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MSU, Moscow, Russia, August 22 - 28, 2013

Self-similarity of high-p_T cumulative hadron production in pA collisions

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JINR, Dubna, Russia

Outline:

- Introduction
- z-Scaling
- Self-similarity of hadron production in pp & pA collisions, $\sqrt{s}$=11.5-38.8 GeV
- Self-similarity of high-p_T cumulative hadron production in pA (A=C,Al,Cu,W)
- Conclusions

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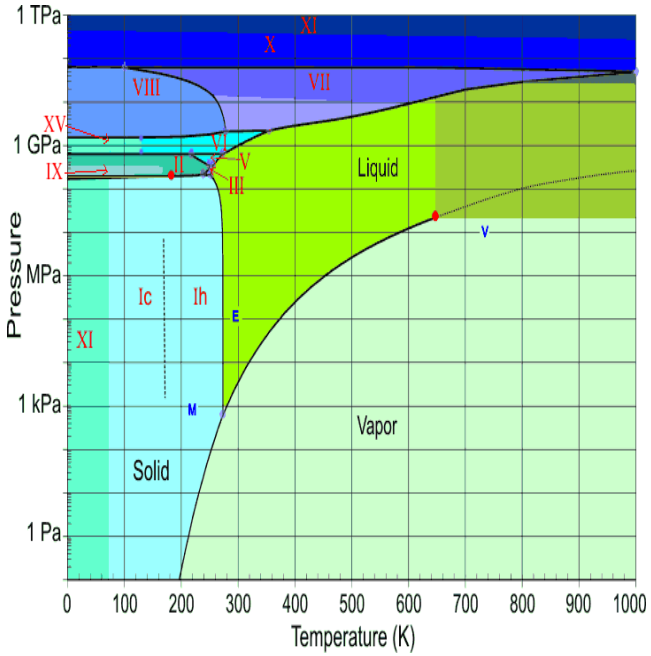
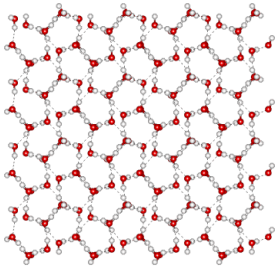
Phase diagram of matter

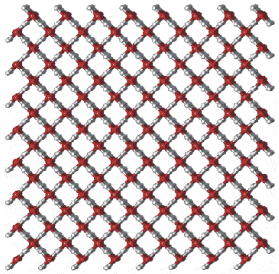
The phase diagram of water is established



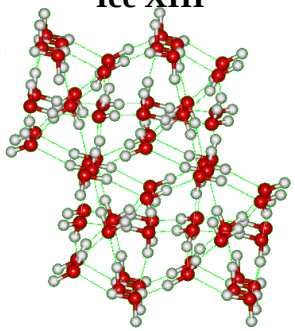
Ice III



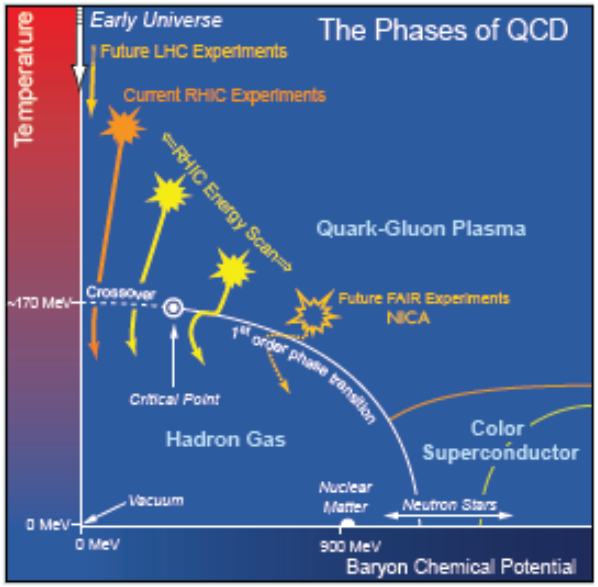
Ice X



Ice XIII



The phase diagram of strongly interacting matter is under study



- **Phases (ice I-XV, liquid, vapor)**
- **Phase boundaries**
- **Phase transitions**
- **Triple Point (16)**
- **Critical Point (2)**

- **Phases - ?**
- **Phase boundaries -?**
- **Phase transitions - ?**
- **Triple Point - ?**
- **Critical Point - ?**

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Motivation

"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.Barenblat,…

Motivation & Goals

z-scaling can be used as a tool to search for new physics in particle production in pp, AA & pA at high energies.

Analysis of new experimental data on inclusive spectra of hadron production in pA collisions to verify properties of z-scaling in high-p_T cumulative region.

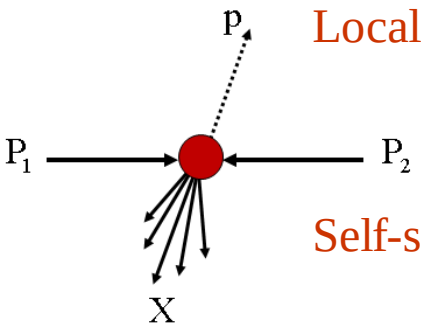
Search for possible signatures of new physics phenomena in inclusive pp & pA collisions.

Discontinuities of the theory parameters δ_1, δ_2 could be signatures of phase transition effects.

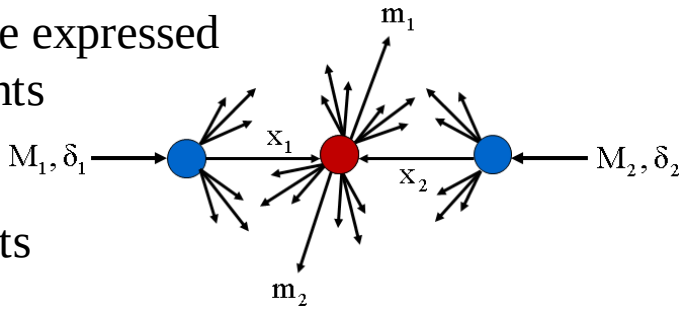
z-Scaling
I.Zborovsky, M.Tokarev,
Yu.Panebratsev, G.Skoro (1996)

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: the self-similarity 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

δ_1, δ_2

$Ed^3\sigma/dp^3$

Scaled inclusive cross section of particles depends in a self-similar way on a single scaling variable z.

$\Psi(z)$

z as self-similarity parameter

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

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

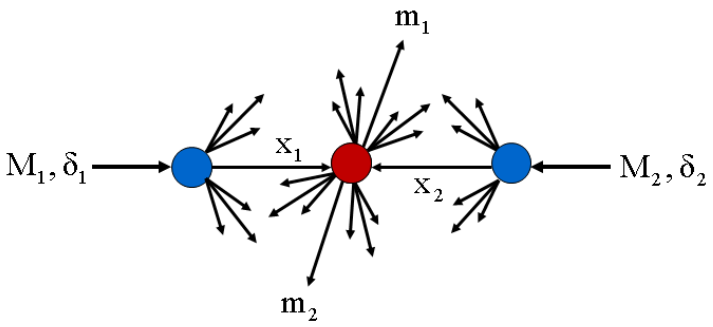
$$\Omega = (1-x_1)^{\delta_1}(1-x_2)^{\delta_2}$$

$$\delta_1 = A_1\delta,\ \delta_2 = A_2\delta$$

- $\sqrt{s_\perp}$ is the transverse kinetic energy of the subprocess consumed on production of m_1 & m_2
- $dN_{ch}/d\eta|_0$ is the multiplicity density of charged particles at $\eta = 0$
- m is an arbitrary constant (fixed at the value of nucleon mass)
- Ω^{-1} is the minimal resolution at which a constituent subprocess can be singled out of the inclusive reaction
- δ_1, δ_2 are parameters characterizing structure of the colliding objects
- x_1, x_2 are the momentum fractions of colliding objects

Scaling function $\Psi(z)$

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



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

$$z \to \alpha(A)\, z, \quad \Psi \to \alpha^{-1}(A)\,\Psi \qquad \alpha(A) \approx 0.9\, A^{0.15}$$

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

- σ_{in} - inelastic cross section
- N - average multiplicity of the corresponding hadron species
- $dN/d\eta$ - pseudorapidity multiplicity density at angle θ (η)
- $J(z,\eta;p_T^2,y)$ - Jacobian
- $Ed^3\sigma/dp^3$ - inclusive cross section

Scaling & Universality

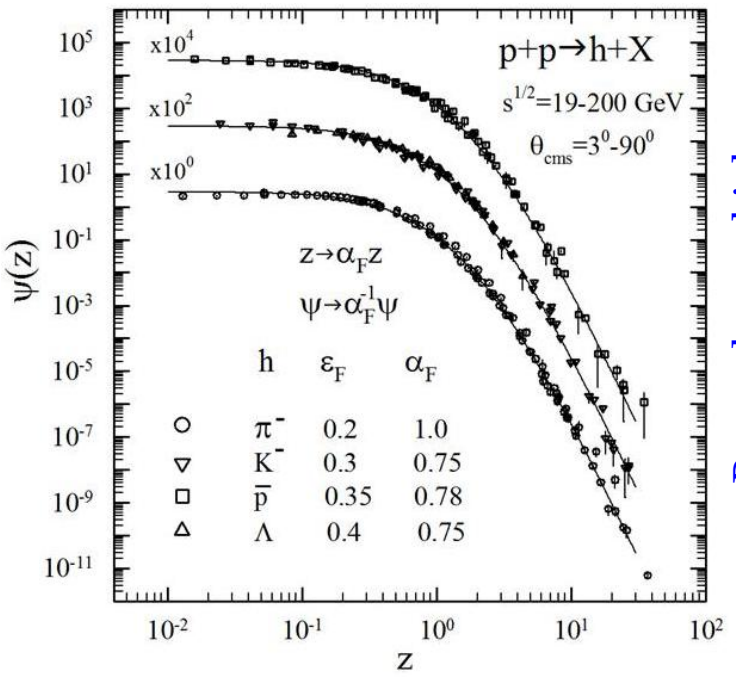
π^-, K^-, $\bar{p}$, Λ
in pp collisions

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

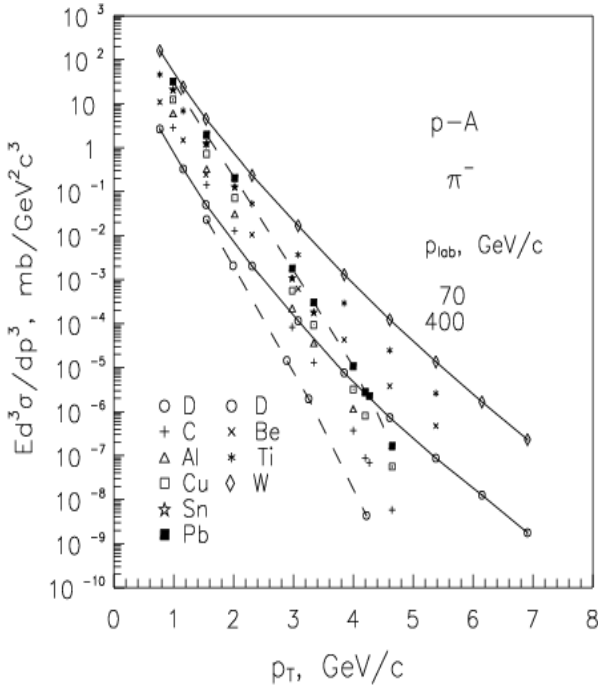
M.Tokarev. & I.Zborovsky
T.Dedovich
Phys.Rev.D75,094008(2007)
Int.J.Mod.Phys.A24,1417(2009)
J. Phys.G: Nucl.Part.Phys.
37,085008(2010)
Int.J.Mod.Phys.A27,1250115(2012)
J.Mod.Phys.3,815(2012)

M.Tokarev, Yu.Panebratsev,
I.Zborovsky, G.Skoro
Int. J. Mod. Phys. A16 (2001) 1281.

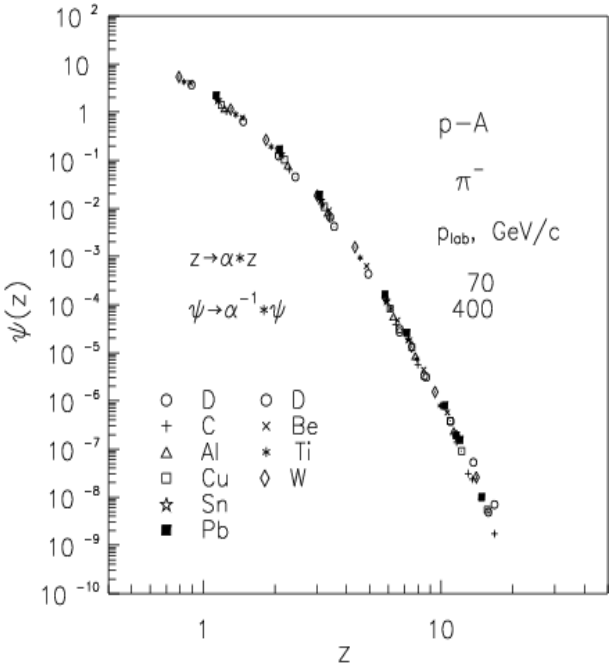
- Energy & angular independence
- Flavor independence (π, K, p, Λ)
- Saturation for z<0.1
- Power law for high z>4

Scaling – "collapse" of data points onto a single curve.

Self-similarity of hadron production in pA



Strong dependence of spectra on $\sqrt{s}$ at high p_T



- Energy independence of $\Psi(z)$
- Power law of $\Psi(z)$ at high z
- A-dependence of $\Psi(z)$

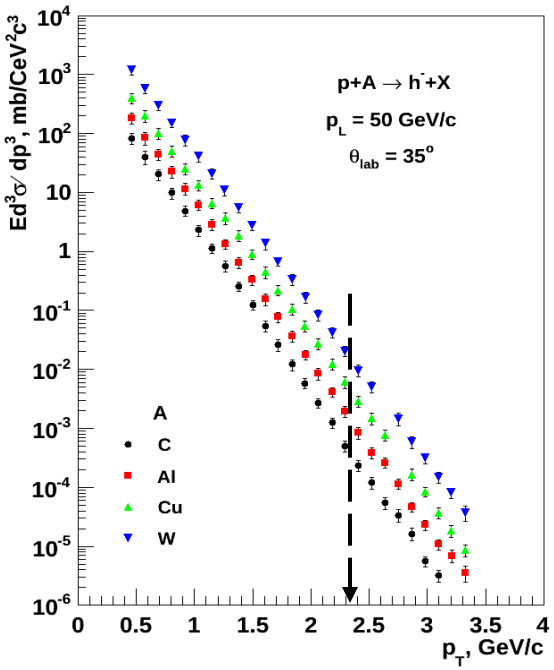
Scale invariance

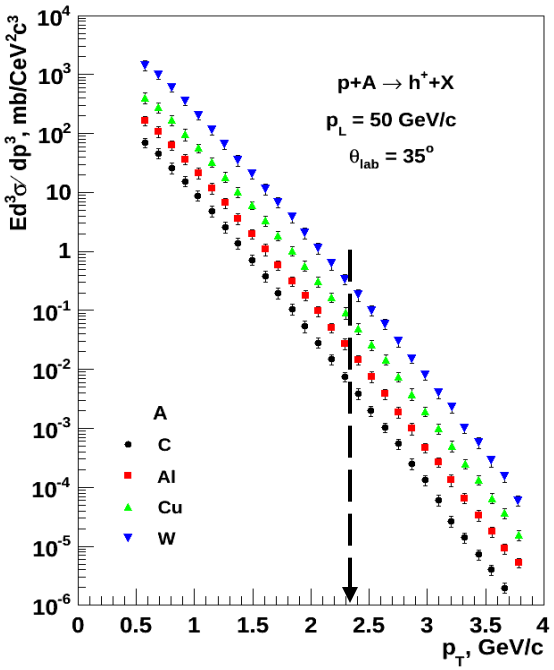
Independence of the shape of the curve on $\{z,\Psi\}$ plane on scale quantities $\sqrt{s}$, p_T ,θ

J.W. Cronin et al., Phys. Rev. D11 (1975) 3105.
D. Antreasyan et al., Phys. Rev. D19 (1979) 764.
V.V.Abramov et al., Sov. J. Nucl. Phys. 41 (1985) 357.

M.T., Yu.Panebratsev, I.Zborovsky, G.Skoro
Int. J. Mod. Phys. A16 (2001) 1281.

High-p_T cumulative hadron spectra in pA at U70





- Spectra in cumulative region: $p_T > 2.5$ GeV/c.
- Smooth behavior of spectra vs. p_T.
- A-dependence of spectra (A=12-184).

The cumulative particle is a particle produced in the region forbidden for free nucleon kinematics:

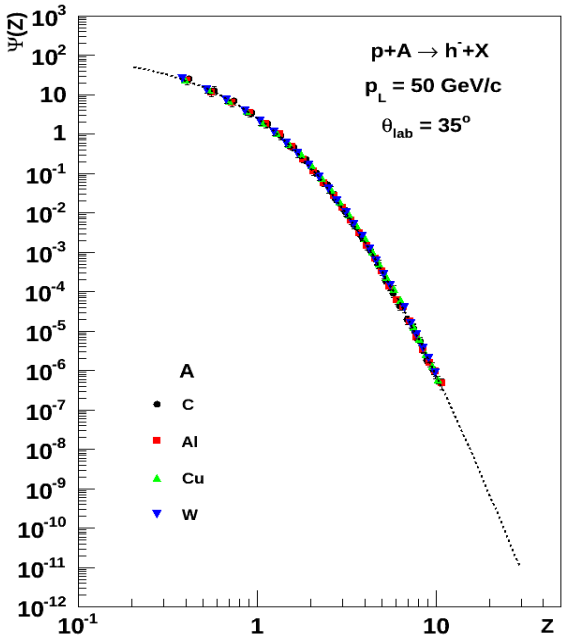
$$P_1 + P_2 \rightarrow p + X$$

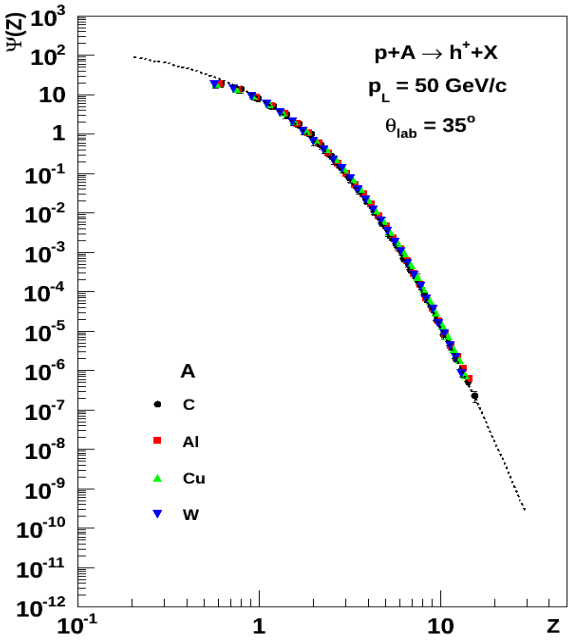
$$(P_1 + P_2 - p)^2 = M_X^2 \Rightarrow p_{max}^A > p_{max}^p$$

N.N.Antonov et al. (IHEP, Protvino)
"Physics of Fundamental Interactions", Russian Academy of Science, ITEP,Moscow, Russia, 21-25 November, 2011.
Seminar LHEP, JINR, Dubna, 6 June, 2012.

High-p_T cumulative hadron spectra in pA at U70

z-presentation





- Universal shape of $\Psi(z)$
- Power law for $z > 4$
- No discontinuty of δ_2

Scale invariance

Independence of the shape of the curve on $\{z,\Psi\}$ plane on scale quantities $\sqrt{s}$, p_T, θ

Self-similarity of high-p_T cumulative production

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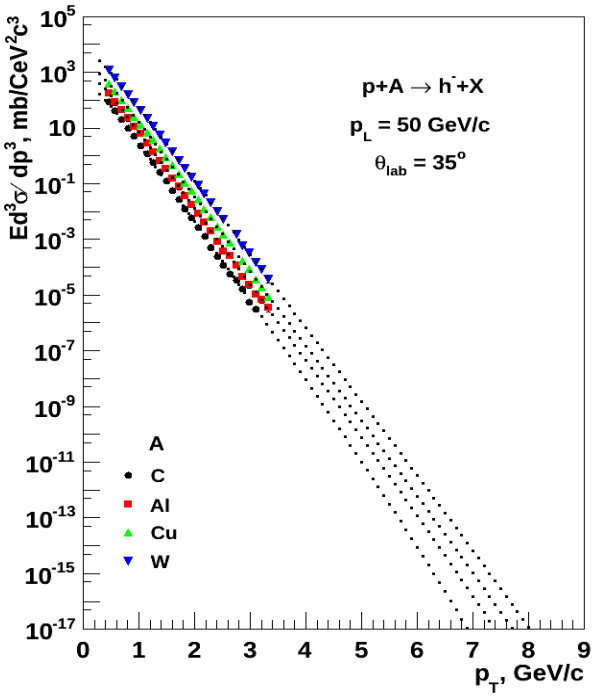
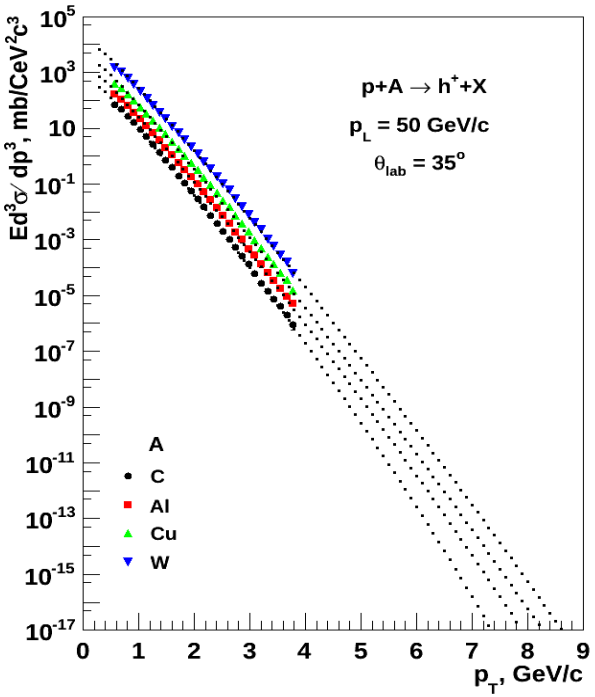
Spectra predictions based on z-scaling





- Spectra in cumulative region: $p_T > 2.5$ GeV/c
- Exponential behavior of spectra vs. p_T
- Verification of the additive law $\delta_A = A\delta_N$

Search for signatures of compressed nuclear matter.

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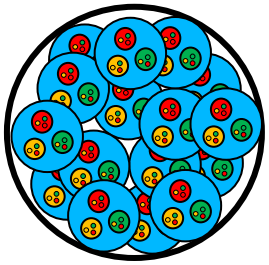
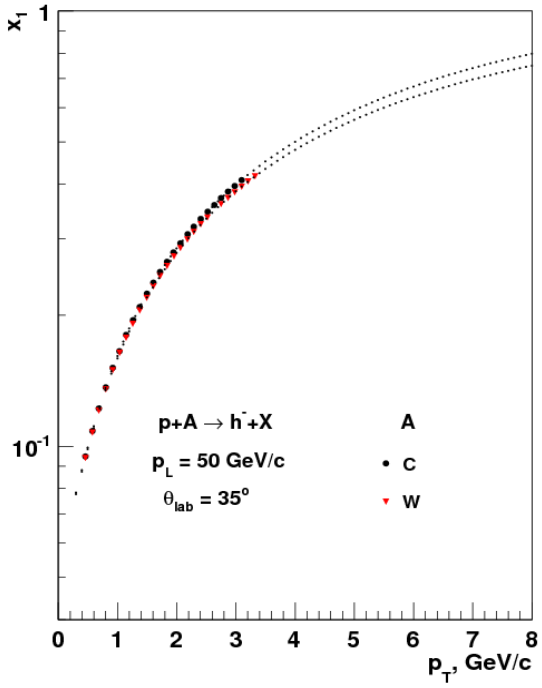
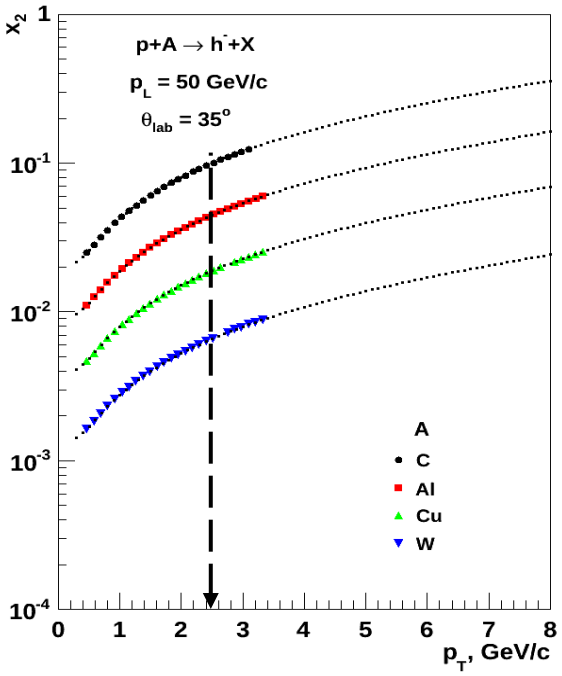
Microscopic scenario of constituent interactions

Momentum fractions x_1, x_2 vs. p_T







Proton fragmentation region

$0 < x_1 < 1$

Non-cumulative region

$x_2 < 1/A$

Nucleus fragmentation region

$0 < x_2 < 1$

Cumulative region

$x_2 > 1/A$

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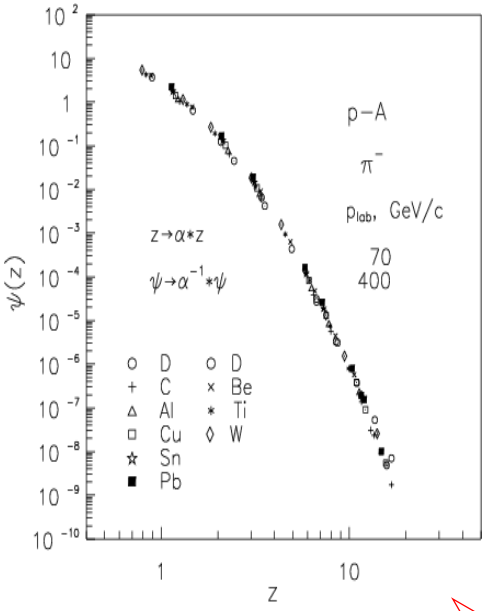
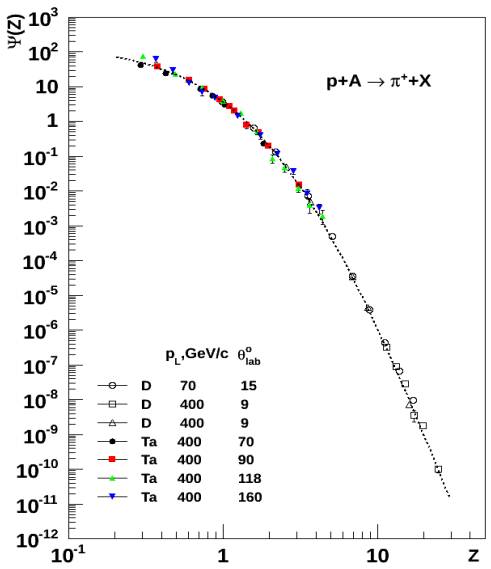
Self-similarity of hadron production in pA

FNAL (J.Cronin, G.Leksin, D.Jaffe) & U70 (R.Sulyaev, V.Gapienko)

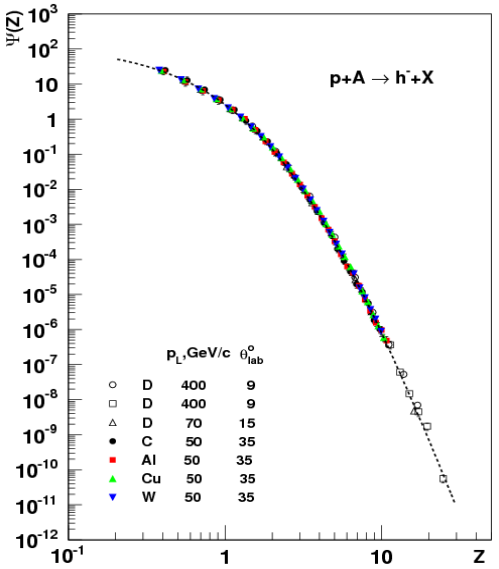
high-p_T & noncumulative



low-p_T & cumulative



high-p_T & cumulative



- Beam Energy Scan in pA
- Spectra of cumulative identified particles
- Multiplicity density $dN_{ch}/d\eta$ vs. $\sqrt{s}$ and η
- Centrality dependence of spectra

Goal: Search for phase transition & CP ⟺ Search for violation of z-scaling

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Conclusions

- The U70 data on cumulative hadron spectra in pA collisions at p_L = 50 GeV/c were analyzed in z-scaling approach.
- Results of this analysis were compared with previous ones from the data obtained by J. Cronin, R. Sulyaev, D. Jaffe and G. Leksin groups.
- Indication on self-similarity of the hadron production in pA collisions at high-p_T in the cumulative region were obtained.

The results can be used to search for new physics phenomena in pA collisions at the U70, SPS, RHIC, LHC & NICA, FAIR


Thank you for your attention!