n_{crit}}$$

$$\eta_{crit} = 1{,}12 - 1{,}175 [4]$$

$$\tilde{\rho}_{crit} = 2{,}6 \pm 0{,}2\ fm^{-2} [1]$$

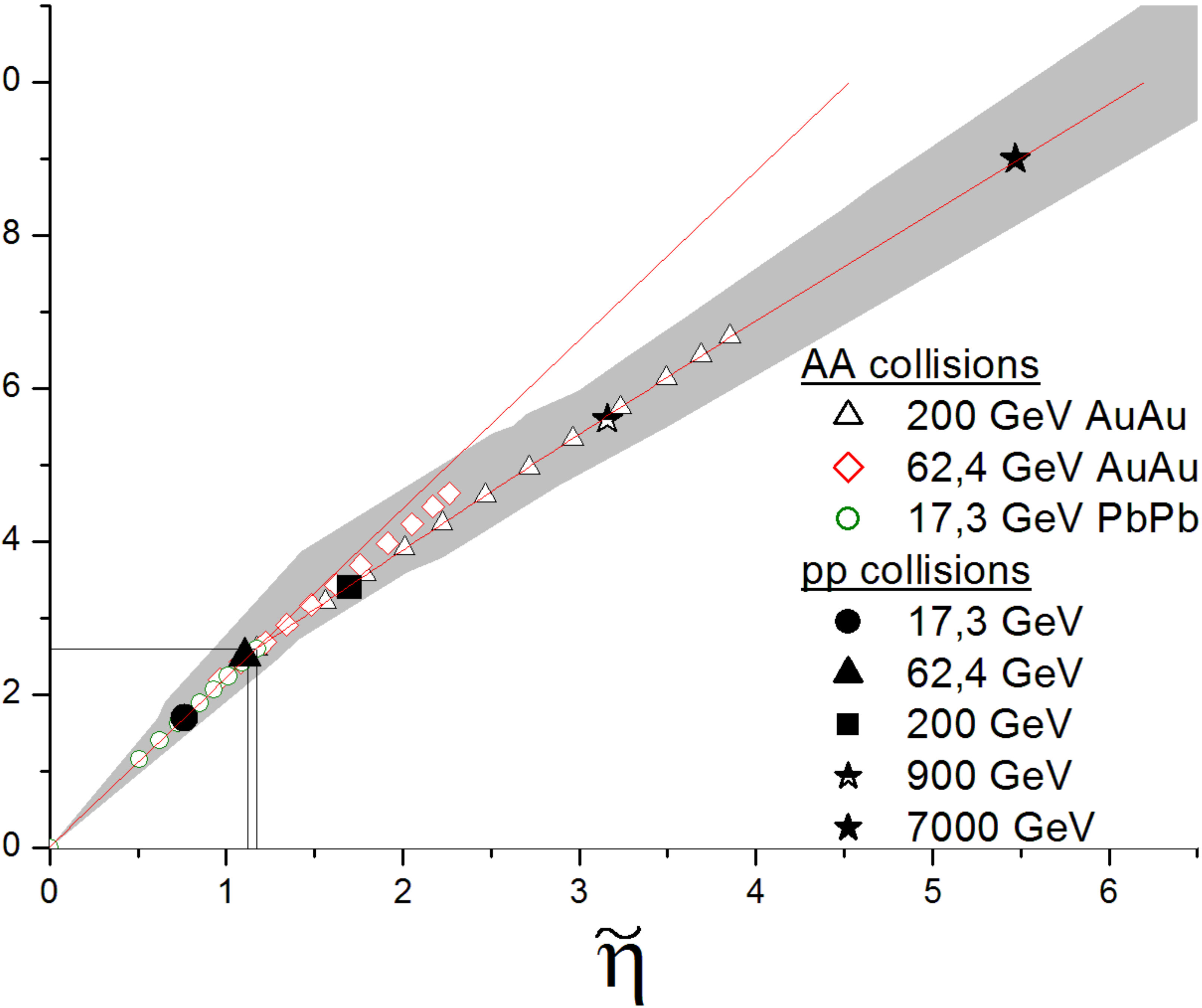
**Parameters of the model**

$$N_{str} = N_V + N_S = N_{part} + aN_{coll}$$


[3] C. Pajares // arXiv:hep-ph/0501125v1 14 Jan 2005
[4] N. Armesto, M.A, Braun, E.G. Ferreiro, C. Pajares// Phys. Rev. Lett. 77, 3736 (1996)
[5]V.V. Vechernin, R.S. Kolevatov, 2007, Yad. Fiz., 2007, Vol. 70, No. 10, pp. 1858–1867.

# Collective effects: from AA to pp and ppbar collisions?

See also: A.Asryan, G.Feofilov, Ivanov, A.Grebenyuck, P.Naumenko, V.Vechernin
"Long-Range Multiplicity Correlation in pp-collisions in ALICE at the LHC". Proceedings of **The XIX International Baldin Seminar on High Energy Physics Problems, JINR, September 29-October 4, 2008 , Dubna, Russia, pp.208-214**



0
8
6
4
2
0
0
1
2
3
4
5
6
η̃
AA collisions
200 GeV AuAu
62,4 GeV AuAu
17,3 GeV PbPb
pp collisions
17,3 GeV
62,4 GeV
200 GeV
900 GeV
7000 GeV

# Estimates for pp collisions (preliminary):

Interaction area S=1 fm^2):

$$\tilde{\eta} = N_{str} \pi r_0^2 / S$$

| √s, GeV | dNch/dy (see[7] for ALICE /LHCdata) | ρ, GeV/fm² | η | Nstr (systematic errors are not shown) |
|---|---|---|---|---|
| **7000** | **6,02** | **9,0 ±0,5** | **5,8 ±0,5** | **24±2** |
| **2360** | **4,68** | **7,0±0,4** | **4,3±0,4** | **18±2** |
| **900** | **3,78** | **5,6±0,4** | **3,3±0,3** | **13±1** |
| 200 | 2,30 | 3,4±0,3 | 1,7±0,2 | 7,1±0,7 |
| 130 | 2,03 | 3,0±0,2 | 1,5±0,1 | 6,0±0,6 |
| 62,4 | 1,64 | 2,5±0,6 | 1,1±0,1 | 4,4±0,5 |
| 19,4 | 1,17 | 1,8±0,5 | 0,8±0,1 | 3,1±0,3 |
| 17,3 | 1,14 | 1,7±0,3 | 0,7±0,1 | 3,0±0,3 |

# Conclusions

- **The method for finding the total number of particle emitting sources (strings ) formed in AA collisions at LHC, SPS and RHIC energies and in pp collisions at LHC is proposed.**
- The onset of ***the near-side low p_t ridge in AA collisions is consistent with the hypothesis of the string percolation phase transition*** that happens at some definite ("critical") number of participating nucleons Npart.
- **Results show that is possible to search for the onset of the "near-side low p_t "ridge" phenomenon" in the very central *Pb+Pb* at *17,3 GeV(SPS) or in Au+Au at 19.6 GeV (RHIC), the ridge phenomena should be seen in all centrality classes in PbPb collisions at the LHC.***
- ***The string density obtained in this approach for the case of protons confirms the earlier predictions of possible collectivity effects in pp collisions that should be visible at the LHC***
- The new kind of particle-emitting sources (CLUSTERS OF FUSED STRINGS) appears as a result of color string interaction in a form of percolation or fusion. In line with **String Fusion Model predictions** this phenomenon could be characterized by the **presence of long-range correlations (including azimuthal), larger <p_t>** of emitted particles (and by the larger strangeness yields)

# Back-up slides

# Percolation and Color Glass Condensate

Both are based on parton coherence phenomena.

**Percolation : Clustering of strings**
**CGC : Gluon saturation**

- **Many of the results obtained in the framework of percolation of strings are very similar to the one obtained in the CGC.**
- **In particular , very similar scaling laws are obtained for the product and the ratio of the multiplicities and transverse momentum.**
- **Both provide explanation for multiplicity suppression and $<p_t>$ scaling with dN/dy.**

**Momentum $Q_s$ establishes the scale in CGC with the corresponding one in percolation of strings**

$$Q_s^2 = \frac{k < p_t^2 >_1}{F(\xi)}$$

**For large value of ξ**

$$Q_s^2 \propto \sqrt{\xi}$$

**The no. of color flux tubes in CGC and the effective no. of clusters of strings in percolation have the same dependence on the energy and centrality.**
**This has consequences in the Long range rapidity correlations and the ridge structure.**

CGC : Y. V. Kovchegov, E. Levin, L McLerran, Phys. Rev. C 63, 024903 (2001).

# Data Analysis

## Using the $p_T$ spectrum to extract $F(\xi)$

**The experimental $p_T$ distribution from pp data is used**

$$\frac{d^2N}{dpt^2} = \frac{a}{(p_0 + pt)^n}$$

Parametrization of STAR 200 GeV

**$p_0 = 1.982$ and $n = 12.877$**

**Phys. Rep. 599 (2015) 1-50**

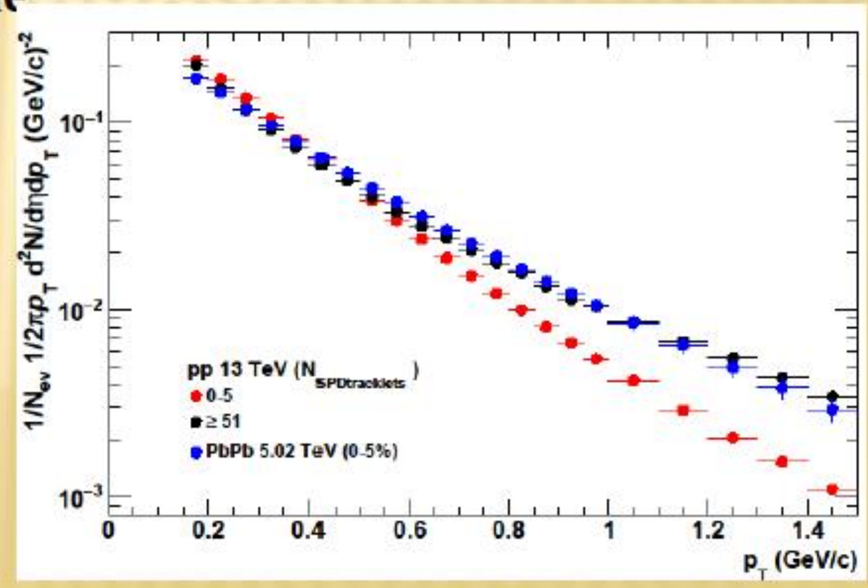
**a, $p_0$ and $n$ are parameters fit to the data.**

**This parameterization can be used for nucleus-nucleus collisions to account for the clustering :**

$$\frac{d^2N}{dpt^2} = \frac{b}{\left(p_0\sqrt{\frac{F(\xi_{pp})}{F(\xi_{AuAu})}} + pt\right)^n}$$

$$F(\xi)_{pp} = 1$$

**ALICE**



# Thermalization

- The origin of the string fluctuation is related to the stochastic picture of the QCD vacuum . Since the average value of color field strength must vanish, it cannot be constant and must vanish from point to point. Such fluctuations lead to the Gaussian distribution of the string.

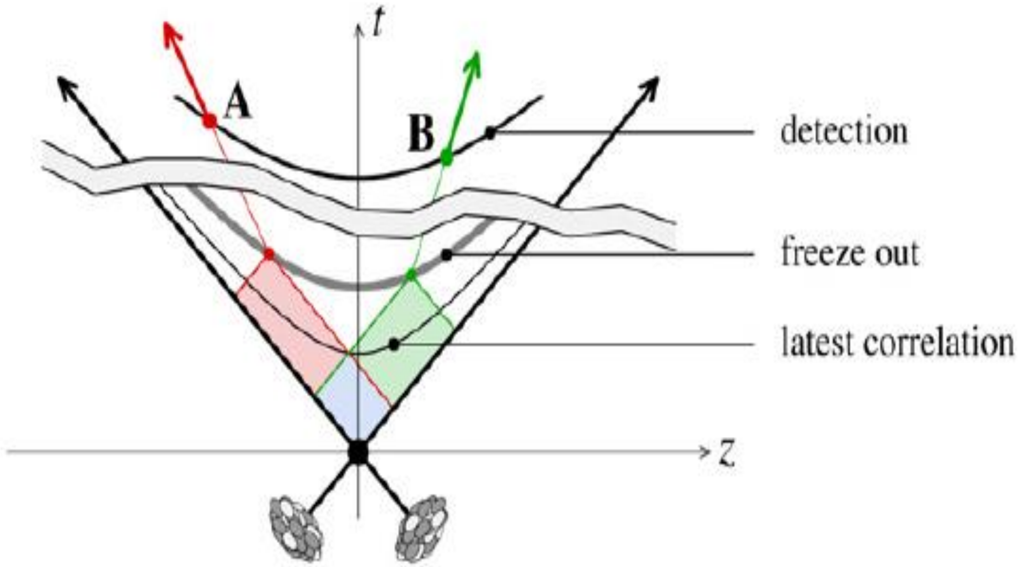
  H. G. Dosch, Phys. Lett. 190 (1987) 177
  A. Bialas, Phys. Lett. B 466 (1999) 301

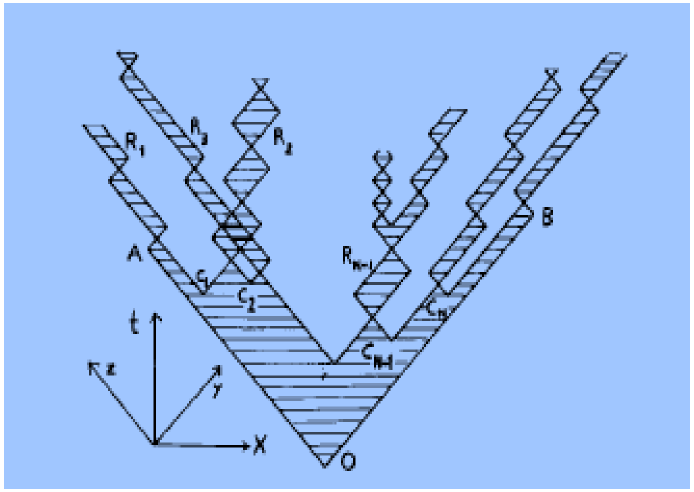
- The fast thermalization in heavy ion collisions can occur through the existence of event horizon caused by rapid deceleration of the colliding nuclei. Hawking-Unruh effect encountered in black holes and for accelerated objects.

  D. Kharzeev, E. Levin , K. Tuchin, Phys. Rev. C75, 044903 (2007)
  H.Satz, Eur. Phys. J. 155, (2008) 167

# LRC: a general question WHY? (both for pp and AA)

Causality requires that correlations – if they exist – of Long Range in rapidity between particles (A and B) detected in any type of collisions in separated rapidity intervals must be made very early:



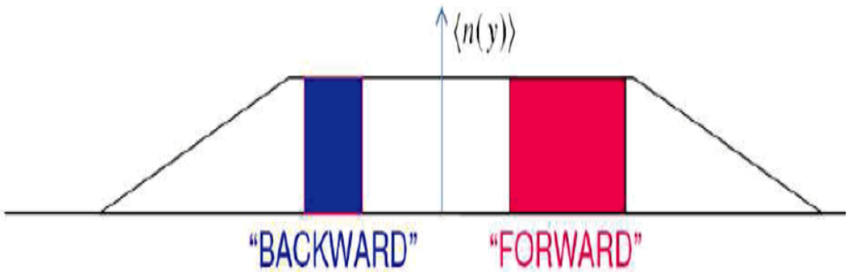



**A.Dumitru et al./ Nuclear Physics A 810 (2008) 91-108**

**X. ARTRU and G. MENNESS1ER,**
“STRING MODEL AND MULTIPRODUCTION”,
Nuclear Physics B70 (1974) 93-115

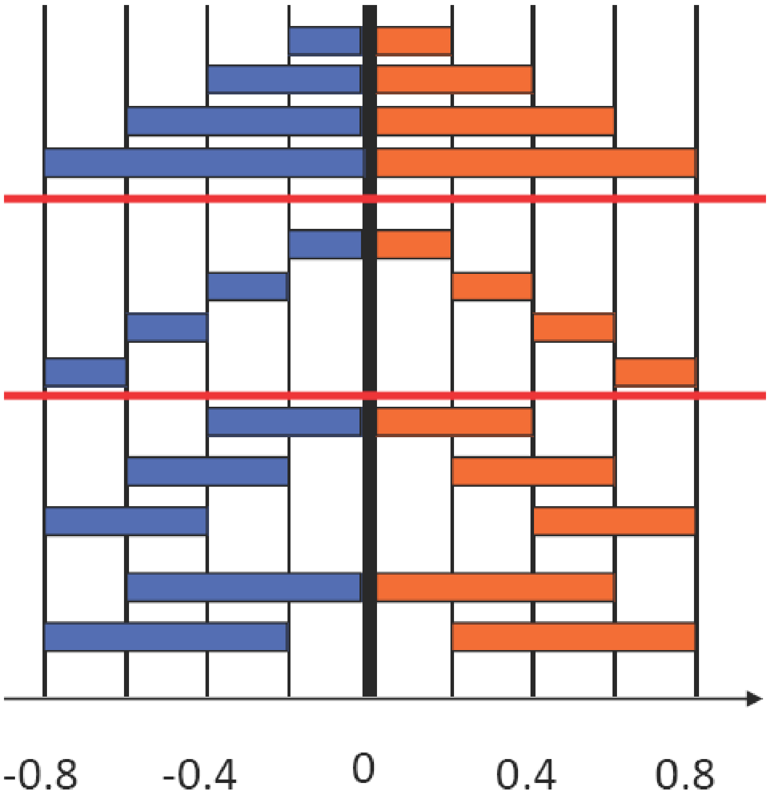
# Forward-Backward (Long Range) Correlations:

*for observables measured in two non-overlapping intervals in pseudorapidity space*




$\delta\eta_B$ $\eta$ gap $\delta\eta_F$

$n_B$ $n_F$




**$n_B$, $n_F$ – the event multiplicity in the BACKWARD and FORWARD pseudorapidity windows**

# The first early experimental indications of LRC (1988)

**Charged particle correlations in $\bar{p}p$ collisions at c.m. energies of 200, 546 and 900 GeV**

UA5 Collaboration

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

$\langle n_B \rangle nF = a + b^* n_F$

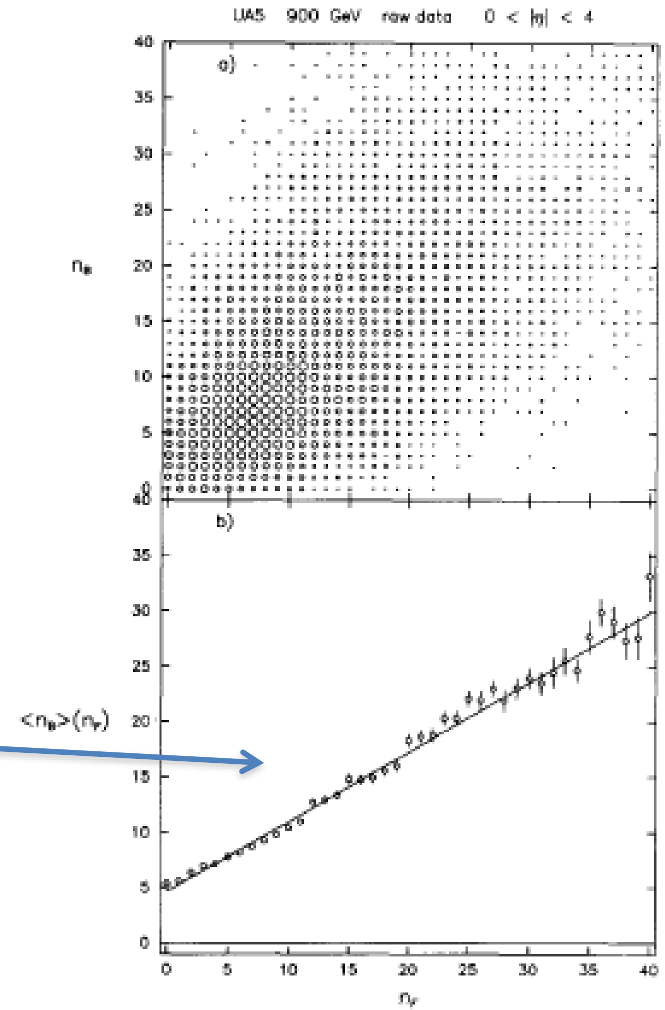



Fig. 12. **a** shows as a scatter plot (the circle area is proportional to the number of events) the backward multiplicity $n_B$ versus the forward multiplicity $n_F$ for raw data in the $\eta$ range $0 < |\eta| < 4$ at 900 GeV. In **b** the average backward multiplicity $\langle n_B \rangle$ as function of the forward multiplicity $n_F$ is plotted for the same data sample. The straight line shows the result of a least squares fit assuming a linear function

# Two methods of calculation

## of multiplicity correlation coefficient *b*

- **Linear regression** [1]:

$$<n_B>_{n_F}=a+b*n_F$$

- **Correlator** [2]:

$$b=\frac{<N_f N_b>-<N_f><N_b>}{<N_f{}^2>-<N_f>^2}=\frac{D_{bf}^2}{D_{ff}^2}$$

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

# Лабораторный семинар, вторник, 17 ноября 2020

- 17:40 - 18:00 Г.Феофилов, Краткая информация по докладу Andrea Dubla "The KF Particle package for particle decay reconstruction”

https://indico.cern.ch/event/957574/

# Usage of KF particle package in HF and Nuclei analyses

"The KF Particle package is optimized for the full physical reconstruction of particle decays and of complex decay chains. Developed within the CBM Collaboration at FAIR, the KF code is used …to study the production of both hadrons with charm and of hypernuclei.

The package is based on the Kalman filter method providing a full set of particle parameters together with their errors including position, momentum, mass, energy, lifetime, etc. It shows a high quality of the reconstructed particles with an improved mass resolution, efficiencies, and signal to background ratios.

It offers tools such as topological or mass constraints, which fully exploit the daughter track information to optimize the mother reconstruction.
We will demonstrate this with some examples from ongoing analyses, and briefly illustrate how we plan to use the KF package for physics feasibility studies for the future stages of ALICE."
Speaker: Andrea Dubla (GSI)

# The KF Particle package for particle decay reconstruction

**Andrea Dubla**, Annalena Kalteyer, Jianhui Zhu,
Carolina Reetz and Silvia Masciocchi

# Outline

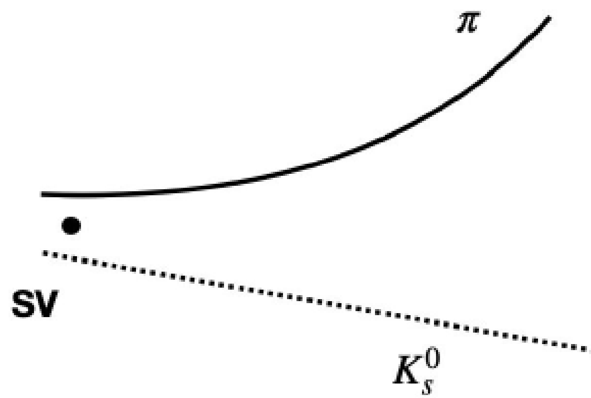
- **Concepts**
  - physical particles
  - reconstruction of decays and decay chains

- **Current results (a selection)**
  - $\Lambda^{+}_{c} \rightarrow pK^{0}$ (other channels also used $\rightarrow \Xi^{0}_{c}$ and $\Omega^{0}_{c}$)
  - ${}_{\Lambda}^{3}H$

- **Ongoing and future activities**
  - unit test
  - basis for physics and feasibility studies with ITS2/3 for $\Lambda_c^{+}$, $\Xi_c^{0,+}$ and $\Omega_c^{0}$
  - charged strange-particle mini tracks in ITS3
  - multi-charm baryon studies

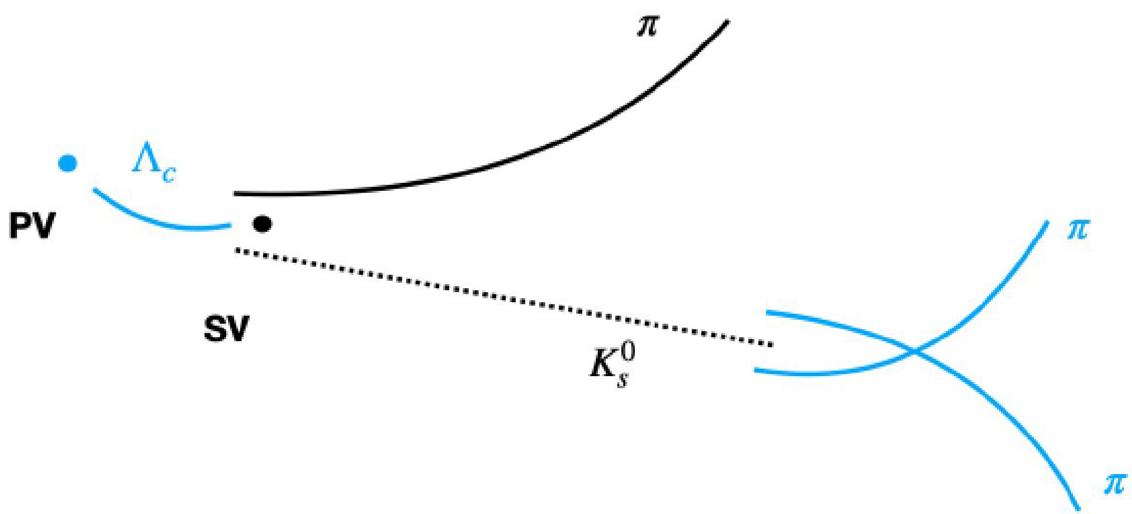
# Concepts

- A particle decay is not only a vertex and an invariant mass



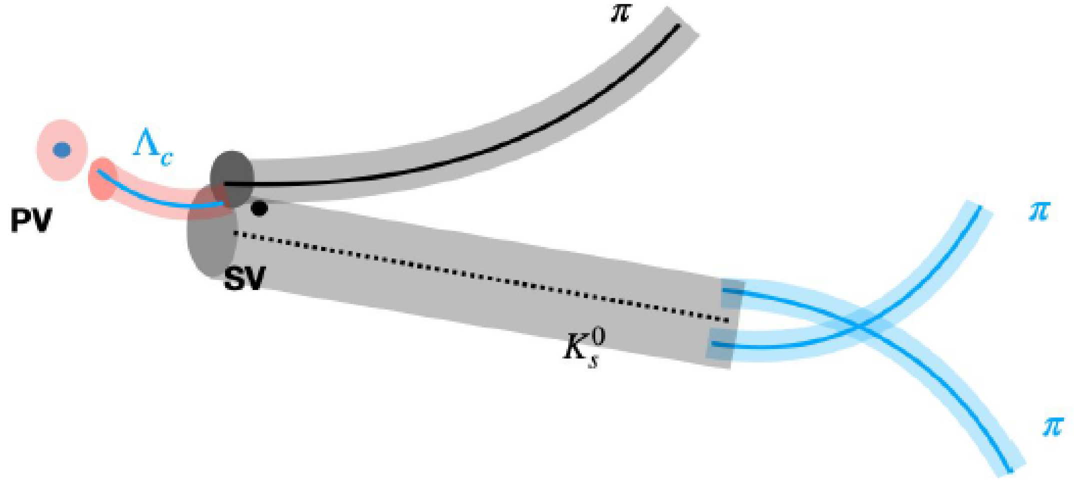
# Concepts

- A particle decay is not only a vertex and an invariant mass
- There is a mother particle, a production vertex where that is produced … and there can be further decays of the daughters



# Concepts

- A particle decay is not only a vertex and an invariant mass
- There is a mother particle, a production vertex where that is produced … and there can be further decays of the daughters
- All of these objects have an identity (with a given probability), a full covariance matrix (which determines their weight in the reconstruction), etc. - - Causality needs to be respected



# Concepts

The KF Particle package is a powerful tool for the
**reconstruction of decaying particles**

Every ***particle*** (daughter or mother) is described by
a state vector **r** and its full covariance matrix **C**

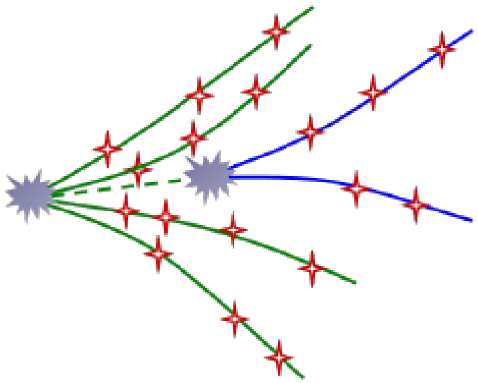
$$\boldsymbol{r}^T = (x, y, z, p_x, p_y, p_z, E, s)$$

$$\boldsymbol{C} = Cov(\boldsymbol{r})$$

Applying the Kalman Filter approach:

- either the propagation along the helix trajectory
- or the fit at a decay vertex
- or the constraint to the production vertex, etc.

**at every step the state vector is updated / improved**



# The framework

- The software and the full framework were developed at GSI for the CBM Collaboration (FAIR): → *Ivan Kisel, Sergey Gorbunov, Maksym Zyzak*
  - used also for the First Level Event Selection (FLES) - *not discussed today*
  - used for reconstruction of decayed particles (also in STAR)

- **Code imported** in alicesw: https://github.com/alisw/KFParticle

**Ivan Kisel *et al.*:**
https://inspirehep.net/literature/1386618
https://www.star.bnl.gov/~bouchet/KFParticle/DOC-2007-May-14-1.pdf
https://inspirehep.net/literature/1229199

KF Particle: S. Gorbunov, PhD thesis
KF Particle Finder: M. Zyzak, PhD thesis

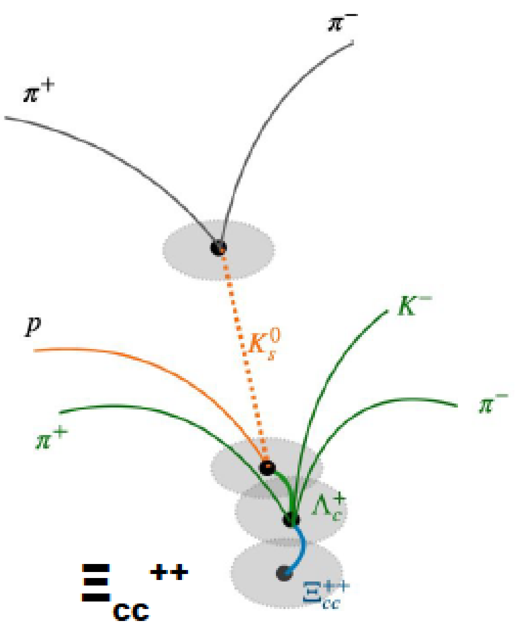
M. Zyzak, et.al. https://git.cbm.gsi.de/m.zyzak/KFParticle
O.Lubynets et al.: https://git.cbm.gsi.de/pwg-c2f/analysis/pf_simple

# Пример:

## Multi-charm baryons

| Decay | B.R. | Decay | B.R. |
| --- | --- | --- | --- |
| $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ + K^- + \pi^+ + \pi^-$ | 5% | $\Xi_{cc}^{++} \rightarrow \Xi_c^+ + \pi^+$ | 5% |
| $\Lambda_c^+ \rightarrow p + K^- + \pi^+$ | 6.35% | $\Xi_c^+ \rightarrow p + K^- + \pi^+$ | 2.2 ± 0.8% [1] |
| | 0.32% | | 0.11% |

$\Xi_{cc}$ decays: BR from 1703.09086 (authors claim ~1% < BR < ~10%)




Thanks to the **extremely long decay chains** → KFParticle will be extremely powerful!!

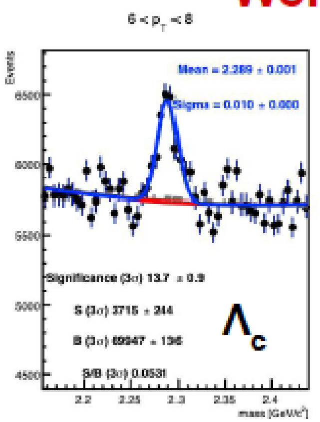
- First test will be done using geometry of ITS2 and parametrization (as in the unit test) for the ITS3 and ALICE 3

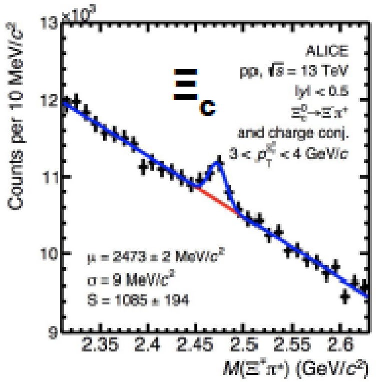


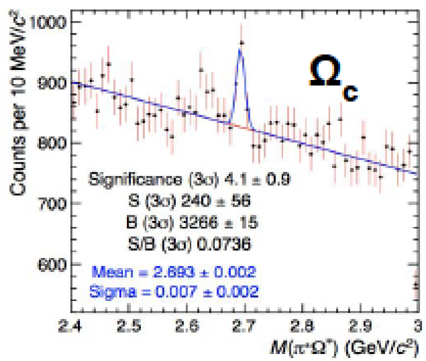
Andrea Dubla

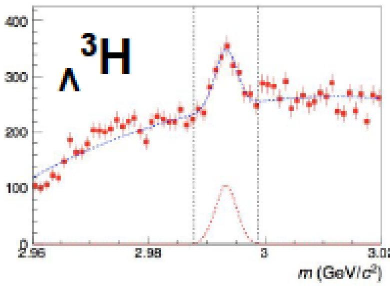
# Summary & Outlook

## Works ongoing and publications

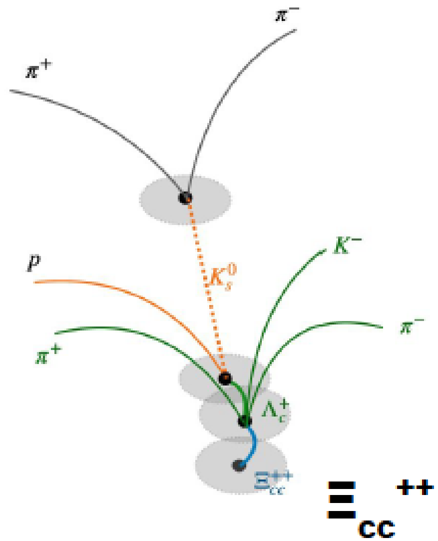



## Analysis in Run 3




## Trigger in pp:

- trigger for events containing **beauty hadrons**
- **charm hadrons** (especially for $\Lambda_c$ and $D^0$) in very high and low multiplicity events.
- Hc-proton/kaon and Hc-Hc(bar) **femtoscopy/correlations**

# Thank you!