“The study of cold dense baryonic matter and multi-quark configurations in processes with high p_T”

S.S. Shimanskiy (JINR, LHEP)

OUTLINE

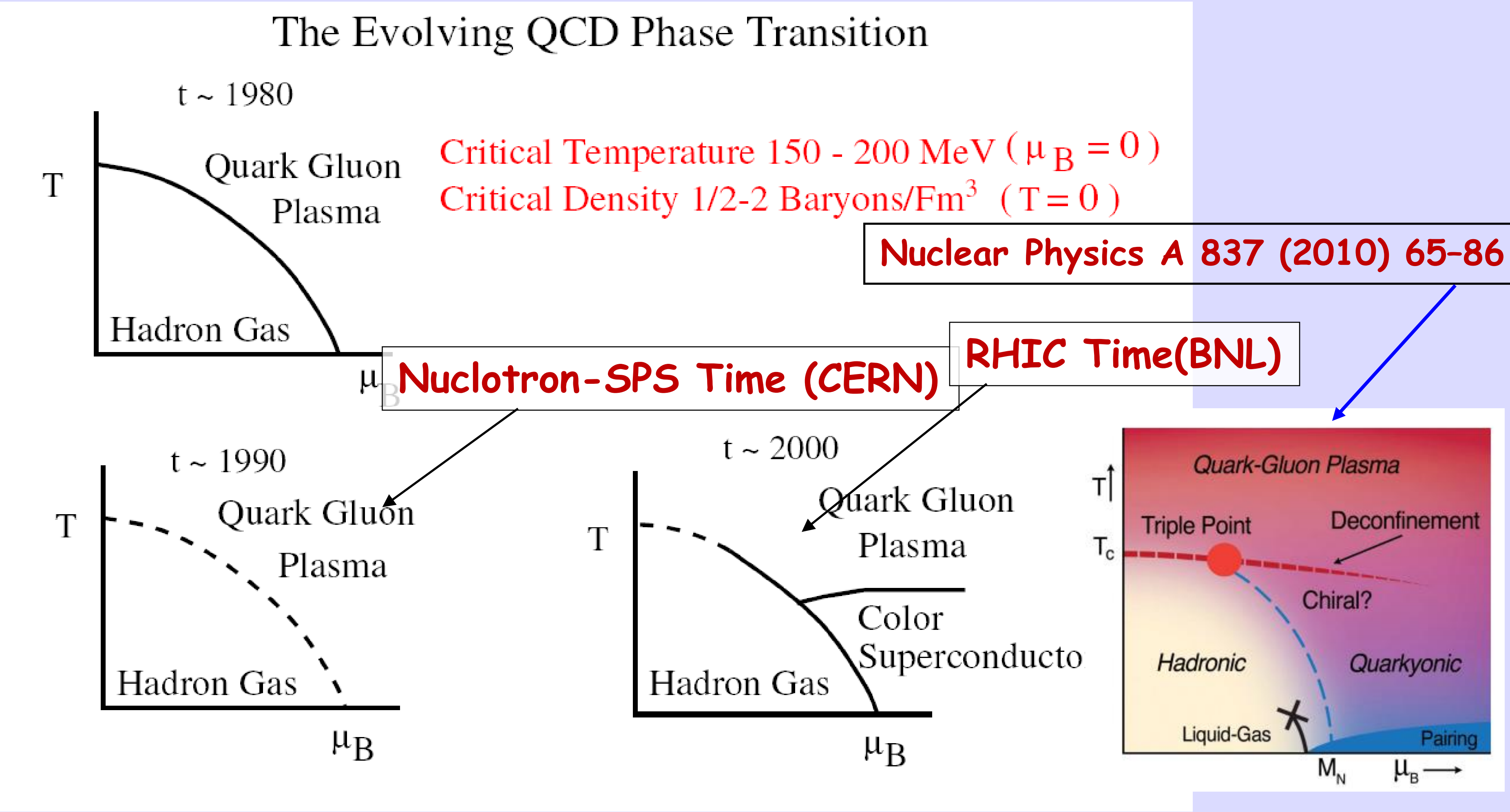
1. The Phase Diagram of Nuclear Matter and Cold Dense Baryonic Matter
2. Discovery and Investigation with Different Probes
3. High p_T probes and SPIN data
3. Future studies

RHIC Physics: 3 Lectures*

Larry McLerran
Physics Department PO Box 5000 Brookhaven National Laboratory Upton, NY 11973 USA

September 13, 2003

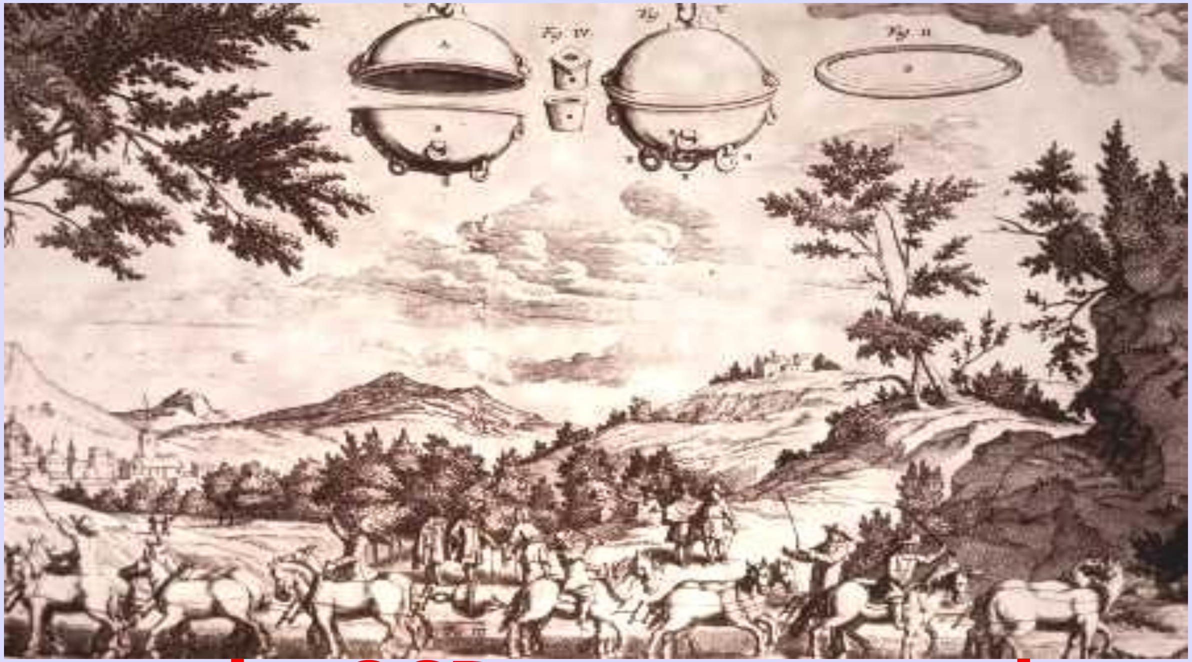
+ CERN Yellow Report 2007-005, p.75 2008-005



Magdeburg hemispheres 1656

Edward Shuryak

ICPAQGP, Kolkata, India, February 8-12, 2005 8-12, 2005



- We cannot pump the QCD vacuum out, but we can pump in something else, namely the Quark-Gluon Plasma –arguments from 1970's
- QGP was looked at as a much simpler thing, to be described by pQCD. We now see it is also quite complicated matter, sQGP…

arXiv:0911.2987v1 [hep-ph] 16 Nov 2009

Proceedings of the DPF-2009 Conference, Detroit, MI, July 27-31, 2009

Theoretical Concepts for Ultra-Relativistic Heavy Ion Collisions

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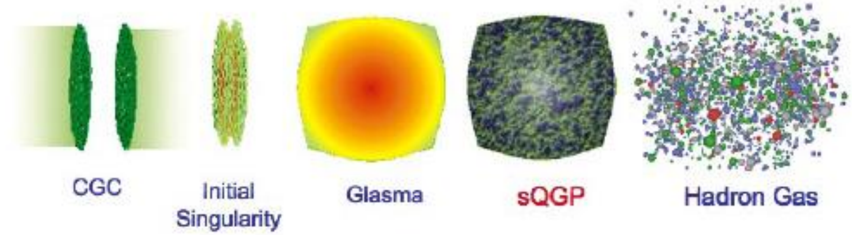


Figure 1: Ultra-relativsitc nuclear collisions and various forms of high energy density matter.

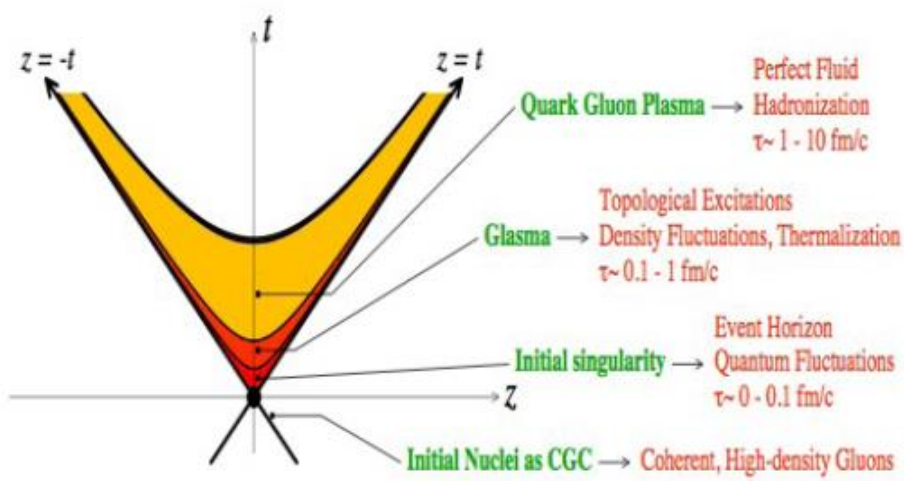
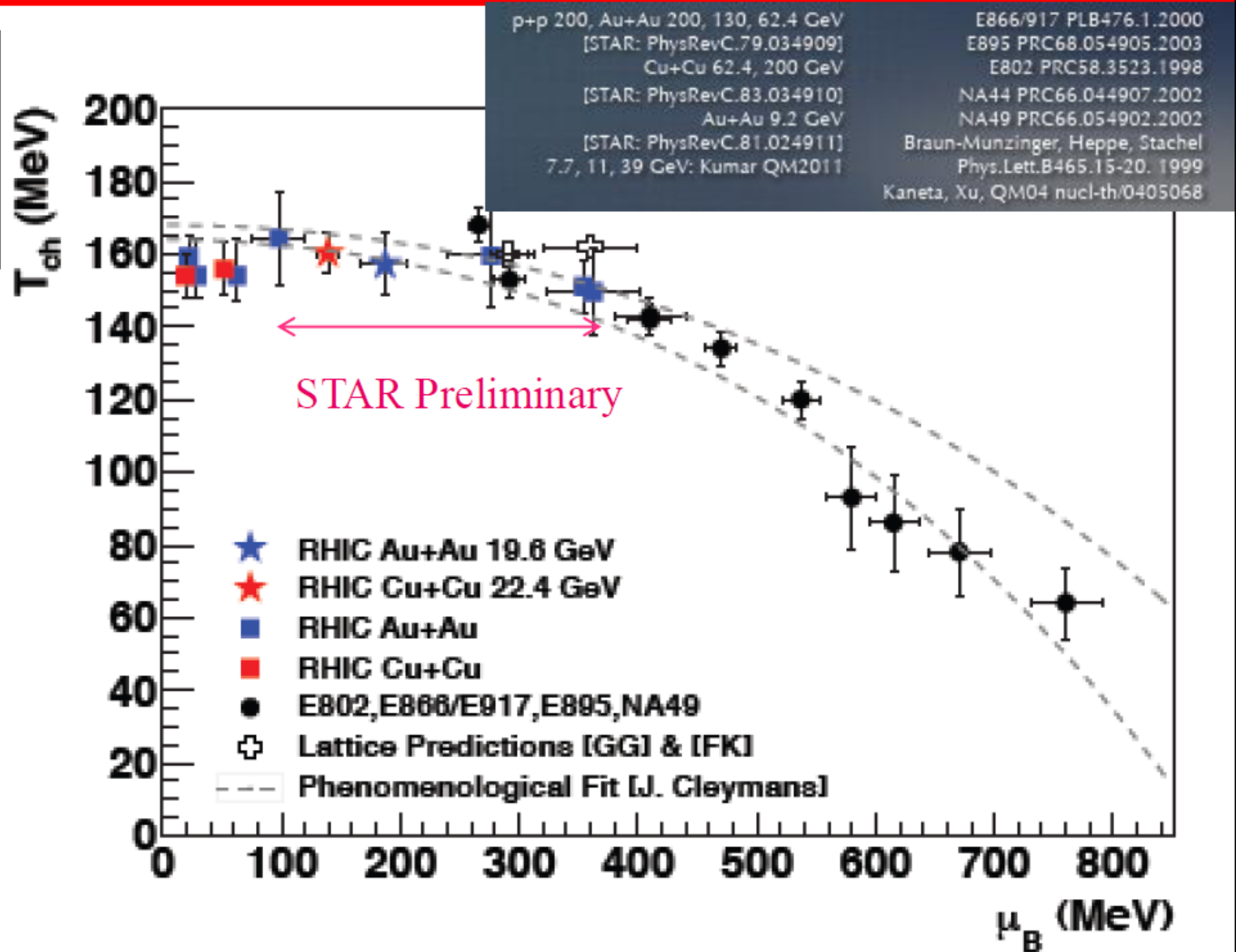


Figure 2: A lightcone diagram for ultra-relativistic hadronic collisions.

Where are We on the Phase Diagram

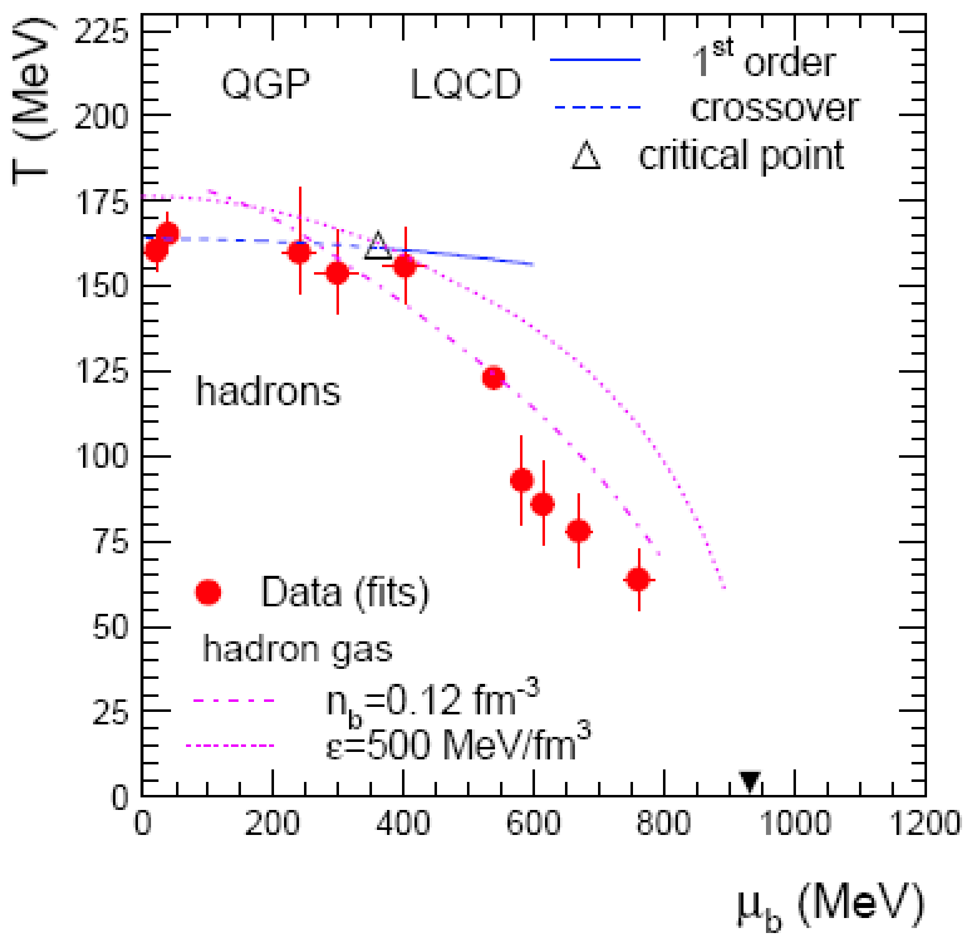
$$\frac{d^6N}{dx^3dp^3} = g\ln\left(\frac{1}{e^{\frac{E-\mu}{T}} \pm 1}\right)$$

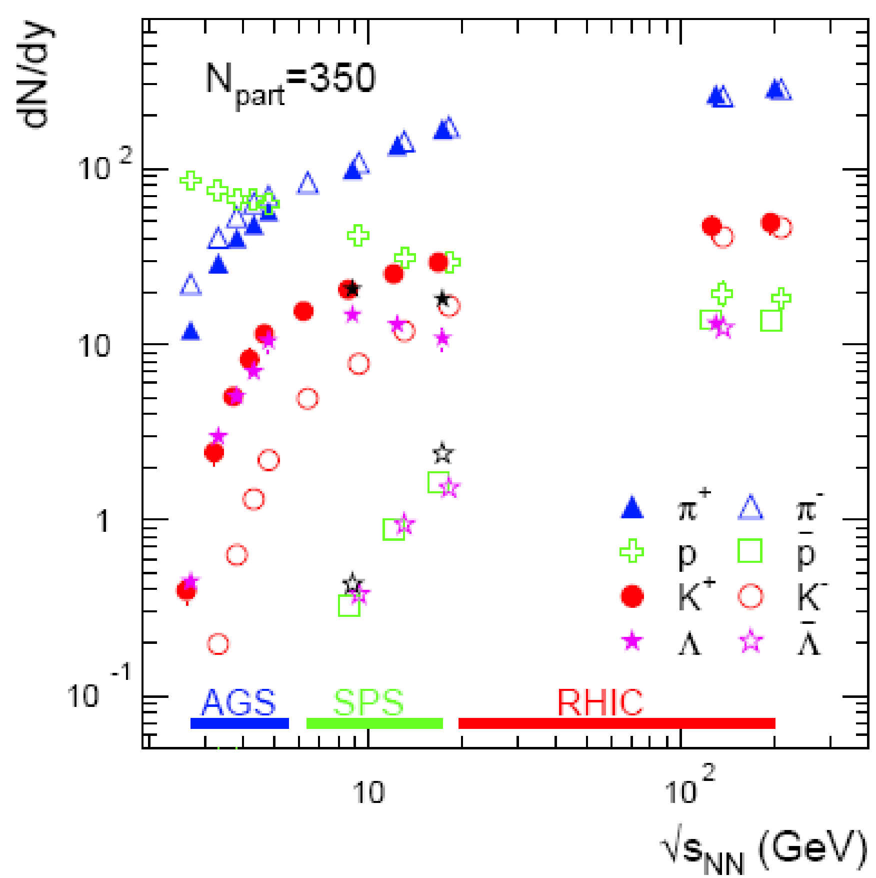
Using the particle ratios from the π, K, and p and a thermal model, we can determine our location on the phase diagram



O. Mall SQM2011

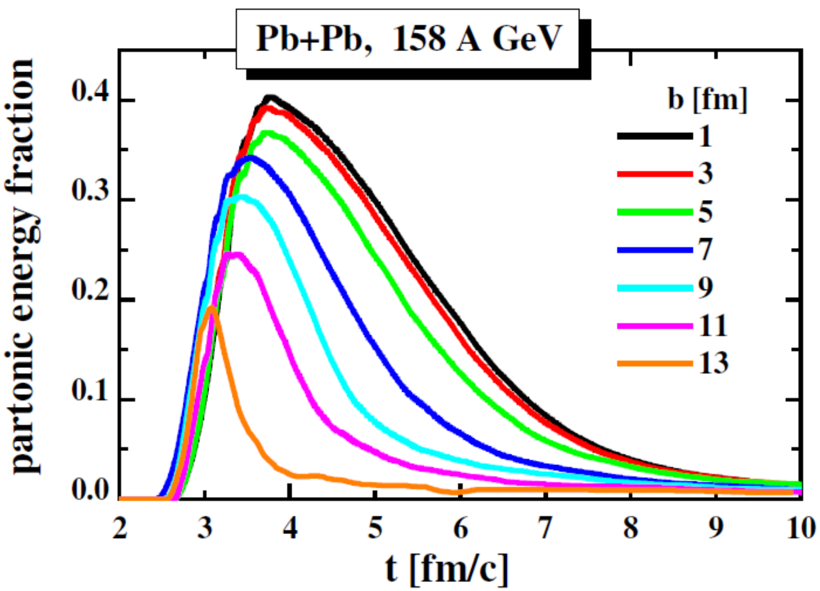
A.Andronic, p.Braun-Munzinger, J. Stachel
nucl-th/0511071

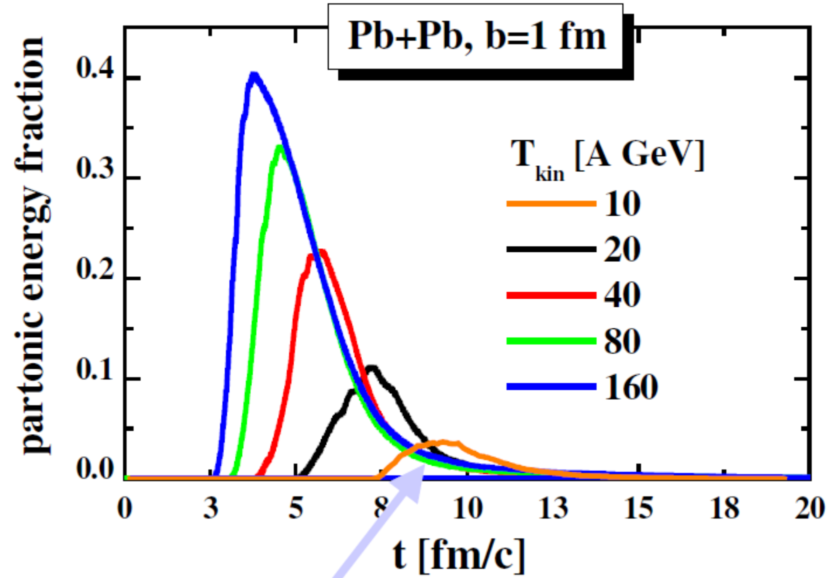




Partonic phase at SPS/FAIR/NICA energies

partonic energy fraction vs centrality and energy



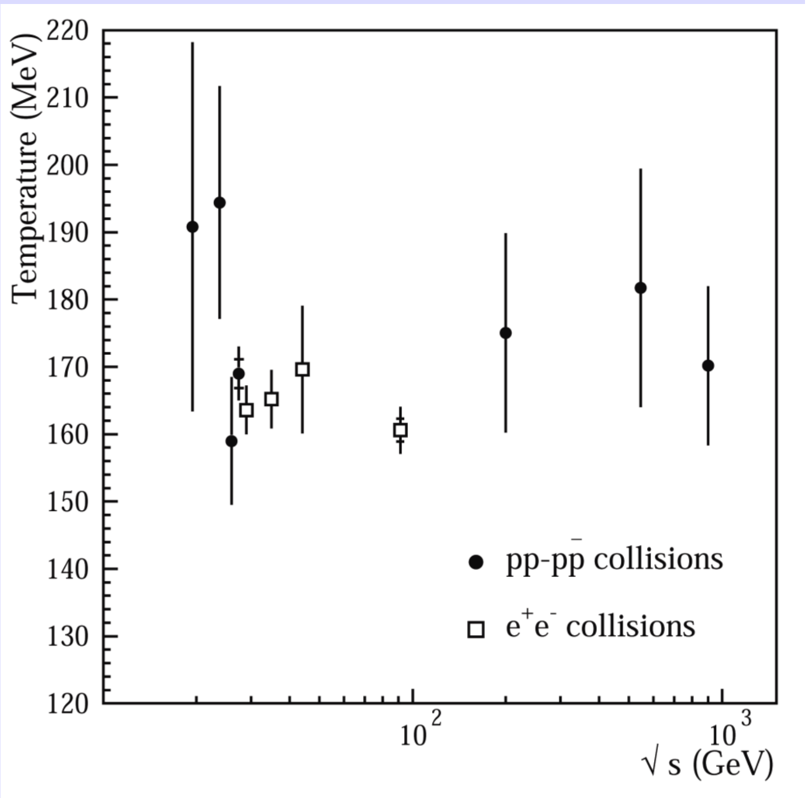


Dramatic decrease of partonic phase with decreasing energy and centrality

Cassing & Bratkovskaya, NPA 831 (2009) 215

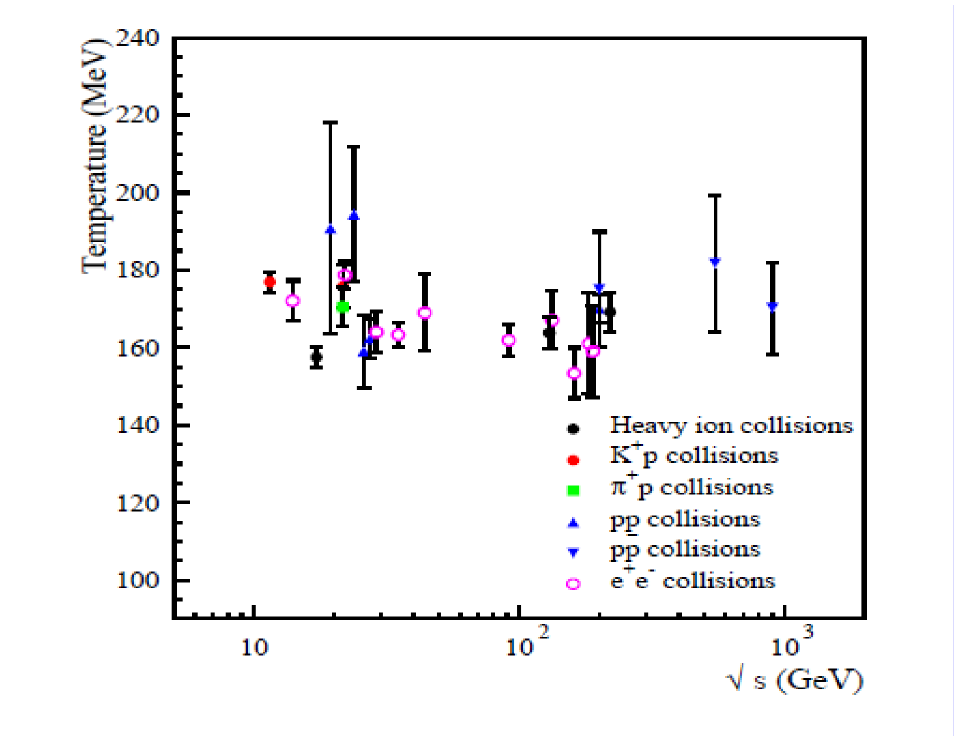
Thermalization in Elementary Collisions ?

Beccatini, Heinz,
Z.Phys. C76 (1997) 269



Helmut Satz

arXiv:1207.0341v1 [hep-ph] 2 Jul 2012



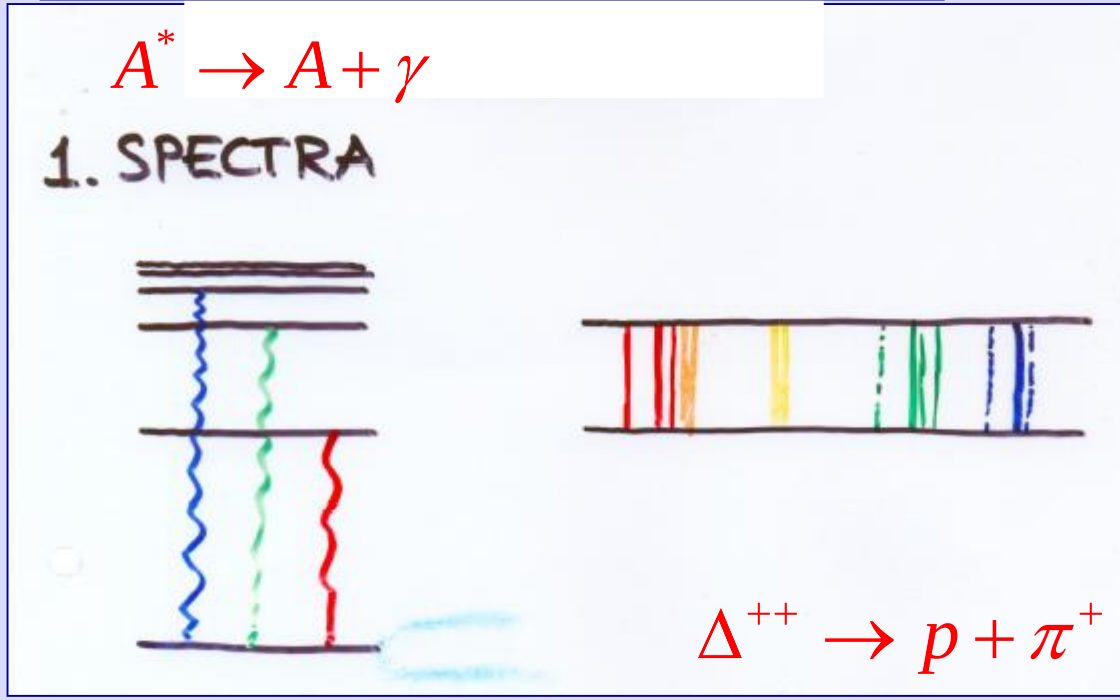
- $T \approx 170$ MeV (good old Hagedorn temperature)
- T_{ch} does not (or only weakly) depends on $\sqrt{s}$
- Universal hadronization mechanism at critical values ?

Discovery and Investigation with Different Probes

F. Close

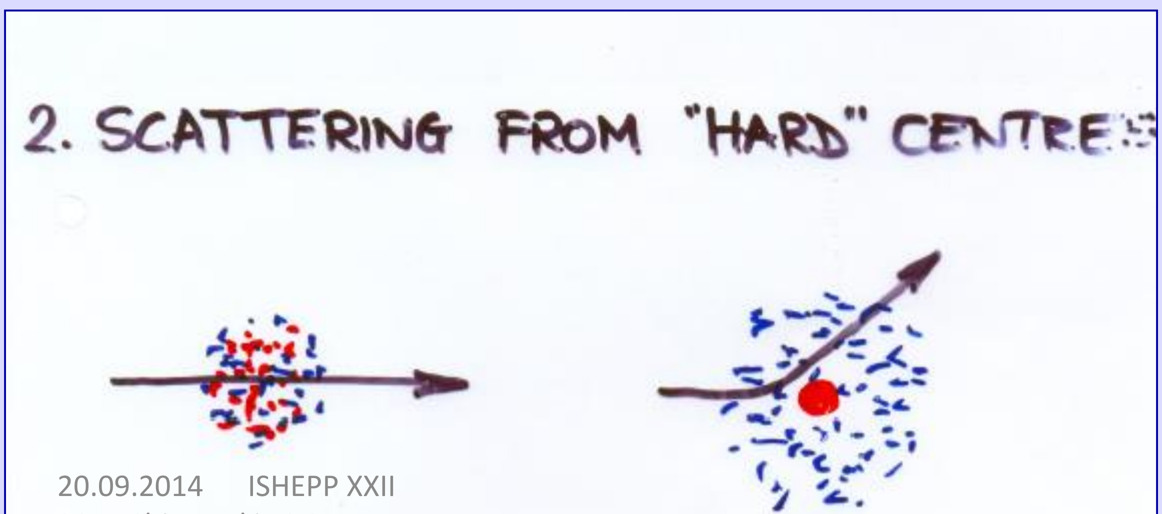
Structure of Matter

Two ways that structure is revealed:



$$A^* \rightarrow A + \gamma$$

$$\Delta^{++} \rightarrow p + \pi^+$$

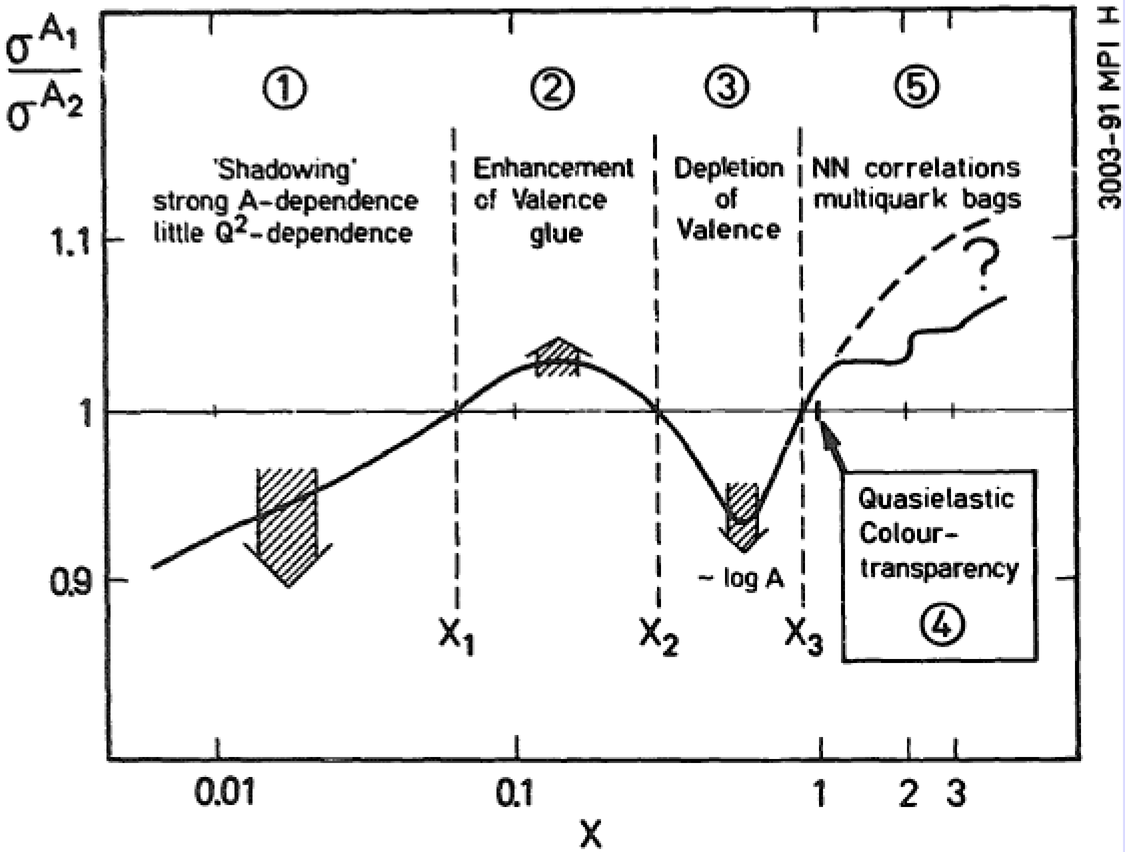


True from atoms to particles…..

DIS with Leptons

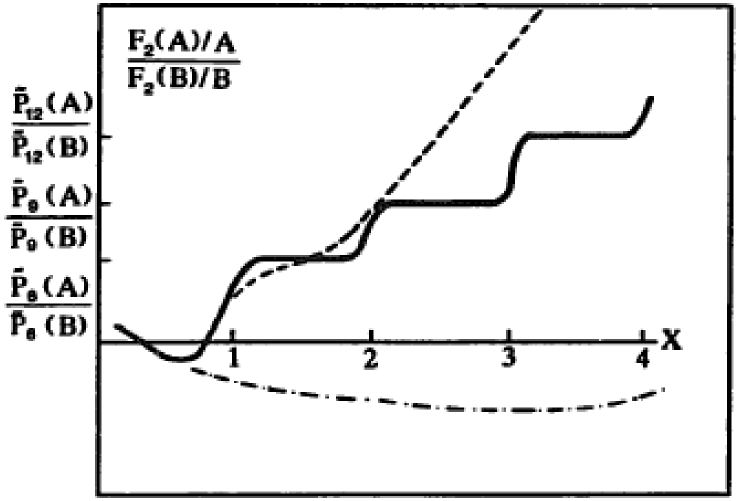
Nuclear Physics A532 (1991) 3c–14c

K.Rith



Region 5: $x_3 < x < x_A$

For a nucleus with atomic mass A the quark distributions can in principle extend to $x_A = A$. $R^A(x)$ is bigger than one. Its behaviour is strongly influenced by Fermi-motion, final state interactions, nucleon-nucleon correlations, or the formation of multiquark clusters. Experimentally this region is essentially unexplored.



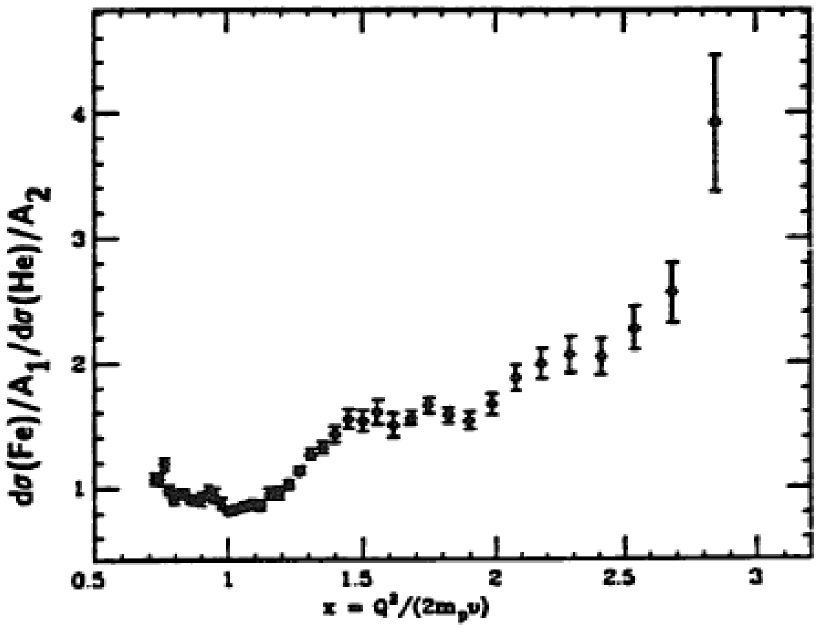


Figure 5. Theoretical predictions for nuclear structure functions at $x > 1$

Figure 6. Preliminary results for σ^{Fe}/σ^{He} from NE-2 at SLAC

32 J. Vary, Proceedings of the 7th Int. Conf. on High Energy Physics problems, Dubna 1984,147.

N.P. Zotov, V.A. Saleev, V.A. Tsarev (Lebedev Inst.)
Published in JETP Lett. 40 (1984) 965-968, Pisma Zh.Eksp.Teor.Fiz. 40 (1984) 200-203

PHYSICAL REVIEW C VOLUME 45, NUMBER 4 APRIL 1992

Nuclear structure functions at $x > 1$

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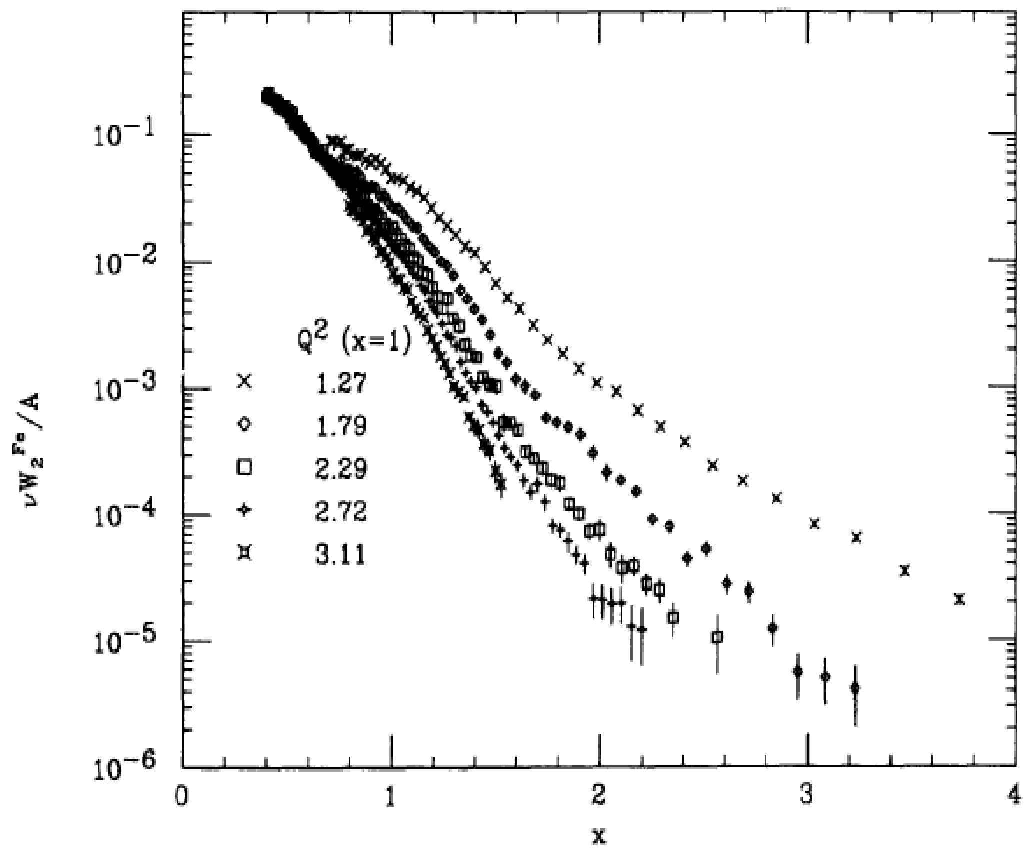

FIG. 1. Measured structure function per nucleon for Fe vs x. The Q^2 value at $x = 1$ is also listed for the different kinematics.

Z. Phys. C 63, 29–36 (1994)

ZEITSCHRIFT FÜR PHYSIK C

Nuclear structure functions in carbon near $x = 1$

BCDMS Collaboration

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D. Jamnik[8], R. Kopp[9], U. Meyer-Berkhout, A. Staude, K.-M. Teichert, R. Tirler[10], R. Voss[1], Č
Sektion Physik der Universität, München, Germany[11]

J. Feltesse, A. Misztajn, A. Ouraou, P. Rich-Hennion, Y. Sacquin, G. Smadja, P. Verrecchia, N
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Received: 1 March 1994

Abstract. Data from deep inelastic scattering of 200 GeV muons on a carbon target with squared four-momentum transfer $52\,\mathrm{GeV}^2 \le Q^2 \le 200\,\mathrm{GeV}^2$ were analysed in the region of the Bjorken variable close to $x = 1$, which is the kinematic limit for scattering on a free nucleon. At this value of x, the carbon structure function is found to be $F_2^C \approx 1.2 \cdot 10^{-4}$. The x dependence of the structure function for $x > 0.8$ is well described by an exponential $F_2^C \propto \exp(-sx)$ with $s = 16.5 \pm 0.6$.

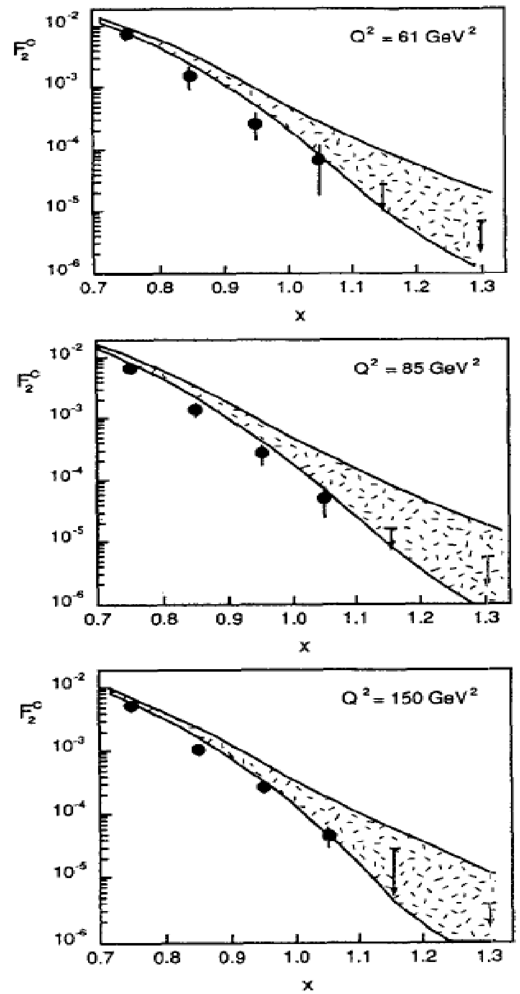

Fig. 7. The nuclear structure function $F_2^C(x)$ as a function of x, at three different values of Q^2. The hatched regions show the range of predictions of [26]

Phys.Rev.Lett. 96 (2006) 082501

Measurement of 2- and 3-Nucleon Short Range Correlation Probabilities in Nuclei

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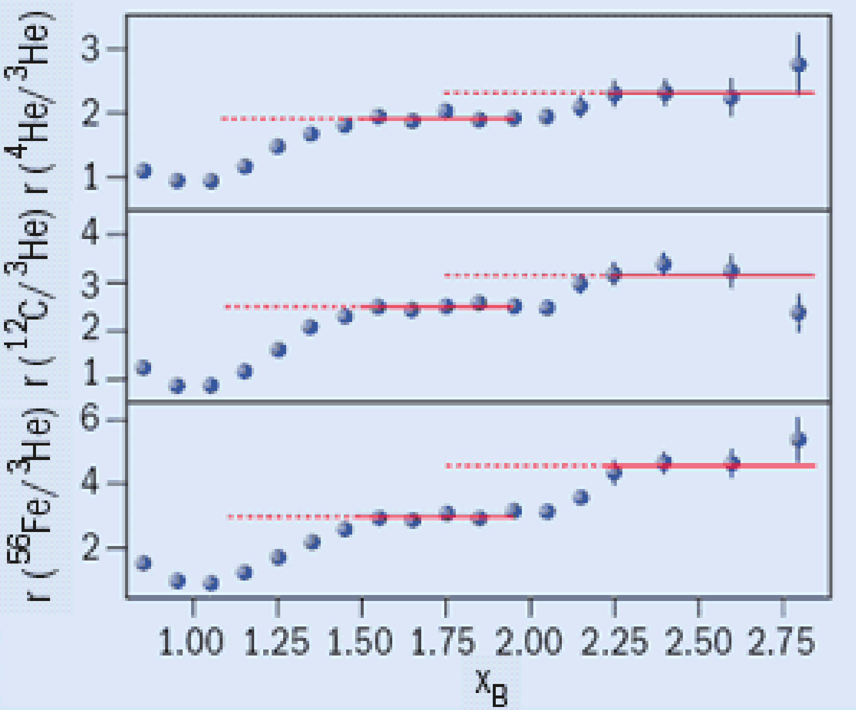
$$r(A, {}^3\mathrm{He}) = \frac{A(2\sigma_{ep} + \sigma_{en})}{3(Z\sigma_{ep} + N\sigma_{en})} \frac{3\mathcal{Y}(A)}{A\mathcal{Y}({}^3\mathrm{He})} C^A_{\mathrm{rad}}, \qquad (2)$$

where Z and N are the number of protons and neutrons in nucleus A, σ_{eN} is the electron-nucleon cross section, $\mathcal{Y}$ is the normalized yield in a given (Q^2, x_B) bin [30] and C^A_{rad} is the ratio of the radiative correction factors for A and ^{3}He ($C^A_{\mathrm{rad}} = 0.95$ and 0.92 for ^{12}C and ^{56}Fe respectively). In our Q^2 range, the elementary cross section correction factor $\frac{A(2\sigma_{ep}+\sigma_{en})}{3(Z\sigma_{ep}+N\sigma_{en})}$ is 1.14 ± 0.02 for C and ^{4}He and 1.18 ± 0.02 for ^{56}Fe. Fig. 1 shows the resulting ratios integrated over $1.4 < Q^2 < 2.6$ GeV^2.



Having these data, we know almost full (≈99%) nucleonic picture of nuclei with $A \le 56$

Fractions / Nucleus	Single particle (%)	2N SRC (%)	3N SRC (%)
^{56}Fe	**76** ± 0.2 ± 4.7	**23.0** ± 0.2 ± 4.7	**0.79** ± 0.03 ± 0.25
^{12}C	**80** ± 02 ± 4.1	**19.3** ± 0.2 ± 4.1	**0.55** ± 0.03 ± 0.18
^{4}He	**86** ± 0.2 ± 3.3	**15.4** ± 0.2 ± 3.3	**0.42** ± 0.02 ± 0.14
^{3}He	**92** ± 1.6	**8.0** ± 1.6	**0.18** ± 0.06
^{2}H	**96** ± 0.8	**4.0** ± 0.8	-----

Using the published data on (p,2p+n) [PRL,90 (2003) 042301] estimate the isotopic composition of 2N SRC in ^{12}C

$a_{pp}(^{12}C) \approx 4 \pm 2\ \%$

$a_{2N}(^{12}C) \approx 20 \pm 0.2 \pm 4.1\ \%$ → $a_{pn}(^{12}C) \approx 12 \pm 4\ \%$

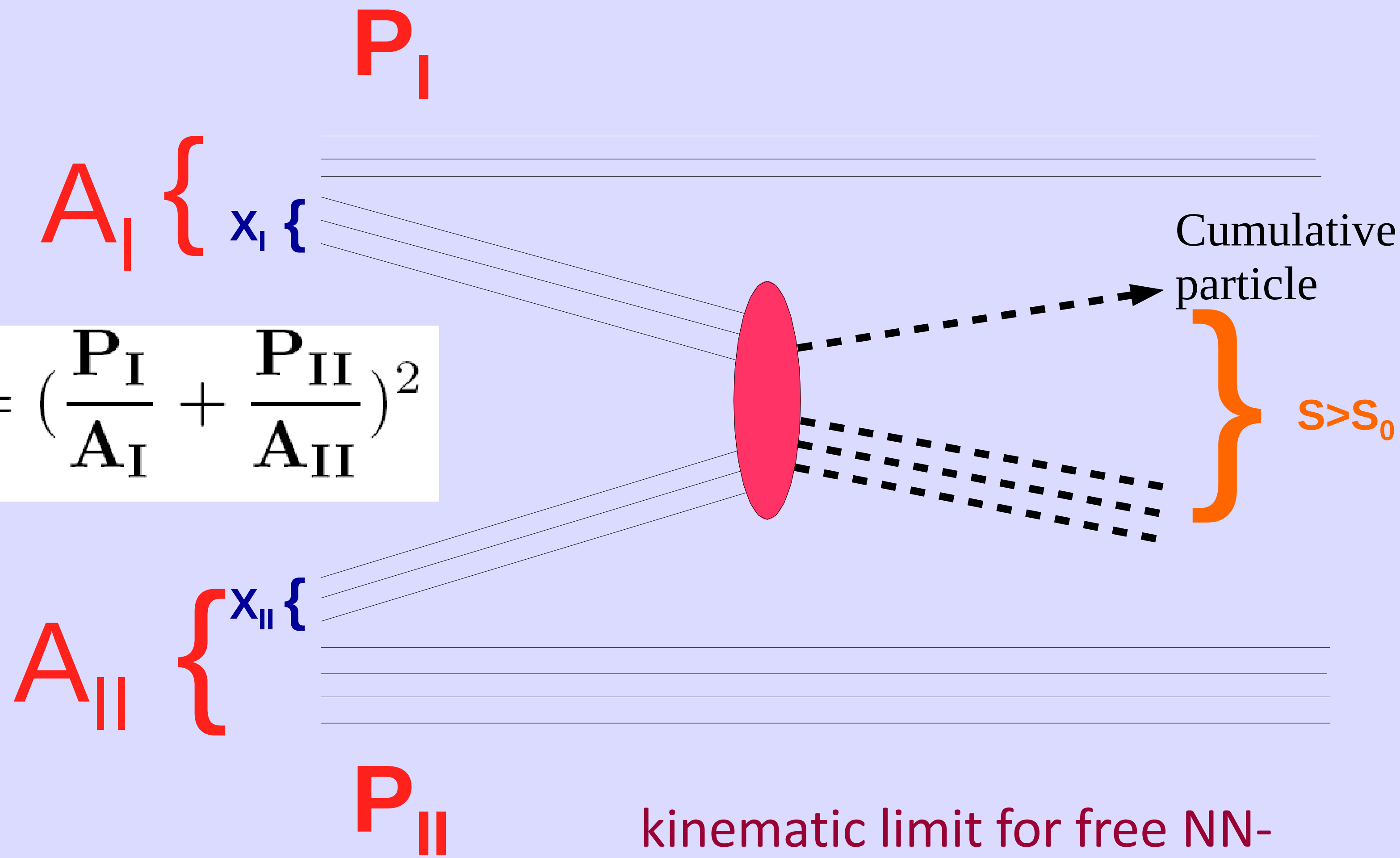
$a_{nn}(^{12}C) \approx 4 \pm 2\ \%$

SPECTRA

$(X_I \cdot M_I) + (X_{II} \cdot M_{II}) \rightarrow m_c + [X_I \cdot M_I + X_{II} \cdot M_{II} + m_2]$

Quark-parton model

$(X_I \cdot P_I) + (X_{II} \cdot P_{II}) \rightarrow M(X_I, X_{II})$



$$s_0 = \left(\frac{\mathbf{P_I}}{\mathbf{A_I}} + \frac{\mathbf{P_{II}}}{\mathbf{A_{II}}}\right)^2$$

kinematic limit for free NN-interaction

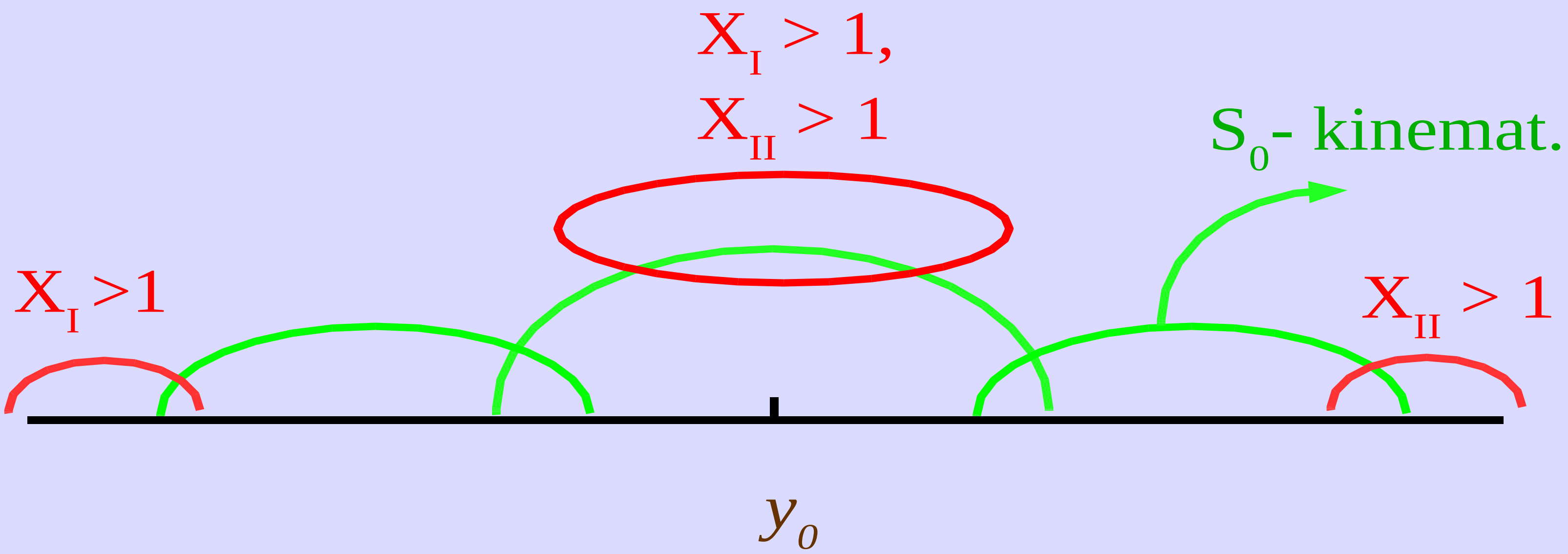
$$s_{cumulative} = (X_I \cdot \frac{P_I}{A_I} + X_{II} \cdot \frac{P_{II}}{A_{II}})^2$$

Cumulative and Subthreshold processes

$$S_{cumulative} > S_0$$

$X_I \in [0, A_I]$ and $X_{II} \in [0, A_{II}]$

$X_I = X_{II} = 1$ - for free NN-interaction kinematical borders S_0



Cumulative processes:

1) $X_I \le 1$ and $X_{II} > 1$ } Fragmentation
2) $X_{II} \le 1$ and $X_I > 1$ } regions
3) $X_I > 1$ and $X_{II} > 1$ Central region

A.V. Efremov (1976) Parton description

A + B → C + X

$$\varepsilon \frac{d^3\sigma}{d^3 p} = \int dx\,dy\,dz\,F_B(y)F_A(x)G_C(z)v(xys, t\frac{x}{z}, u\frac{y}{z})$$

X_{II} X_{I}

Fragmentation regions

$\mu + N_{min} \cdot m \rightarrow m_c + [\, N_{min} \cdot m + \Delta]$

for $E_\mu >> m_i$, E_c

$$X = N_{\min} = Q \cong \frac{(E_c - \beta_\mu \cdot P_c \cdot \cos\theta_c)}{m} + \ldots \equiv X_I (X_{II})$$

Stavinsky (1970's)

Common case for AA-collisions

V.S. Stavinsky JINR Rapid Communications N18-86, p.5 (1986)

$(X_I \cdot M_I) + (X_{II} \cdot M_{II}) \rightarrow m_c + [X_I \cdot M_I + X_{II} \cdot M_{II} + m_2\,]$

$$S_{\min}^{1/2} = \min(S^{1/2}) = \min[(X_I \cdot P_I + X_{\mathrm{II}} \cdot P_{II})^{1/2}]$$

Volume 67B, number 1 PHYSICS LETTERS 14 March 1977

ТЕОРИЯ

LARGE MOMENTUM PION PRODUCTION IN PROTON NUCLEUS COLLISIONS AND THE IDEA OF "FLUCTUONS" IN NUCLEI

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and

V.K. LUKYANOV and A.I. TITOV
Joint Institute for Nuclear Research, Dubna, USSR

Received 27 January 1977

It is shown that in proton-nucleus collisions, the production of pions with large momenta can be explained by the assumption of the existence of nuclear density fluctuations ("fluctuons") at short distances of the nucleon core radius order, with the mass of several nucleons.

The purpose of this note is to realize the idea [4] that the cumulative effect is connected largely with a suggestion on the existence in nuclei of the so-called fluctuons. Earlier fluctuons were proposed [7] in order to understand the nature of the "deuteron peak" in the pA-scattering cross section at large momentum transfers [8] and also to interpret the pd-scattering cross section [9]. Compressional fluctuations of mass $M_k = km_p$ of nucleons in the small volume $V_\xi = \frac{4}{3}\pi r_\xi^3$ where r_ξ is the fluctuon radius were assumed.

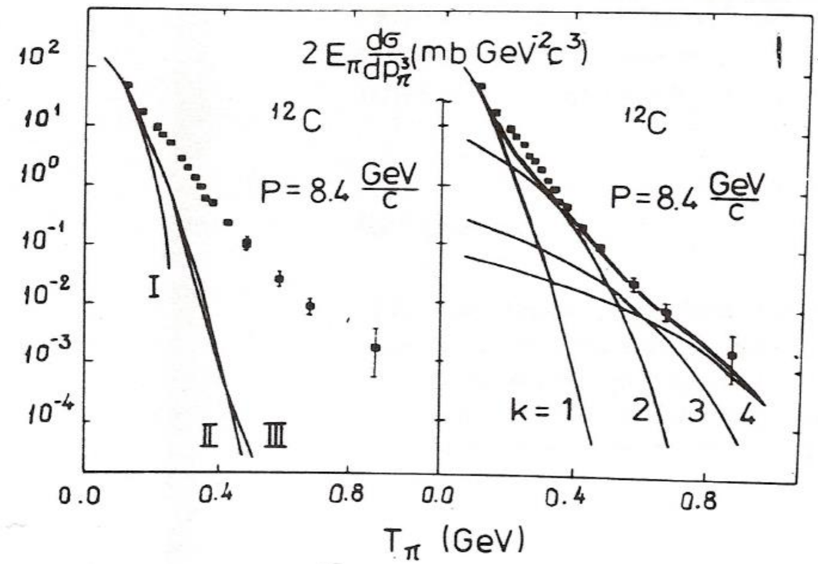


Fig. 1. (a) Calculations of the invariant pion production cross section for ^{12}C: I – for the free proton target; II – with fermi motion; III – the relativization effect. (b) The contributions of separate fluctuons with mass $M_k = km_p$ where k is the order of cumulativity.

Fluctons Probability inside nuclei

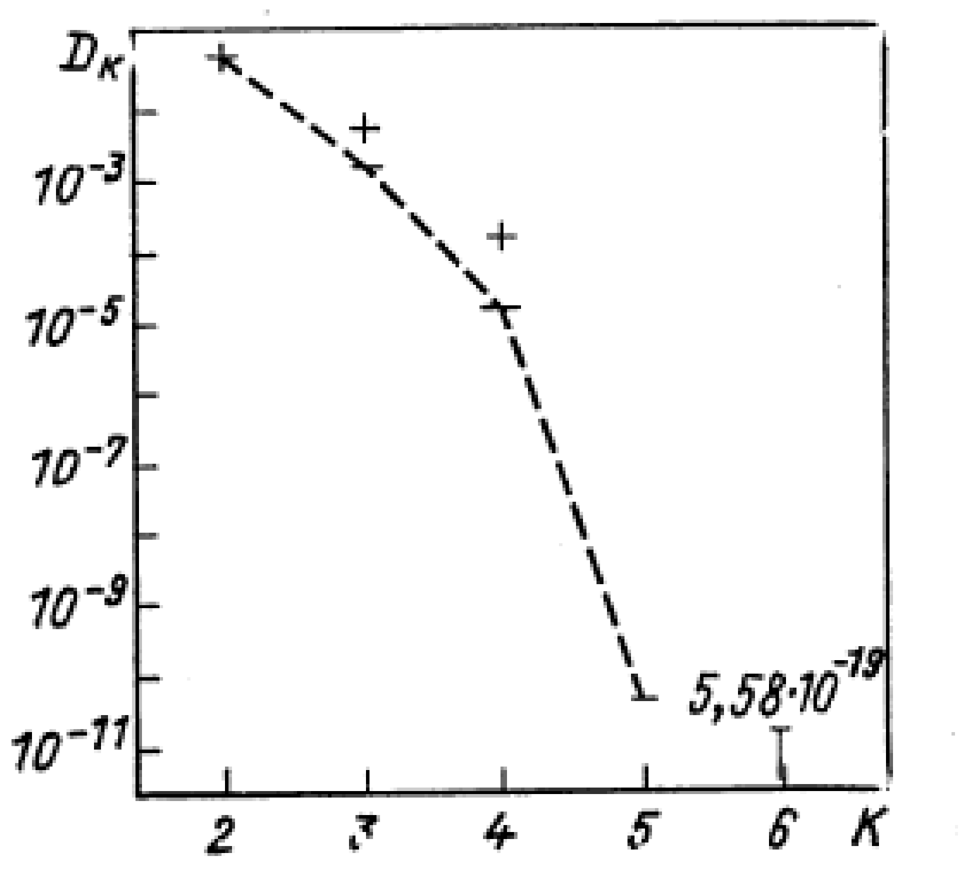


Рис. 19. Вероятность существования флуктонов с k нуклонами в ядрах

A - dependence (1974-…)

$$\varepsilon \frac{d\sigma}{dp}(p + A \to \pi) \sim \begin{cases} A - heavy\_nuclei \\ A^{n>1} - light\_nuclei \end{cases}$$

$$\varepsilon \frac{d\sigma}{dp}(p + A \to B) \sim \begin{cases} A^{5|/3} - for\_d \\ A^{2} - for\_t \end{cases}$$

The same time Cronin team at FNAL have seen about the same A-dependence for pA(for 200, 300, 400 GeV protons) high p_T Particle production

Schroeder L.S. et al. **// Phys. Rev. Lett. 1979. V. 43, n. 24. P. 1787**
A.M.Baldin et al., Yad.Fiz., 20, 1975, p.1201

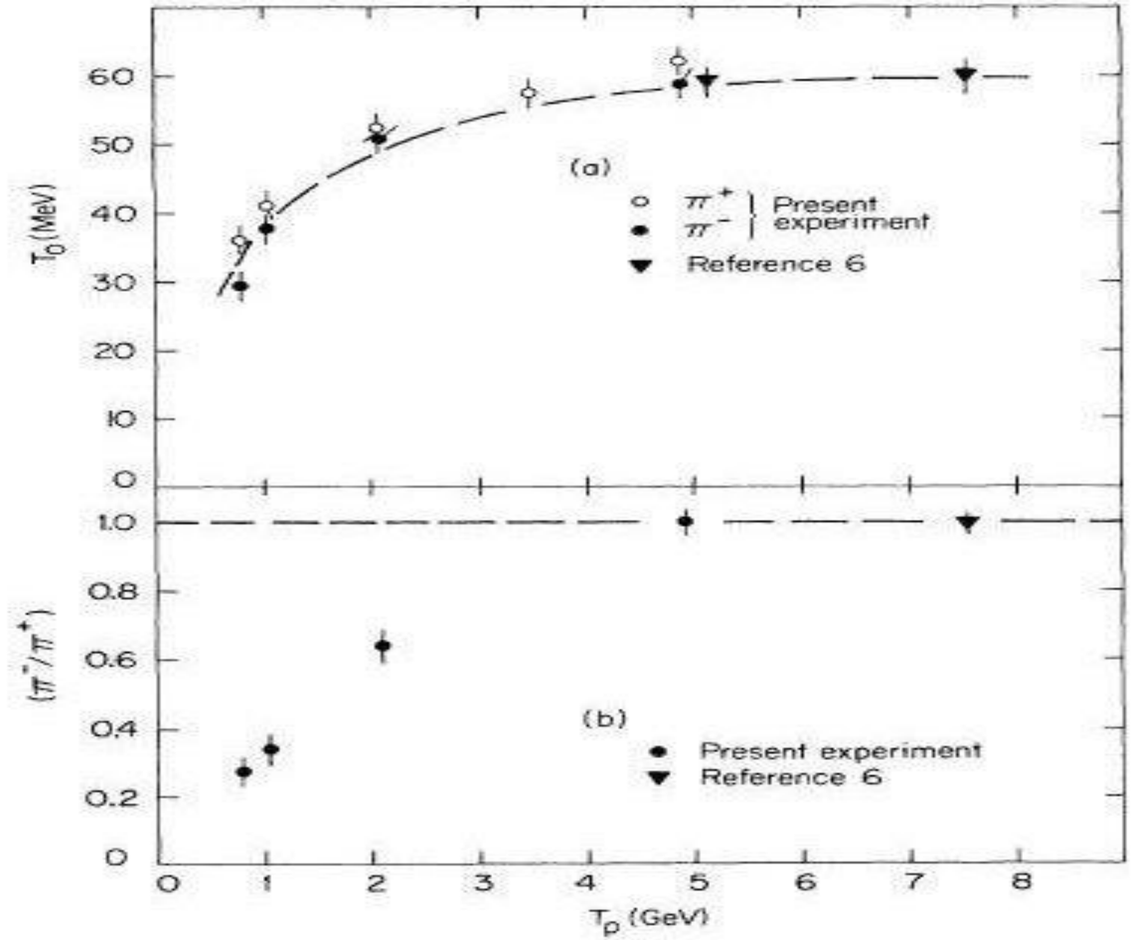
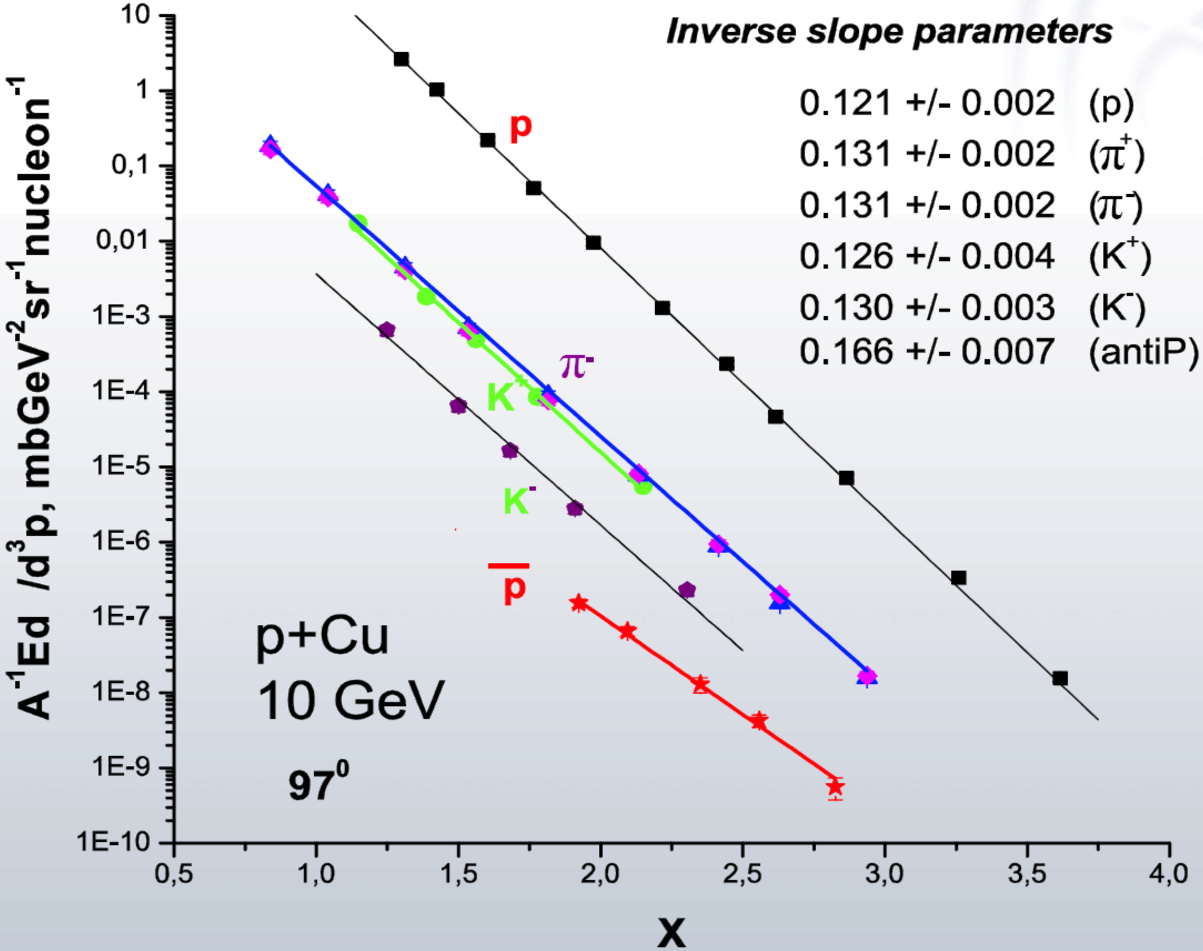


FIG. 1. Energy dependence of (a) T_0 parameter for pions, and (b) the π^-/π^+ ratio at 180° obtained by integrating each spectra up to 100 MeV for p-Cu collisions from 0.8 to 4.89 GeV. The dashed curve in both cases refers to the predictions of the "effective-target" model (Refs. 3 and 4).



FAS @ ITEP (Boyarinov et.al Yad.Fiz 57 (1994) 1452)

X – minimal target mass [m_N] needed to produce particle

A.A. Baldin's parameterization

Phys. At. Nucl. 56(3), p.385(1993)

$$\Pi = \frac{1}{2}(X_I^2 + X_{II}^2 + 2\cdot X_I \cdot X_{II} \cdot \gamma_{I,II})^{\frac{1}{2}} = \frac{1}{2\cdot m}\cdot S_{\min}^{\frac{1}{2}}$$

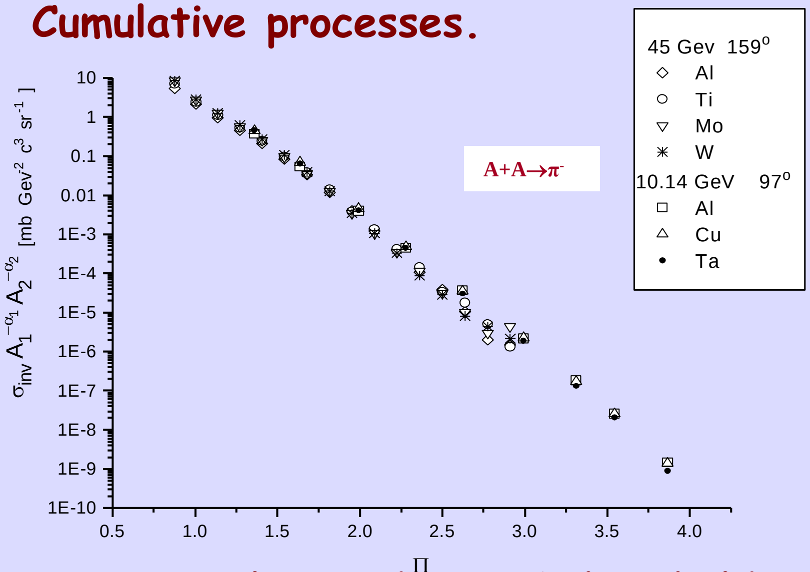
$$\gamma_{I,II} = \frac{(P_I \cdot P_{II})}{M_I \cdot M_{II}}$$

Inclusive data parameterization

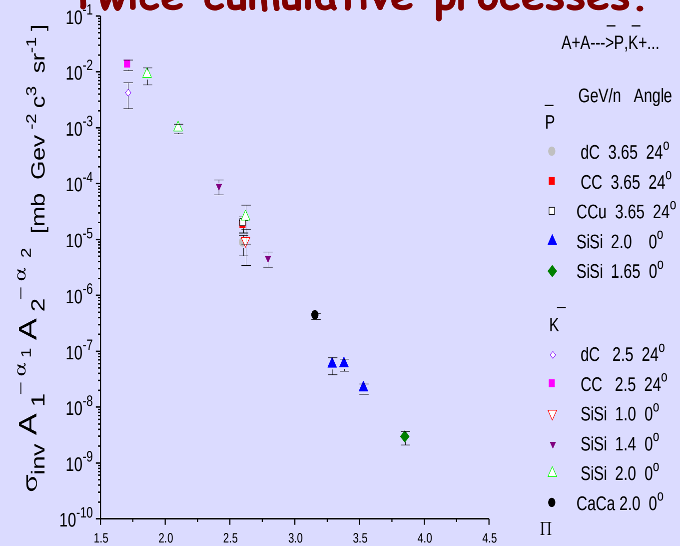
$$E\cdot\frac{d^3\sigma}{dp^3} = C_1 \cdot A_I^{\frac{1}{3}+\frac{X_I}{3}} \cdot A_{II}^{\frac{1}{3}+\frac{X_{II}}{3}} \cdot \exp(-\frac{\Pi}{C_2}),$$

$$C_1 = 2200[mb\cdot GeV^{-2}\cdot c^3\cdot sr^{-1}], C_2 = 0.127$$

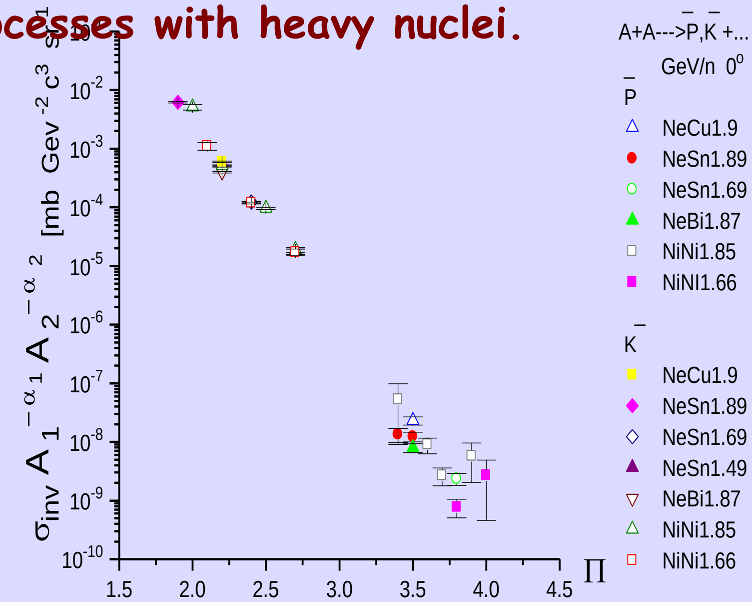
Cumulative processes.



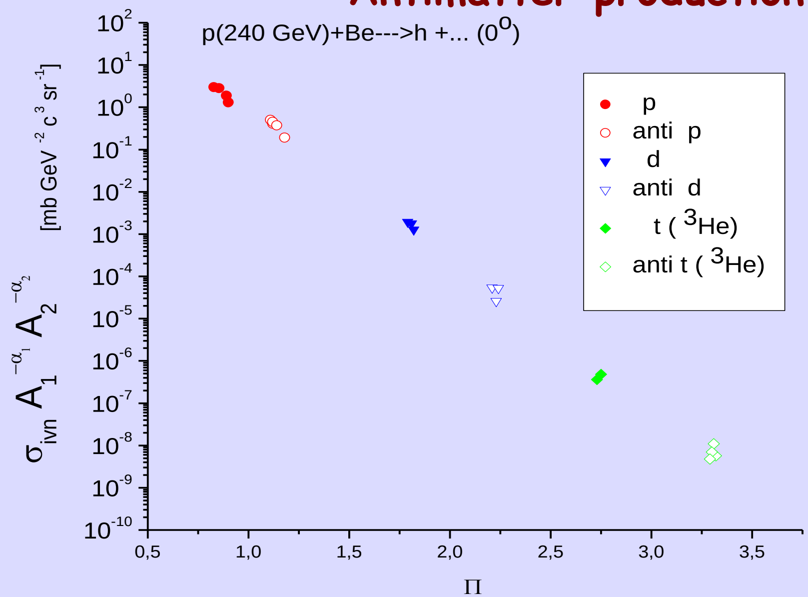
Twice cumulative processes.



Twice cumulative deep subthreshold processes with heavy nuclei.



Antimatter production.



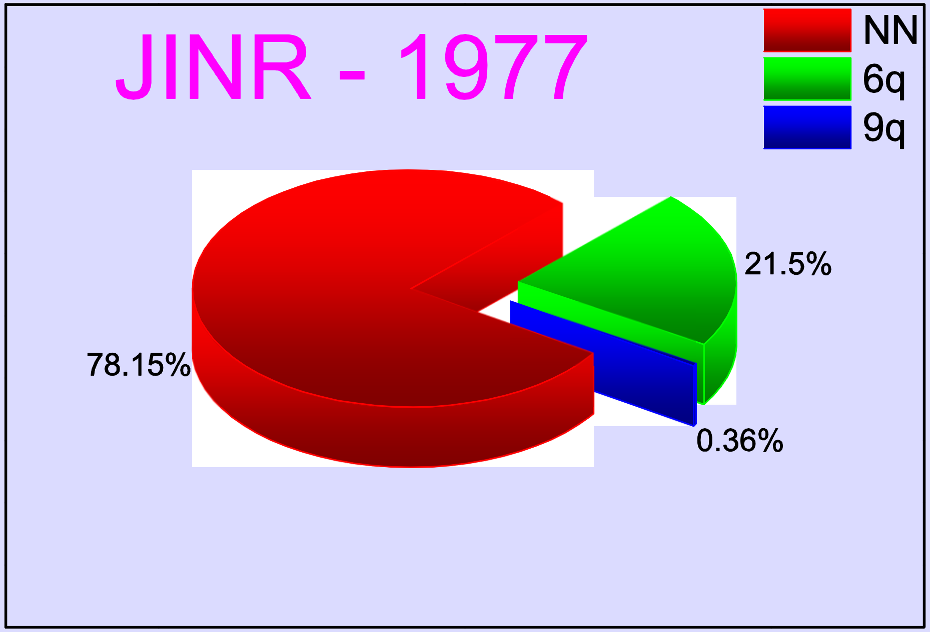
^{12}C - structure

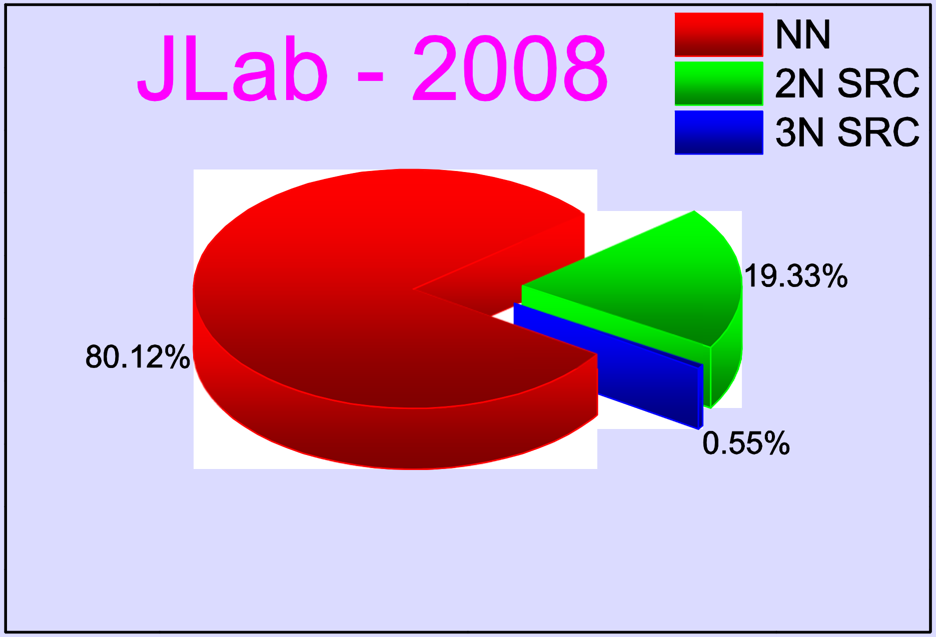
RNP - program at JINR

V.V.B., V.K.Lukyanov, A.I.Titov, PLB, 67, 46(1977)

eA - program at JLab

R.Subedi et al., Science 320 (2008) 1476-1478
e-Print: arXiv:0908.1514 [nucl-ex]





Correlation Measurements

And why high p_T probes?

PHYSICAL REVIEW C VOLUME 51, NUMBER 2 FEBRUARY 1995

Probing short-range nucleon correlations in high-energy hard quasielastic *pd* reactions

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M. Strikman
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(Received 4 May 1994)

The main new result of this paper is the calculation of the initial and final state interaction in a hard exclusive proton-deuteron reaction. We find that for spectator momenta ≤ 350 MeV/c and $p_t \sim 0$ the effect of initial and final state interactions can be accounted for by rescaling the cross section calculated within the plane-wave impulse approximation. We show that the strong dependence of the amplitude for NN hard scattering on the collision energy and the exclusive nature of the quasielastic large-angle *pd* scattering can be used to magnify the effects of short-range nucleon correlations. The feasibility to investigate in this kinematical region the role of relativistic effects in the deuteron wave function is demonstrated by comparing the predictions of different relativistic approaches. It is demonstrated also that in these kinematics the final and initial state interactions reduce sensitivity of the cross section to uncertainties in the high-momentum component of the deuteron wave function. We also find that for $p_z \sim 0$ and 150 MeV/$c \geq p_t \geq 50$ MeV/c initial and final state interaction strongly reduce the cross section while relativistic effects are very small. This kinematic is optimal for color-transparency studies. Binding effects due to short-range correlations in the deuteron are discussed as well.

PACS number(s): 13.75.Cs, 25.10.+s, 25.40.Ep

E850/EVA (BNL)

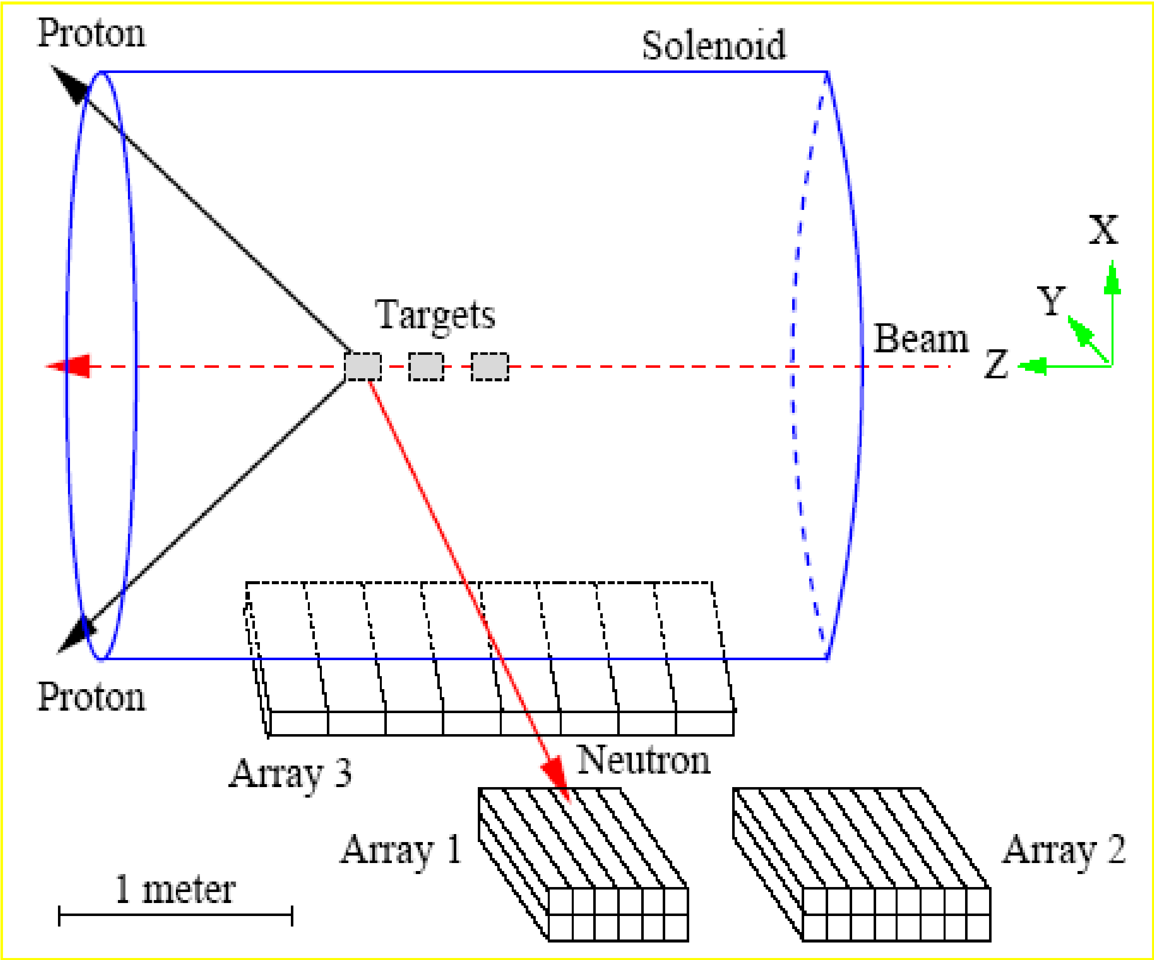

Figure I.3: A schematic view of the EVA solenoid and the neutron counters in the 1998 measurement.

n-p Short-Range Correlations from $(p, 2p + n)$ Measurements

A. Tang,[1] J. W. Watson,[1] J. Aclander,[2] J. Alster,[2] G. Asryan,[4,3] Y. Averichev,[8] D. Barton,[4] V. Baturin,[6,5] N. Bukhtoyarova,[4,5] A. Carroll,[4] S. Gushue,[4] S. Heppelmann,[6] A. Leksanov,[6] Y. Makdisi,[4] A. Malki,[2] E. Minina,[6] I. Navon,[2] H. Nicholson,[7] A. Ogawa,[6] Yu. Panebratsev,[8] E. Piasetzky,[2] A. Schetkovsky,[6,5] S. Shimanskiy,[8] and D. Zhalov[6]

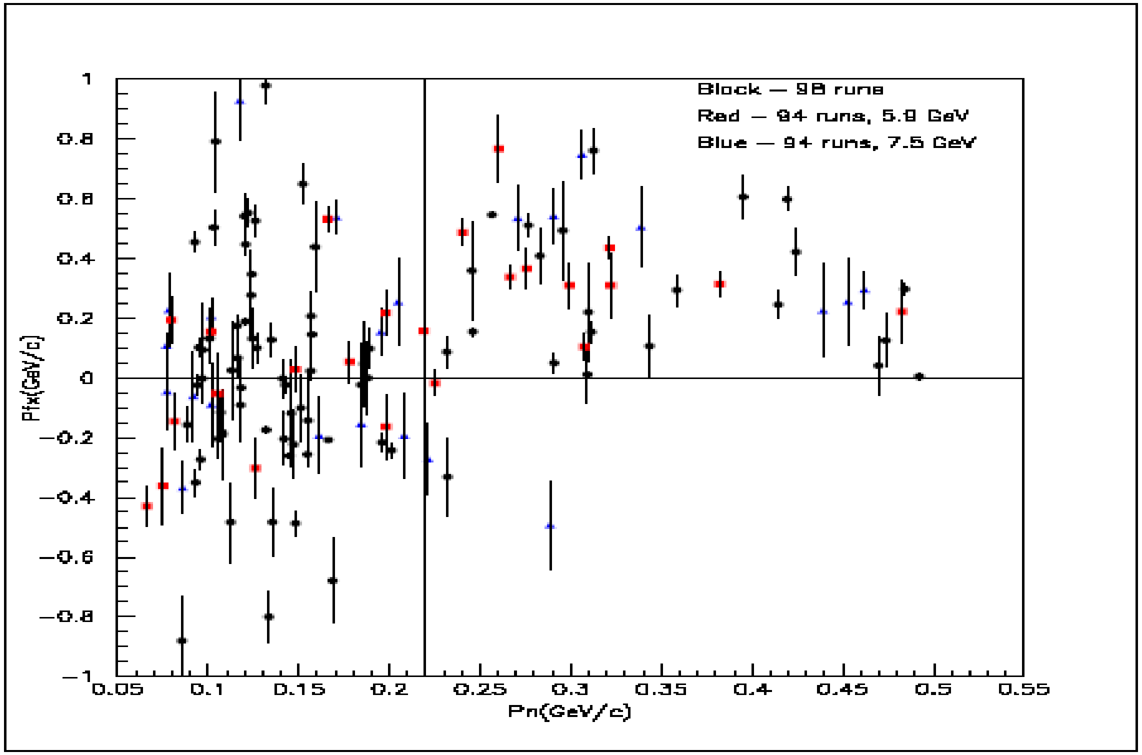

Figure I.5: The vertical component of the target nucleon momentum vs. the total neutron momentum.The positive vertical axis is the upward direction. The events shown are for triple coincidences of the neutron with the two high energy protons emerging from the QE $C(p, 2p)$ reaction. The squares are for the 5.9 GeV/c incident beam and the triangles are for 7.5 GeV/c. The dots are preliminary unpublished data from the 1998 runing period. We associate the events in the upper right corner with NN SRC.

Physica Scripta. Vol. 48, 210–213, 1993

Distortions of the Spectra of Cumulative Mesons by Multiscattering in Nuclei

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Joint Institute for Nuclear Research, Dubna, SU-101000 Moscow, Russia

Abstract

The quantitative estimates of multiscattering distortions of momentum spectra for cumulative pions and kaons in $p + A \rightarrow \pi(K^{\pm}) + X$ reaction at angles close to 180° are reported. The calculations for C, Al, Mo, W nuclei were made by using Monte Carlo simulation on the basis of the intranuclear cascade model. The fluctuon model of cumulative particles generation was used to give initial momentum and angular distributions of mesons. Multiscattering on the intranuclear nucleons causes the difference between the initial and observed (distorted by FSI-final state interactions in nuclei) meson spectra, which increases with increasing of atomic number. Due to the rescattering and absorption of pions and kaons by intranuclear nucleons their absolute yields decrease by about 2–5 times in the momentum range $p = 0.3$–1 GeV/c for medium and heavy nuclei. The relative distortions of the slope parameters of the momentum spectra are 3–10%. The correction of cross sections with account of FSI leads to the amplification of A-dependences for π, $K^{\pm}$ and to their bringing together. Taking into account FSI is also important when the ratios of particles yield of different types are considered. The K^{+}/K^{-}-ratio corrections can reach a factor of about 3. Obtained values of distortions effects for cumulative reactions demonstrate evidently the necessity to account of FSI for data obtained in experiments with nuclei at momenta of reaction products < 1–2 GeV/c.

Local processes in NN kinematic

Production of anti-protons in the proton - nucleus interactions at 10.1-Gev/c. A.A. Sibirtsev, G.A. Safronov, G.N. Smitnov, Yu.V. Trebuchovsky (Moscow, ITEP). 1991. Published in Yad.Fiz. 53 (1991) 191-199

$$p + A \rightarrow h(0^0) + X$$

ИЗМЕРЕНИЕ СЕЧЕНИЙ ОБРАЗОВАНИЯ АДРОНОВ С ИМПУЛЬСОМ ДО 2 ГэВ/c В ПРОТОН-ЯДЕРНЫХ СТОЛКНОВЕНИЯХ ПРИ 70 ГэВ

БАРКОВ Л. М., ЗОЛОТОРЁВ М. С., КОТОВ В. И. [1], ЛЕБЕДЕВ П. К., МАКАРЬИНА Л. А. [2], МИШАКОВА А. П. [2], ОХАПКИН В. С., РЗАЕВ Р. А. [1], САХАРОВ В. П. [1], СМАХТИН В. П., ШИМАНСКИЙ С. С.

ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ СО АН СССР

(Поступила в редакцию 2 августа 1982 г.)

Sov.J.Nucl.Phys.37:732,1983

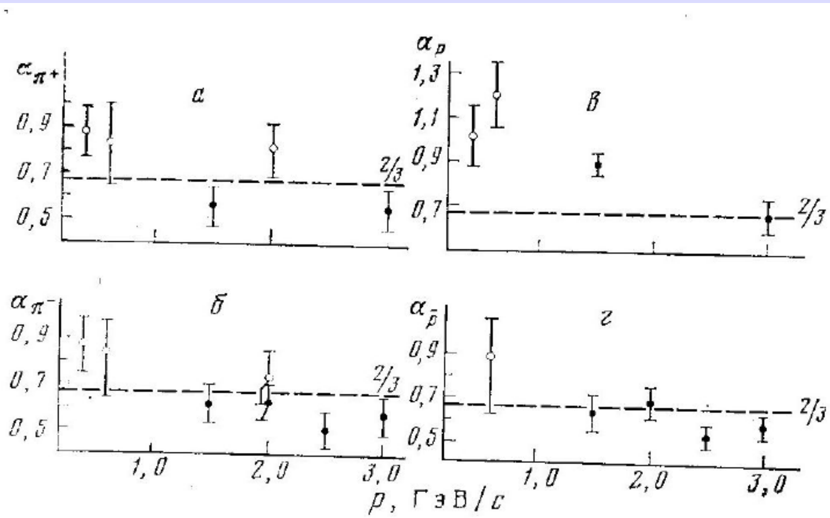

Рис. 4. Зависимость показателя α от импульса для положительных пионов (a), отрицательных пионов ($б$), протонов ($в$) и антипротонов ($г$) (● – [11], ○ – данная работа)

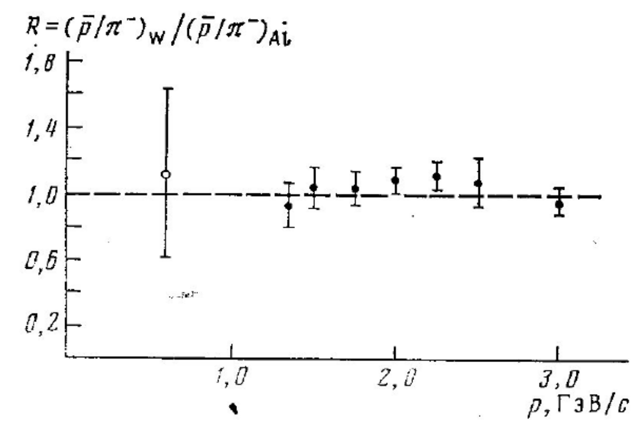

Рис. 6. Сравнение отношений выходов антипротонов и отрицательных пионов для W и Al мишеней в зависимости от импульса частиц (● – [11], ○ – данная работа)

arXiv:0908.0062v1 [nucl-ex] 2 Aug 2009

Short-Distance Structure of Nuclei

D W Higinbotham[1], E Piasetzky[2] and S A Wood[1]

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Abstract.

One of Jefferson Lab's original missions was to further our understanding of the short-distance structure of nuclei. In particular, to understand what happens when two or more nucleons within a nucleus have strongly overlapping wave-functions; a phenomena commonly referred to as short-range correlations. Herein, we review the results of the (e, e'), $(e, e'p)$ and $(e, e'pN)$ reactions that have been used at Jefferson Lab to probe this short-distance structure as well as provide an outlook for future experiments. ‡

Probing Cold Dense Nuclear Matter

R. Subedi,[1] R. Shneor,[2] P. Monaghan,[3] B. D. Anderson,[1] K. Aniol,[4] J. Annand,[5] J. Arrington,[6] H. Benaoum,[7,8] F. Benmokhtar,[9] W. Bertozzi,[3] W. Boeglin,[10] J.-P. Chen,[11] Seonho Choi,[12] E. Cisbani,[13] B. Craver,[14] S. Frullani,[13] F. Garibaldi,[13] S. Gilad,[3] R. Gilman,[11,15] O. Glamazdin,[16] J.-O. Hansen,[11] D. W. Higinbotham,[11]* T. Holmstrom,[17] H. Ibrahim,[18] R. Igarashi,[19] C.W. de Jager,[11] E. Jans,[20] X. Jiang,[15] L.J. Kaufman,[9,22] A. Kelleher,[17] A. Kolarkar,[23] G. Kumbartzki,[15] J. J. LeRose,[11] R. Lindgren,[14] N. Liyanage,[14] D. J. Margaziotis,[4] P. Markowitz,[10] S. Marrone,[24] M. Mazouz,[25] D. Meekins,[11] R. Michaels,[11] B. Moffit,[17] C. F. Perdrisat,[17] E. Piasetzky,[2] M. Potokar,[26] V. Punjabi,[27] Y. Qiang,[3] J. Reinhold,[10] G. Ron,[2] G. Rosner,[28] A. Saha,[11] B. Sawatzky,[14,29] A. Shahinyan,[30] S. Širca,[26,31] K. Slifer,[14] P. Solvignon,[29] V. Sulkosky,[17] G. M. Urciuoli,[13] E. Voutier,[25] J. W. Watson,[1] L.B. Weinstein,[18] B. Wojtsekhowski,[11] S. Wood,[11] X.-C. Zheng,[3,6,14] and L. Zhu[32]

The protons and neutrons in a nucleus can form strongly correlated nucleon pairs. Scattering experiments, where a proton is knocked-out of the nucleus with high momentum transfer and high missing momentum, show that in ^{12}C the neutron-proton pairs are nearly twenty times as prevalent as proton-proton pairs and, by inference, neutron-neutron pairs. This difference between the types of pairs is due to the nature of the strong force and has implications for understanding cold dense nuclear systems such as neutron stars.

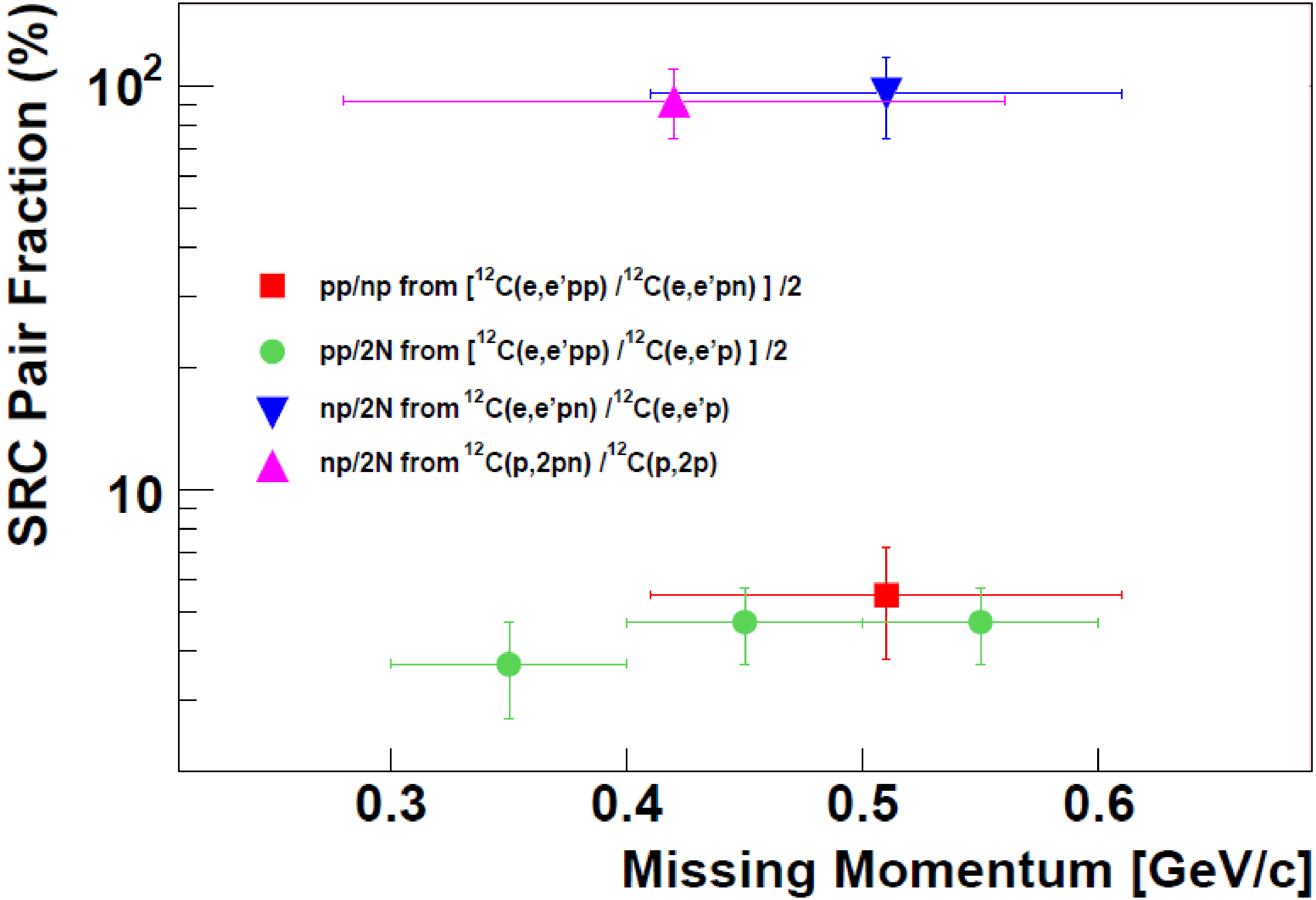
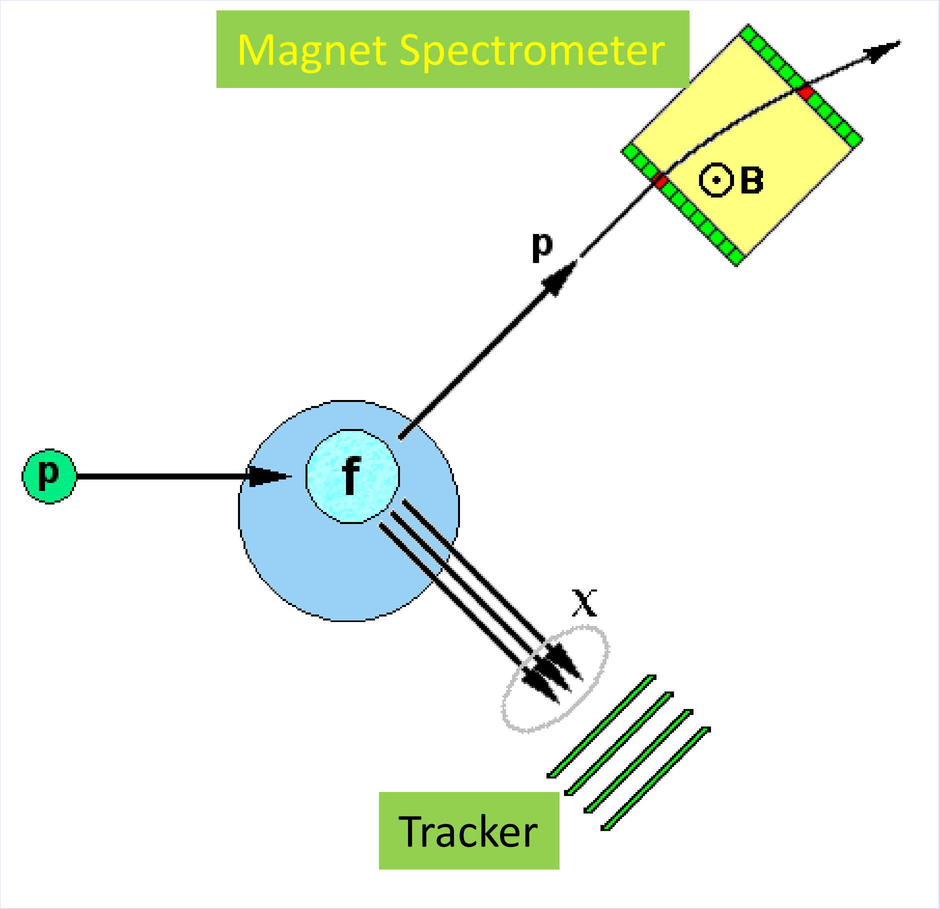


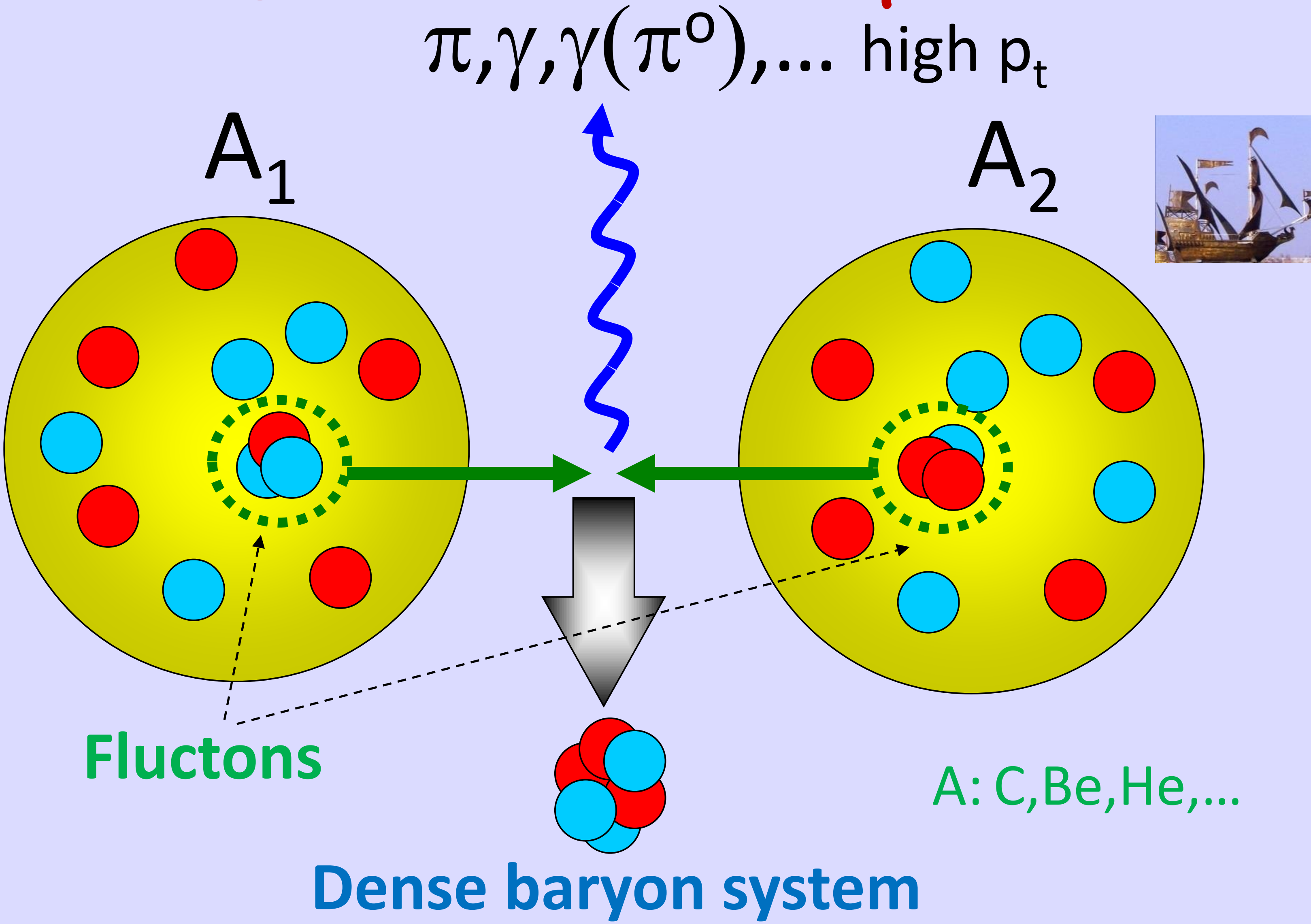
Figure 7. The fractions of correlated pair combinations in carbon as obtained from the $(e, e'pp)$ to $(e, e'pn)$ reactions [48], as well as from previous $(p, 2pn)$ data [45]. From Subedi R *et al.* (Hall A) 2008 *Science* **320** 1476. Reprinted with permission from AAAS.

The Correlation Measurements with hadrons
pA->h+X

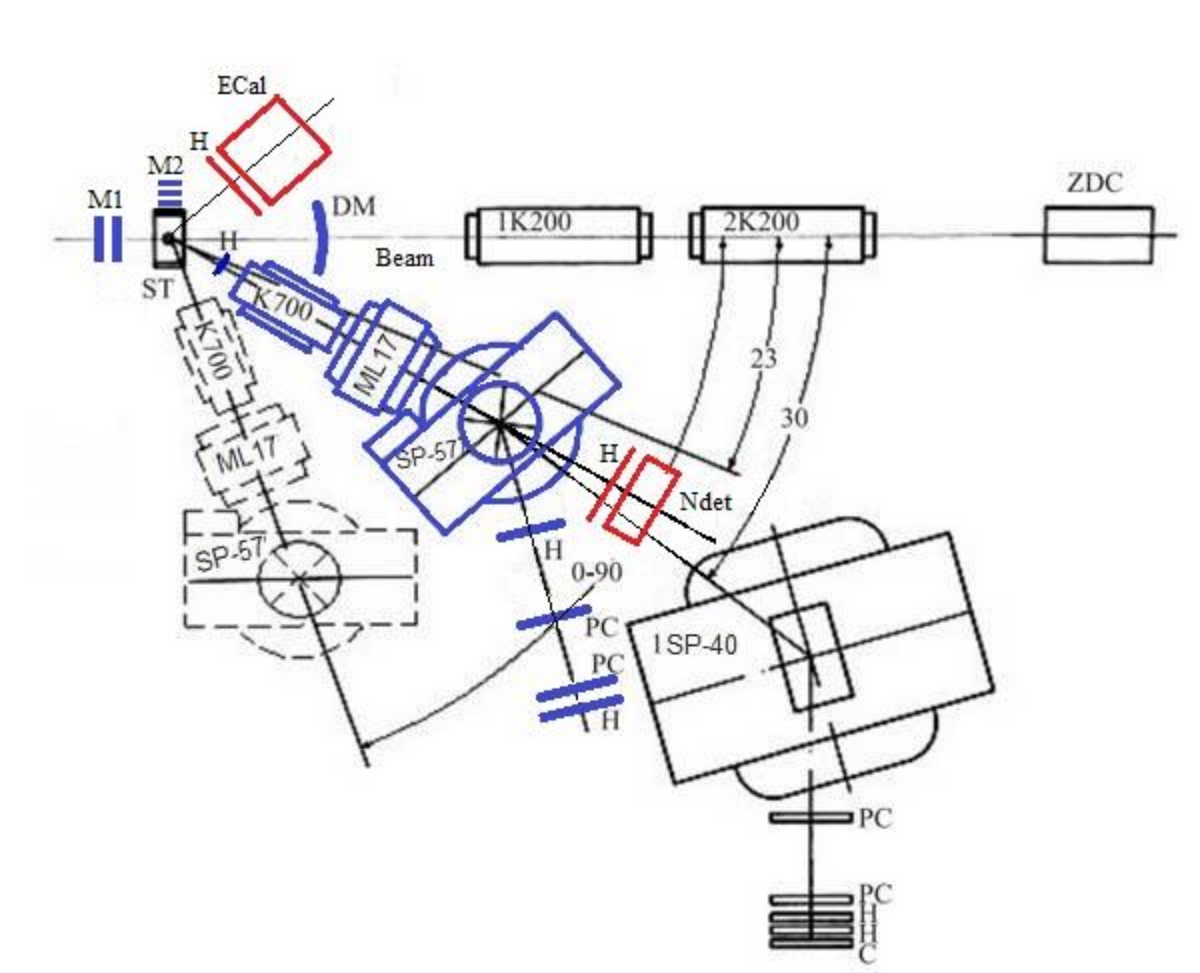
$x_T \sim 1$



FLINT@ITEP: $^{12}C + Be \to \gamma + X$

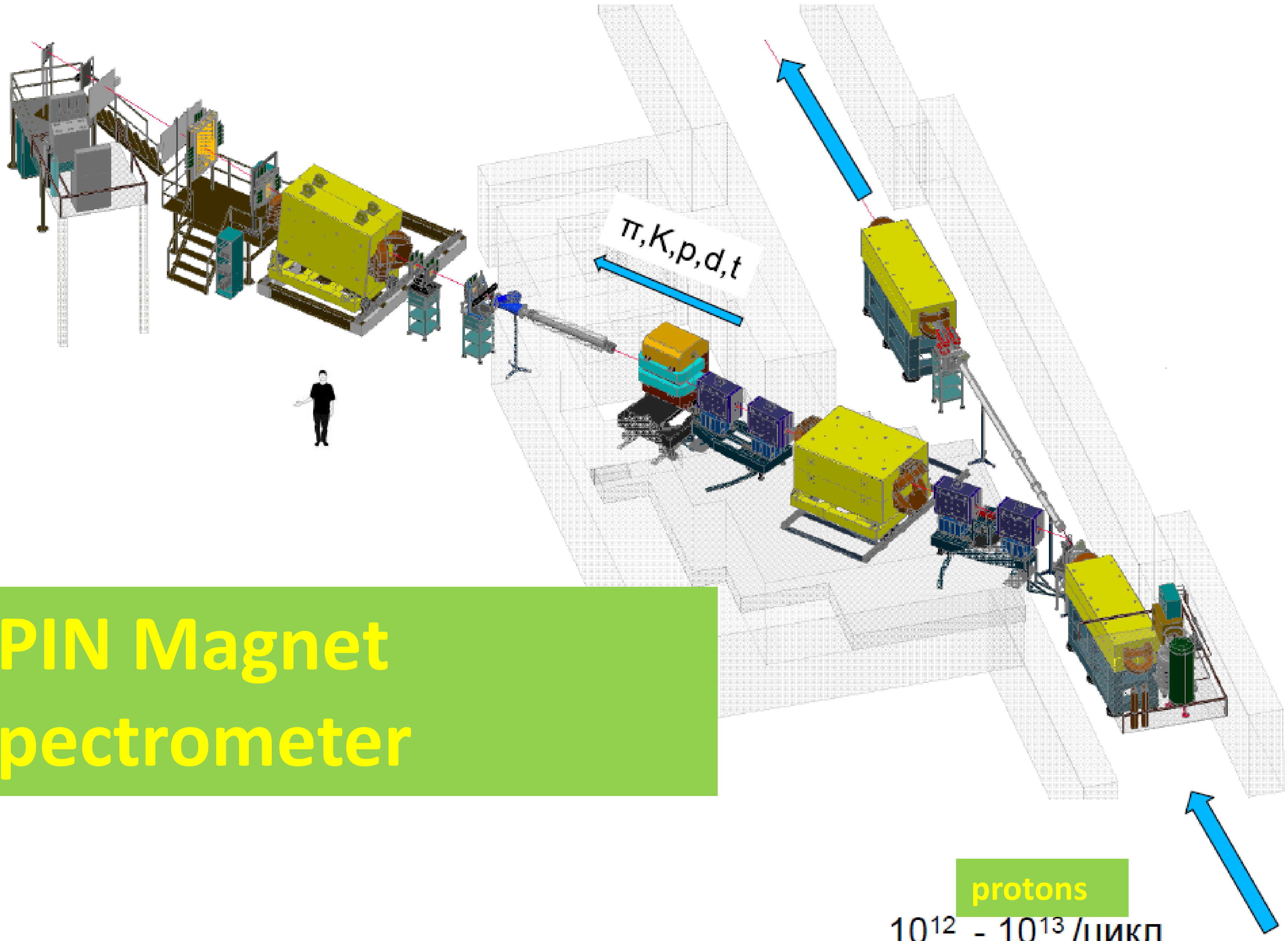


Experiment MARUSYA-FLINT at JINR



Scheme of experimental set-up MARUSYA-FLINT: ST - target station, M1, M2- scintillation monitors, DM- multiplicity detectors, H- scintillation hodoscopes, ZDC - hadron calorimeter, PC - proportional chambers, C – cherenkov counter, ML17, K100 - quadrupole lens, SP-57, SP-40 - dipole magnets, ECal - electromagnetic calorimeter

Magnetic spectrometer:
For P_t = 0,3-0,8 GeV/s used magnet SP-57
For P_t = 0,6-2 GeV/s used magnet SP-57 and SP-40
Coordinate system on scintillation hodoscopes provide resolution 2-5% in area 0,3-0,8 GeV/s



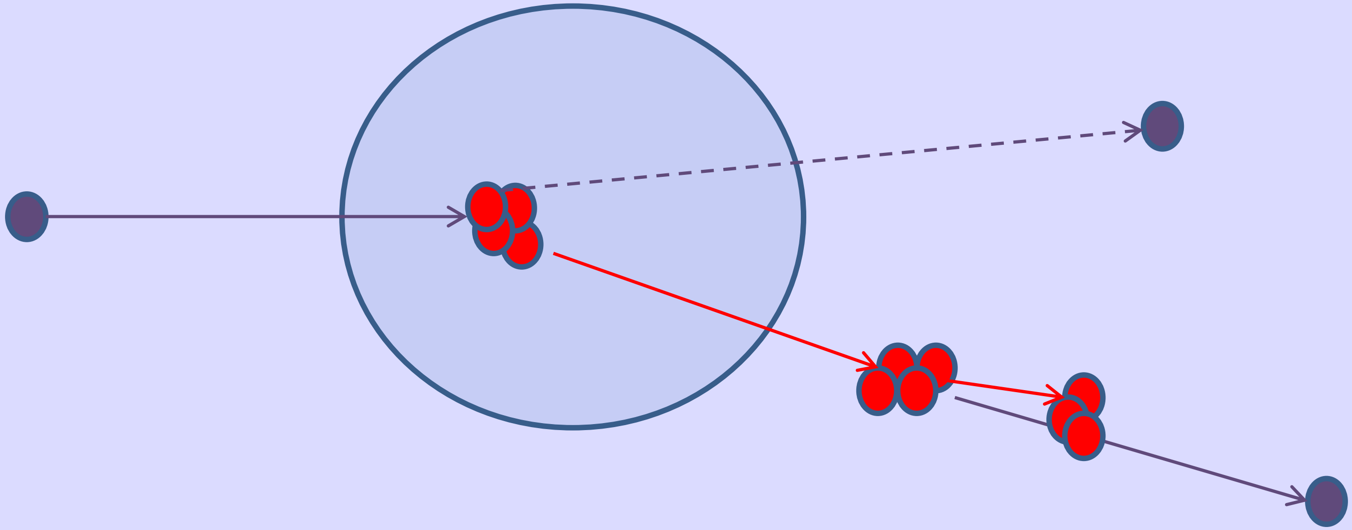
SPIN Magnet Spectrometer

protons

10^{12} - 10^{13} /цикл

Flucton fragmentation – same side flow

Momentum up to 6.5 GeV/c and p_T up to 3.5 GeV/c

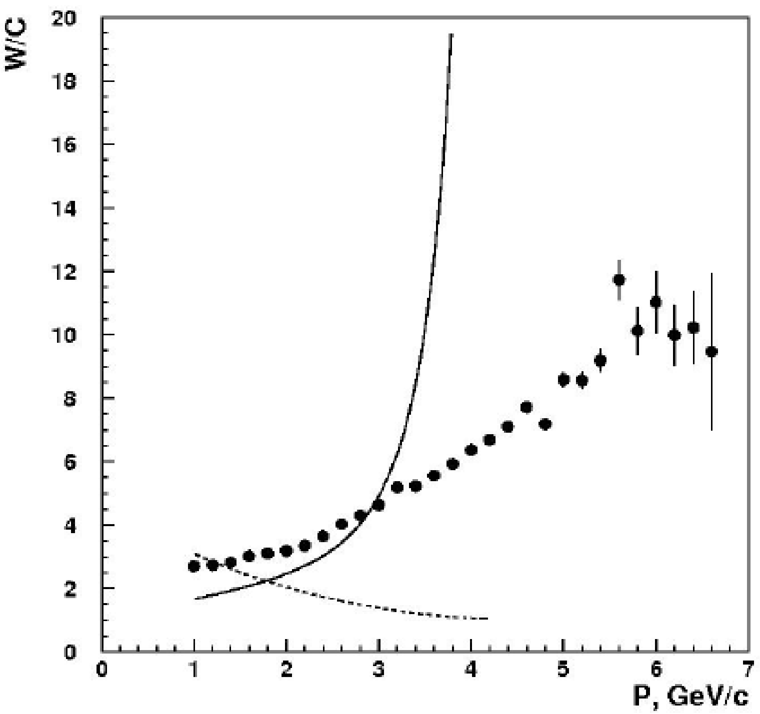


Physics of Atomic Nuclei, 2013, Vol. 76, No. 10, pp. 1213–1218

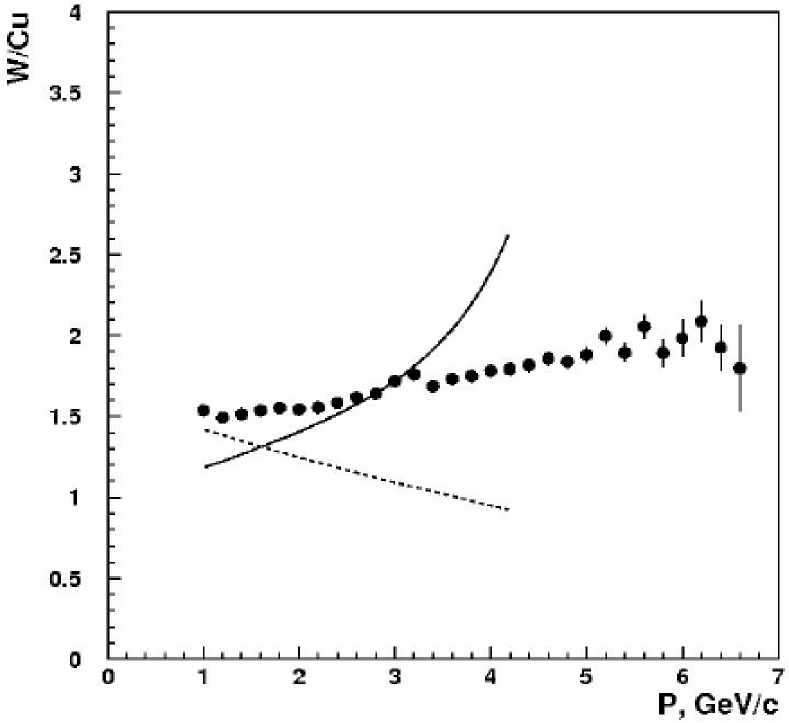
h⁺ – spectrum

Сплошные кривые: HIJING 1.3 http://www-nsdth.lbl.gov/~xnwang/hijing/doc.html
Пунктирные кривые: UrQMD 3.3 http://urqmd.org/

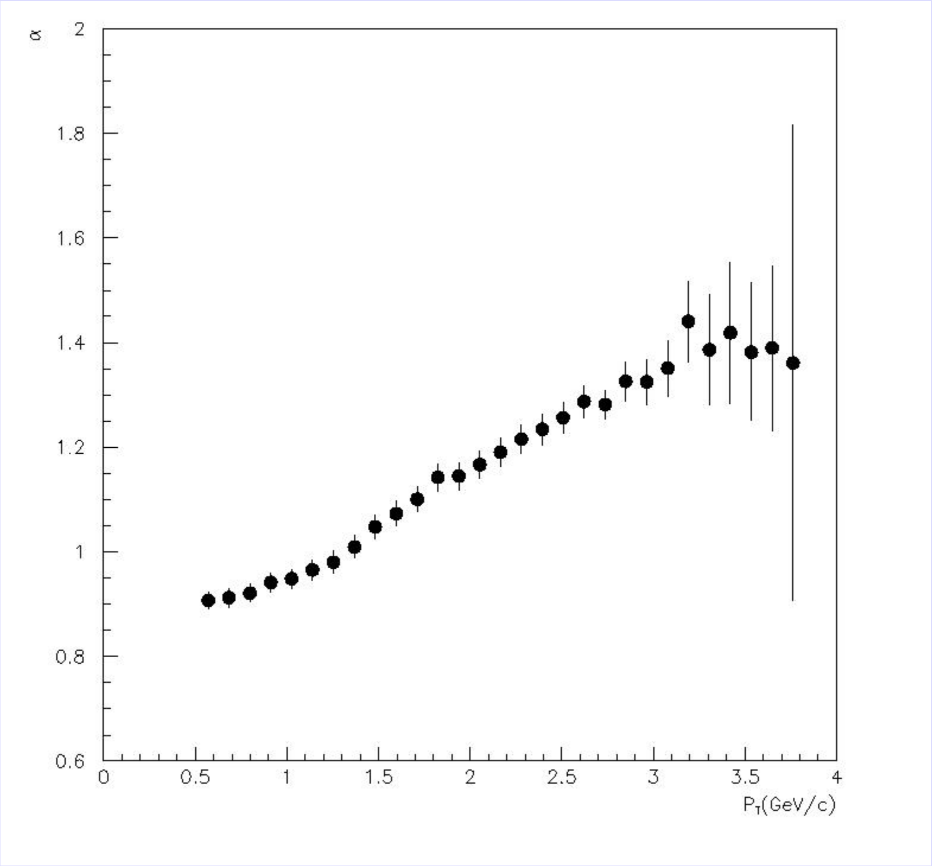
W / C



W / Cu



A-dependence

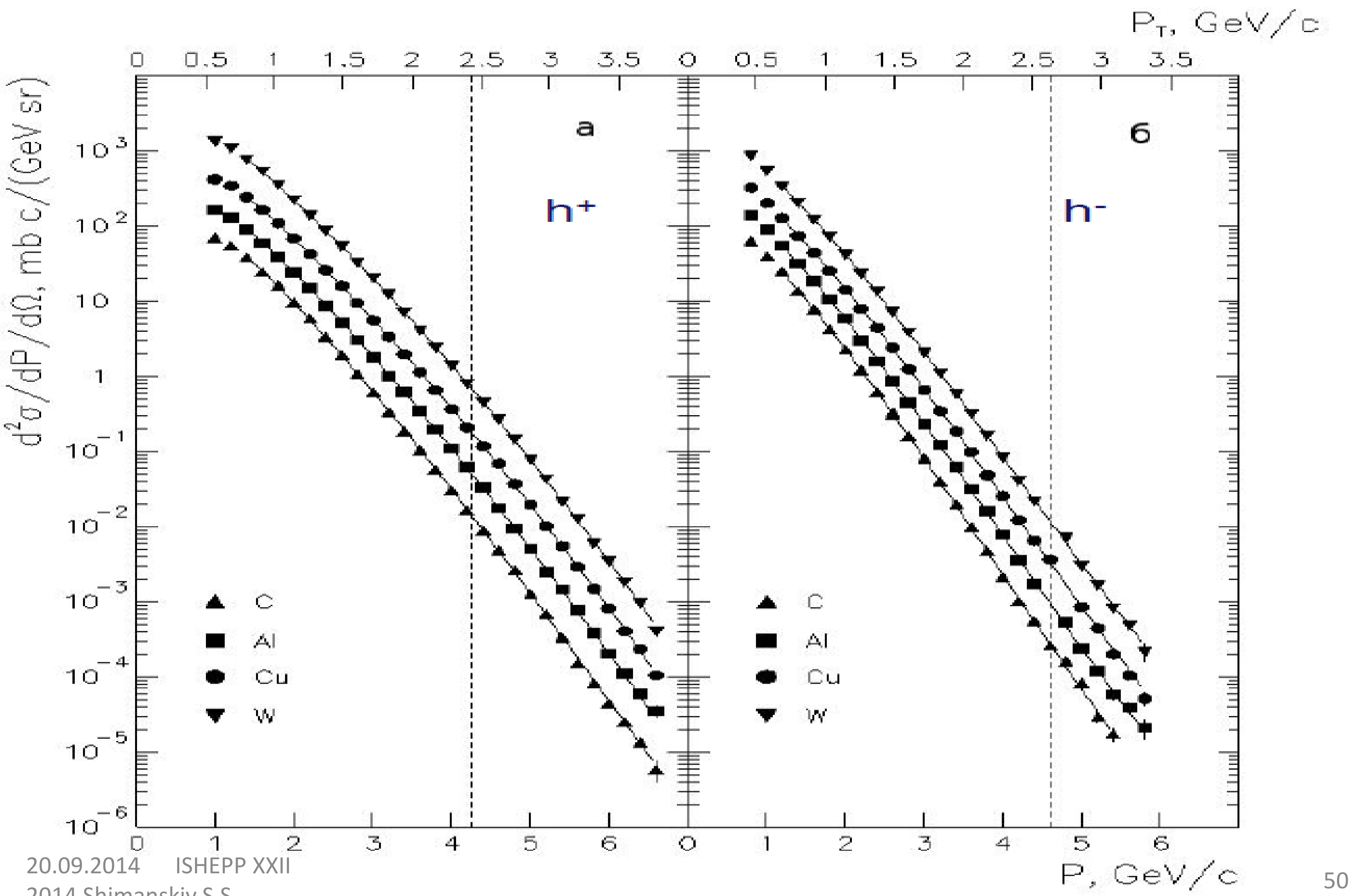


$$\sigma \sim A^{\alpha}$$

$$\alpha = \ln\left(\frac{\sigma_w}{\sigma_c}\right) / \ln\left(\frac{A_w}{A_c}\right)$$

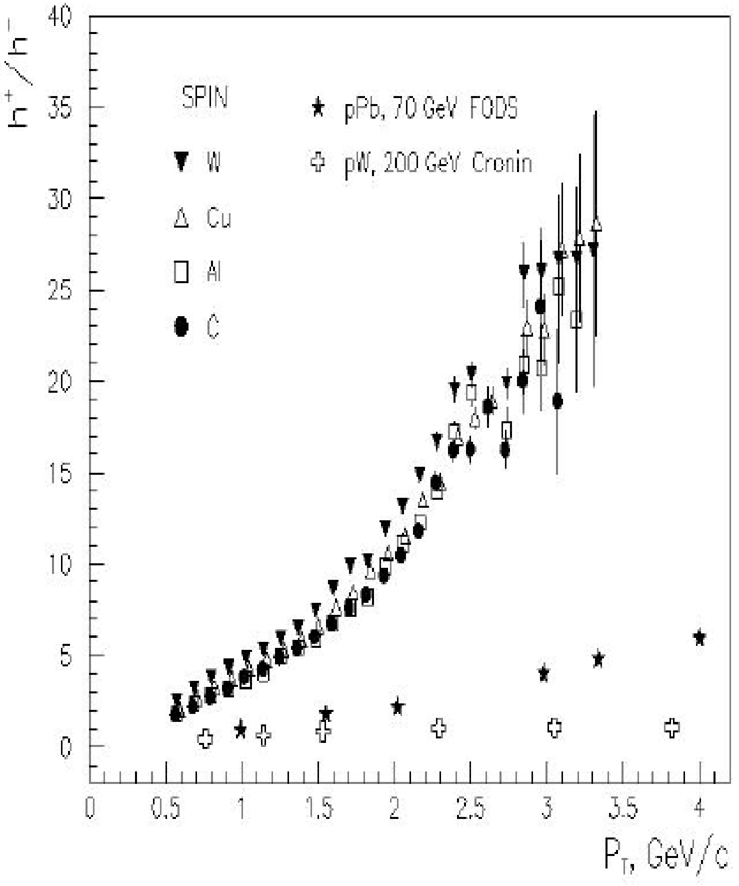
We deal with multinucleon configuration, but local this interaction?

[2012]

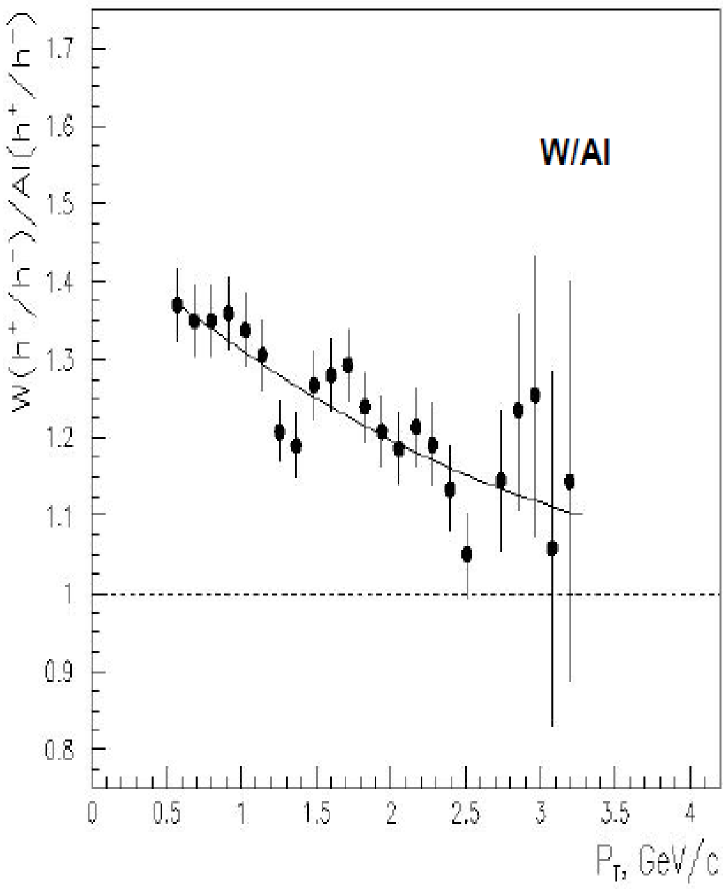


P_T, GeV/c
0
0.5
1
1.5
2
2.5
3
3.5
d²σ/dP/dΩ, mb c/(GeV sr)
10³
10²
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
a
6
h⁺
h⁻
C
Al
Cu
W
P, GeV/c
0
1
2
3
4
5
6

Ratio

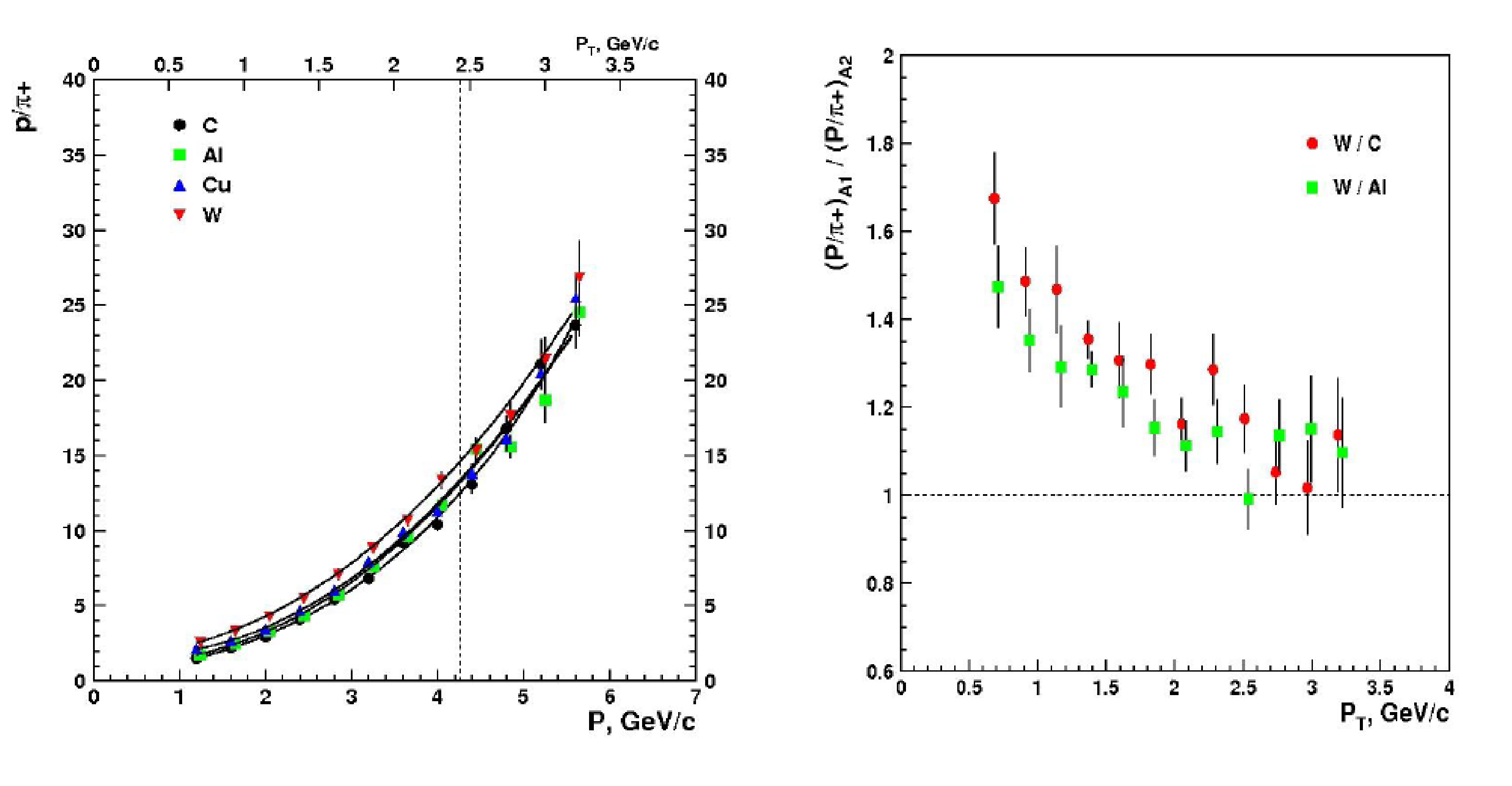


h^+/h^-
SPIN
W
Cu
Al
C
pPb, 70 GeV FODS
pW, 200 GeV Cronin
P_T, GeV/c



$W(h^+/h^-)/Al(h^+/h^-)$
W/Al
P_T, GeV/c

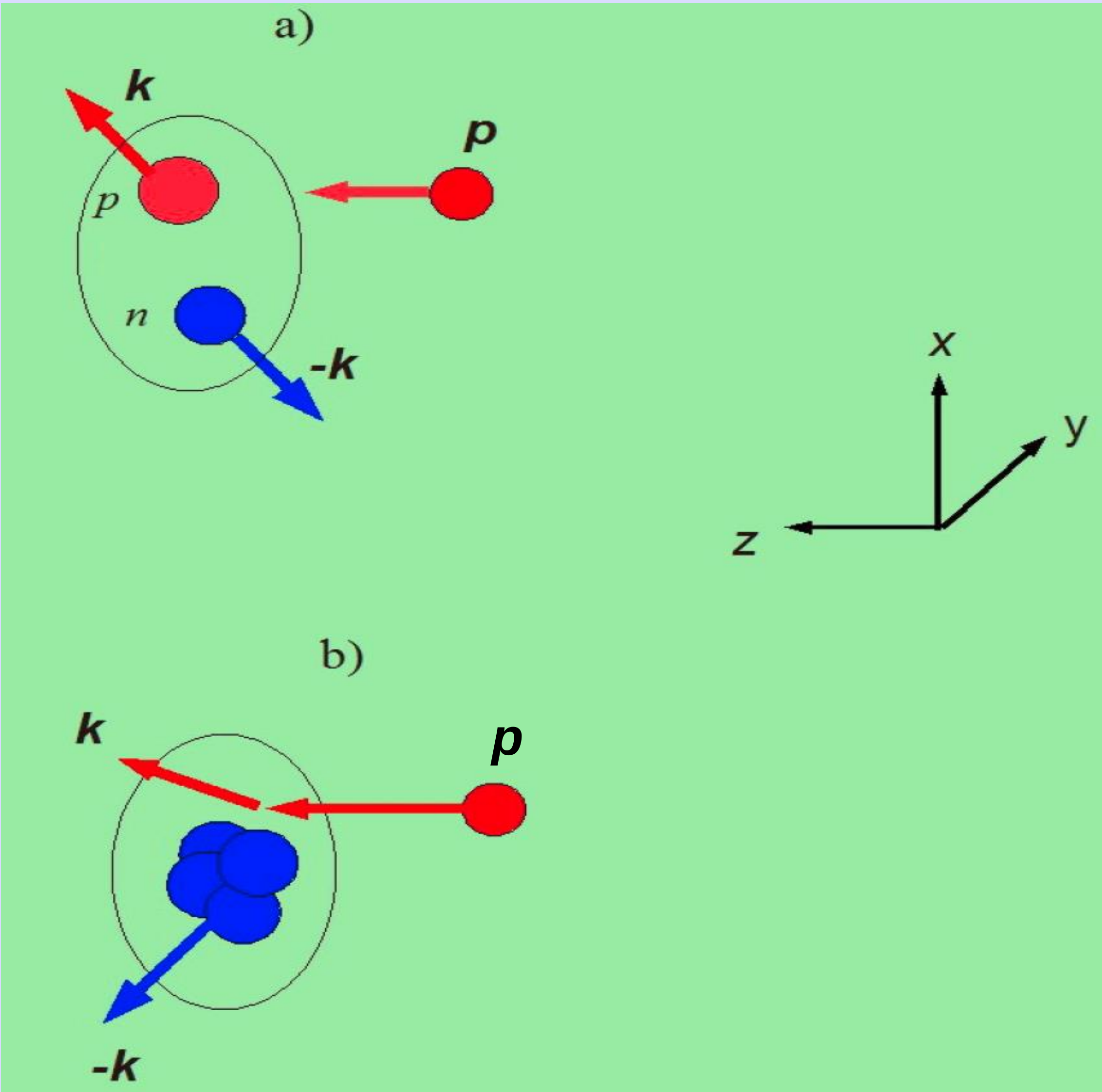
Ratio p/π^+ (2013)



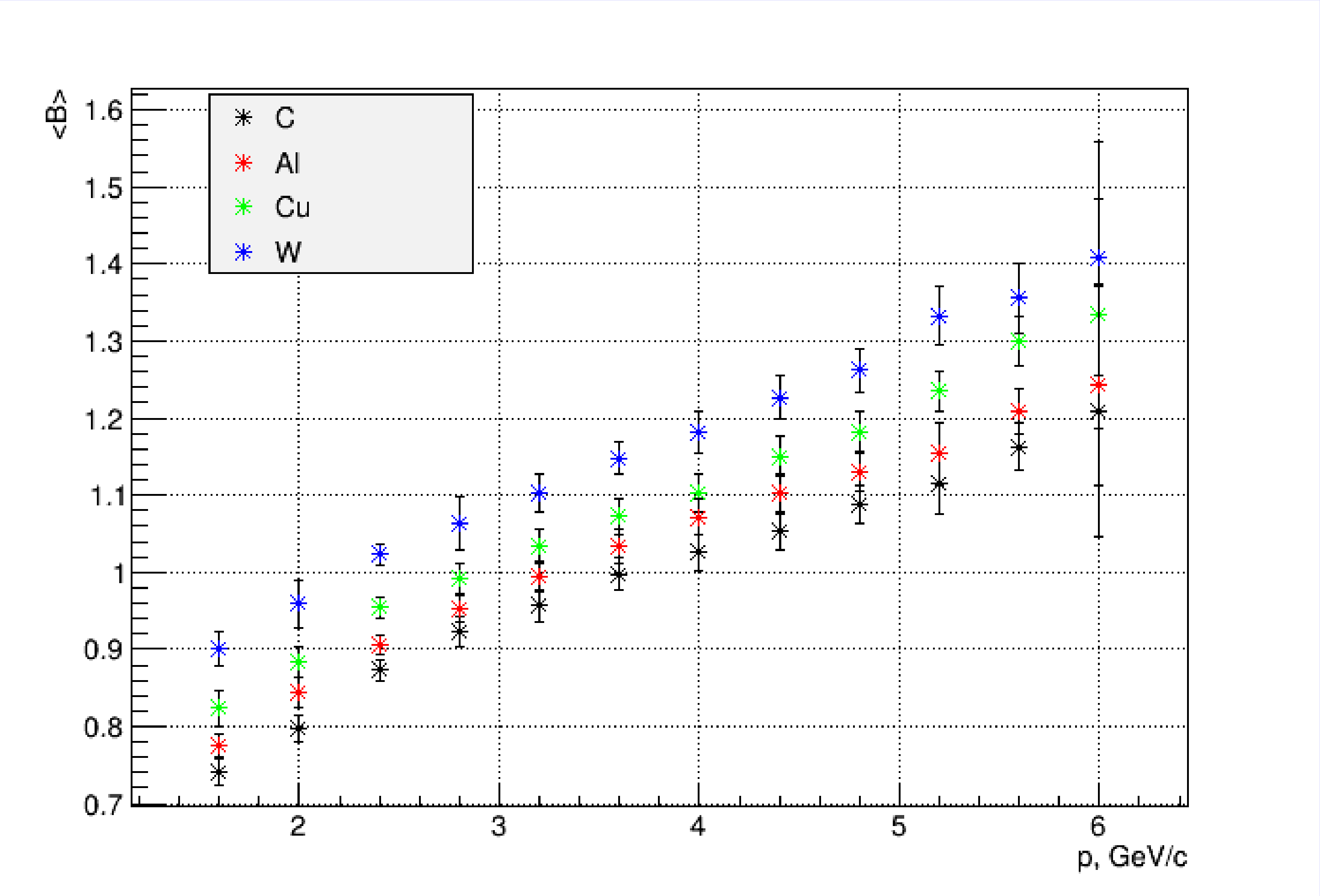
Knot out cold dense nuclear configurations

SRC configuration

Multiquark configuration



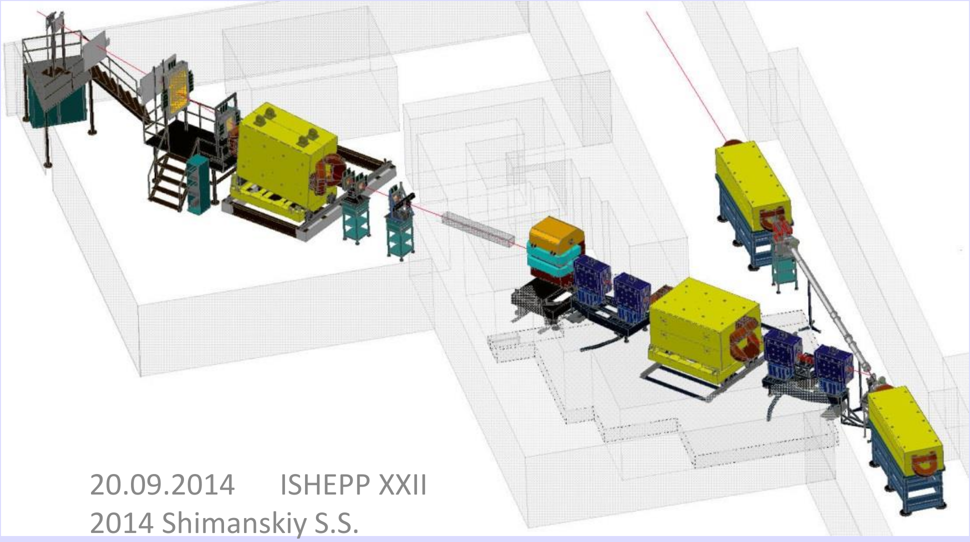
Average baryon number <B>



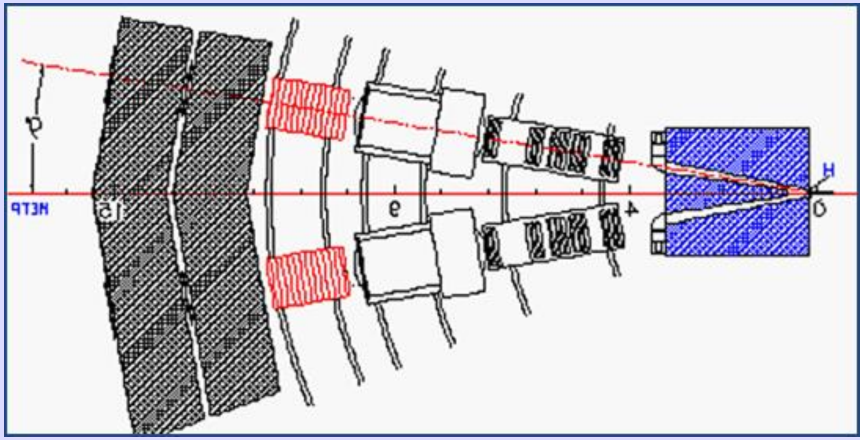
OUR FUTURE STUDIES

IHEP, Protvino

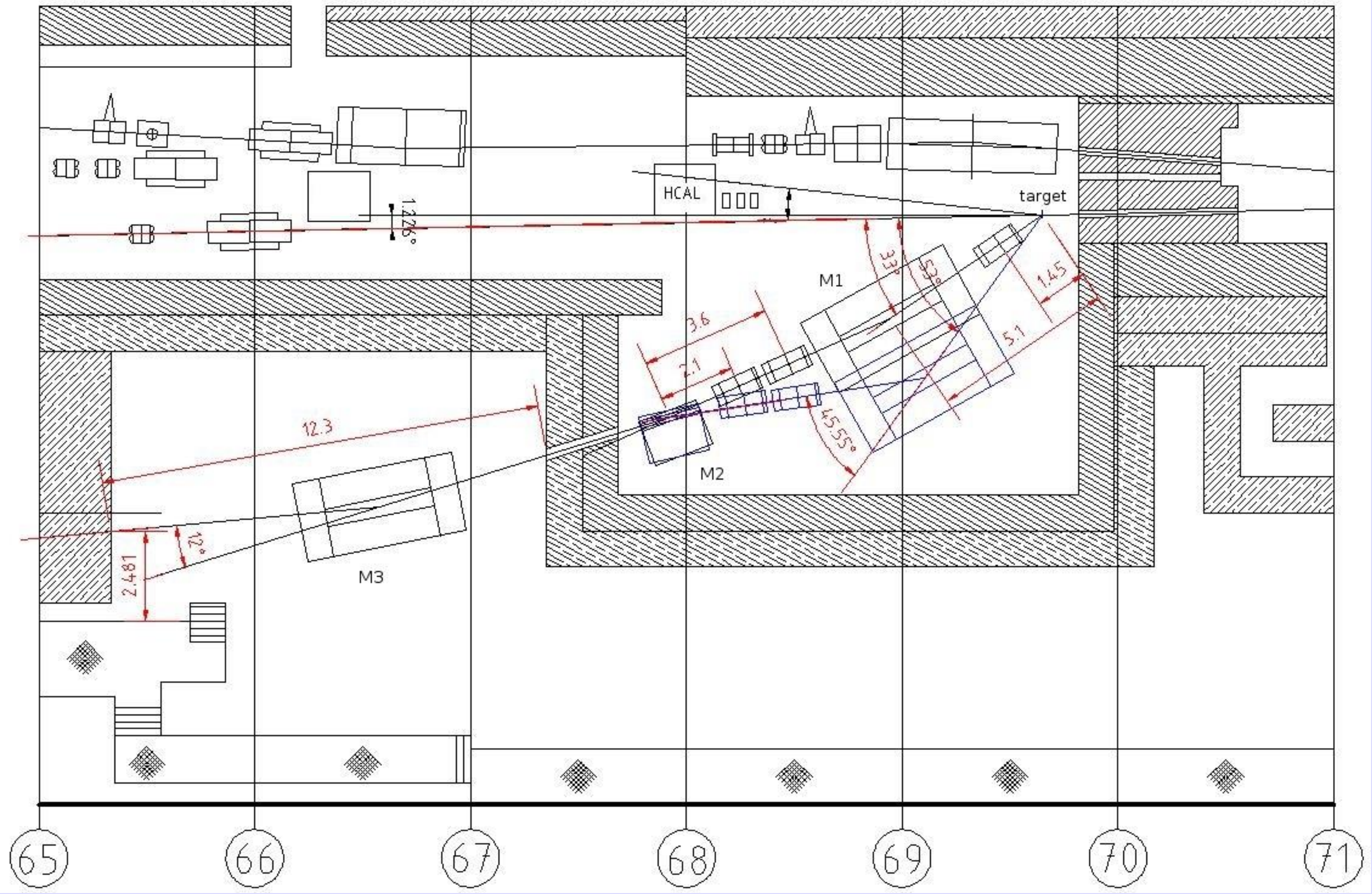
SPIN



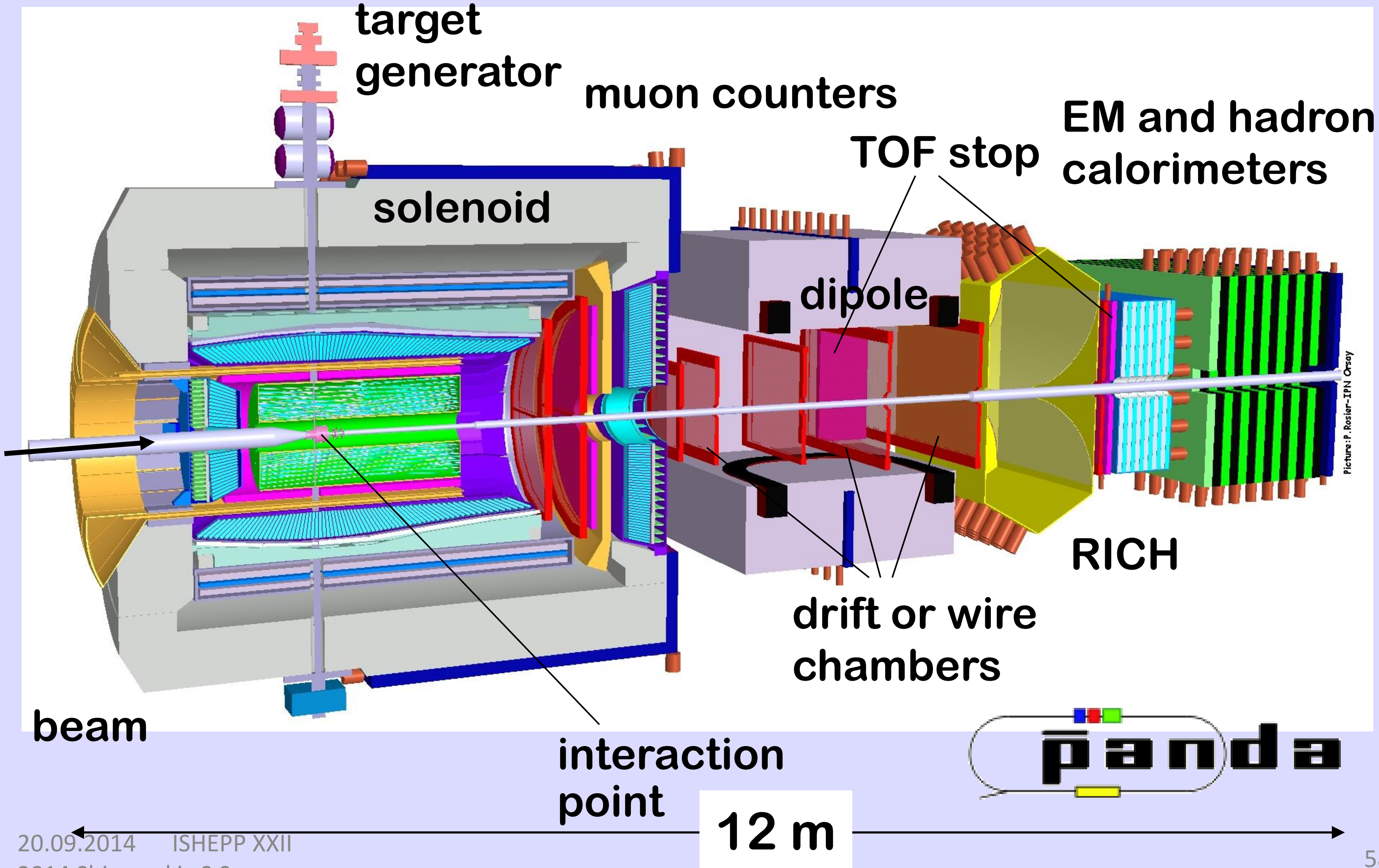
FODS



Proposed structure of the two arms FLUKTON detector and location in 23rd proton beam line at U70



The PANDA Detector $\overline{p} + p(A) \to \overline{p}' + \{X\}$



PANDA experiment at FAIR

(JINR Participation)

2.2. High p_T $p\bar{p}$ collisions and deep inelastic nuclear reactions with PANDA

(S.S.Shimanskiy)

PANDA experiment provides an opportunity to study the properties of the color high density nuclear matter (CHDNM), which differs from Quark Gluon Plasma (QGP) state [1]. To detect the CHDNM one has to study the p A - collisions in kinematical region beyond the kinematical limits for interacting with free nucleons (named as cumulative processes).

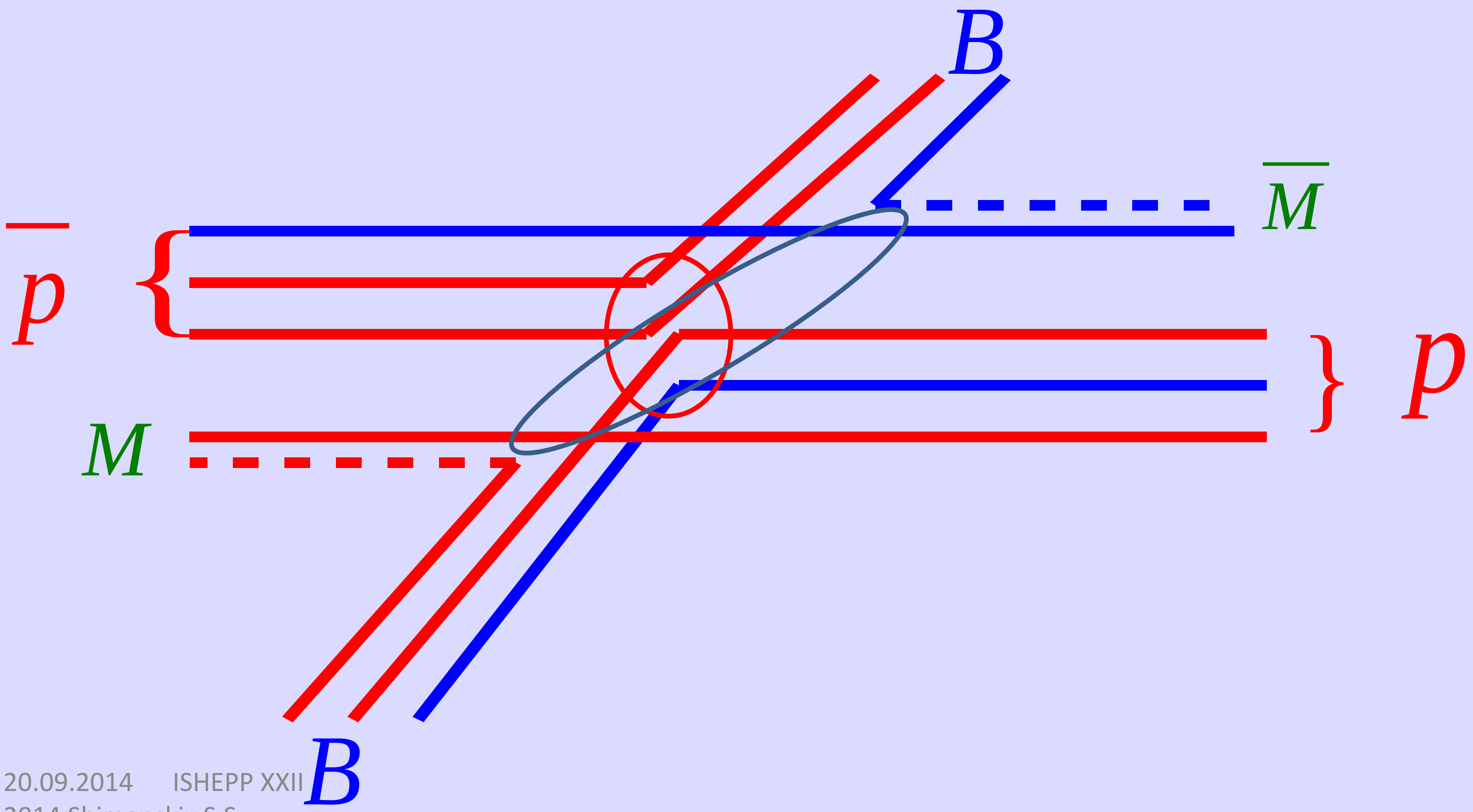
We propose [7] to perform the measurement of three deep inelastic antiproton-nuclei processes (DINP):

- The first one is a DINP $\bar{p}+A \to \bar{p}+ < mN >$, where m is an average number of nucleons. The final state antiproton must have $x_T = \frac{2p_T}{\sqrt{s}} \sim 1$, where $s = (p_{\bar{p}} + p_N)^2$. The aim is to see the dependence on the cumulative number X. SRC mechanism predicts <m> ≈ 1 and no dependence on X.
- The second process is the subthreshold J/Ψ (and D-mesons) production: $\bar{p}+A \to J/\Psi + X \to \mu^+\mu^- + X$ at $E_{beam} \geq 2-3$ GeV. Dimuon pair must have $E^{\mu\mu} \geq 1.5$ GeV. The aim is to measure the cross section of this process which can be greater than the subthreshold cross section of antiproton production $p+A \to \bar{p}+X$ [8] which is already measured [4]. There is a prediction that the case σ($\bar{p}+A \to J/\Psi + X$) > σ($p+A \to \bar{p}+X$) can be treated in favor of "flucton" hypothesis.

Exclusive reactions as way to resolve problems

$B\ (p, \Lambda, \Delta\ldots),\ M\ (\pi, K, l\ldots)$

$$\bar{p} + p \to \bar{B}B + \bar{M}M$$



$\bar{p}p$ studies at $x_T \sim 1$

$$\bar{p}p \to \bar{p}p$$
$$\bar{p}p \to \bar{n}n - ?$$

The counting rules and isotopic symmetry studies, $p_T \sim 2$ GeV/c anomaly(?)

$$\bar{p}p \to \bar{p}p + \pi\pi(KK)$$
$$\bar{p}p \to \bar{\Lambda}\Lambda + KK(\pi\pi, \mu\mu)$$
$$\bar{p}p \to \bar{\Delta}\Delta$$

Detail vertexes studies:

$$q(\bar{q}) + \bar{q}(q) - (quark - antiquark)$$
$$q(\bar{q}) + \overline{qq}(qq) - (quark - antidiquark)$$
$$qq + \overline{qq} - (diquark - antidiquark)$$

END

Progress in Particle and Nuclear Physics 69 (2013) 1–27

Review

Color transparency: Past, present and future

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ARTICLE INFO

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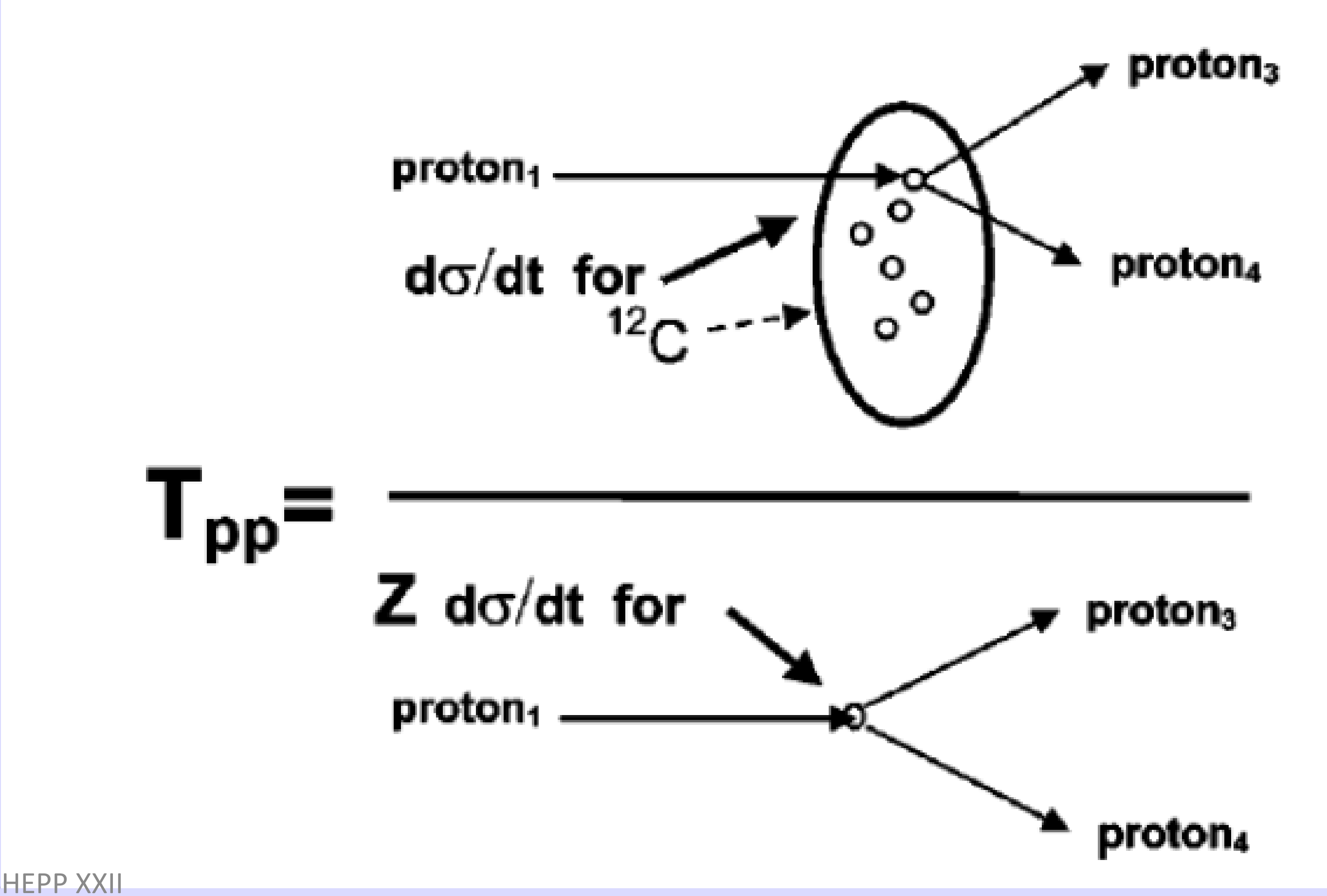
QCD in Nuclei
Color transparency
Onset
Exclusive processes

ABSTRACT

We review a unique prediction of Quantum Chromo Dynamics, called color transparency (CT), where the final (and/or initial) state interactions of hadrons with the nuclear medium must vanish for exclusive processes at high momentum transfers. We retrace the progress of our understanding of this phenomenon, which began with the discovery of the J/ψ meson, followed by the discovery of high energy CT phenomena, the recent developments in the investigation of the onset of CT at intermediate energies and the directions for future studies.

Color(nuclear) transparency in 90^0 c.m. quasielastic $A(p,2p)$ reactions

The incident momenta varied from 5.9 to 14.4 GeV/c, corresponding to $4.8 < Q^2 < 12.7$ $(GeV/c)^2$.



Color(nuclear) transparency

VOLUME 87, NUMBER 21 PHYSICAL REVIEW LETTERS 19 NOVEMBER 2001

Energy Dependence of Nuclear Transparency in C(*p*,2*p*) Scattering

A. Leksanov,[5] J. Alster,[1] G. Asryan,[3,2] Y. Averichev,[8] D. Barton,[3] V. Baturin,[5,4] N. Bukhtoyarova,[3,4] A. Carroll,[3] S. Heppelmann,[5] T. Kawabata,[6] Y. Makdisi,[3] A. Malki,[1] E. Minina,[5] I. Navon,[1] H. Nicholson,[7] A. Ogawa,[5] Yu. Panebratsev,[8] E. Piasetzky,[1] A. Schetkovsky,[5,4] S. Shimanskiy,[8] A. Tang,[9] J. W. Watson,[9] H. Yoshida,[6] and D. Zhalov[5]

$$T_{CH} = T \int d\alpha \int d^2\vec{P}_{FT}\, n(\alpha, \vec{P}_{FT}) \frac{(\frac{d\sigma}{dt})_{pp}(s(\alpha))}{(\frac{d\sigma}{dt})_{pp}(s_0)}$$

$$\alpha \equiv A\frac{(E_F - P_{Fz})}{M_A} \simeq 1 - \frac{P_{Fz}}{m_p}$$

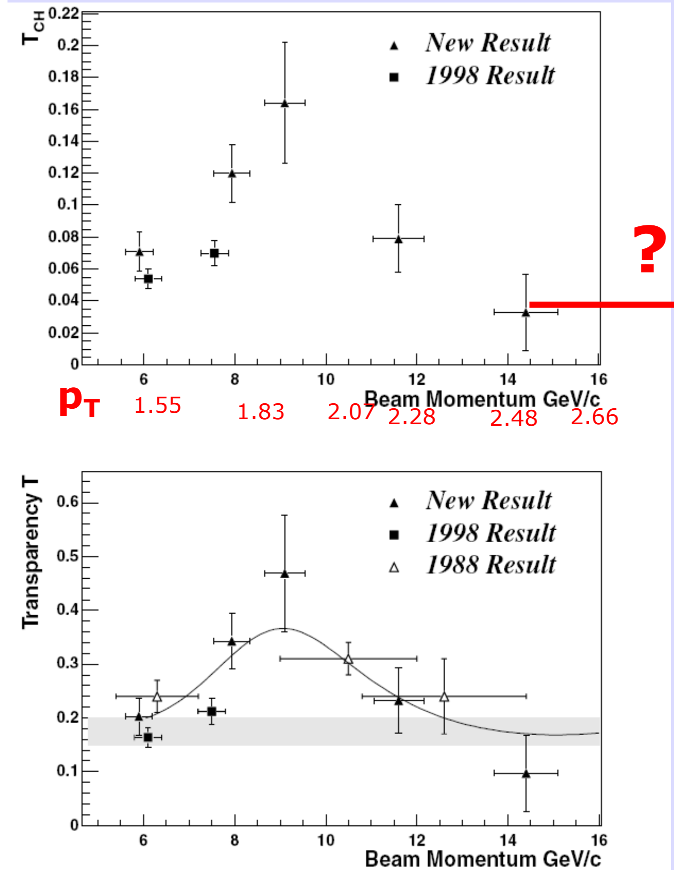


FIG. 2. Top: The transparency ratio T_{CH} as a function of the beam momentum for both the present result and two points from the 1998 publication [3]. Bottom: The transparency T versus beam momentum. The vertical errors shown here are all statistical errors, which dominate for these measurements. The horizontal errors reflect the α bin used. The shaded band represents the Glauber calculation for carbon [9]. The solid curve shows the shape R^{-1} as defined in the text. The 1998 data cover the c.m. angular region from 86°–90°. For the new data, a similar angular region is covered as is discussed in the text. The 1988 data cover 81°–90° c.m.

The nuclear modification factor at RHIC and LHC

- quantify departure from binary scaling in AA

→ ratio of yield in AA versus reference collisions

- e.g.: reference is pp → R_{AA}

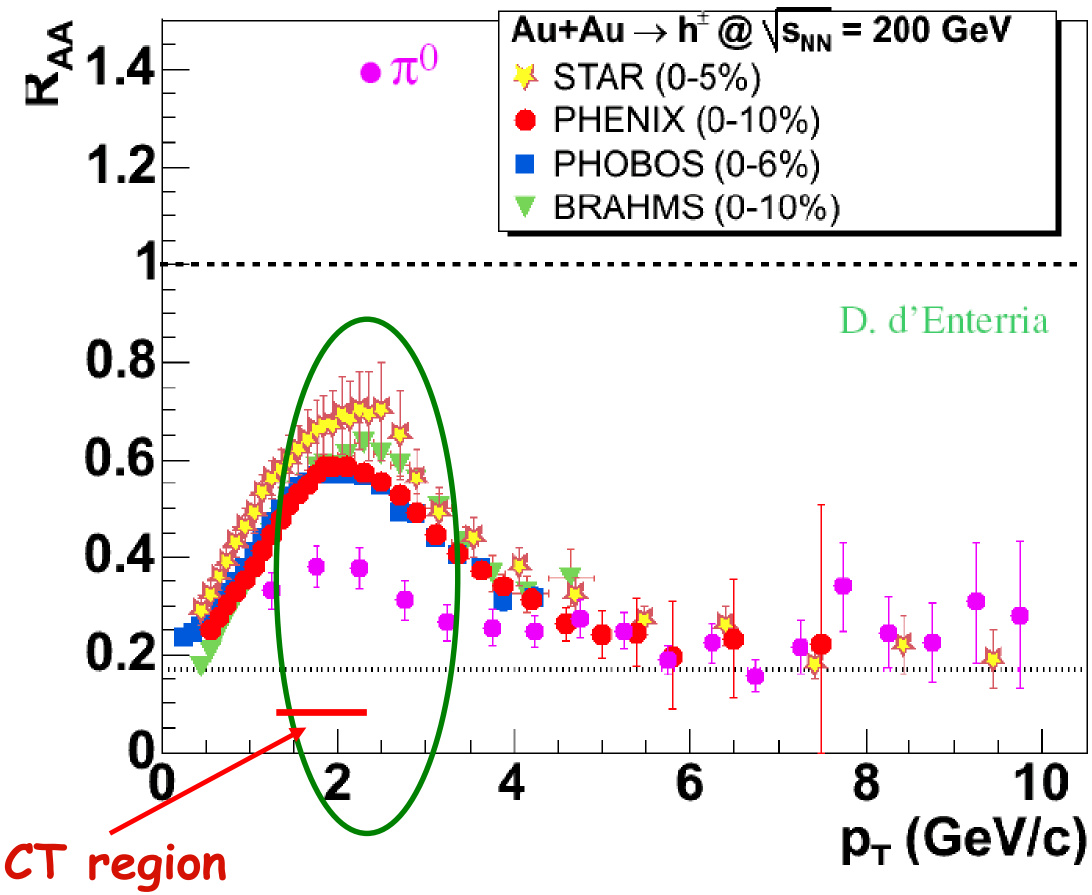
$$R_{\mathrm{AA}} = \frac{\mathrm{Yield}_{\mathrm{AA}}}{\mathrm{Yield}_{\mathrm{pp}}} \cdot \frac{1}{\langle Nbin \rangle_{\mathrm{AA}}}$$

- …or peripheral AA → Rcp ("central to peripheral")

$$R_{\mathrm{cp}} = \frac{\mathrm{Yield}_{\mathrm{AA,\ central}}}{\mathrm{Yield}_{\mathrm{AA,\ periph}}} \cdot \frac{\langle Nbin \rangle_{\mathrm{AA,\ periph}}}{\langle Nbin \rangle_{\mathrm{AA,\ central}}}$$

high p_t suppression seen by all experiments

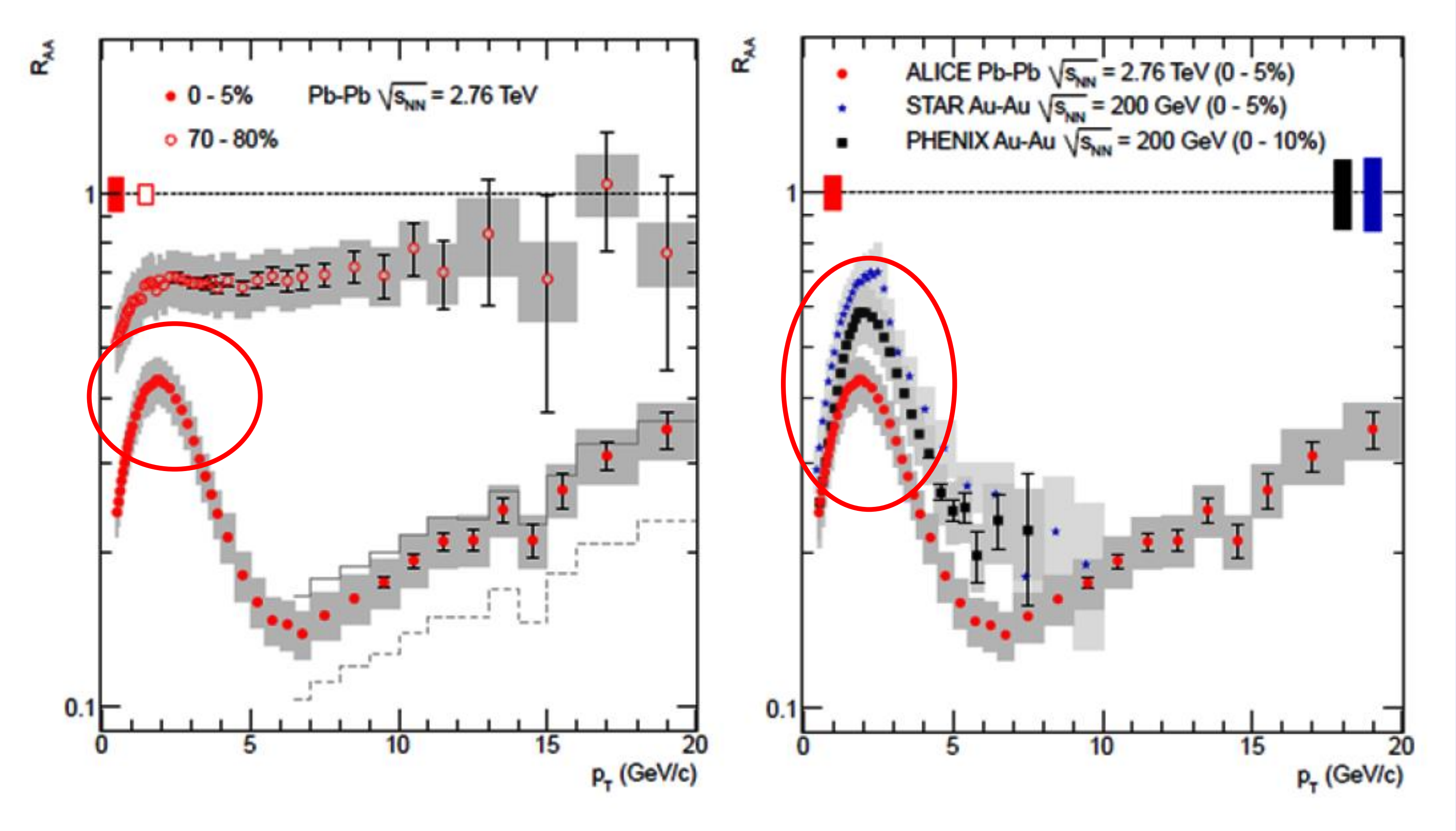
R_{AA}=yield(AuAu)/N_{coll} yield(pp)



- all expts. see large suppression in AuAu
- π^0 lower than $h^{\pm}$
- no suppression in dAu rather Cronin enhancement → medium effect, not incoming partons

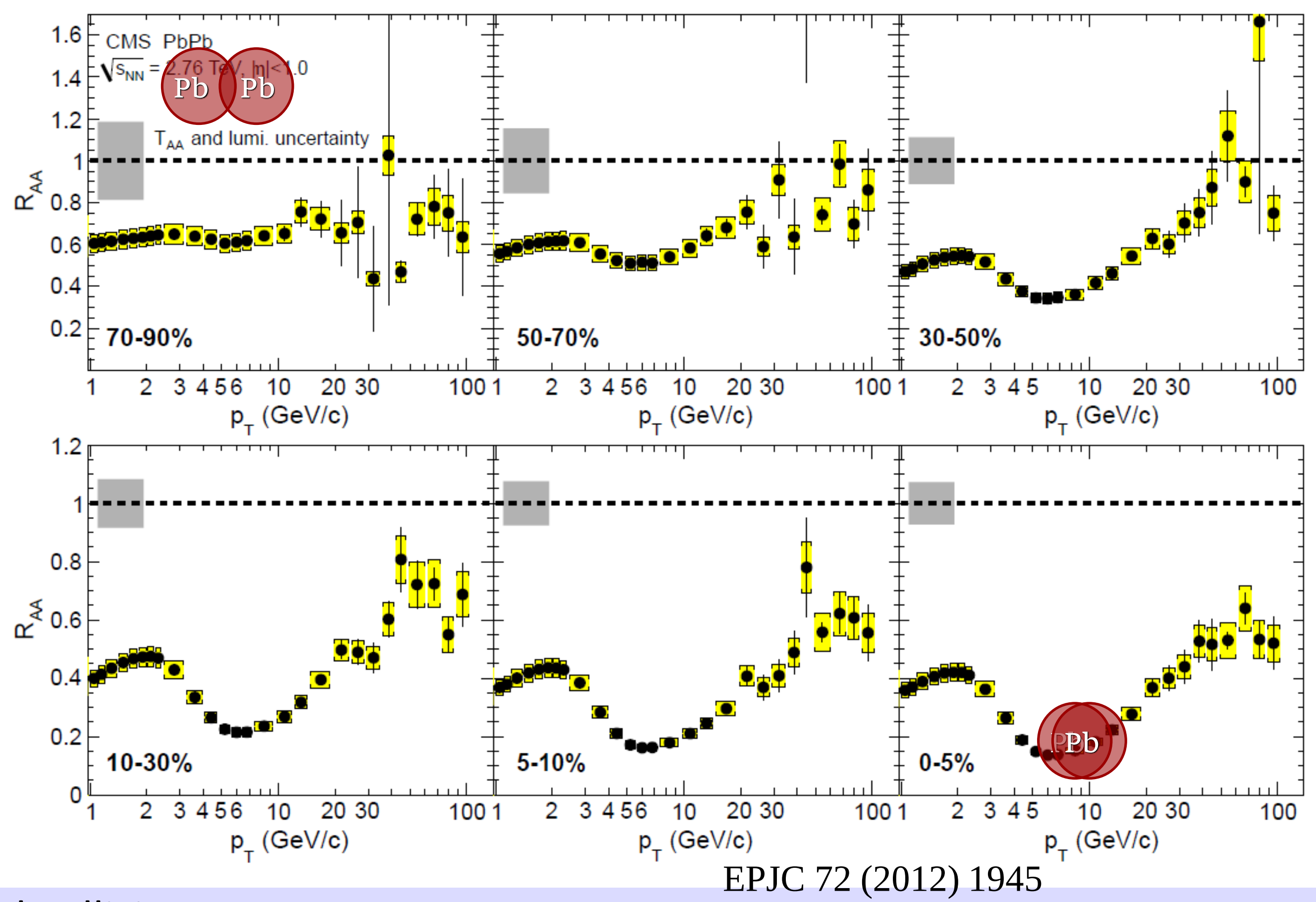
- reasonable agreement between 4 experiments

p_T~2 GeV/c anomaly at high energy (RHIC and LHC)



Charged hadron suppression in Pb-Pb

$$R_{AA} = \frac{{N_{Jet}}^{AA}/N_{coll}}{{N_{Jet}}^{pp}}$$



EPJC 72 (2012) 1945

For central collisions:

- A pronounced minimum at $P_T = 6 - 7\ GeV$ where $R_{AA} \approx 0.2$
- At higher P_T R_{AA} rises and levels off above 40 GeV
- Suppression at high P_T at the same level as jet suppression

J.W. Cronin et al., Production of hadrons at large transverse momentum at 200, 300, and 400 GeV, Phys.Rev. D, v.11, N 11, 3105-3123 (1975)

p_T ~ 2 GeV/c region

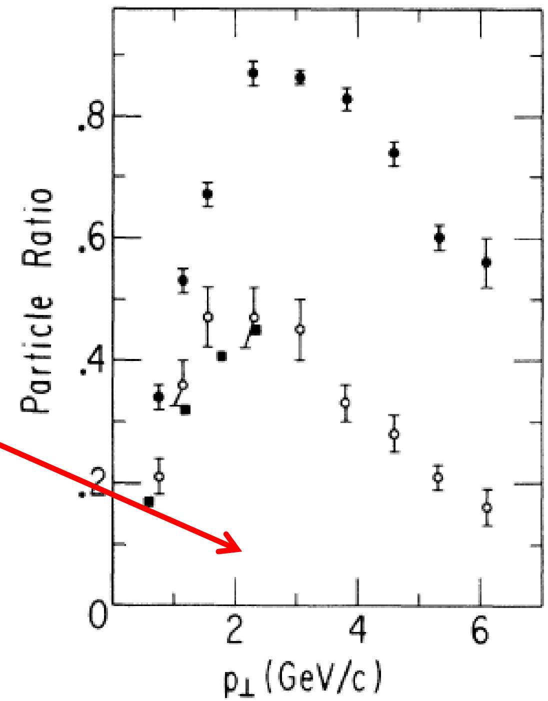


FIG. 20. Comparison of the cross-section ratio p/π^+ measured on tungsten at $\sqrt{s}=23.7$ GeV (closed circles), with that obtained by extrapolation to $A=1$ (open circles). Ratios obtained from the British-Scandinavian collabortion (Ref. 23) at $\sqrt{s}=23.4$ GeV are also plotted (closed squares).

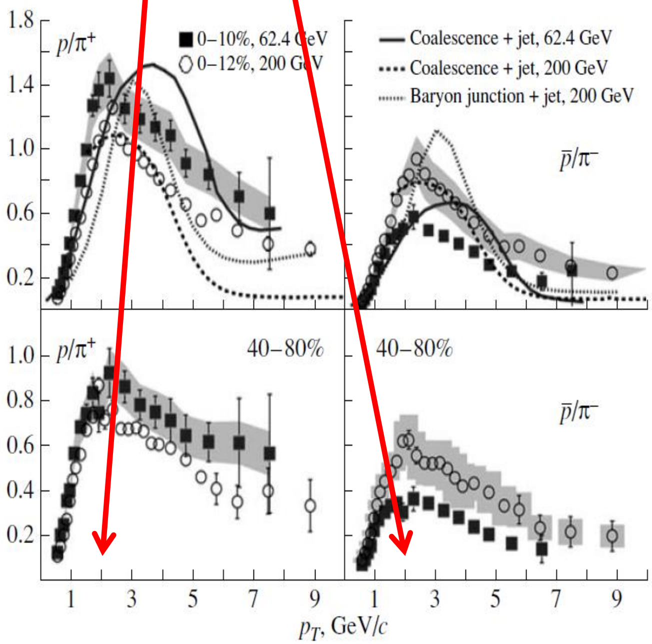
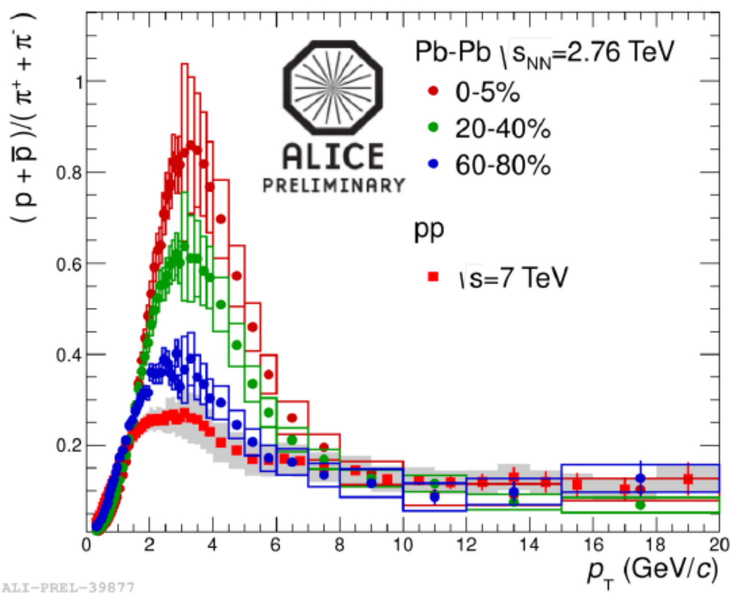
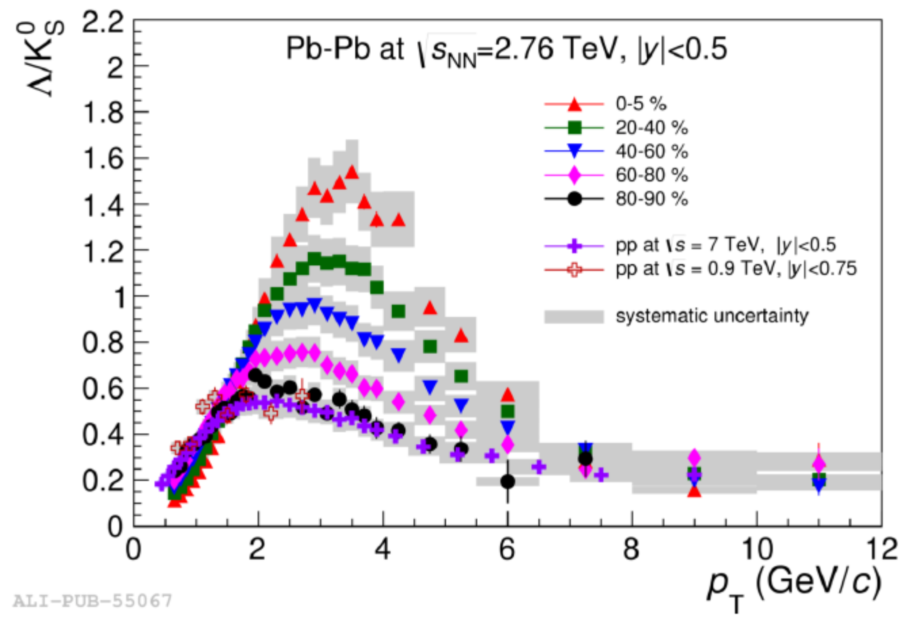


Fig. 3. [10] Ratio of the cross sections for the production of protons and charged pions as a function of the transverse momentum for various degrees of centrality and two beam energies of 62.4 and 200 GeV: (points) results of the STAR experiment and (curves) results of model calculations.

V.S. Pantuev ***Physics of Atomic Nuclei, 2009, Vol. 72, No. 12, pp. 1971–1981***

Baryon anomaly in Pb-Pb





- Baryon to meson ratio increasing with centrality for p_T < 8 GeV/c.
  - Enhancement at moderate p_T is consistent with radial flow
  - May be explained by quark recombination from QGP (coalescence model)
- For p_T > 8 GeV/c no dependence on centrality and collision system
  - Consistent with fragmentation in vacuum

$p\uparrow p\uparrow \rightarrow pp(90^0)$

E.A. Crosbie et al., Phys.Rev. D, vol.23, N3,1981

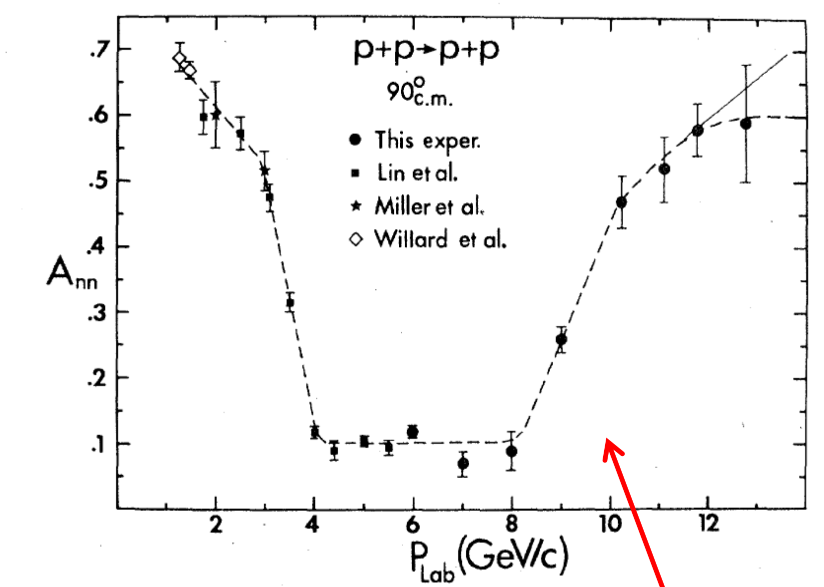


FIG. 2. Plot of the spin-spin correlation parameter A_{nn} for $p+p\rightarrow p+p$ at $90°_{c.m.}$ as a function of incident beam momentum. The dashed and solid lines are hand-drawn possible fits.

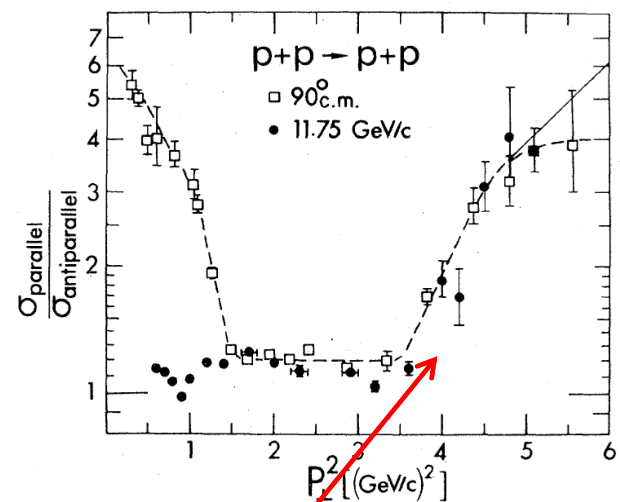


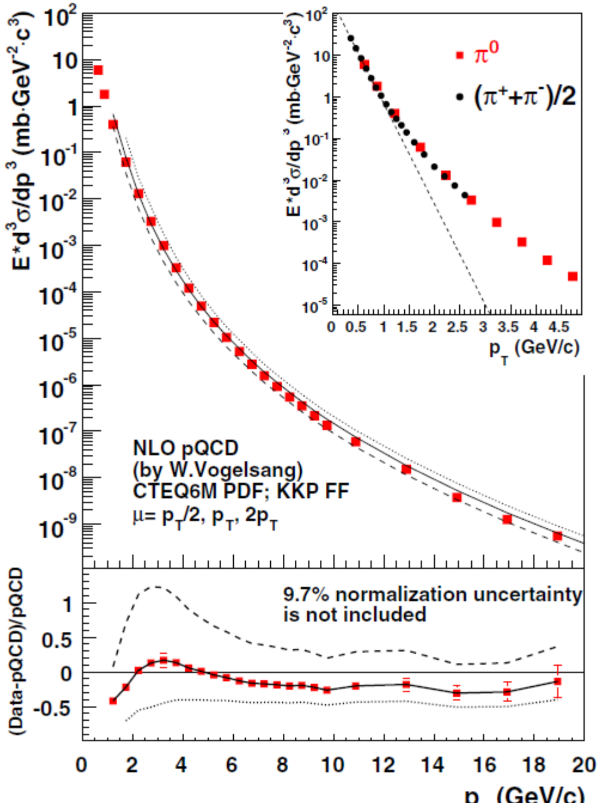
FIG. 3. Plot of the ratio of the spin-parallel to spin-antiparallel differential cross sections, as a function of $P_{\perp}^2$, for p-p elastic scattering. The squares are the fixed-angle data at $90°_{c.m.}$, with the incident energy varied. The circles are data (Refs. 5, 11) with the momentum held fixed at 11.75 GeV/c while the scattering angle is varied. The dashed and solid lines are hand-drawn possible fits to the $90°_{c.m.}$ data.

$p_T \sim 2$ GeV/c

pp -> π + X

PHYSICAL REVIEW D **76**, 051106(R) (2007)

Inclusive cross section and double helicity asymmetry for π^0 production in $p + p$ collisions at $\sqrt{s} = 200$ GeV: Implications for the polarized gluon distribution in the proton



for higher p_T. This is the basis for applying the pQCD formalism to the double helicity asymmetry data with $p_T > 2$ GeV$/c$.

PHYSICAL REVIEW D **79**, 012003 (2009)

Inclusive cross section and double helicity asymmetry for π^0 production in $p + p$ collisions at $\sqrt{s} = 62.4$ GeV

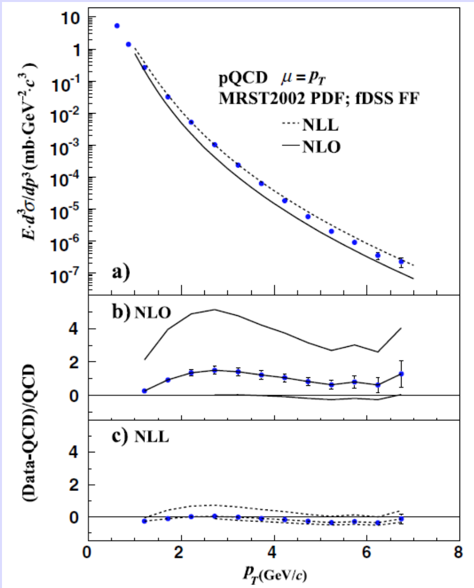


Fig. 4(b). A similar drop in the parameter n at $x_T \gtrsim 0.1$ was observed at ISR energies [12]. Figure 4(b) also shows the possible transition from soft- to hard-scattering regions in π^0 production at $p_T \sim 2$ GeV$/c$. A similar conclusion was derived from the shape of the π^0 spectrum at $\sqrt{s} = 200$ GeV in [5]. This can serve as a basis for applying the pQCD formalism to the double helicity asymmetry data with $p_T > 2$ GeV$/c$ in order to allow access to ΔG.

Тема	Re: Cumulative at high p_T
От	Boris Kopeliovich
Кому	Stepan
Ответить	bzk@mpi-hd.mpg.de
Дата	23.01.2012 7:42

«I think that the main problem in understanding of high pT hadrons at the energies of Serpukhov is why you see more protons than pions. This was claimed long time ago by the Sulyaev's group and I remember hot debates in that back in the 80s. Those debated ended up with no clear conclusion. Much later an excess of baryons was observed by the STAR at RHIC and was called "baryon anomaly". Again, no good explanation has been proposed so far. I might have my own explanation, but haven't written anything so far. Anyway, my point is, if we do not understand the mechanism of production of baryons dominating at high pT, we should not make any certain conclusions about the cumulative mechanisms.»

- Date: Wed, 27 Feb 2013 13:58:35 +0100
- Subject: Re: test
- From: yuri@lpthe.jussieu.fr
- To: "Stepan" <Stepan.Shimanskiy@jinr.ru>
- User-Agent: SquirrelMail/1.4.22-2.fc15
- MIME-Version: 1.0

Уважаемые коллеги,

Позвольте поделиться некоторыми соображениями по поводу программы корреляционных исследований при взаимодействии адронов и ядер на ФОДС, в той её части, которая касается многопартонных соударений.

С недавнего времени многопартонные взаимодействия (MPI) привлекают пристальное внимание как теоретиков, так и экспериментаторов. С одной стороны, MPI – дополнительный источник многоструйных КХД событий, которые являются фоновыми для поисков новой физики на LHC. С другой стороны,

MPI – потенциальный источник новой информации о партонной структуре нуклона. В конце 90–ых начале 00–х появились результаты первых экспериментальных исследований на Tevatron'е. Они продемонстрировали, во–первых, существование двойных жёстких соударений и, во–вторых, существование существенных корреляций между партонами в протоне (сечение MPI оказалось вдвое больше, чем если бы два

партона внутри протона были независимы). На сегодняшний день теоретики разработали адекватный инструмент для описания двойных жёстких соударений – обобщённое двухпартонное распределение (generalized double parton distribution) G. Адекватные монтекарловские модели для описания MPI находятся

в стадии разработки. Используя данные HERA по електророждению векторных мезонов, структуру этого нового объекта можно предсказать в области 0.001 < x < 0.1. В то же время, в области x > 0.1 информация о G практически отсутствует. Пертурбативные эффекты в G (весьма серьёзные при больших поперечных импульсах регистрируемых частиц и/или струй) находятся под контролем. Однако, о непертурбативной корреляции партонов внутри волновой функции адрона информации у нас нет. Без прямой

экспериментальной информации прогресс в этой области вряд ли возможен. Важно, что для экспериментального изучения этих корреляций не нужны сверхвысокие энергии. Достаточно правильно заданных вопросов и грамотного поставленного эксперимента. Чрезвычайно важной представляется возможность разделения процессов по флейвору участвующих партонов. Измерять корреляции частиц в конечном состоянии вместо адронных струй представляется мне предпочтительным. Дело в том, что эта наблюдаемая содержит ту же информацию о корреляции начальных партонов, что и измерение струй, однако свободна от неопределённостей, связанных с выбором и использованием алгоритма по определению

струй. Серпуховскому ускорителю и установке ФОДС важная задача изучения партонных корреляций в протоне вполне по плечу.

Ю. Докшицер

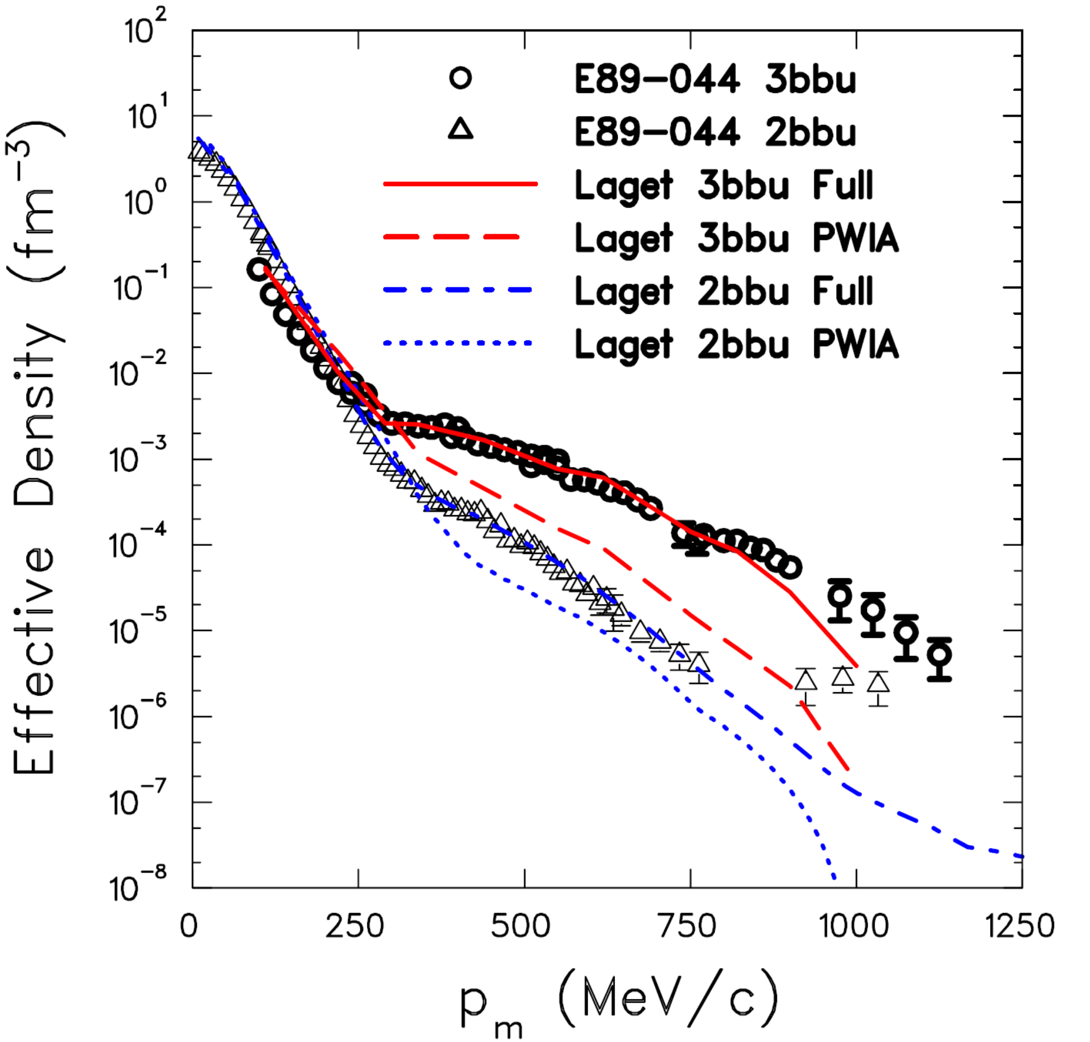


Figure 3. Proton effective momentum density distributions in ^{3}He extracted from ^{3}He$(e, e'p)pn$ three-body break-up (3bbu) is shown as the open black circles and the ^{3}He$(e, e'p)d$ two-body break-up (2bbu) is shown as open black triangles. The three-body break-up (3bbu) integration covers E_M from threshold to 140 MeV. The results are compared to calculations from J.-M. Laget [25] which explain the dominance of the continuum cross section at large missing momentum as a strong interference between short-range correlations and final-state interactions. Reprinted with permission from Benmokhtar F *et al.* (Hall A) 2005 *Phys. Rev. Lett.* **94** 082305.

Fiz. Elem. Chast. At. Yadra. 2005. V. 36. P. 954

CURRENT EXPERIMENTS USING POLARIZED BEAMS OF THE JINR VBLHE ACCELERATOR COMPLEX

F. Lehar

DAPNIA, CEA/Saclay, Gif-sur-Yvette Cedex, France

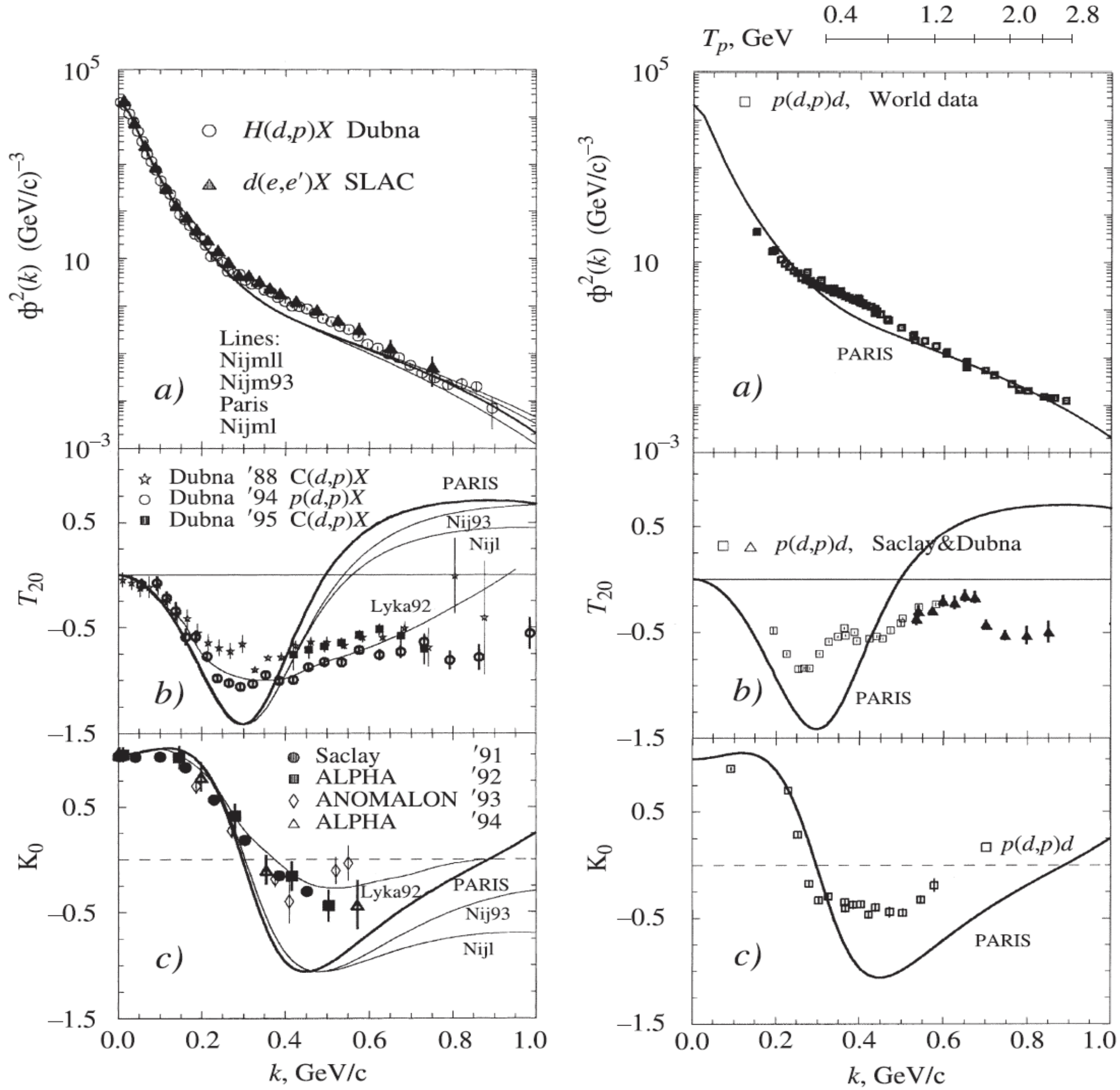


Рис. 5. Сводка данных экспериментов по фрагментации (слева) и упругому рассеянию «назад» (справа) поляризованных и неполяризованных дейтронов

RHIC press release after analysis of first 3 years

BROOKHAVEN
NATIONAL LABORATORY

Contact: Karen McNulty Walsh, (631) 344-8350 or Mona S. Rowe, (631) 344-5056

RHIC Scientists Serve Up "Perfect" Liquid

New state of matter more remarkable than predicted -- raising many new questions

April 18, 2005

TAMPA, FL -- The four detector groups conducting research at the Relativistic Heavy Ion Collider (RHIC) -- a giant atom "smasher" located at the U.S. Department of Energy's Brookhaven National Laboratory -- say they've created a new state of hot, dense matter out of the quarks and gluons that are the basic particles of atomic nuclei, but it is a state quite different and even more remarkable than had been predicted. In peer-reviewed papers summarizing the first three years of RHIC findings, the scientists say that instead of behaving like a gas of free quarks and gluons, as was expected, the matter created in RHIC's heavy ion collisions appears to be more like a liquid.