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on High Energy Physics Problems
Relativistic Nuclear Physics & Quantum Chromodynamics
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Scaling properties of negative particle production in Au+Au collisions from BES-I at RHIC

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Contents

- Introduction
- z-Scaling (ideas, definitions,…)
- Properties of data z-presentation
- Self-similarity of negative particle production in AuAu collisions at RHIC
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- Summary

Motivation & Goals

Search for signatures of a phase transition in nuclear matter produced in heavy ion collisions at high energies

Systematic analysis of hadron spectra
in pp, pA and AA collisions to search for general features
of structure, interaction and fragmentation over a wide scale range

z-Scaling as a tool in high energy physics

Development of z-scaling approach
for description of hadron production in AA collisions
and verification of self-similarity principle

- New analysis of STAR data on negative particle spectra in AuAu collisions from BES-I
- Verification of scaling properties of spectra in z-presentation
- Development of microscopic scenario of hadron production in AA

Fundamental principles and symmetries

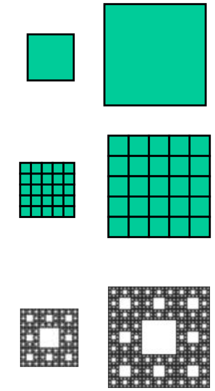
"Fundamental symmetry principles dictate the basic laws of physics, control the structure of matter, and define the fundamental forces in Nature."

Leon M. Lederman

Self-similarity is a property of physical phenomena and the principle to construct theories.

"Scaling" and "Universality" are concepts developed to understanding critical phenomena. Scaling means that systems near the critical points exhibiting self-similar properties are invariant under transformation of a scale. According to universality, quite different systems behave in a remarkably similar fashion near the respective critical points. Critical exponents are defined only by symmetry of interactions and dimension of the space. H.Stanley, G.Barenblatt,…

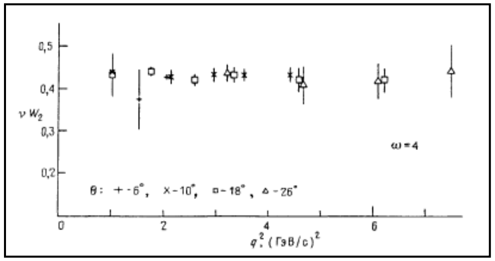
Self-similarity



- A self-similar object is exactly or approximately similar to a part of itself (i.e. the whole has the same shape as one or more of the parts).
- Self-similarity is a typical property of fractals.
- Scale invariance is an exact form of self-similarity where at any magnification there is a smaller piece of the object that is similar to the whole.

Description of a process in terms of
a scaling function and similarity parameter

Reynolds number	Mach number	Bjorken variable
$Re = \rho VD/\eta$	$Ma = v/c$	$x = -q^2/2(pq)$
laminar & turbulent flow	subsonic & supersonic wave	low x & high x

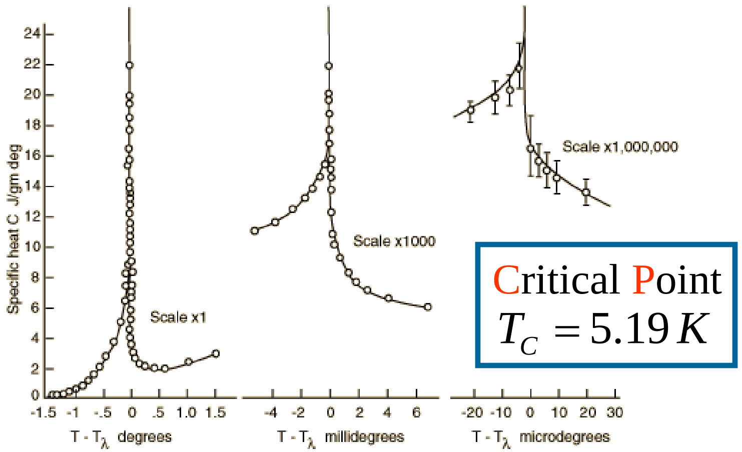


shock wave, explosion, confinement

Violation of a scaling is an indication of new phenomena

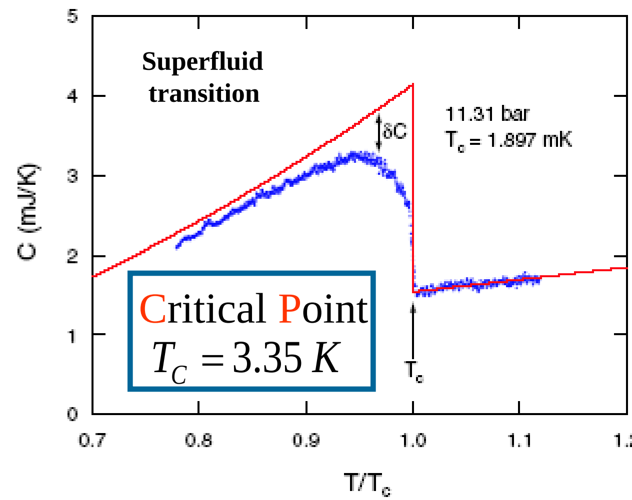
Discontinuity of specific heat near a Critical Point

Specific heat of liquid ^{4}He



H.E. Stanley, 1971

Heat capacity of liquid ^{3}He



H. Choi et al., PRL 96, 125301 (2006)

- Near a critical point the singular part of thermo-dynamic potentials is a Generalized Homogeneous Function (GHF).
- The Gibbs potential $G(\lambda^{a_\varepsilon}\varepsilon, \lambda^{a_p} p) = \lambda G(\varepsilon, p)$ is GHF of (ε, p).

$$c_V \sim |\varepsilon|^{-\alpha} \qquad \varepsilon \equiv (T\text{-}T_c)/T_c \qquad c_V = -T(d^2G/dT^2)$$

Critical exponents define the behavior
of thermo-dynamical quantities nearby the Critical Point.

Self-similarity: z-scaling

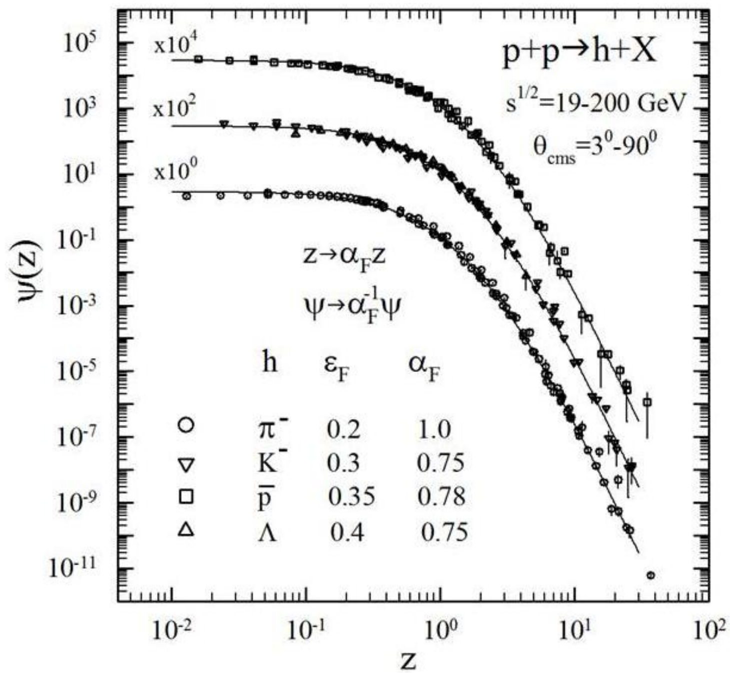
Inclusive cross sections of π^-, K^-, $\bar{p}$, Λ in pp collisions

FNAL:
PRD 75 (1979) 764

ISR:
NPB 100 (1975) 237
PLB 64 (1976) 111
NPB 116 (1976) 77
(low p_T)
NPB 56 (1973) 333
(small angles)

STAR:
PLB 616 (2005) 8
PLB 637 (2006) 161
PRC 75 (2007) 064901

Saturation at low z



Power law at high z

Energy scan of spectra
at U70, ISR, S$\bar{p}$pS, SPS, HERA, FNAL(fixed target), Tevatron, RHIC, LHC

MT & I.Zborovsky
T.Dedovich
Phys.Rev.D75,094008(2007)
Int.J.Mod.Phys.A24,1417(2009)
J. Phys.G: Nucl.Part.Phys. 37,085008(2010)
Int.J.Mod.Phys.A27,1250115(2012)
J.Mod.Phys.3,815(2012)

- Energy & angular independence
- Flavor independence (π, K, $\bar{p}$, Λ)
- Saturation for $z < 0.1$
- Power law $\Psi(z) \sim z^{-\beta}$ for high $z > 4$

Scaling – "collapse" of data points onto a single curve.
Universality classes – hadron species (ε_F, α_F).

Self-similarity of strangeness production in pp at RHIC

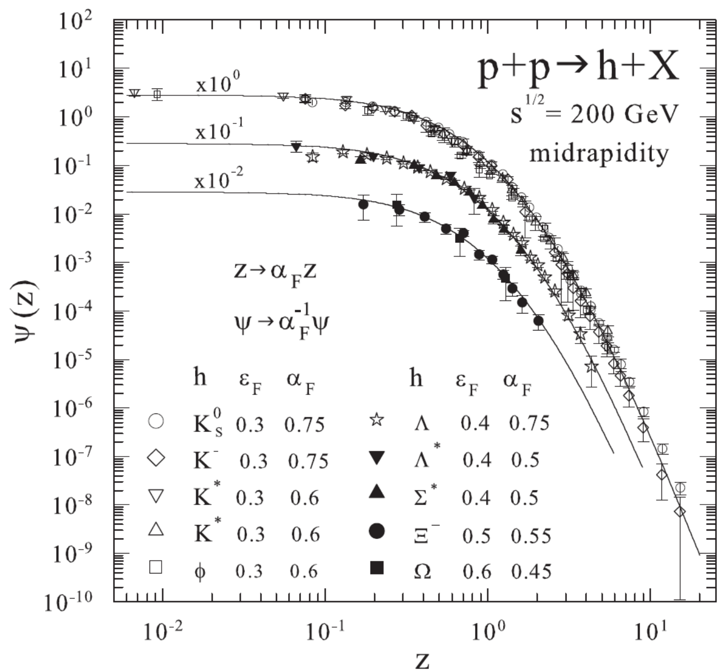
Universality: flavor independence of the scaling function

K_S^0, K^-, K^*, ϕ, Λ, Ξ, Ω, Σ^*, Λ^*

M.T.& I.Zborovský
Int.J.Mod.Phys. A32,1750029(2017)

Solid line for π^- meson is a reference frame

$\varepsilon_\pi = 0.2, \quad \alpha_\pi = 1$



STAR
PRL 92 (2004) 092301
PRL 97 (2006) 132301
PLB 612 (2005) 181
PRC 71 (2005) 064902
PRC 75 (2007) 064901
PRL 108 (2012) 072302

PHENIX
PRC 75 (2007) 051902
PRD 83 (2011) 052004
PRC 90 (2014) 054905

- Energy independence
- Angular independence
- Flavor independence
- Saturation for z < 0.01

- Power law $\Psi(z) \sim z^{-\beta}$ at large z
- ε_F, α_F independent of p_T, $s^{1/2}$

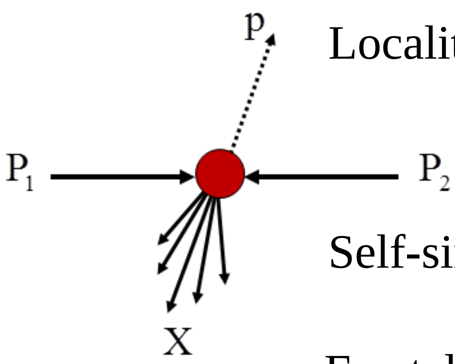
Properties of $\Psi(z)$ in pp collisions

- Energy independence of $\Psi(z)$ ($s^{1/2} > 20$ GeV)
- Angular independence of $\Psi(z)$ ($\theta_{cms}=3^0$-90^0)
- Multiplicity independence of $\Psi(z)$ ($dN_{ch}/d\eta=1.5$-26)
- Saturation of $\Psi(z)$ at low z ($z < 0.1$)
- Power law, $\Psi(z) \sim z^{-\beta}$, at high z ($z > 4$)
- Flavor independence of $\Psi(z)$ ($\pi, K, \varphi, \Lambda, .., D, J/\psi, B, \Upsilon, \ldots$, top)

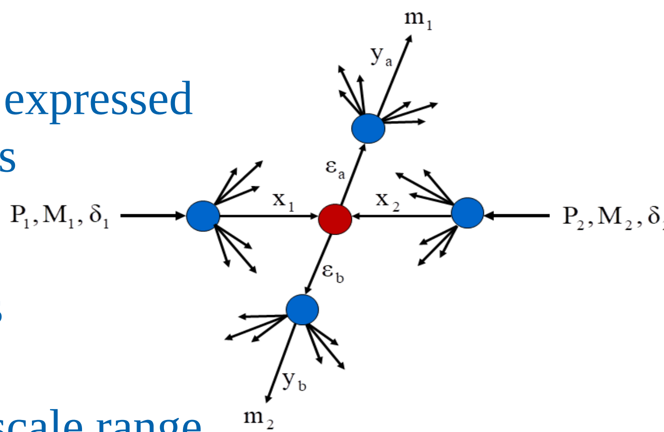
These properties reflect self-similarity, locality, and fractality
of hadron interactions at a constituent level.
It concerns the structure of the colliding objects,
constituent interactions and fragmentation process.

z-Scaling

Principles: locality, self-similarity, fractality



Locality: collisions of hadrons and nuclei are expressed via interactions of their constituents (partons, quarks and gluons,...).



Self-similarity: interactions of the constituents are mutually similar.

Fractality: self-similarity is valid over a wide scale range.

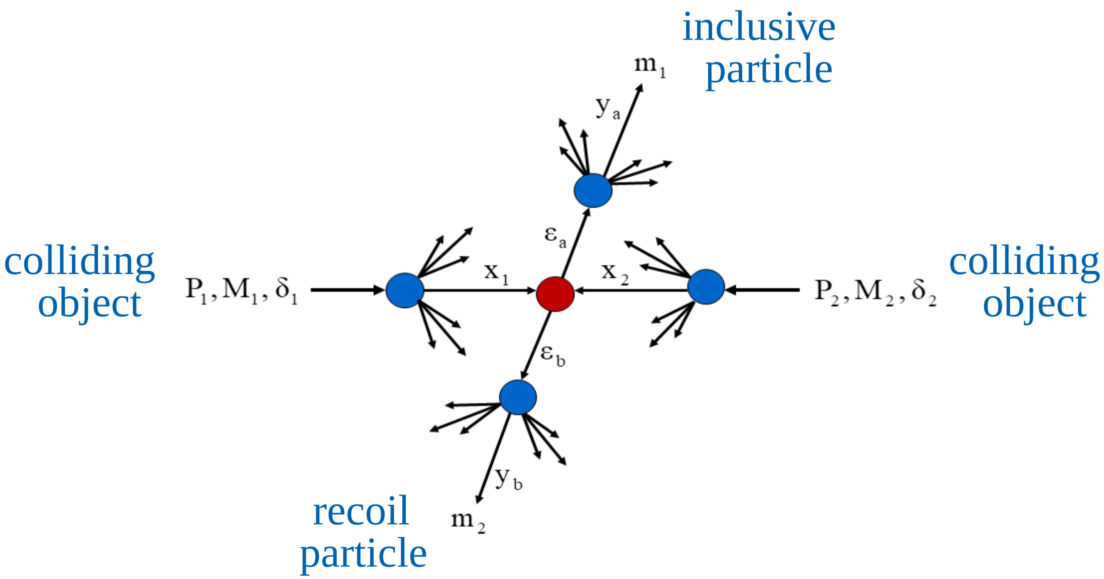
Hypothesis of z-scaling :

$s^{1/2}$, p_T, θ_{cms} — Inclusive particle distributions can be described in terms of constituent sub-processes and parameters characterizing bulk properties of the system. — x_1, x_2, y_a, y_b $\delta_1, \delta_2, \varepsilon_a, \varepsilon_b, c$

$Ed^3\sigma/dp^3$ — Scaled inclusive cross section of particles depends in a self-similar way on a single scaling variable z. — $\Psi(z)$

Locality

Collisions of colliding objects are expressed via interactions of their constituents



P_1, P_2, p – momenta of colliding and produced particles

M_1, M_2, m_1 – masses of colliding and produced particles

x_1, x_2 – momentum fractions of colliding particles carried by constituents

y_a, y_b – momentum fractions of scattered constituents carried by inclusive particle and its recoil

δ_1, δ_2 – fractal dimensions of colliding particles

$\varepsilon_a, \varepsilon_b$ – fractal dimensions of scattered constituents (fragmentation dimensions)

m_2 – mass of recoil particle

Elementary sub-process:

$$(x_1M_1) + (x_2M_2) \rightarrow (m_1/y_a) + (x_1M_1+x_2M_2+m_2/y_b)$$

Momentum conservation law for sub-process

$$(x_1P_1+x_2P_2-p/y_a)^2 = M_X^2$$

Mass of recoil system

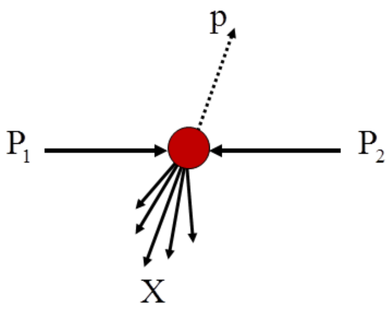
$$M_X = x_1M_1+x_2M_2+m_2/y_b$$

M.Tokarev, I.Zborovský
Yu.Panebratsev, G.Skoro
Phys.Rev.D54 5548 (1996)
Int.J.Mod.Phys.A16 1281 (2001)

Self-similarity

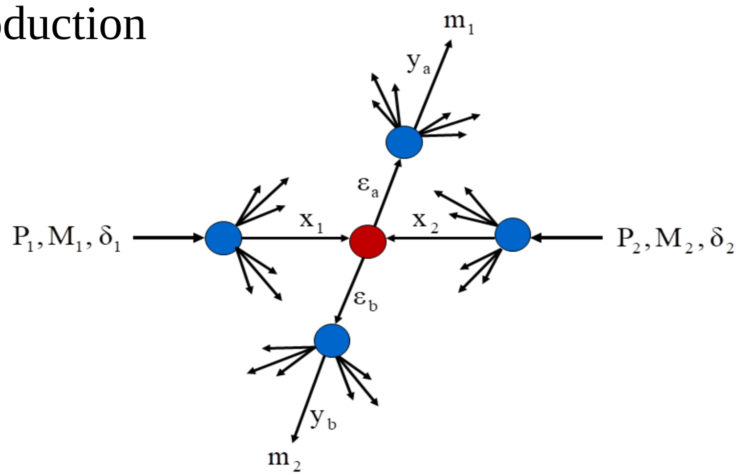
Interactions of constituents are mutually similar

The self-similarity parameter z is a dimensionless quantity, expressed through the dimensional values P_1, P_2, p, M_1, M_2, m_1, m_2, characterizing the process of inclusive particle production



$$z = z_0 \cdot \Omega^{-1}$$

$$z_0 = \frac{s_\perp^{1/2}}{(dN_{ch}/d\eta|_0)^c m_N}$$



- Ω^{-1} is the minimal resolution at which a constituent sub-process can be singled out of the inclusive reaction
- $s_\perp^{1/2}$ is the transverse kinetic energy of the sub-process consumed on production of m_1 & m_2
- $dN_{ch}/d\eta|_0$ is the multiplicity density of charged particles at $\eta = 0$
- c is a parameter interpreted as a "specific heat" of created medium
- m_N is an arbitrary constant (fixed at the value of nucleon mass)

Fractality

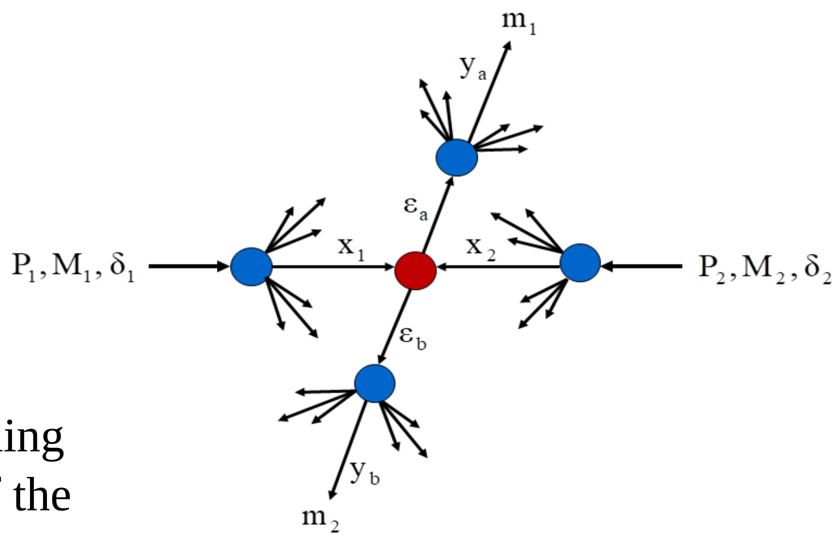
Self-similarity over a wide scale range

Fractal measure

$$z = z_0 \cdot \Omega^{-1}$$

$$\Omega = (1-x_1)^{\delta_1}(1-x_2)^{\delta_2}(1-y_a)^{\varepsilon_a}(1-y_b)^{\varepsilon_b}$$

$$0 < x_1, x_2 < 1 \qquad 0 < y_a, y_b < 1$$



Ω is relative number of configurations containing a sub-process with fractions x_1, x_2, y_a, y_b of the corresponding 4-momenta

δ_1, δ_2, ε_a, ε_b are parameters characterizing structure of the colliding objects and fragmentation process, respectively

$\Omega^{-1}(x_1, x_2, y_a, y_b)$ characterizes resolution at which a constituent sub-process can be singled out of the inclusive reaction

The fractal measure z diverges as the resolution Ω^{-1} increases.

$$z(\Omega)|_{\Omega^{-1}\to\infty} \to \infty$$

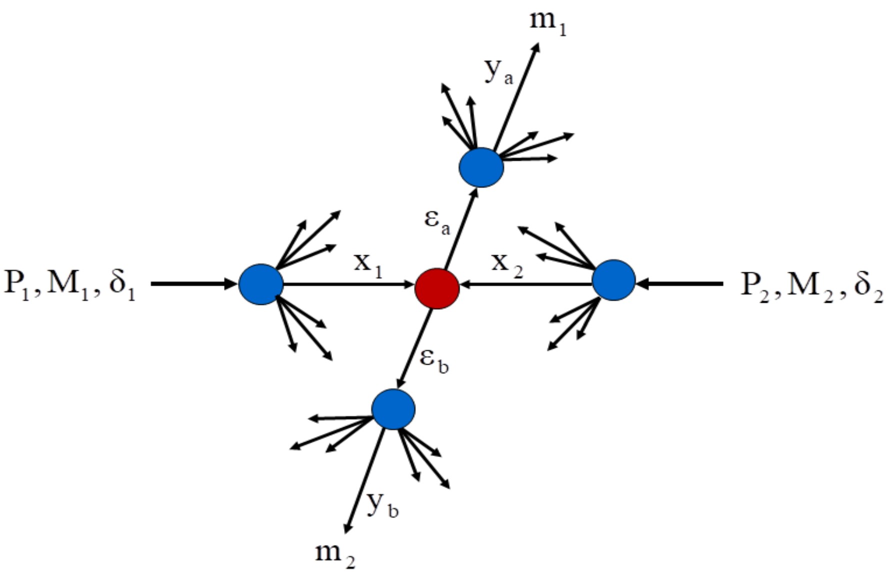
Momentum fractions x_1, x_2, y_a, y_b

Principle of minimal resolution: The momentum fractions x_1, x_2 and y_a, y_b are determined in a way to minimize the resolution Ω^{-1} of the fractal measure z with respect to all constituent sub-processes taking into account 4-momentum conservation law:

Momentum conservation law

$$(x_1 P_1 + x_2 P_2 - p/y_a)^2 = M_X^2$$

$$\begin{cases} \partial\Omega/\partial x_1 \big|_{y_a=y_a(x_1,x_2,y_b)} = 0 \\ \partial\Omega/\partial x_2 \big|_{y_a=y_a(x_1,x_2,y_b)} = 0 \\ \partial\Omega/\partial y_b \big|_{y_a=y_a(x_1,x_2,y_b)} = 0 \end{cases}$$



Resolution of sub-process

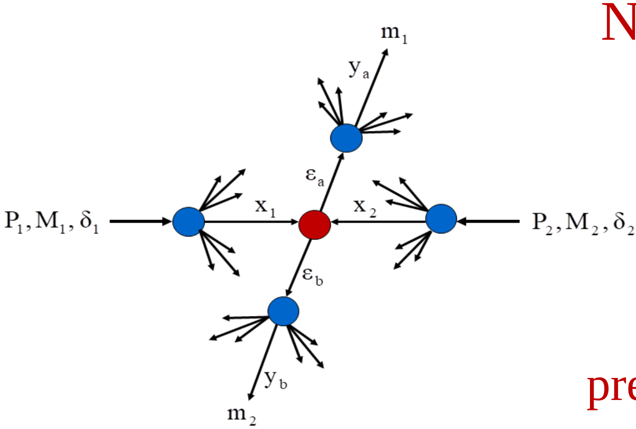
$$\Omega^{-1} = (1-x_1)^{-\delta_1}(1-x_2)^{-\delta_2}(1-y_a)^{-\varepsilon_a}(1-y_b)^{-\varepsilon_b}$$

Fractions x_1, x_2, y_a, y_b are expressed via Lorentz invariants – scalar products of 4-D momenta and particle masses.

Mass of recoil system

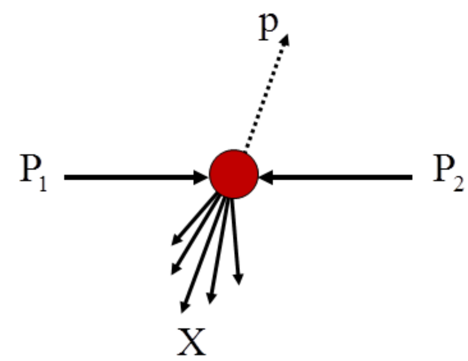
$$M_X = x_1 M_1 + x_2 M_2 + m_2/y_b$$

Scaling function $\Psi(z)$



Normalization condition

$$\int_0^\infty \Psi(z)dz = 1$$



Scale transformation

$$z \to \alpha_F z \qquad \Psi(z) \to \alpha_F^{-1}\Psi(z)$$

preserves the normalization condition

$$\Psi(z) = \frac{\pi}{(dN/d\eta)\cdot\sigma_{inel}} \cdot J^{-1} \cdot E\frac{d^3\sigma}{dp^3} \quad \Longleftrightarrow \quad \int E\frac{d^3\sigma}{dp^3} dy d^2p_\perp = \sigma_{inel} \cdot < N >$$

- σ_{in} - the inelastic cross section
- $<N>$ - the average multiplicity
- $dN/d\eta$ - the multiplicity density
- $J(z,\eta;p_T^2,y)$ - the Jacobian
- $Ed^3\sigma/dp^3$ - the inclusive cross section

The scaling function $\Psi(z)$ is probability density to produce the inclusive particle with the corresponding z.

Self-similarity of h^- hadron production in pp collisions

pp is of interest by itself:
- verification and search for new features
- search for a phase transition with different probes

pp interactions is a reference frame for pA and AA physics

V.V. Abramov et al., Sov. J. Nucl. Phys. 31 (1980) 484
V.V. Abramov et al., JETP Lett. 33 (1981) 289
D. Antreasyan et al., Phys. Rev. D 19 (1979) 764
D. E. Jaffe et al., Phys. Rev. D 40 (1989) 2777
A. Breakstone et al., Z. Phys. C 69 (1995) 55
D. Drijard et al., Nucl. Phys. B 208 (1982) 1
G. Agakishiev et al., Phys. Rev. Lett. 108 (2012) 072302

Self-similarity of h^- production in pp

Self-similarity parameter

$$z = z_0 \Omega^{-1}$$

$$z_0 = \frac{s_\perp^{1/2}}{(dN_{ch}/d\eta|_0)^c m_N}$$

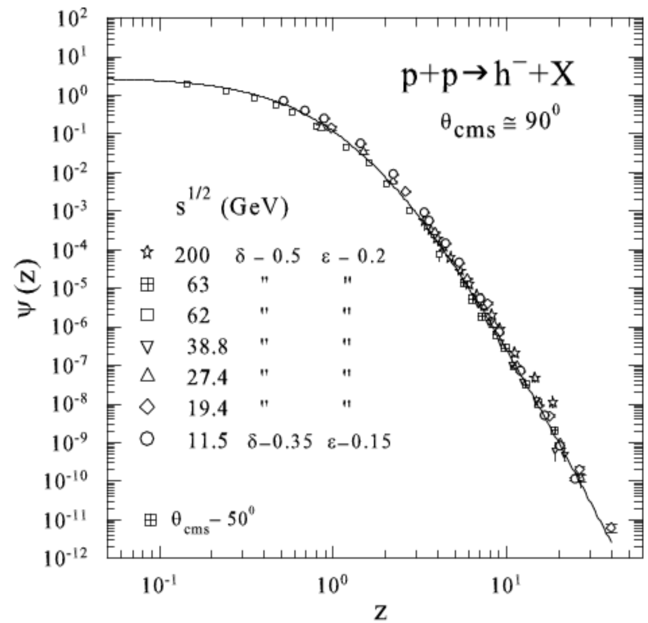
$$\Omega = (1-x_1)^\delta (1-x_2)^\delta (1-y_a)^{\varepsilon_F} (1-y_b)^{\varepsilon_F}$$

- $dN_{ch}/d\eta|_0$ - multiplicity density
- c - “specific heat” of bulk matter
- δ - proton fractal dimension
- ε_F - fragmentation fractal dimension

Scaling function

$$\Psi(z) = \frac{\pi}{(dN/d\eta)\cdot\sigma_{inel}} \cdot J^{-1} \cdot E\frac{d^3\sigma}{dp^3}$$

“Collapse” of data onto a single curve



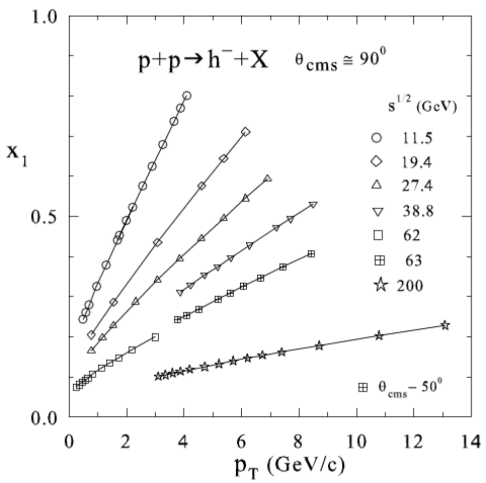
- Energy independence of $\Psi(z)$
- Centrality independence of $\Psi(z)$
- Power law at high z
- Saturation at low z

Universality: the same shape of Ψ vs. $\sqrt{s}$, p_T

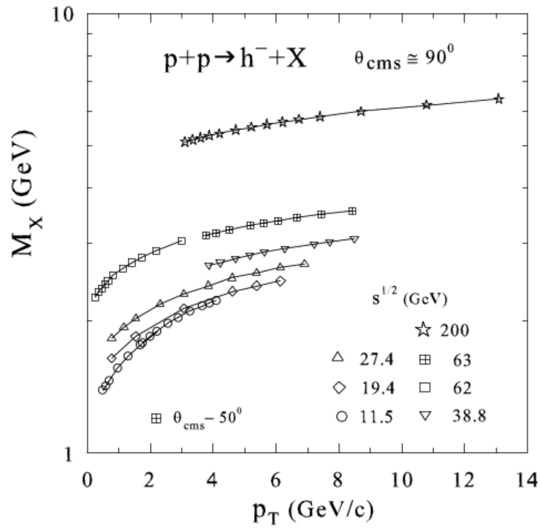
Sub-process of h^- production in pp

Constituent level of particle production in terms of

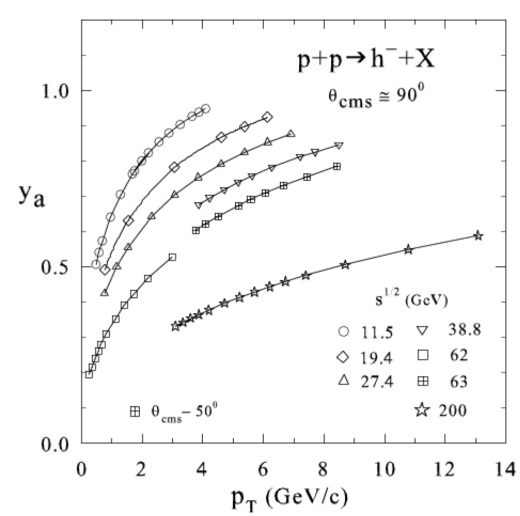
Momentum fraction x_1



Recoil mass M_X



Energy loss $\Delta E/E \sim (1-y_a)$



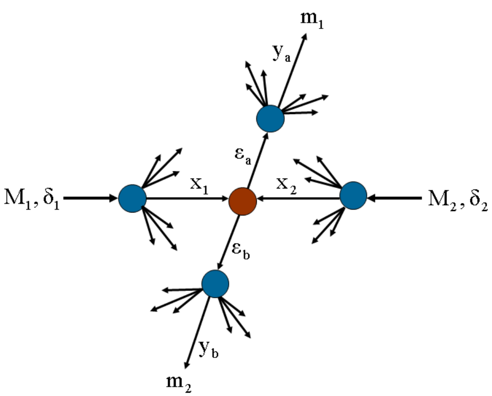
Momentum fraction
- increases with p_T
- decreases with $\sqrt{s}$

Recoil mass
- increases with p_T
- increases with $\sqrt{s}$

Constituent energy loss
- decreases with p_T
- increases with $\sqrt{s}$

- pp is a reference frame for pA and AA
- physics at high x_1 and p_T $\rightarrow$ nearby a kinematic boundary
- asymptotic behavior of $\Psi(z)$ at high z $\rightarrow$ power law

Constituent energy loss in pp



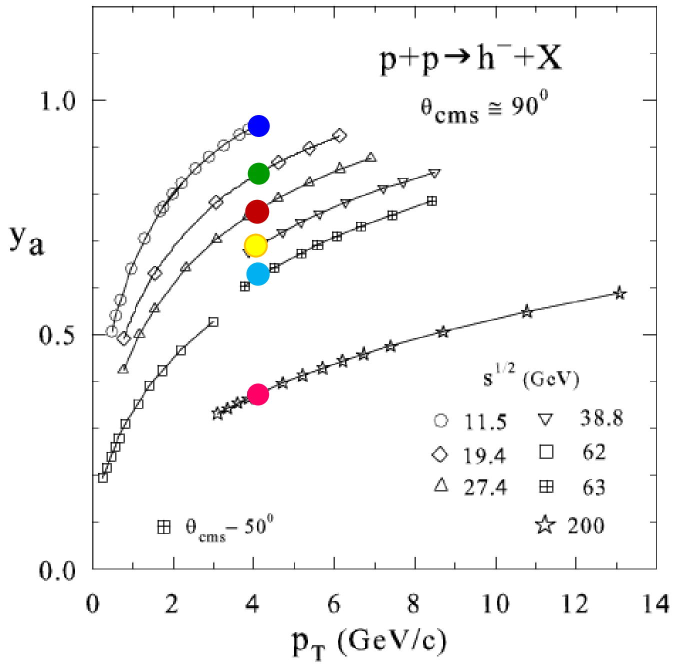
$(x_1P_1+x_2P_2-q)^2 = M_X^2$

$q=p/y_a$

p – momentum of produced hadron

q – momentum of scattered constituent

Energy loss $\Delta E/E \sim (1-y_a)$



p_T= 4 GeV/c

5 % energy loss $q \approx 4.2$ GeV/c
17 % energy loss $q \approx 4.8$ GeV/c
25 % energy loss $q \approx 5.3$ GeV/c
32 % energy loss $q \approx 5.9$ GeV/c
38 % energy loss $q \approx 6.5$ GeV/c
68 % energy loss $q \approx 12.5$ GeV/c

Energy loss

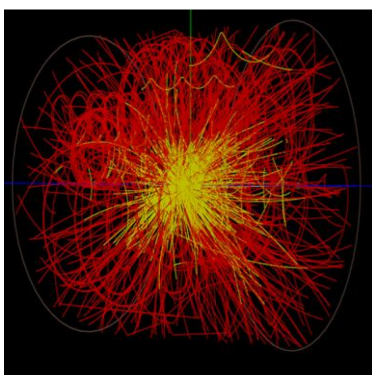
- decreases with p_T
- increases with $\sqrt{s}$

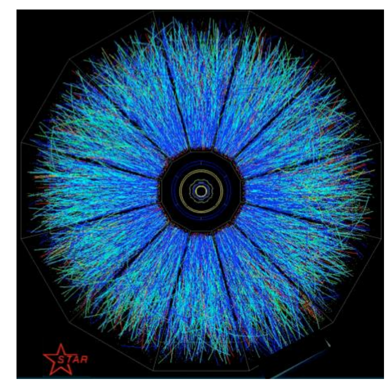
Search for scaling features in AuAu at RHIC

Probing a microscopic structure of a hot and high density nuclear matter at multiple length scales

Self-similarity of hadron production

RHIC beam energy scan with Au+Au:
$\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 62, 130, 200 GeV





Int. J. Mod.Phys. (2015) 1560103

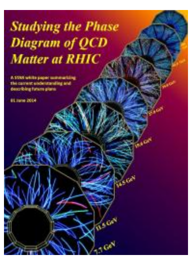
Fundamental principles and symmetries

Phase transition and critical phenomena in usual matter (gas, liquid, solid)

“Scaling” and “Universality” are concepts developed to understanding critical phenomena. Scaling means that systems near the critical points exhibiting self-similar properties are invariant under transformation of a scale. According to universality, quite different systems behave in a remarkably similar fashion near the respective critical points. Critical exponents are defined only by symmetry of interactions and dimension of the space.

H.Stanley, G.Barenblatt,…

Phase transition and critical phenomena in nuclear matter

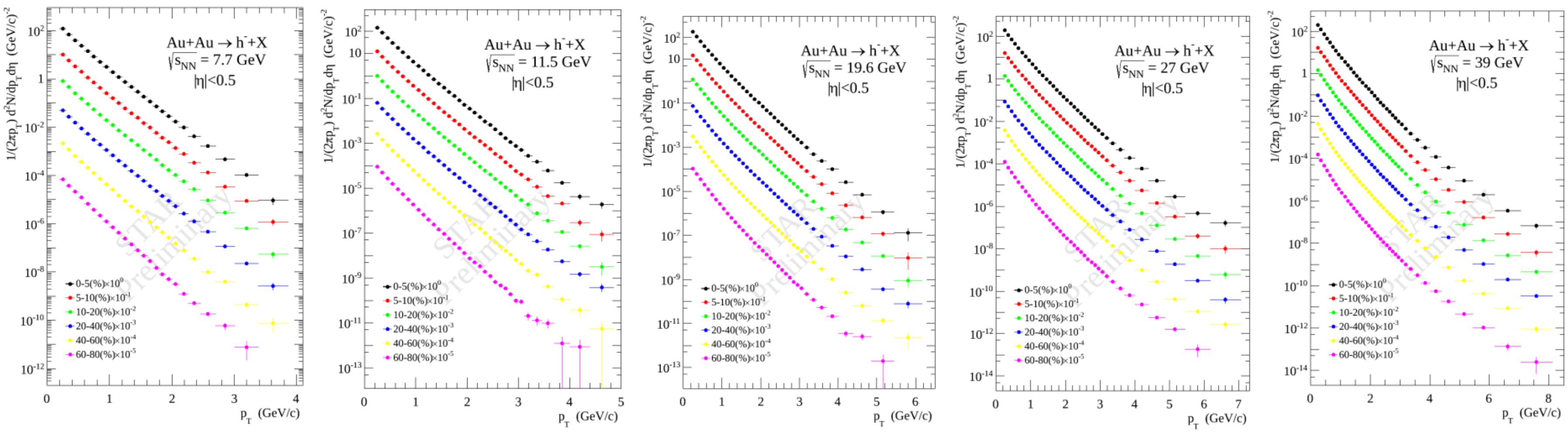


The idea is to vary the collision energy and look for the signatures of QCD phase boundary and QCD critical point i.e. to span the phase diagram from the top RHIC energy (lower μ_B) to the lowest possible energy (higher μ_B). To look for the phase boundary, we would study the established signatures of QGP at 200 GeV as a function of beam energy. Turn-off of these signatures at particular energy would suggest the crossing of phase boundary. Similarly, near critical point, there would be enhanced fluctuations in multiplicity distributions of conserved quantities (net-charge, net-baryon).

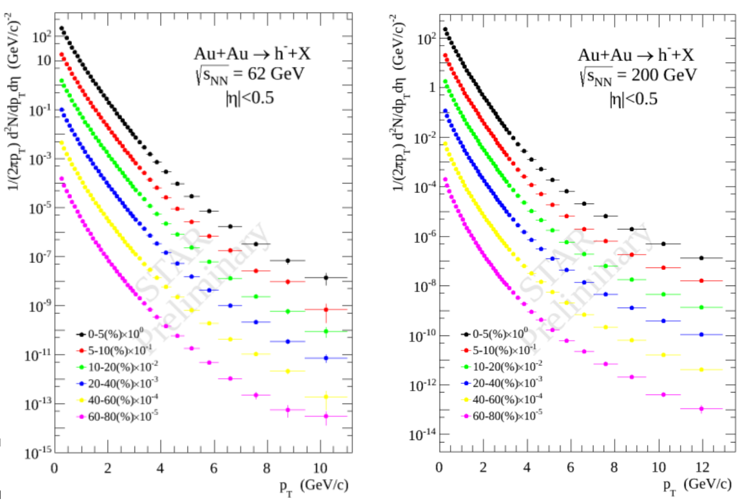
STAR collaboration

Transverse momentum spectra in Au+Au

BES-I energies



Top RHIC energies



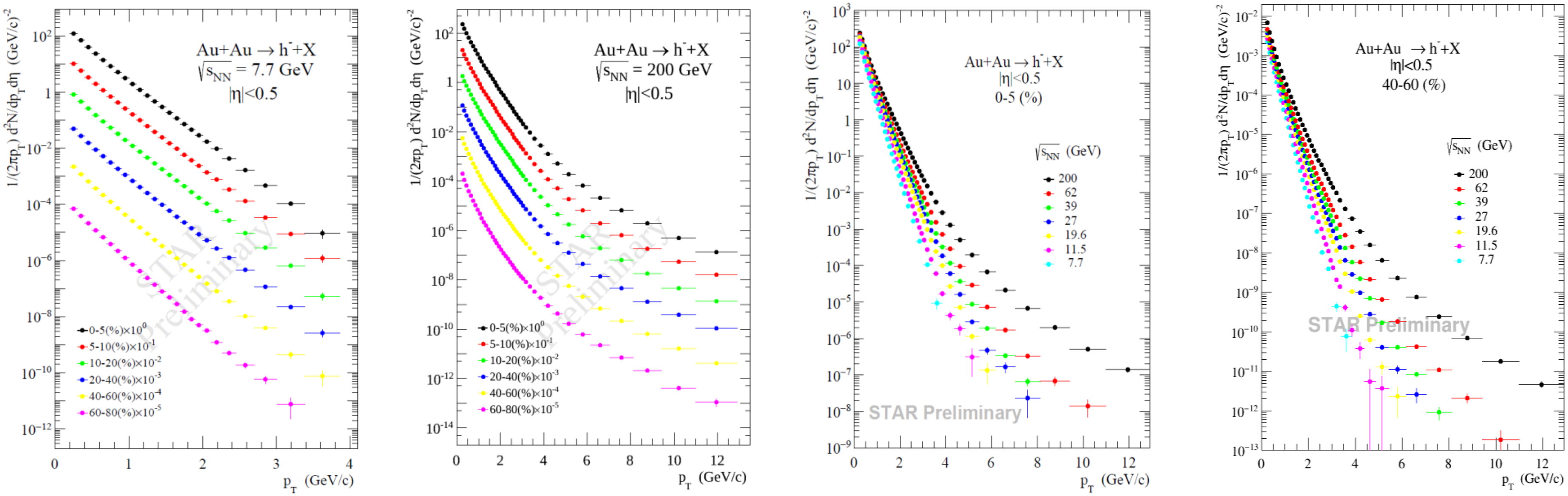
Wide kinematic and dynamical range of particle production:

- Beam energy $\sqrt{s_{NN}}$ = 7-200 GeV
- Centrality 80% - 5% ($dN_{ch}/d\eta|_0 \approx$10-600)
- Transverse momentum p_T = 0.2-12 GeV/c

Unprecedented conditions
to search for new phenomena in nuclear matter
produced in heavy ion collisions.

Au+Au Spectra vs. dimensional measurable

Ed^3N/dp^3 & $P_{1,2}$, $M_{1,2}$, p, m, $dN/d\eta$



- Centrality dependence of spectra
- Exponential behavior of spectra at low p_T for all energies $\sqrt{s_{NN}}$
- Power behavior of spectra at high p_T and energy $\sqrt{s_{NN}}$

- Energy dependence of spectra
- Difference of yields at various energies strongly increases with p_T for all centralities

The particle yield changes by 7-9 orders of magnitude

Self-similarity in Au+Au collisions

Self-similarity parameter

$$z = z_0 \Omega^{-1}$$

$$z_0 = \frac{s_\perp^{1/2}}{(dN_{ch}/d\eta|_0)^c m_N}$$

$$\Omega = (1-x_1)^{\delta_{A_1}}(1-x_2)^{\delta_{A_2}}(1-y_a)^{\varepsilon}(1-y_b)^{\varepsilon}$$

- $dN_{ch}/d\eta|_0$ - multiplicity density
- c_{AA} - "specific heat" of bulk matter
- δ_A - nucleus fractal dimension
- ε_{AA} - fragmentation dimension

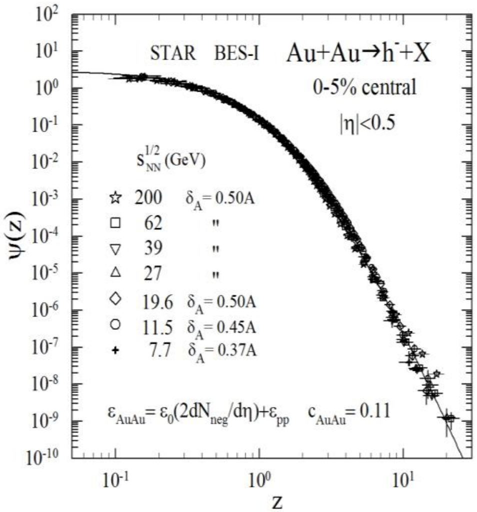
AA collisions:

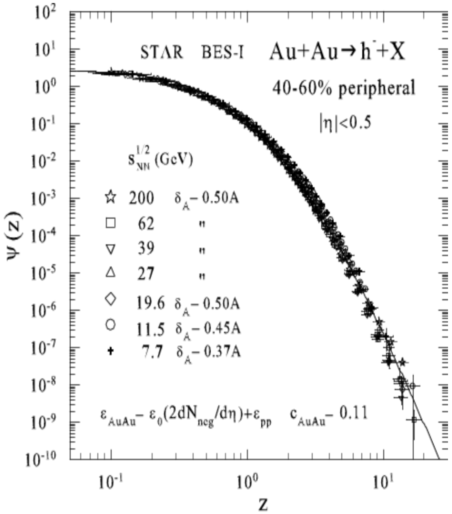
$$\delta_A = A\delta$$

$$\varepsilon_{AA} = \varepsilon_0 (dN_{AA}/d\eta) + \varepsilon_{pp}$$

$$\Psi(z) = \frac{\pi}{(dN/d\eta)\,\sigma_{inel}} J^{-1} E \frac{d^3\sigma}{dp^3}$$

"Collapse" of data points onto a single curve





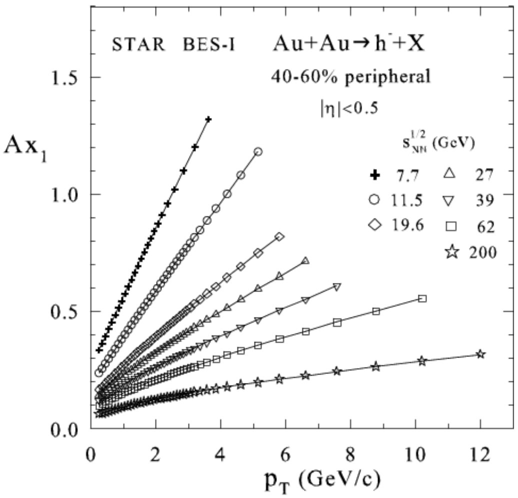
- Energy independence of $\Psi(z)$
- Centrality independence of $\Psi(z)$
- Dependence of ε_{AA} on multiplicity
- Power law at low- and high-z regions

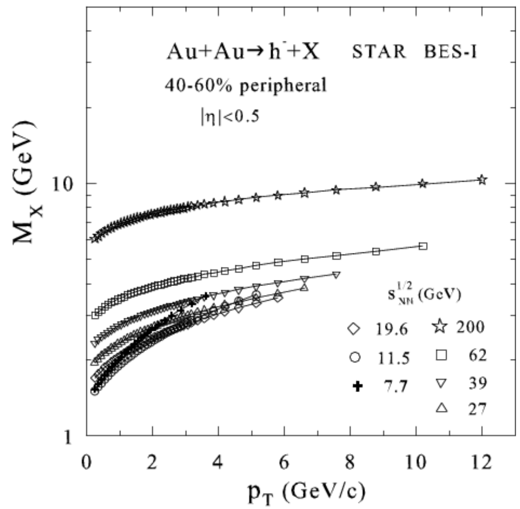
Indication of the decrease of δ for $\sqrt{s_{NN}} < 19.6$ GeV

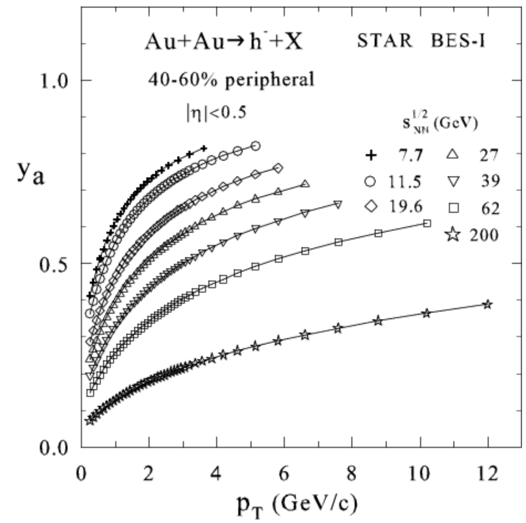
Self-similarity of h⁻ production in peripheral Au+Au

Constituent level of particle production in terms of

Momentum fraction Ax_1 | **Recoil mass M_X** | **Energy loss $\Delta E/E \sim (1-y_a)$**







Momentum fraction
- increases with p_T
- decreases with $\sqrt{s_{NN}}$

Recoil mass
- increases with p_T
- increases with $\sqrt{s_{NN}}$

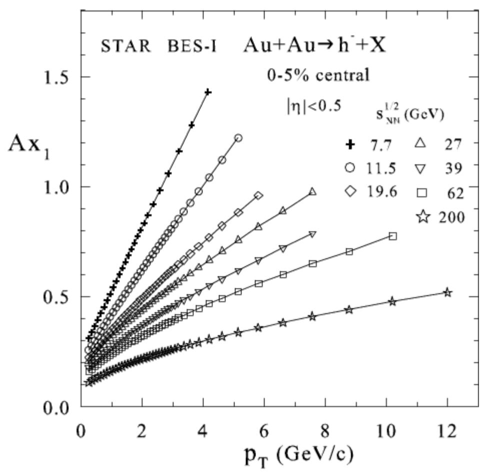
Energy loss
- decreases with p_T
- increases with $\sqrt{s_{NN}}$

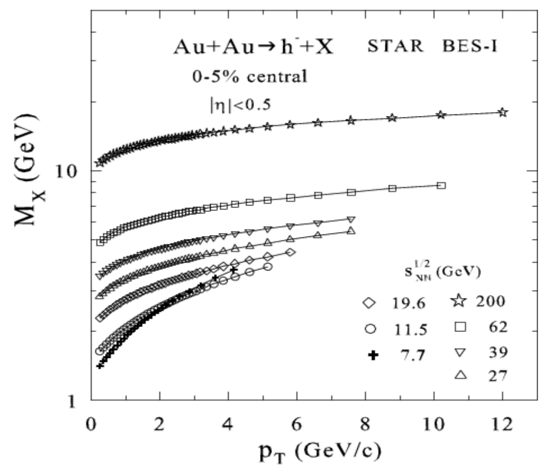
- High x_1 and p_T → compressed matter
- High y_a → low energy loss, clear PT & CP signatures

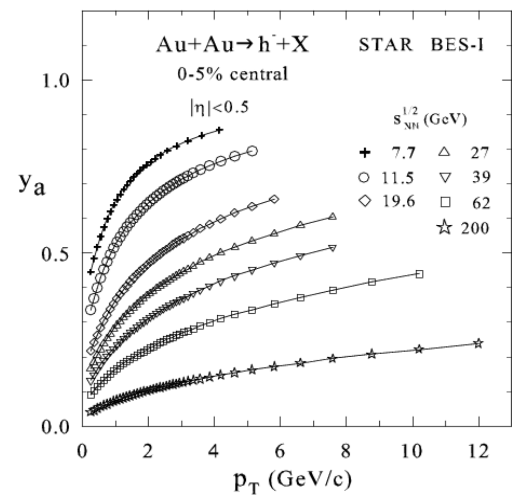
Self-similarity of h^- production in central Au+Au

Constituent level of particle production in terms of

Momentum fraction Ax_1 | Recoil mass M_X | Energy loss $\Delta E/E \sim (1-y_a)$







Momentum fraction
- increases with p_T
- decreases with $\sqrt{s_{NN}}$

Recoil mass
- increases with p_T
- increases with $\sqrt{s_{NN}}$

Energy loss
- decreases with p_T
- increases with $\sqrt{s_{NN}}$

- High x_1 and p_T $\to$ compressed matter
- Large M_X $\to$ high density recoil sysytem
- High y_a $\to$ low energy loss, clear PT & CP signatures

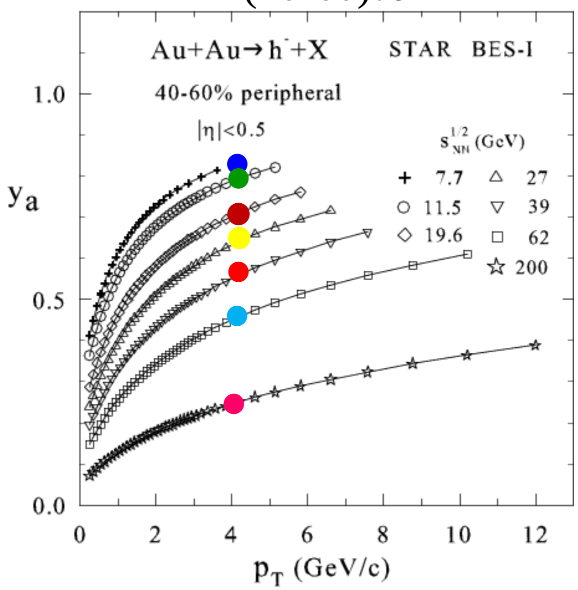
Constituent energy loss in Au+Au

Energy loss $\Delta E/E \sim (1-y_a)$

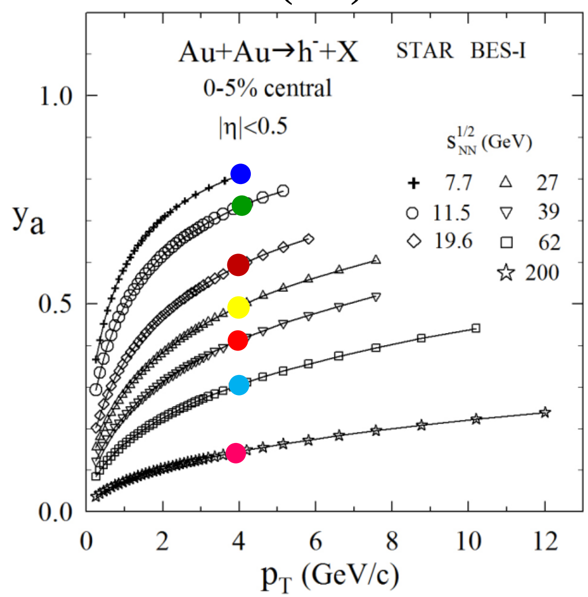
p_T – transverse momentum of produced hadron
q – momentum of scattered constituent

$p_T = 4$ GeV , $q = p_T / y_a$

(40-60)%



(0-5)%



(40-60)%:

20 % **energy loss** $q \approx 5$ GeV/c

22 % **energy loss** $q \approx 5.1$ GeV/c

30 % **energy loss** $q \approx 5.7$ GeV/c

35 % **energy loss** $q \approx 6.2$ GeV/c

45 % **energy loss** $q \approx 7.3$ GeV/c

55 % **energy loss** $q \approx 8.9$ GeV/c

75 % **energy loss** $q \approx 16$ GeV/c

(0-5)%:

20 % **energy loss** $q \approx 5$ GeV/c

25 % **energy loss** $q \approx 5.3$ GeV/c

40 % **energy loss** $q \approx 6.7$ GeV/c

50 % **energy loss** $q \approx 8$ GeV/c

60 % **energy loss** $q \approx 10$ GeV/c

70 % **energy loss** $q \approx 13.3$ GeV/c

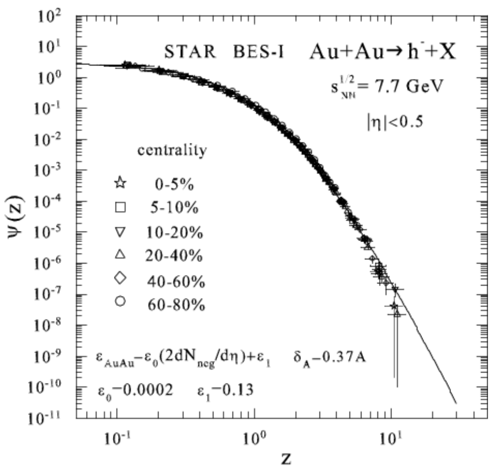
85 % **energy loss** $q \approx 26.6$ GeV/c

Energy loss

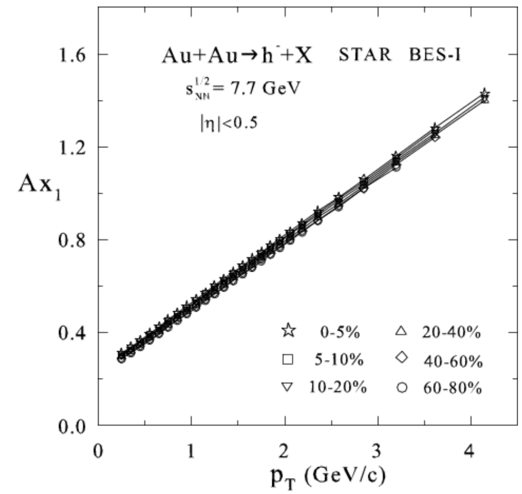
- decreases with p_T
- increases with $\sqrt{s_{NN}}$
- increases with centrality

Scaling function, momentum fractions and recoil mass vs. centrality and p_T at $\sqrt{s_{NN}}$ =7.7 GeV & $|\eta|<0.5$

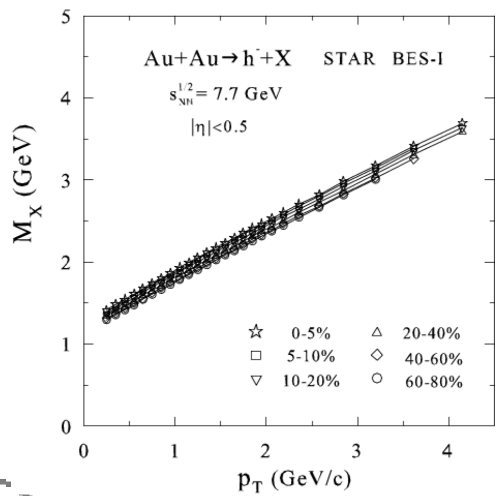
$Au+Au \rightarrow h^- + X$

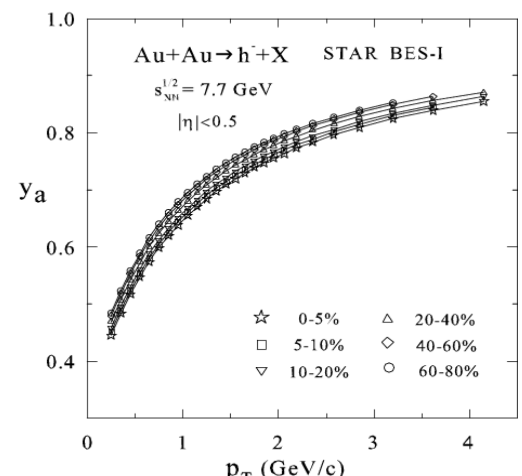


- Scaling behavior of $\Psi(z)$
- Weak dependence of Ax_1, y_a, M_X on centrality
- Cumulative region is reached
- Smooth dependence vs. variables



- Power behavior of $\Psi(z)$ at $z<0.4$
- Power behavior of $\Psi(z)$ at $z>4$
- Linear dependence of M_X and Ax_1 on p_T for all centralities
- Growth and flattening of y_a vs. p_T
- Decrease of $\delta_A = A\delta$ with $\sqrt{s_{NN}}$

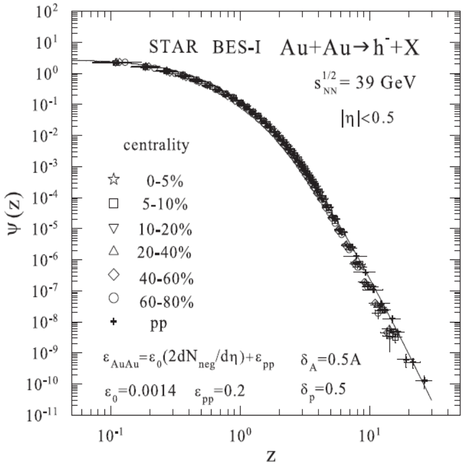




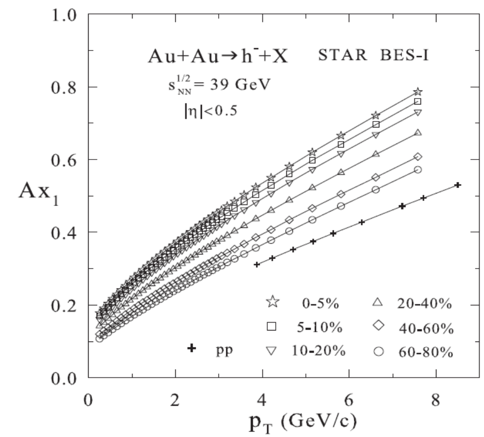
Goal: search for discontinuity and correlation of model parameters δ, c, ε

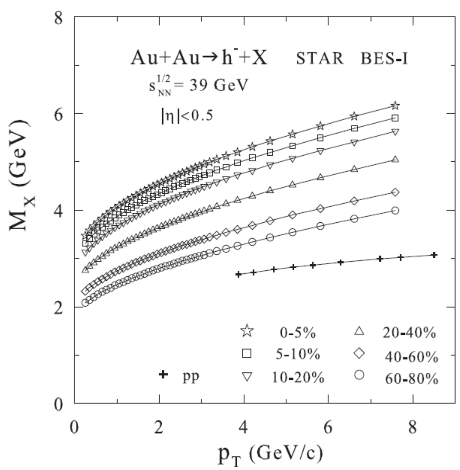
Scaling function, momentum fractions and recoil mass vs. centrality and p_T at $\sqrt{s_{NN}}$ =39 GeV & $|\eta|<0.5$

$Au+Au \rightarrow h^- + X$

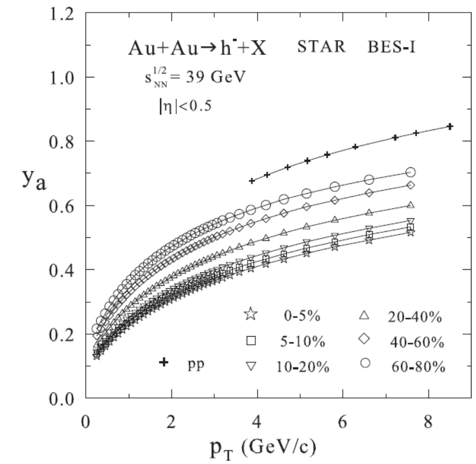


- Scaling behavior of $\Psi(z)$
- Strong dependence of Ax_1, y_a, M_X on centrality
- Cumulative region is not reached
- Smooth dependence vs. variables





- Power behavior of $\Psi(z)$ at $z<0.4$
- Power behavior of $\Psi(z)$ at $z>4$
- Growth of Ax_1, y_a, and M_X on p_T for all centralities
- Independence of $\delta_A = A\delta$ on $\sqrt{s_{NN}}$



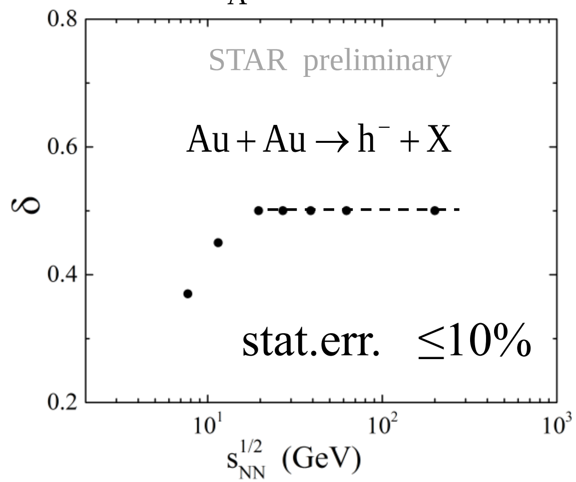
Goal: search for discontinuity and correlation of model parameters δ, c, ε

Model parameters: δ_A, ε_{AA}, c_{AA}

Parameters δ_A, ε_{AA}, c_{AA} are determined from the requirement of scaling behavior of Ψ as a function of self-similarity parameter z

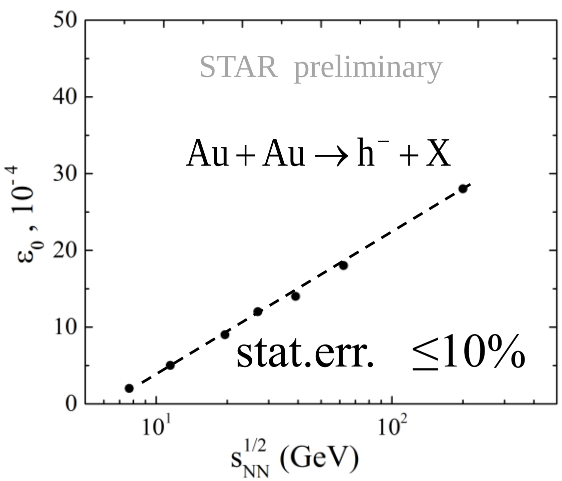
Nucleus fractal dimension

$$\delta_A = A \cdot \delta$$



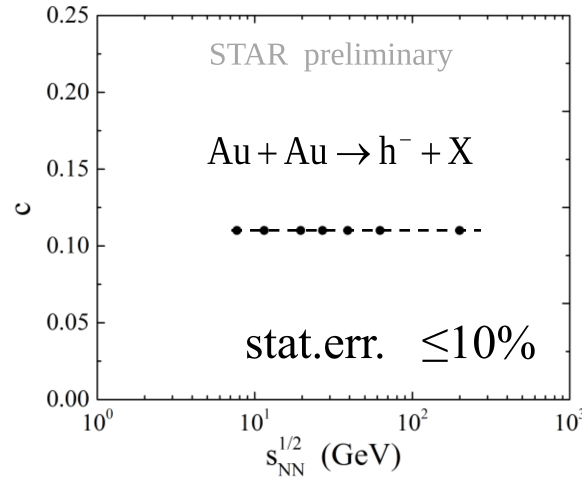
Fragmentation dimension

$$\varepsilon_{AA} = \varepsilon_0 (dN_{AA}/d\eta) + \varepsilon_{pp}$$



"Specific heat"

$$c_{AA}$$



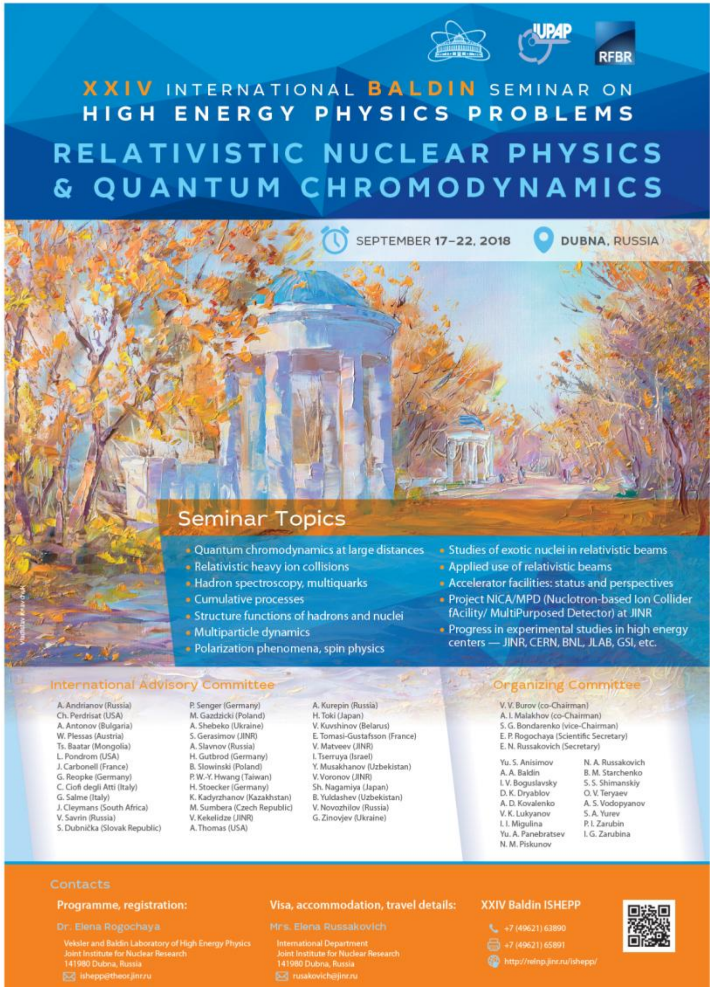
- δ_A decreases with energy for $\sqrt{s_{NN}} \leq 20$ GeV
- δ_A is independent of energy for $\sqrt{s_{NN}} \geq 20$ GeV
- ε_{AA} increases with energy
- c_{AA} is independent of energy

Search for discontinuity and correlations of the model parameters.

Conclusions

- New results of analysis of experimental data on negative hadrons produced in Au+Au collisions at RHIC from BES-I program in the framework of z-scaling were presented.
- New confirmation of scaling properties of data z-presentation in AA collisions were obtained.
- The dependence of momentum fractions, recoil mass vs. collision energy, centrality and transverse momentum was studied.
- The constituent energy loss for a wide kinematic range and centrality of events was estimated.
- STAR BES-I data in z-presentation demonstrate smooth behavior vs. a collision energy, centrality over a wide range of p_T .
- Discontinuities of model parameters – fractal dimensions δ_A , ε_{AA} and "heat capacity" c_{AA} , are not visible.
- Parameter correlations as signatures of phase transition and Critical Point were discussed.

The obtained results can be of interest in searching for a Critical Point and signatures of phase transition in nuclear matter produced at SPS, RHIC and LHC in present, and FAIR & NICA in future.

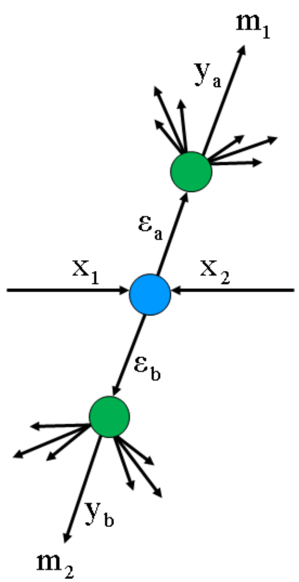


Thank you for attention !

Back-up Slides

Transverse kinetic energy $\sqrt{s_\perp}$

$$s_\perp^{1/2} = \underbrace{y_1(s_\lambda^{1/2} - M_1\lambda_1 - M_2\lambda_2) - m_1}_{\text{energy consumed for the inclusive particle } m_1} + \underbrace{y_2(s_\chi^{1/2} - M_1\chi_1 - M_2\chi_2) - m_2}_{\text{energy consumed for the recoil particle } m_2}$$



Fraction decomposition: $x_{1,2} = \lambda_{1,2} + \chi_{1,2}$

$$\lambda_{1,2} = \kappa_{1,2}/y_1 + \nu_{1,2}/y_2$$

$$\chi_{1,2} = (\mu_{1,2}^2 + \omega_{1,2}^2)^{1/2} \mp \omega_{1,2}$$

$$\omega_{1,2} = \mu_{1,2} U, \quad U = \frac{\alpha - 1}{2\sqrt{\alpha}}\xi, \quad \alpha = \frac{\delta_2}{\delta_1}$$

$$\xi^2 = (\lambda_1\lambda_2 + \lambda_0)/[(1-\lambda_1)(1-\lambda_2)]$$

$$\kappa_{1,2} = \frac{(P_{2,1}p)}{(P_2P_1)}, \quad \nu_{1,2} = \frac{M_{2,1}m_2}{(P_2P_1)}$$

$$\mu_{1,2}^2 = \alpha^{\pm 1}(\lambda_1\lambda_2 + \lambda_0)\frac{1-\lambda_{1,2}}{1-\lambda_{2,1}}$$

$$\lambda_0 = \bar{\nu}_0/y_2^2 - \nu_0/y_1^2$$

$$\bar{\nu}_0 = \frac{0.5m_2^2}{(P_1P_2)}, \quad \nu_0 = \frac{0.5m_1^2}{(P_1P_2)}$$

$$s_\lambda = (\lambda_1 P_1 + \lambda_2 P_2)^2$$

$$s_\chi = (\chi_1 P_1 + \chi_2 P_2)^2$$

The scaling function $\Psi(z)$ and self-similarity parameter z are expressed via Lorentz invariants.