

"Exotic multiquarks states at PANDA"

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PLAN

1. Diquarks, exotic states and nonperturbative lows;
2. Cold superDense Baryonic Matter (**CsDBM**).

PANDA advantages

The unique beam - no worldwide (FNAL closed antiproton activity) and $\Delta p/p \sim 10^{-5}$. 1-PHASE - SIS18 beams?

The unique detector - $\Delta\Omega \sim 4\pi$ -exclusive reactions investigation (correlations, backward range); working at luminosity $\sim 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ - the very rare events can be investigated; PID - close to full energy range and neutron registration.

Diquarks (proof of existence and properties)

Multiquark states have been discussed since the 1st page of the quark model

A SCHEMATIC MODEL OF BARYONS AND MESONS *

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Received 4 January 1964



If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" 1-3), we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "bootstrap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone 4). Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electromagnetic, and gravitational interactions by means

ber $n_t - n_{\bar{t}}$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles d^- , s^- , u^0 and b^0 exhibit a parallel with the leptons.

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" 6) q and the members of the anti-triplet as anti-quarks \bar{q} . Baryons can now be constructed from quarks by using the combinations $(q q q)$, $(q q q \bar{q})$, etc., while mesons are made out of $(q \bar{q})$, $(q q \bar{q} \bar{q})$, etc. It is assuming that the lowest baryon configuration $(q q q)$ gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q \bar{q})$ similarly gives just **1** and **8**.

Diquarks

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Among the useful phenomenological ideas is the notion of a diquark. Gell-Mann (1964) first mentioned the possibility of diquarks in his original paper on quarks. Later, Ida and Kobayashi (1966) and Lichtenberg and Tassie (1967) introduced diquarks in order to describe a baryon as a composite state of two particles, a quark and diquark. Around the same time, states having some or all of the quantum numbers of diquarks were introduced in certain group-theoretical schemes by Bose (1966), Bose and Sudarshan (1967), and Miyazawa (1966, 1968).

Aside from questions of principle, lattice calculations suffer because an enormous amount of computer time is necessary to achieve very modest results. Thus, at present, calculations with lattice gauge theory are not a satisfactory substitute for calculations with phenomenological models.

Kim V.T.

E2-87-75

Diquarks as a Source of Large- p_{\perp} Baryons
in Hard Nucleon Collisions

The production of nucleons, symmetric nucleon pairs, and Λ^0 -hyperons with large p_{\perp} in pp-collisions is discussed in the framework of a dominating scalar (ud)-diquark nucleon model. The necessity of making allowance for higher twists-diquarks for explaining strong scaling breaking in p/π^+ ratio is shown. The approximate equation $\Lambda/p \approx k^+/\pi^+$ is predicted in this model.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1987

Diquarks

V.T. Kim (1987)

$pp \rightarrow p+X, pp \rightarrow pp+X$

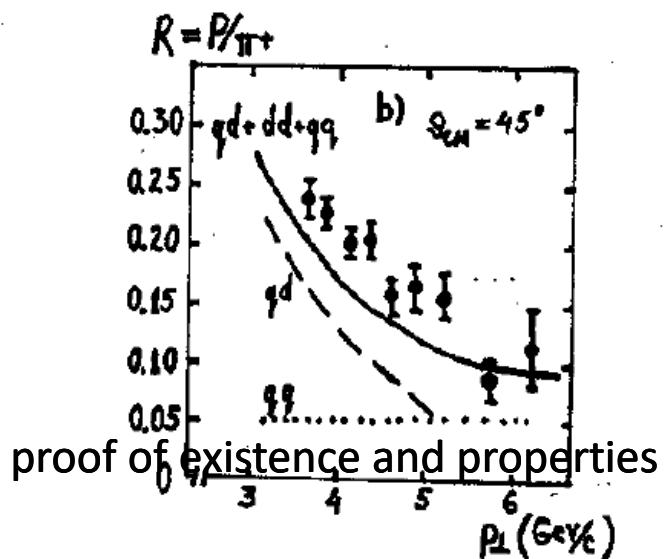
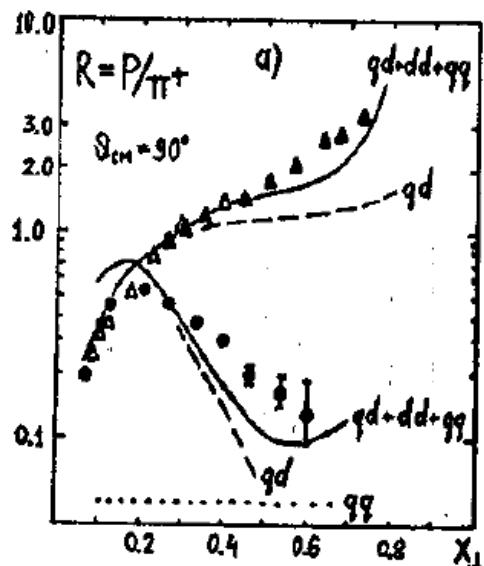


Fig. 1. $R = P/\pi^+$ -ratio in pp -collisions. a) $\theta_{CM} = 90^\circ$: ● - FNAL data/16/ at $\sqrt{s} = 23.4$ GeV ($E_L = 300$ GeV); △, ▲ - IHEP (Serpukhov) data/19,20/ at $\sqrt{s} = 11.5$ GeV ($E_L = 70$ GeV). b) $\theta_{CM} = 45^\circ$: ● - ISR CERN data/18/ at $\sqrt{s} = 62$ GeV ($E_L \approx 1900$ GeV).

The result of calculations of $pp \sim ppX$ processes/29/ (symmetric -proton-pair production) according to the formula in work/30/ for the double inclusive cross section, which in general must be applied carefully/31/ , is shown in Fig.2. The main contribution to the cross section of production of proton pairs with transverse momenta opposite and equal in values is given by diquark-diquark scattering.

2. LARGE- P_T BARYON PRODUCTION AND P/π^+ -RATIO

It is known that the problem of large- P_T baryon production in hadronic collisions cannot be solved in the framework of the elastic quark scattering model/26/. As a result, phenomenological higher twists models appear: CIM/3/, diquarks/10-14/, etc./15/ .

The quark-diquark configuration probability in a nucleon, obtained by us, is equal to about 70%; note, however, that the value of this probability is defined by approximate relationship (1) between elastic cross sections of $q\bar{q}$ - and qd - subprocesses/14/ .

Another test may be done by measuring large- P_T Λ^0 -hyperon cross sections in proton collisions. In the dominating scalar (ud)-diquark model the ratio $\Lambda^0/p \approx K^+/\pi^+ = 0.3 \div 0.5$ must almost be independent of P_T and \sqrt{s} .

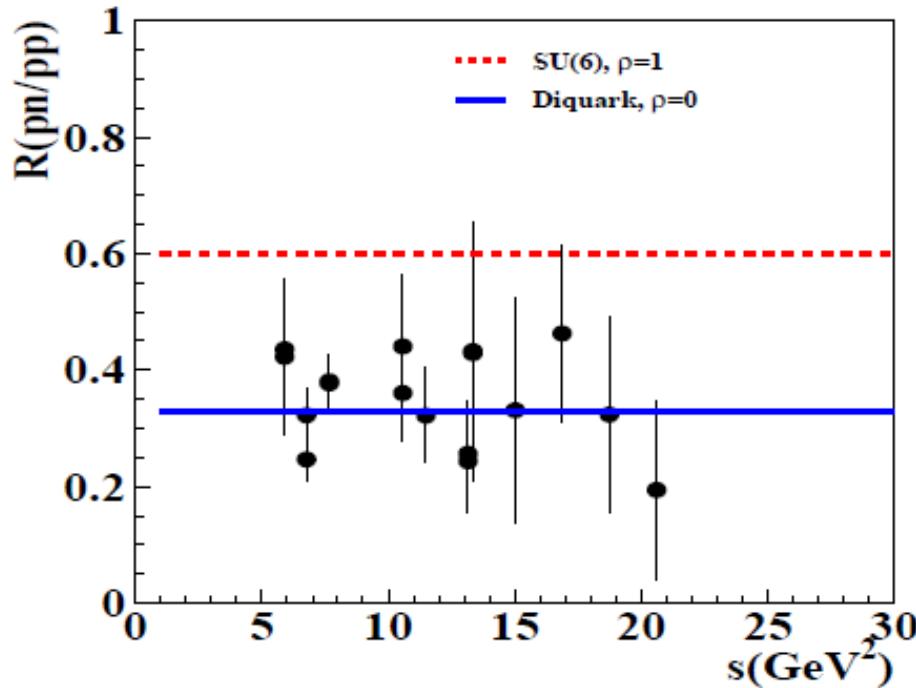
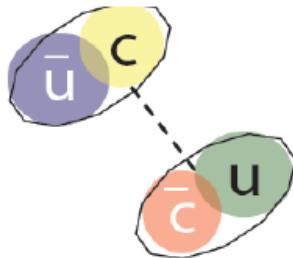


FIG. 2: (Color online) Ratio of the $pn \rightarrow pn$ to $pp \rightarrow pp$ elastic differential cross sections as a function of s at $\theta_{c.m.}^N = 90^\circ$.

Tetraquarks (X, Y, Z)?



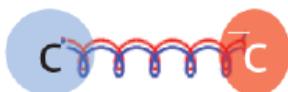
Molecular states:

- Loosely bound states of a pair of mesons,
- bound by the long-range color-singlet pion exchange,
- weakly bound, mesons tend to decay as if they were free.



Tetraquarks:

- bound states of four quarks,
- bound by colored-force between quarks,
- decay through rearrangement,
- many states with the same multiplet, some are with non-zero charge, or strangeness



Hybrids:

- bound states with a pair of quarks and one excited gluon
- Lattice and model predictions for lowest lying charmonium hybrid m~4200 MeV

Where we can more say about
domination of constituents
quarks?

In 1973 were published two articles :

Matveev V.A., Muradyan R.M., Tavkhelidze A.N. Lett. Nuovo Cimento 7,719 (1973);

Brodsky S., Farrar G. Phys. Rev. Lett. 31,1153 (1973)

Predictions that for momentum $p_{\text{beam}} \geq 5 \text{ GeV}/c$ in any binary large-angle scattering ($\theta_{\text{cm}} > 40^\circ$) reaction at large momentum transfers $Q = \sqrt{-t}$:



$$\frac{d\sigma}{dt}_{A+B \rightarrow C+D} \sim S^{-(n_A+n_B+n_C+n_D-2)} f\left(\frac{t}{S}\right)$$

where n_A, n_B, n_C and n_D the amounts of elementary constituents in A,B,C and D.

$$s = (p_A + p_B)^2 \quad \text{and} \quad t = (p_A - p_C)^2,$$

$$\frac{d\sigma}{dt}_{pp \rightarrow pp} \sim S^{-10} \quad \text{and} \quad \frac{d\sigma}{dt}_{\pi p \rightarrow \pi p} \sim S^{-8}$$

$$E_{\text{CM}}^{22} \frac{d\sigma}{dt}(\gamma d \rightarrow pn) / \text{kb GeV}^{20}$$

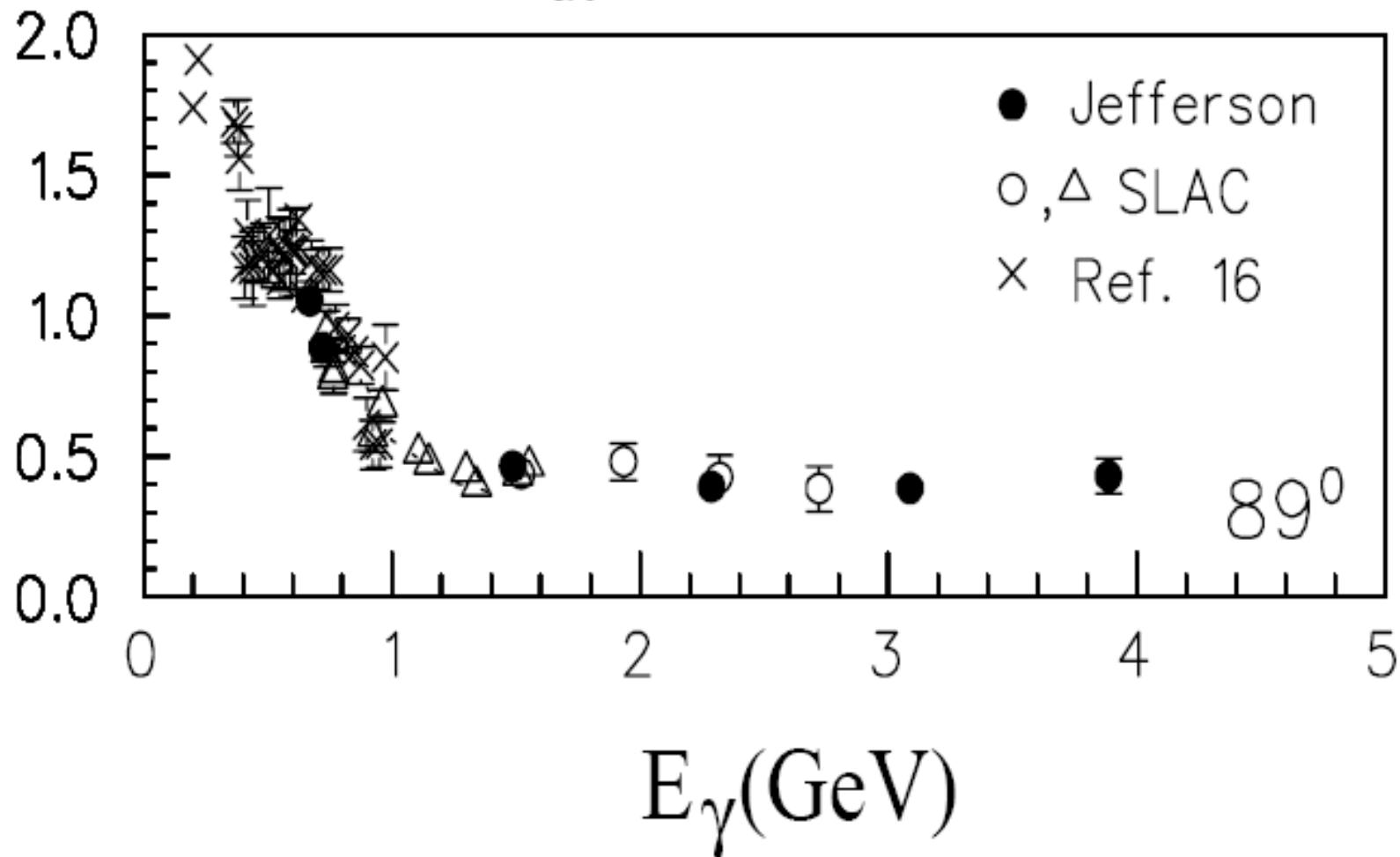


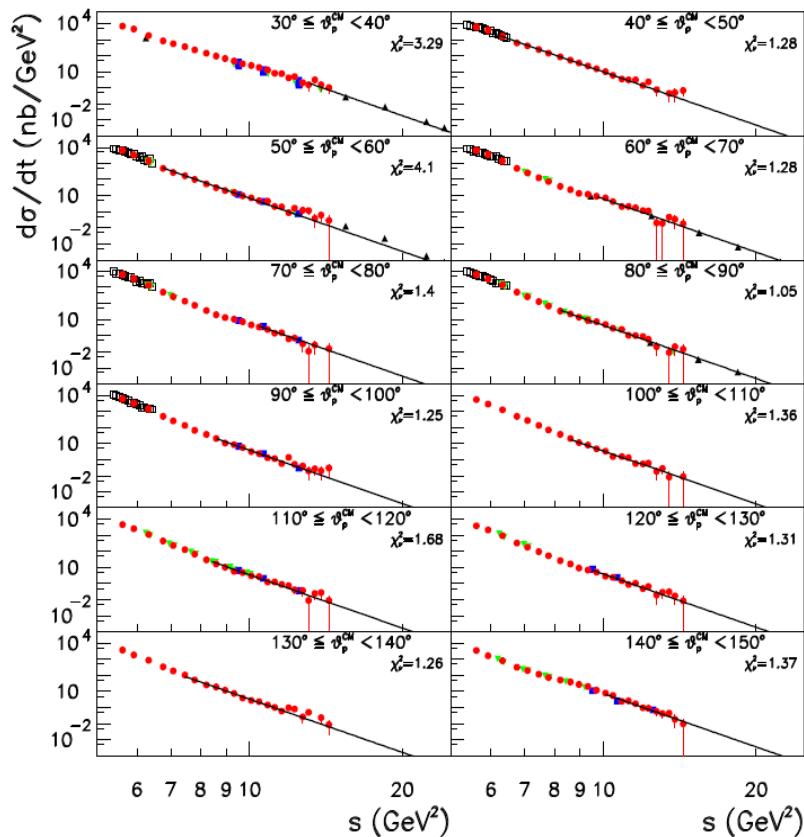
Fig. 1: Large angle γ -disintegration of a deuteron [28].

Light-Front QCD*

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SLAC-PUB-10871

November 2004



$$s^{11} \frac{d\sigma}{dt}(\gamma d \rightarrow pn) \sim$$

constant at fixed CM angle

Figure 8: Fits of the cross sections $d\sigma/dt$ to s^{-11} for $P_T \geq P_T^{th}$ and proton angles between 30° and 150° (solid lines). Data are from CLAS (full/red circles), Mainz(open/black squares), SLAC (full-down/green triangles), JLab Hall A (full/blue squares) and Hall C (full-up/black triangles). Also shown in each panel is the χ_ν^2 value of the fit. From Ref. [160].

Indication of asymptotic scaling in the reactions $dd \rightarrow p^3\text{H}$, $dd \rightarrow n^3\text{He}$ and $pd \rightarrow pd$

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It is shown that the differential cross sections of the reactions $dd \rightarrow n^3\text{He}$ and $dd \rightarrow p^3\text{H}$ measured at c.m.s. scattering angle $\theta_{cm} = 60^\circ$ in the interval of the deuteron beam energy 0.5–1.2 GeV demonstrate the scaling behaviour, $d\sigma/dt \sim s^{-22}$, which follows from constituent quark counting rules. It is found also that the differential cross section of the elastic $dp \rightarrow dp$ scattering at $\theta_{cm} = 125^\circ$ – 135° follows the scaling regime $\sim s^{-16}$ at beam energies 0.5–5 GeV. These data are parameterized here using the Reggeon exchange.

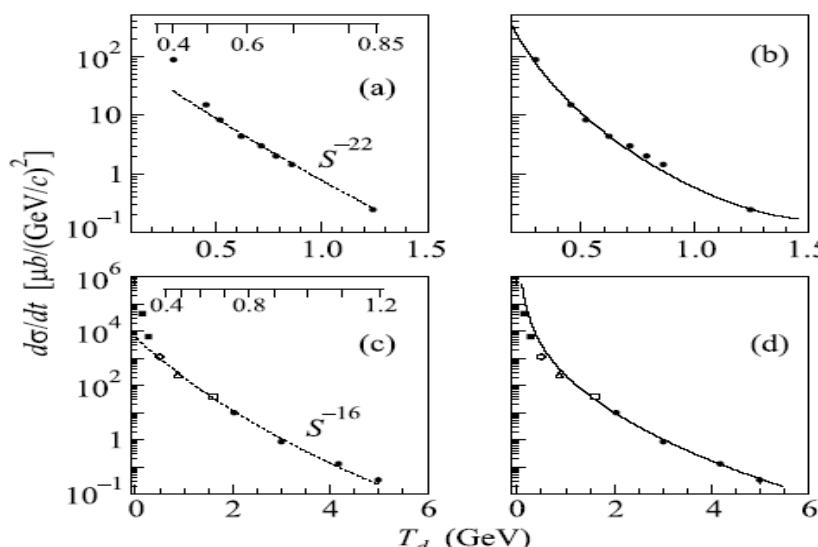


Fig.2. The differential cross section of the $dd \rightarrow n^3\text{He}$ and $dd \rightarrow p^3\text{H}$ reactions at $\theta_{cm} = 60^\circ$ (a), (b) and $dp \rightarrow dp$ at $\theta_{cm} = 127^\circ$ (c), (d) versus the deuteron beam kinetic energy. Experimental data in (a), (b) are taken from [20]. In (c), (d), the experimental data (black squares), (○), (△), (open square) and (●) are taken from [22–26], respectively. The dashed curves give the s^{-22} (a) and s^{-16} (c) behaviour. The full curves show the result of calculations using Regge formalism given by Eqs. (2), (3), (4) with the following parameters: (b) – $C_1 = 1.9 \text{ GeV}^2$, $R_1^2 = 0.2 \text{ GeV}^{-2}$, $C_2 = 3.5$, $R_2^2 = -0.1 \text{ GeV}^{-2}$; (d) – $C_1 = 7.2 \text{ GeV}^2$, $R_1^2 = 0.5 \text{ GeV}^{-2}$, $C_2 = 1.8$, $R_2^2 = -0.1 \text{ GeV}^{-2}$. The upper scales in (a) and (c) show the relative momentum q_{pn} (GeV/c) in the deuteron for the ONE mechanism

Comparison of 20 exclusive reactions at large t

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We report a study of 20 exclusive reactions measured at the AGS at 5.9 GeV/c incident momentum, 90° center of mass. This experiment confirms the strong quark flow dependence of two-body hadron-hadron scattering at large angle. At 9.9 GeV/c an upper limit had been set for the ratio of cross sections for $(\bar{p}p \rightarrow \bar{p}p)/(pp \rightarrow pp)$ at 90° c.m., with the ratio less than 4%. The present experiment was performed at lower energy to gain sensitivity, but was still within the fixed angle scaling region. A ratio $R(\bar{p}p/pp) \approx 1/40$ was measured at 5.9 GeV/c, 90° c.m. in comparison to a ratio near 1.7 for small angle scattering. In addition, many other reactions were measured, often for the first time at 90° c.m. in the scaling region, using beams of π^\pm , K^\pm , p , and \bar{p} on a hydrogen target. There are similar large differences in cross sections for other reactions: $R(K^-p \rightarrow \pi^+\Sigma^-/K^-p \rightarrow \pi^-\Sigma^+) \approx 1/12$, for example. The relative magnitudes of the different cross sections are consistent with the dominance of quark interchange in these 90° reactions, and indicate that pure gluon exchange and quark-antiquark annihilation diagrams are much less important. The angular dependence of several elastic cross sections and the energy dependence at a fixed angle of many of the reactions are also presented.

TABLE I. Measured reactions presented in this paper. The reactions are written as $(\text{beam} + \text{target}) \rightarrow (\text{spectrometer particle} + \text{side particle})$. Reactions 1, 2, 3, 17, and 18 were measured with either final-state particle in the spectrometer.

Meson-baryon reactions	
1	$\pi^+p \rightarrow p\pi^+$
2	$\pi^-p \rightarrow p\pi^-$
3	$K^+p \rightarrow pK^+$
4	$K^-p \rightarrow pK^-$
5	$\pi^+p \rightarrow p\rho^+$
6	$\pi^-p \rightarrow p\rho^-$
7	$K^+p \rightarrow pK^{*+}$
8	$K^-p \rightarrow pK^{*-}$
9	$K^-p \rightarrow \pi^-\Sigma^+$
10	$K^-p \rightarrow \pi^+\Sigma^-$
11	$K^-p \rightarrow \Lambda\pi^0$
12	$\pi^-p \rightarrow \Lambda K^0$
13	$\pi^+p \rightarrow \pi^+\Delta^+$
14	$\pi^-p \rightarrow \pi^-\Delta^+$
15	$\pi^-p \rightarrow \pi^+\Delta^-$
16	$K^+p \rightarrow K^+\Delta^+$
Baryon-baryon reactions	
17	$pp \rightarrow pp$
18	$\bar{p}p \rightarrow \bar{p}\bar{p}$
19	$\bar{p}p \rightarrow \pi^+\pi^-$
20	$\bar{p}p \rightarrow K^+K^-$

TABLE V. The scaling between E755 and E838 has been measured for eight meson-baryon and 2 baryon-baryon interactions at $\theta_{\text{c.m.}} = 90^\circ$. The nominal beam momentum was 5.9 GeV/c and 9.9 GeV/c for E838 and E755, respectively. There is also an overall systematic error of $\Delta n_{\text{syst}} = \pm 0.3$ from systematic errors of $\pm 13\%$ for E838 and $\pm 9\%$ for E755.

No.	Interaction	Cross section		$n=2$ ($\frac{d\sigma}{dt} \sim 1/s^{n-2}$)
		E838	E755	
1	$\pi^+ p \rightarrow p\pi^+$	132 ± 10	4.6 ± 0.3	6.7 ± 0.2
2	$\pi^- p \rightarrow p\pi^-$	73 ± 5	1.7 ± 0.2	7.5 ± 0.3
3	$K^+ p \rightarrow pK^+$	219 ± 30	3.4 ± 1.4	$8.3^{+0.6}_{-1.0}$
4	$K^- p \rightarrow pK^-$	18 ± 6	0.9 ± 0.9	≥ 3.9
5	$\pi^+ p \rightarrow p\rho^+$	214 ± 30	3.4 ± 0.7	8.3 ± 0.5
6	$\pi^- p \rightarrow p\rho^-$	99 ± 13	1.3 ± 0.6	8.7 ± 1.0
13	$\pi^+ p \rightarrow \pi^+\Delta^+$	45 ± 10	2.0 ± 0.6	6.2 ± 0.8
15	$\pi^- p \rightarrow \pi^-\Delta^-$	24 ± 5	≤ 0.12	≥ 10.1
17	$p\bar{p} \rightarrow p\bar{p}$	3300 ± 40	48 ± 5	9.1 ± 0.2
18	$\bar{p}p \rightarrow \bar{p}p$	75 ± 8	≤ 2.1	≥ 7.5

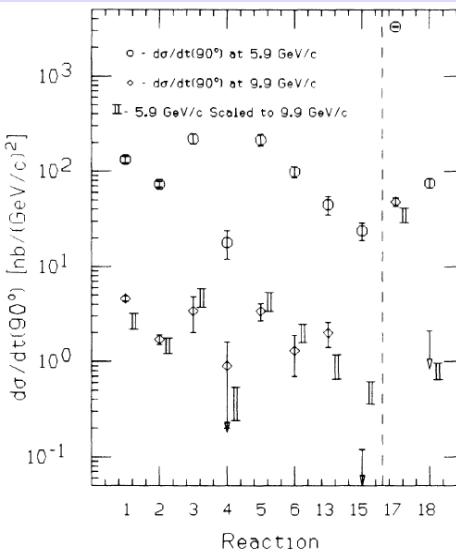
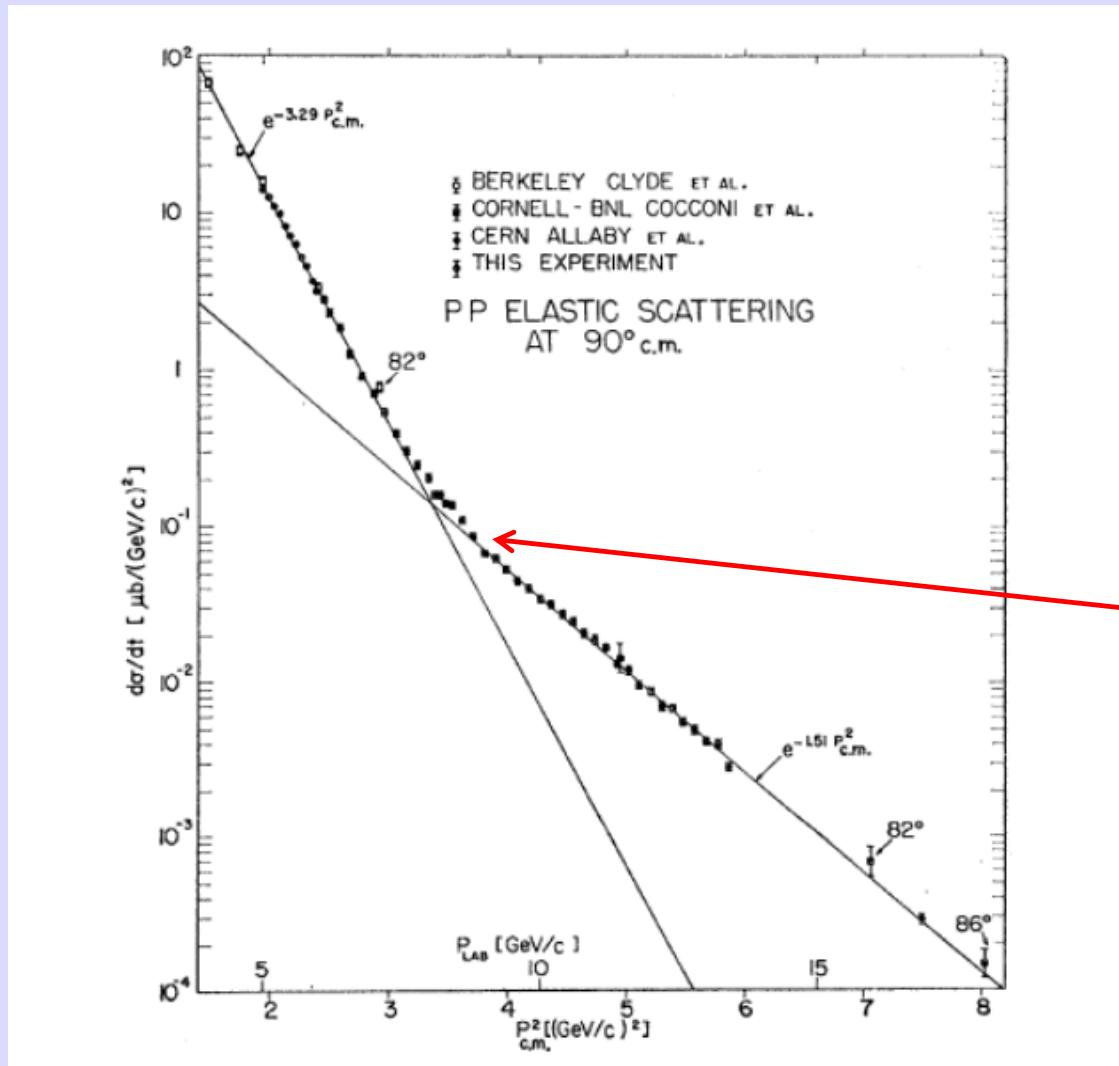


FIG. 26. The scaling between E755 and E838 has been calculated for eight meson-baryon and 2 baryon-baryon interactions at $\theta_{\text{c.m.}} = 90^\circ$. The beam momentum for E838 was 5.9 GeV/c, corresponding to $s = 11.9 \text{ GeV}^2$ for meson-baryon reactions and $s = 12.9 \text{ GeV}^2$ for baryon-baryon reactions. For the 9.9 GeV/c momentum of E755, the corresponding values of s are 19.6 and 20.5 GeV 2 .

In which range of energy
to provide investigation?

pp \rightarrow pp (90°)

C.W. Akerlof et al., Phys. Rev., vol. 159, N5, 1138-1149, 1967



Color(nuclear) transparency for proton

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

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

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

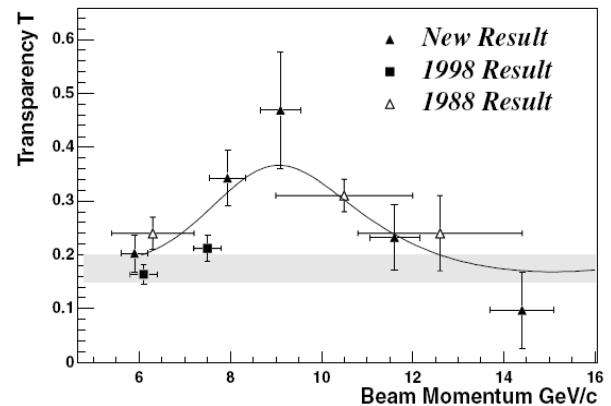
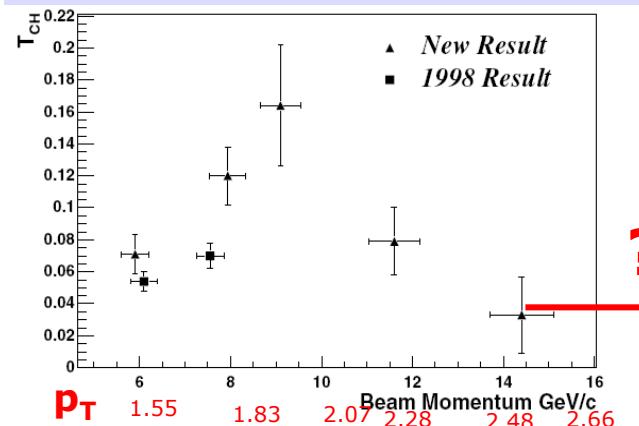


FIG. 2. Top: The transparency ratio T_{CH} as a function of the beam momentum for both the present result and two points from the 1998 publication [3]. Bottom: The transparency T versus beam momentum. The vertical errors shown here are all statistical errors, which dominate for these measurements. The 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.

Energy dependence of spin-spin effects in p - p elastic scattering at 90° c.m.

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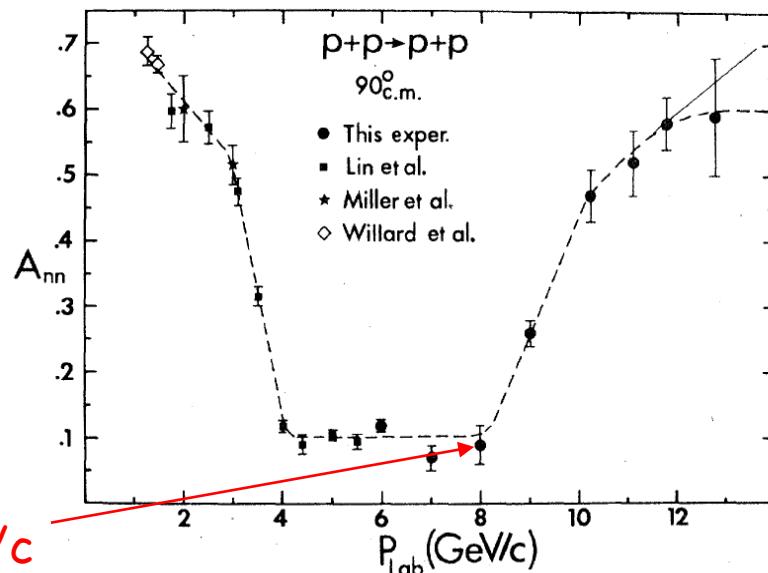
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The energy dependence of the spin-parallel and spin-antiparallel cross sections for $p + p \rightarrow p + p$ at 90° c.m. was measured for beam momenta between 6 and 12.75 GeV/c. The ratio $(d\sigma/dt)_{\text{parallel}} : (d\sigma/dt)_{\text{antiparallel}}$ at 90° is about 1.2 up to 8 GeV/c and then increases rapidly to a value of almost 4 near 11 GeV/c. Our data indicate that this ratio may depend only on the variable P_\perp^2 , and suggests that the ratio may reach a limiting value of about 4 for large P_\perp^2 .



8 GeV/c

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.

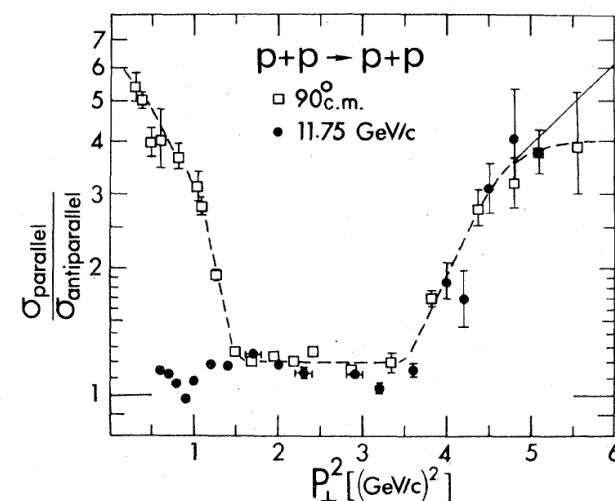


FIG. 3. Plot of the ratio of the spin-parallel to spin-antiparallel differential cross sections, as a function of P_\perp^2 , for p - p elastic scattering. The squares are the fixed-angle data at 90° c.m., with the incident energy varied. The circles are data (Refs. 5, 11) with the momentum held fixed 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.

Scaling Laws at Large Transverse Momentum*

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The application of simple dimensional counting to bound states of pointlike particles enables us to derive scaling laws for the asymptotic energy dependence of electromagnetic and hadronic scattering at fixed c.m. angle which only depend on the number of constituent fields of the hadrons. Assuming quark constituents, some of the $s \rightarrow \infty$, fixed- t/s predictions are $(d\sigma/dt)_{\pi p} \rightarrow \pi p \sim s^{-8}$, $(d\sigma/dt)_{pp} \rightarrow pp \sim s^{-10}$, $(d\sigma/dt)_{\gamma p} \rightarrow \pi p \sim s^{-7}$, $(d\sigma/dt)_{\gamma p} \rightarrow \gamma p \sim s^{-6}$, $F_\pi(q^2) \sim (q^2)^{-1}$, and $F_{\gamma p}(q^2) \sim (q^2)^{-2}$. We show that such scaling laws are characteristic of renormalizable field theories satisfying certain conditions.

Our central result for exclusive scattering¹ is

$$(d\sigma/dt)_{AB \rightarrow CD} \sim s^{2-n} f(t/s) \quad (1)$$

($s \rightarrow \infty$, t/s fixed). Here n is the total number of leptons, photons, and quark components (i.e., elementary fields) of the initial and final states. This result follows heuristically if the only physical dimensional quantities are particle masses and momenta. We begin by considering a world in which a hadron would become a collection of free quarks with equal momenta if the strong interactions were turned off. Note that the dimen-

¹This result for elastic scattering has been obtained independently by V. Matveev, R. Muradyan, and A. Tavkhelidze, Joint Institute for Nuclear Research Report No. D2-7110, 1973 (to be published). We thank J. Kissis for bringing this work to our attention.

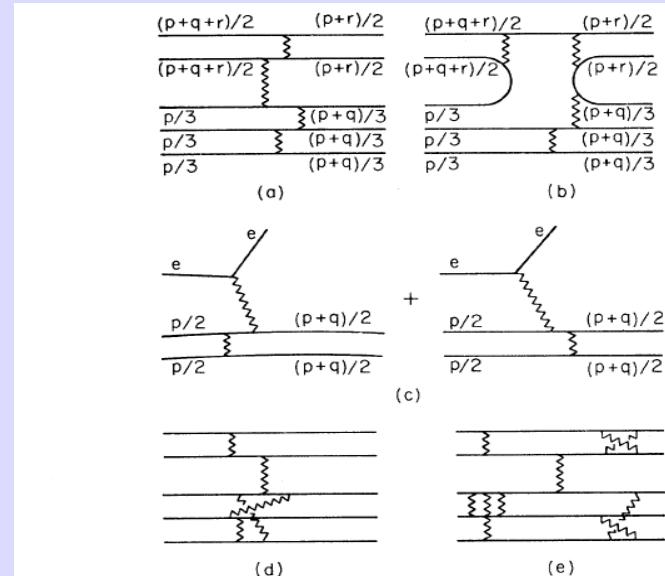
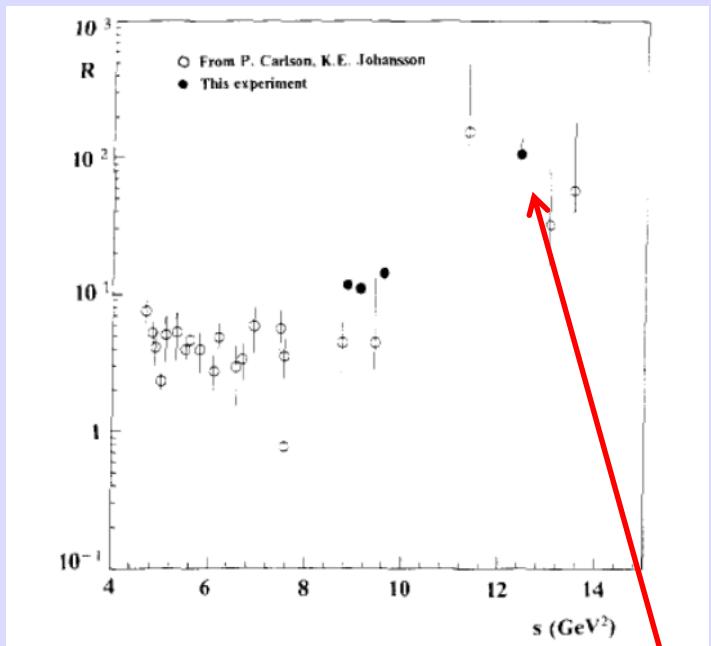


FIG. 1. Typical Born diagrams for large-momentum-transfer elastic scattering in the quark picture. (a) $\pi p \rightarrow \pi p$ (quark scattering), (b) $\pi p \rightarrow \pi p$ (quark interchange), (c) $e\pi \rightarrow e\pi$, (d) an irreducible loop diagram, (e) ²³a reducible loop diagram.

p p



$$R = \frac{\sigma(pp \rightarrow pp)}{\sigma(p\bar{p} \rightarrow p\bar{p})} (90^\circ \text{ c.m.})$$

$p_T \sim 2 \text{ GeV}/c$ region

C. Baglin et al., Phys.Lett. B, vol.225, N3, 296-300, 1989

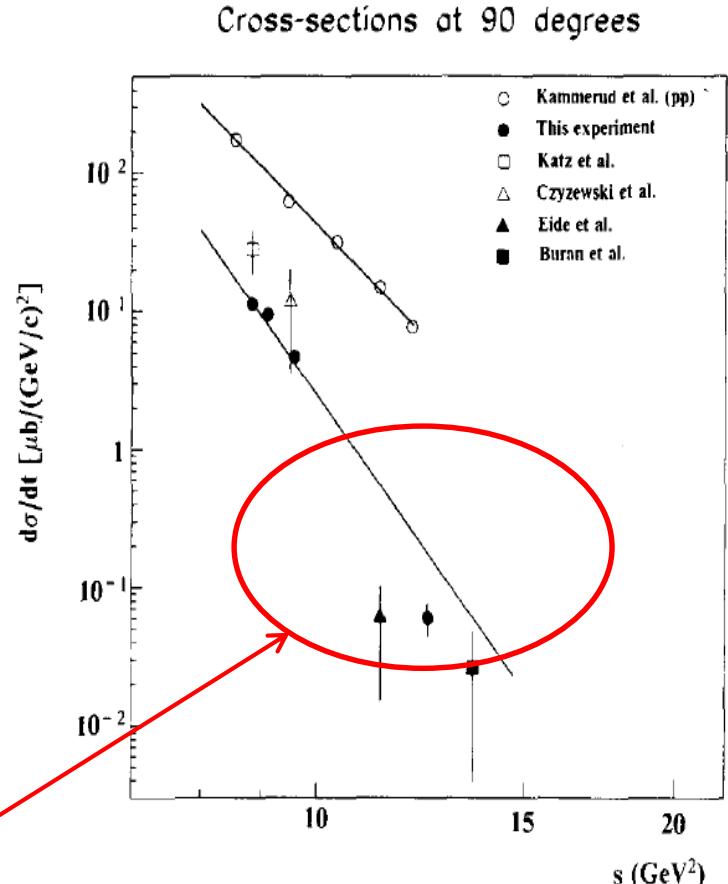


Fig. 3. The $p\bar{p}$ and $p p$ elastic differential cross sections at 90° CM as function of the square of the CM energy, s . Open circles are $p p$ data from ref. [6]. These data fit well to the drawn curve proportional to s^{-9} . The remaining points are $p\bar{p}$ data. Shaded from this experiment. Otherwise from ref. [7] (open square), ref. [8] (open triangle) ref. [9] (shaded triangle) and ref. [10] (shaded square). The lower curve is an s^{-n} fit to four data points of this experiment, neglecting systematic errors. One obtains $n=12.3 \pm 0.2$, but evidently the data do not seem to follow this kind of a power law.

Which reactions need to provide investigation?

(Half)-exclusive NN studies at $x_T \sim 1$



$B(p, n, \Lambda, \Delta \dots D(?)), M(\pi, K, \dots)$

Mechanisms of hyperons polarization

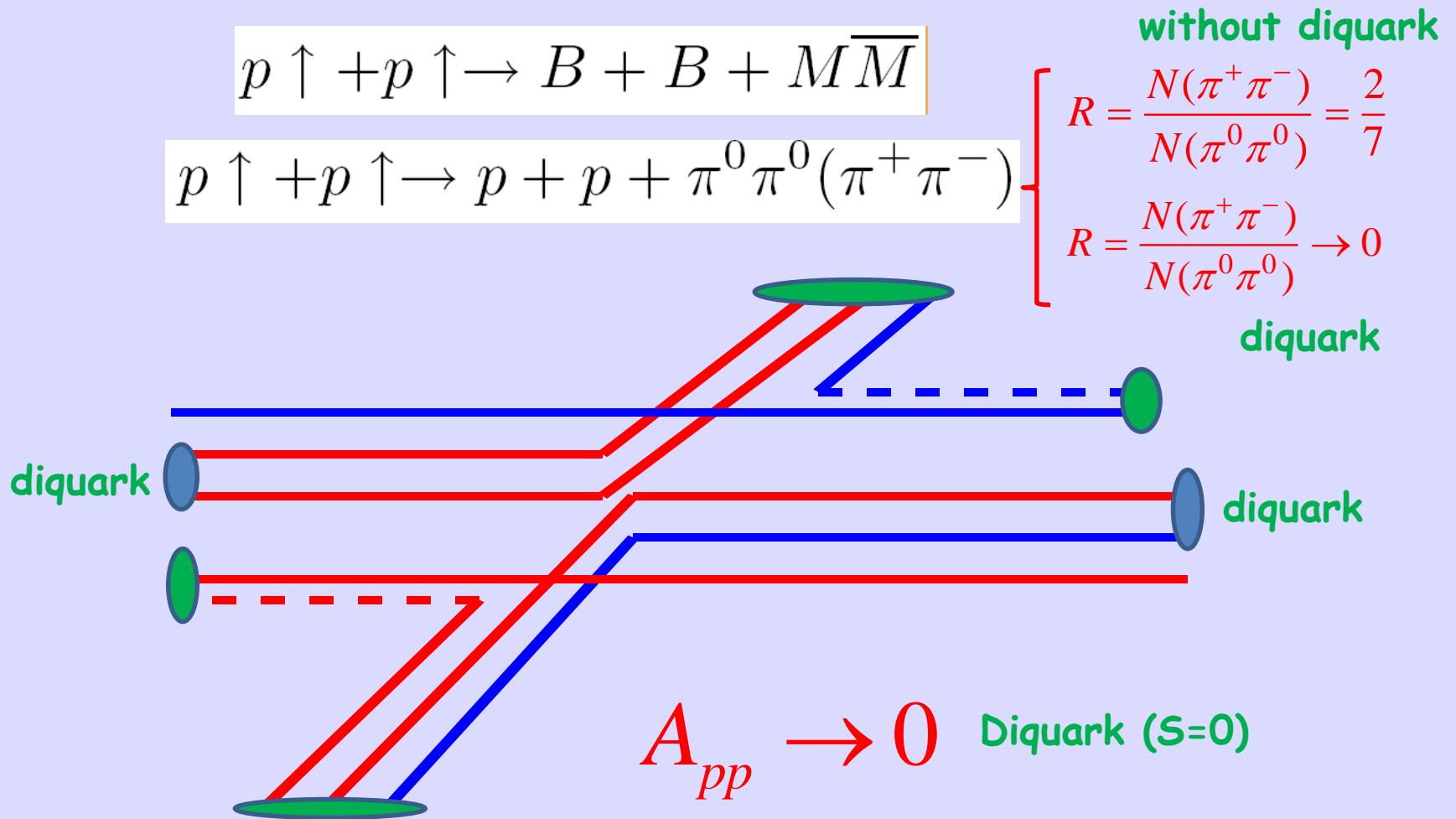


} The counting rules and isotopic symmetry studies, $p_T \sim 2 \text{ GeV}/c$ anomaly



} Detail vertexes studies and spin structure of the interaction vertex:
 $q + (q) - (\text{quark} - \text{quark})$
 $q + (qq) - (\text{quark} - \text{diquark})$
 $(qq) + (qq) - (\text{diquark} - \text{diquark})$

High p_T exclusive reactions \rightarrow MPI



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

$$\left. \begin{array}{l} \bar{p}p \rightarrow \bar{p}p \\ \bar{p}p \rightarrow \bar{n}n - ? \end{array} \right\}$$

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

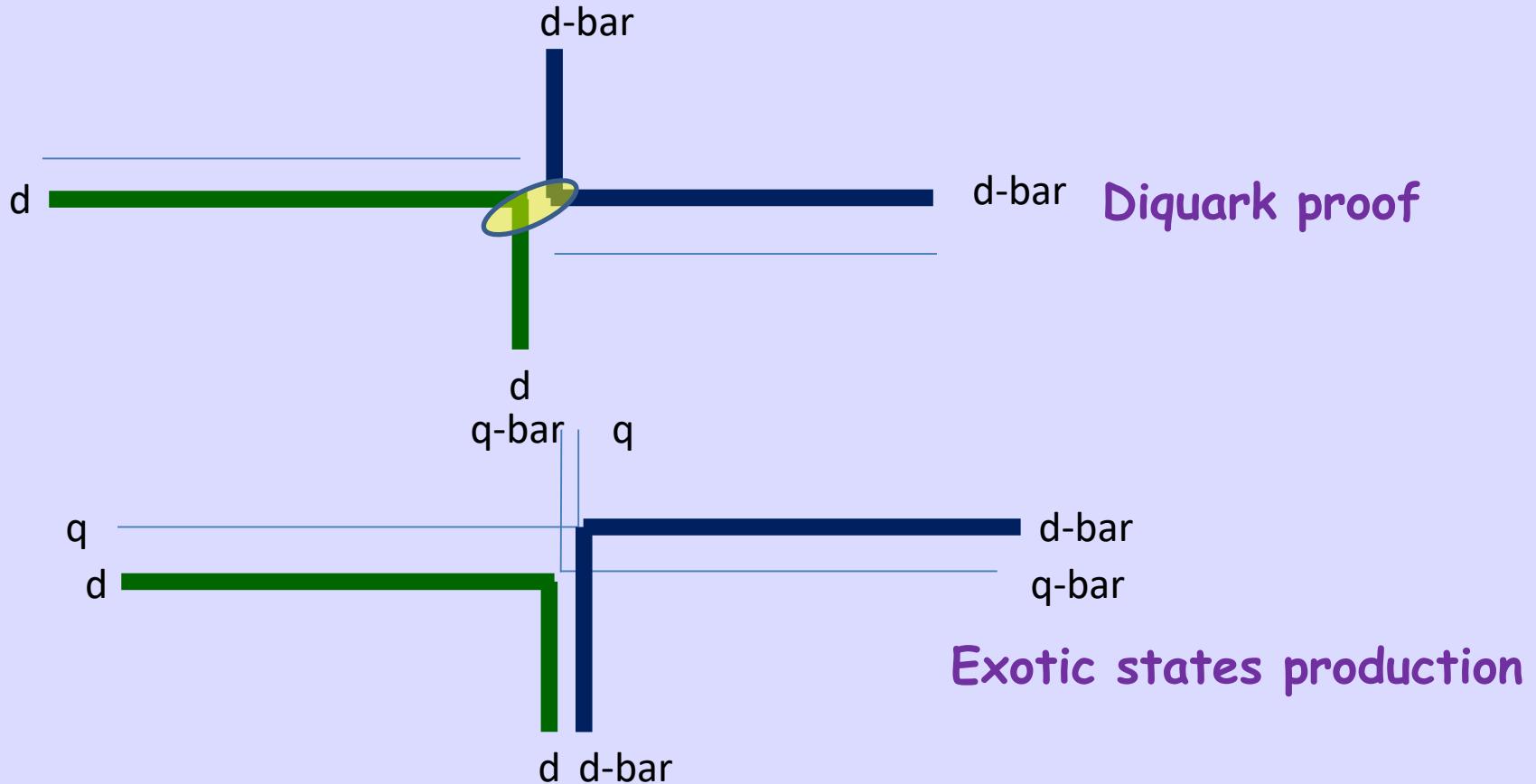
$$\left. \begin{array}{l} \bar{p}p \rightarrow \bar{p}p + \pi\pi(KK) \\ \bar{p}p \rightarrow \bar{\Lambda}\Lambda + KK(\pi\pi, \mu\mu) \\ \bar{p}p \rightarrow \bar{\Delta}\Delta \end{array} \right\}$$

Detail vertexes studies:

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

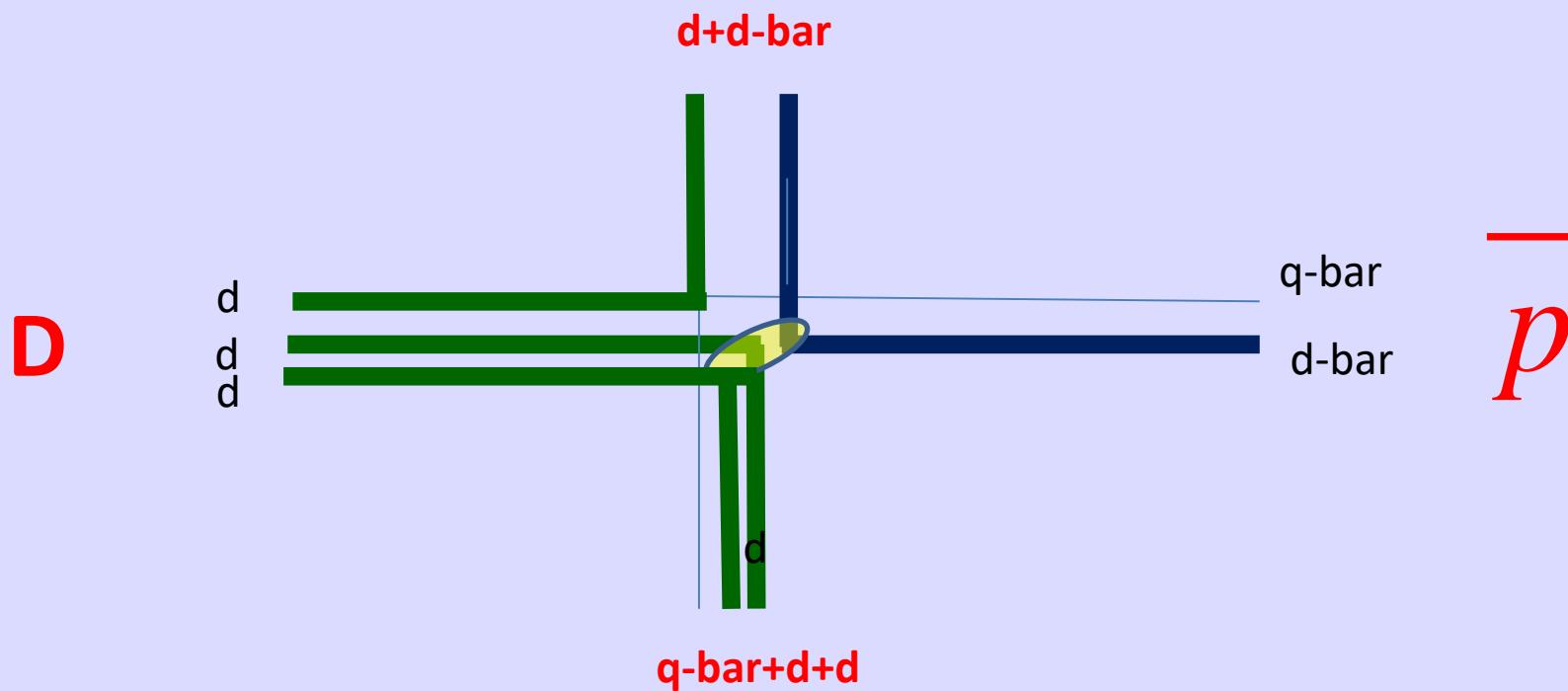
—

Exotic states production $p\bar{p}$ - reactions with tetraquarks production



Kim's-bar mechanisms

$\bar{p}d$ - reaction with tetraquarks
+ pentaquark production



CsDBM

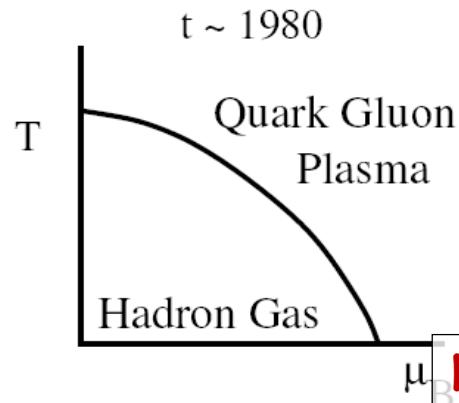
Larry McLerran

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

September 13, 2003

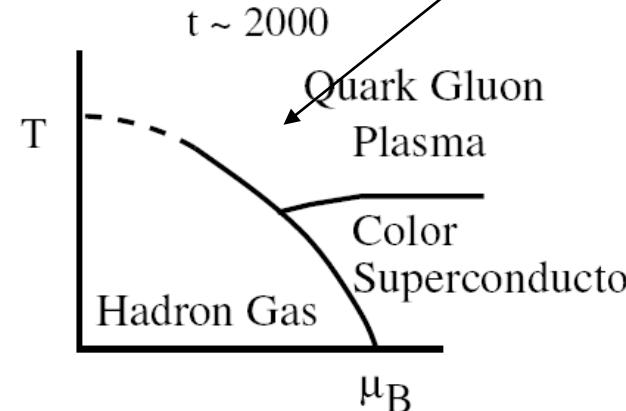
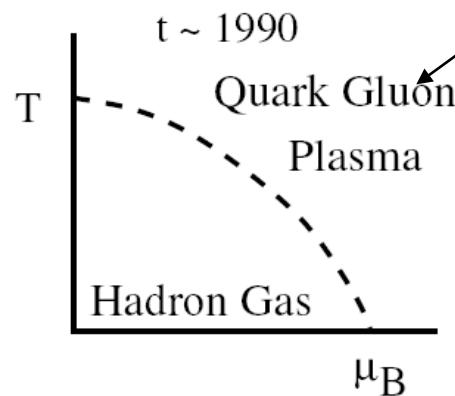
+ CERN Yellow Report
2007-005, p.75
2008-005

The Evolving QCD Phase Transition



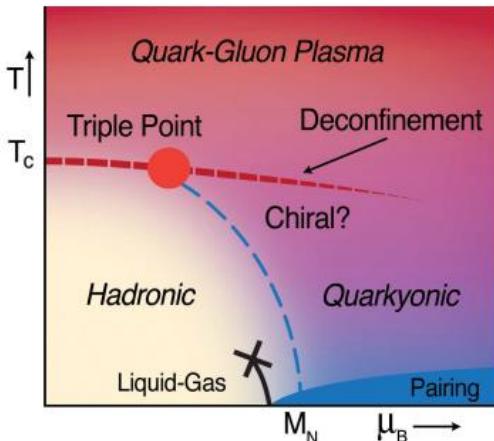
Critical Temperature 150 - 200 MeV ($\mu_B = 0$)
Critical Density 1/2-2 Baryons/Fm³ ($T = 0$)

Nuclear Physics A 837 (2010) 65-86



Nuclotron-SPS Time (CERN)

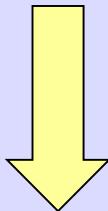
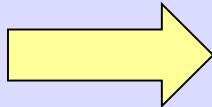
RHIC Time(BNL)



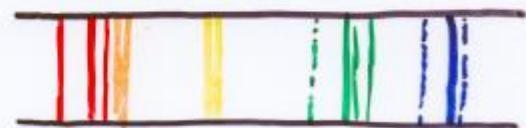
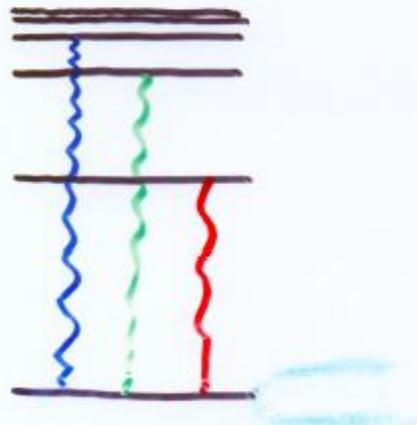
F. Close

Structure of Matter

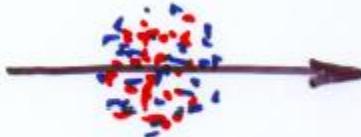
Two ways that structure is revealed:



1. SPECTRA



2. SCATTERING FROM "HARD" CENTRES



True from atoms to particles....

SPECTRA

...с помощью ускорения тяжелых ядер, обладающих более высоким зарядом, можно было бы сравнительно дешевым способом в короткие сроки получить пучки частиц рекордно высоких энергий.

...it is possible to obtain the record high energy particle beams by means of accelerating the heavy nuclei with large charges

январь 1971

АКАДЕМИЯ НАУК СССР

Ордена Ленина

Физический институт им П.Н. Лебедева

10 Гэв, а ядра гелия с энергией 20 Гэв, а ядра гелия с энергией 100 Гэв. Возникает естественное предположение, что не получатся ли в результате столкновения ядер, например, неона, обладающих энергией 10 Гэв, пучки вторичных частиц, полученные пока только в Серпуховском ускорителе? Утвердительный ответ на этот вопрос означал бы, что с помощью ускорения тяжелых ядер, обладающих более высоким зарядом, можно было бы сравнительно дешевым способом в короткие сроки получить пучки частиц рекордно высоких энергий.

Цель настоящей заметки – рассмотреть этот вопрос и сделать определенные предсказания.

Обычно на вопрос о возможности передачи большой энергии составным ядром отдельному (например, сво-

ИНЫХ
ЧЕНИЯ
РИ
АРЯДНЫХ

него време-
и электрон-
ц, обладаю-
обладающих
в principle
ляемых час-
) большую,
е кратности
хрофазотро-

с энергией

ядра гелия с энергией 20 Гэв,
с энергией 100 Гэв. Возни-
кает естес-
твенно пред-
положение,

что не полу-
чается ли в резуль-
тате столкнове-
ния ядер, напри-
мер, неона, об-
ладающих эн-
ергией 10 Гэв, пучки вторичных час-
тиц, полу-
ченные пока толь-
ко в Серпуховском уско-
рителе?

Jim Baggott HIGGS

The Invention and Discovery of the ‘God Particle’

Oxford University Press, 2012

FOREWORD

by Steven Weinberg

“Like many other theorists, I did not fully accept the existence of quarks until the 1973 work of David Gross and Frank Wilczek, and David Politzer. They showed that in the theory of quarks and strong nuclear forces known as quantum chromodynamics, the strong force gets weaker with decreasing distance”.



P1 - 5819

А.М. Балдин, Н. Гиордэнеску, В.Н. Зубарев,
А.Д. Кириллов, В.А. Кузнецов, Н.С. Мороз,
В.Б. Радоманов, В.Н. Рамжин, В.А. Свиридов,
В.С. Ставинский, М.И. Януга

НАБЛЮДЕНИЕ ПИОНОВ
ВЫСОКОЙ ЭНЕРГИИ
ПРИ СТОЛКНОВЕНИИ РЕЛЯТИВИСТСКИХ
ДЕЙТОНОВ С ЯДРАМИ

1971

The first experimental data

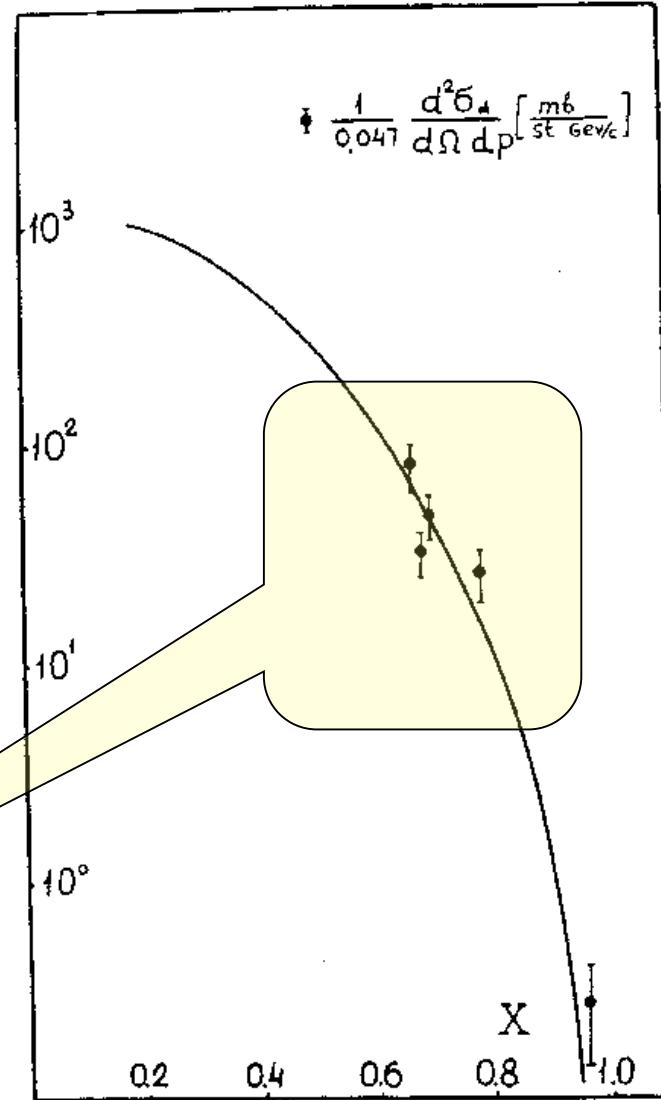


Рис. 3. Сравнение экспериментальных данных по сечению рождения пиона дейtronами с теоретической функцией, описывающей сечение рождения пиона protонами.

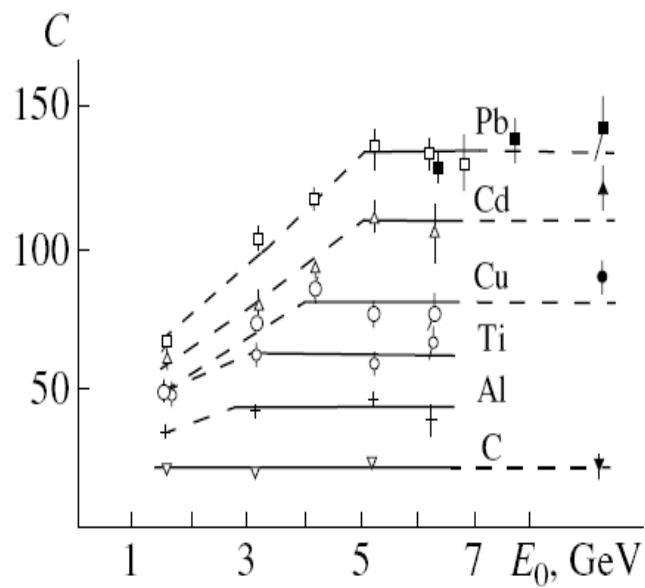


Fig. 3. The coefficient $C(T_0 = 125$ MeV) in the parametrization of the invariant function $f = C \exp(-T/T_0)$ in the reaction $pA(C, Al, Ti, Cu, Cd, Pb) \rightarrow pX$ for a proton escape angle of 120° in the laboratory frame versus the incident-proton energy. The filled circles refer to the initial energy of 400 GeV.

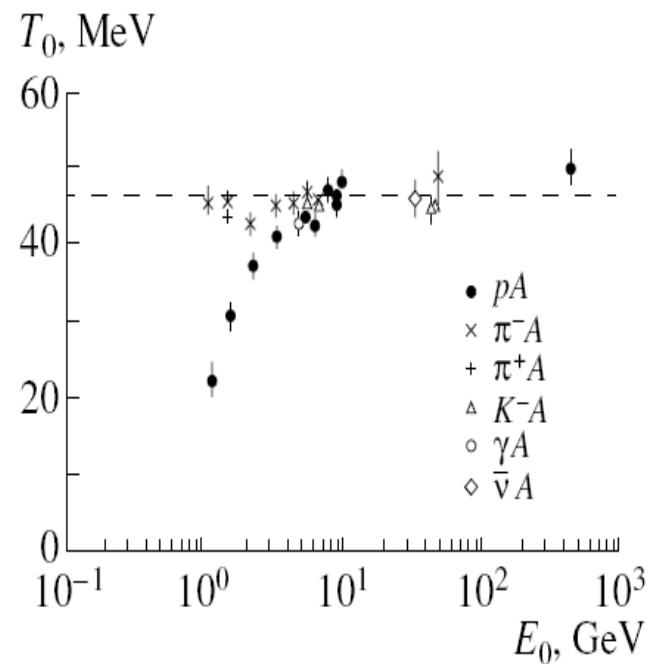
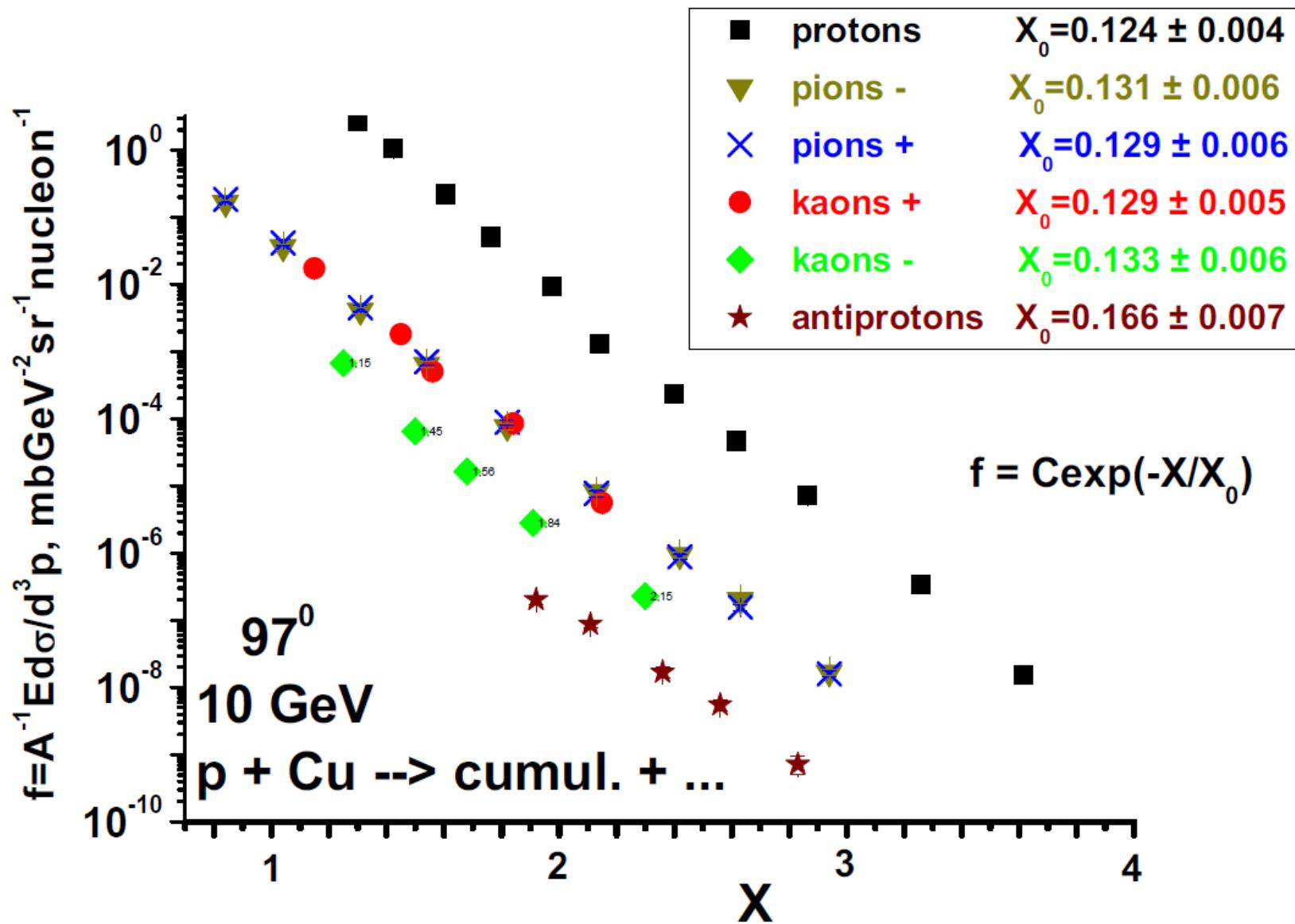


Fig. 5. Dependence of the slope parameter T_0 for the invariant function of the protons escaping under the action of $p, \pi^\pm, K^-, \gamma, \bar{\nu}$ with various energies E_0 ; the escape angle is 120° in the laboratory frame.



THEORIES

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

V.V. BUROV

The Moscow State University, Moscow, USSR

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.

27.05.2015 PANDA meeting
Shamansky S.S.

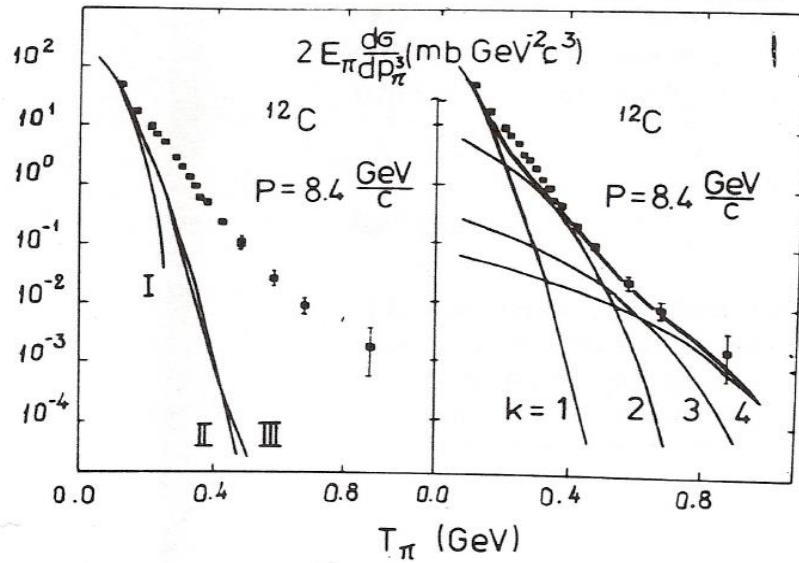


Fig. 1. (a) Calculations of the invariant pion production cross section for ^{12}C : I – for the free proton target; II – with fermi motion; III – the relativization effect. (b) The contributions of separate fluctuons with mass $M_k = km_p$ where k is the order of cumulativity.

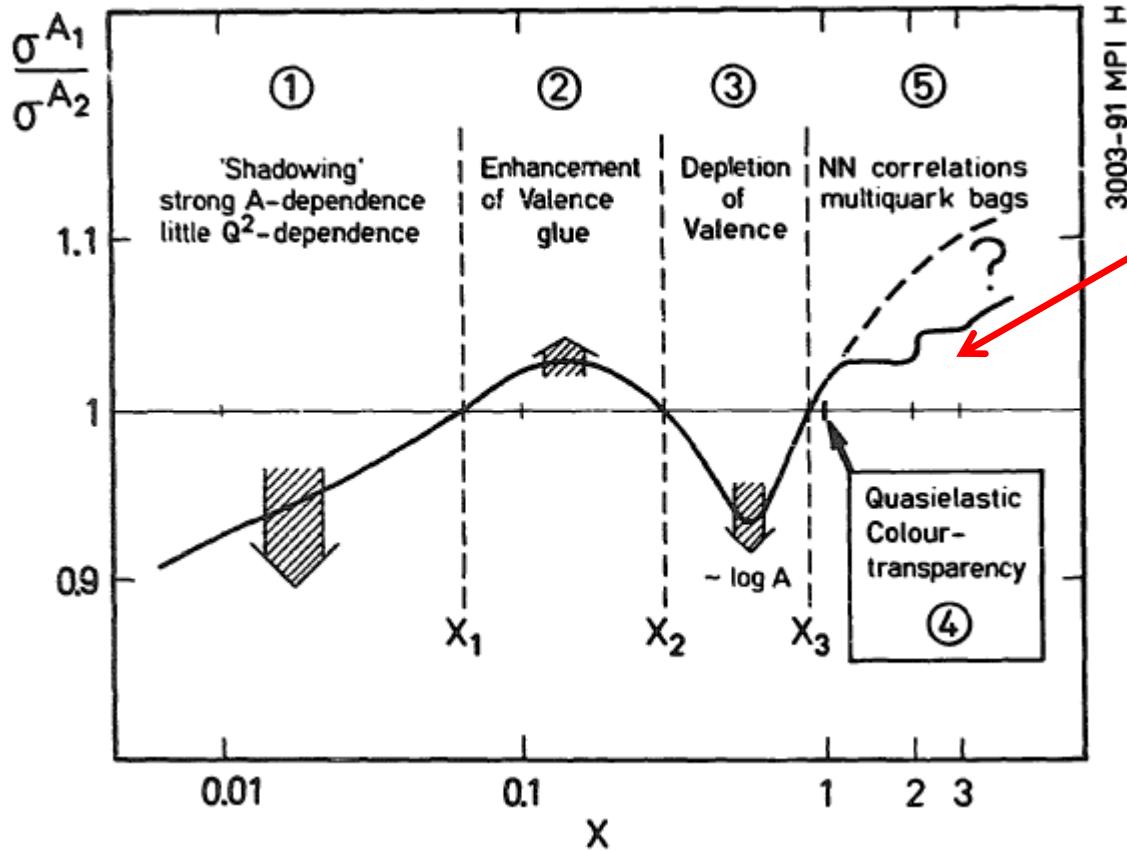
Fluctons Probability inside nuclei



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

**DIS in the cumulative
region.**

Cumulative
kinematical
region



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.

Nuclear structure functions at $x > 1$

B. W. Filippone, R. D. McKeown, R. G. Milner,* and D. H. Potterveld†

Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California 91125

D. B. Day, J. S. McCarthy, Z. Meziani,‡ R. Minehardt, R. Sealock, and S. T. Thornton

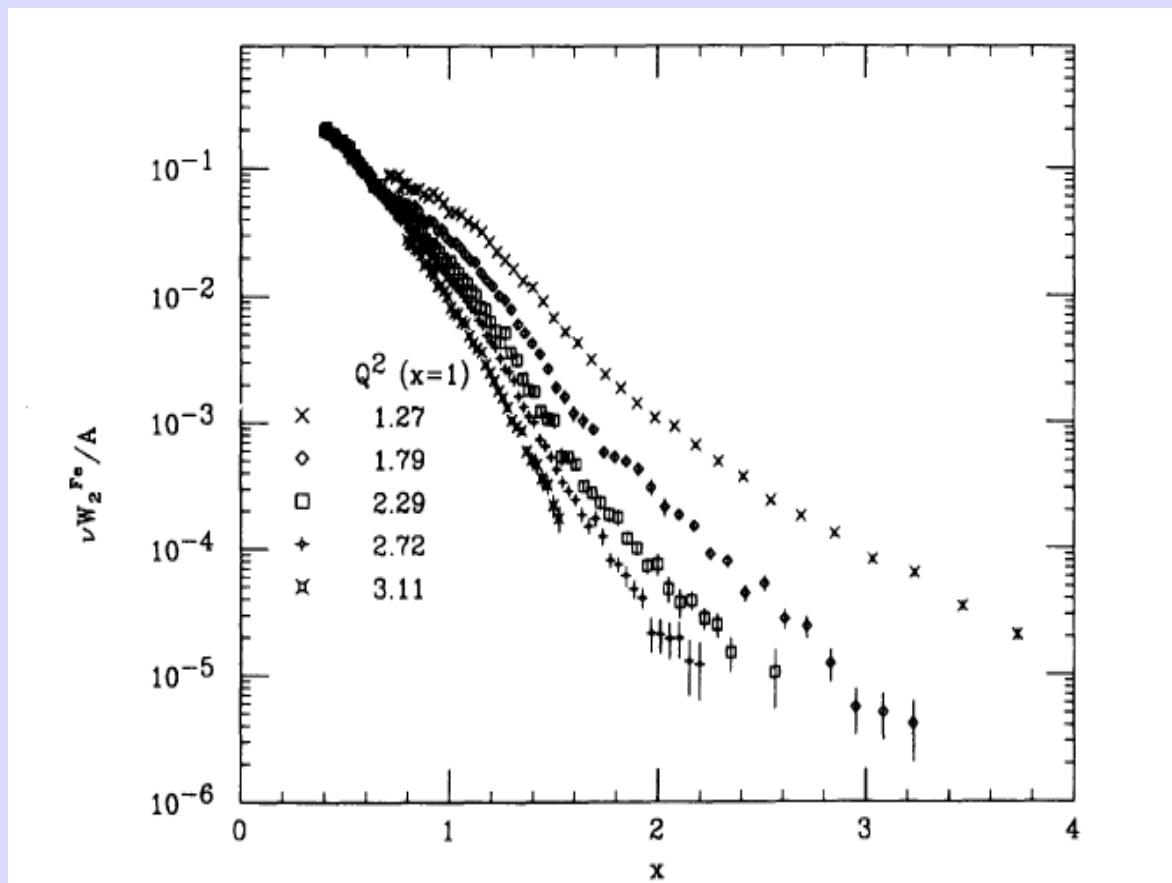
Institute of Nuclear and Particle Physics and Department of Physics, University of Virginia, Charlottesville, Virginia 22901

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.

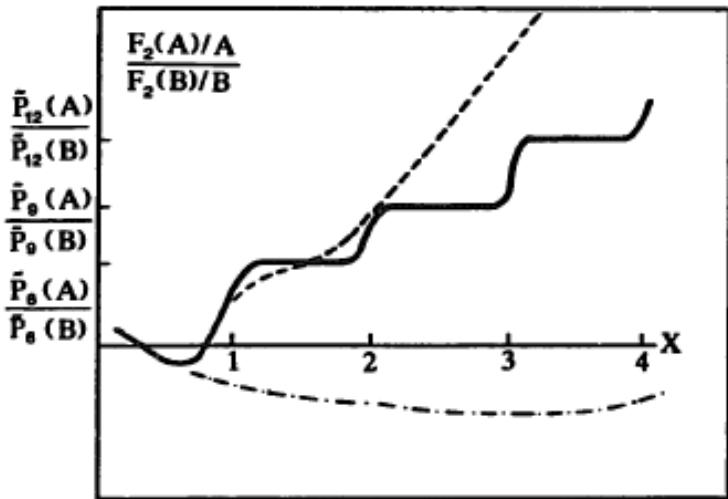


Figure 5. Theoretical predictions for nuclear structure functions at $x > 1$

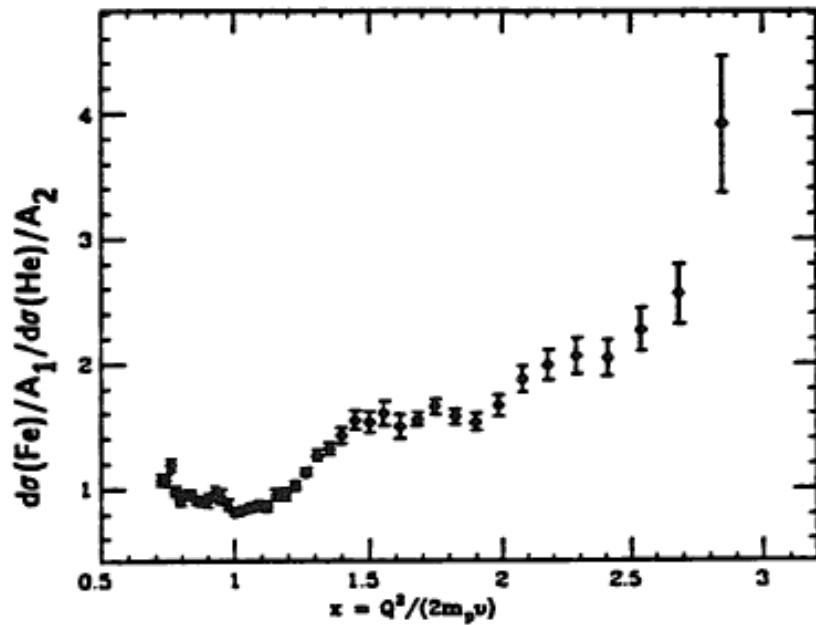


Figure 6. Preliminary results for σ^{Fe}/σ^{He} from NE-2 at SLAC

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

Nuclear structure functions in carbon near $x = 1$

BCDMS Collaboration

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Dipartimento di Fisica dell'Università and INFN, Bologna, Italy

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CERN, Geneva, Switzerland

V.I. Genchev⁶, J. Hladky³, I.A. Golutvin, Yu.T. Kiryushin, V.S. Kiselev, V.G. Krivokhizhi
 S. Nemeček³, D.V. Peshekhonov, P. Reimer³, I.A. Savin, G.I. Smirnov, S. Sultanov⁶, A.G. Vo
 Joint Institut for Nuclear Research, Dubna, Russia

D. Jamnik⁸, R. Kopp⁹, U. Meyer-Berkhout, A. Staude, K.-M. Teichert, R. Tirler¹⁰, R. Voss¹, Č
 Sektion Physik der Universität, München, Germany¹¹

J. Feltesse, A. Misztajn, A. Ouraou, P. Rich-Hennion, Y. Sacquin, G. Smadja, P. Verrecchia, M
 DAPNIA-SPP, Centre d'Etudes de Saclay, CEA, Gif-sur-Yvette, France

Received: 1 March 1994

Abstract. Data from deep inelastic scattering of 200 GeV muons on a carbon target with squared four-momentum transfer $52 \text{ GeV}^2 \leq Q^2 \leq 200 \text{ GeV}^2$ 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 $s = 16.5 \pm 0.6$.

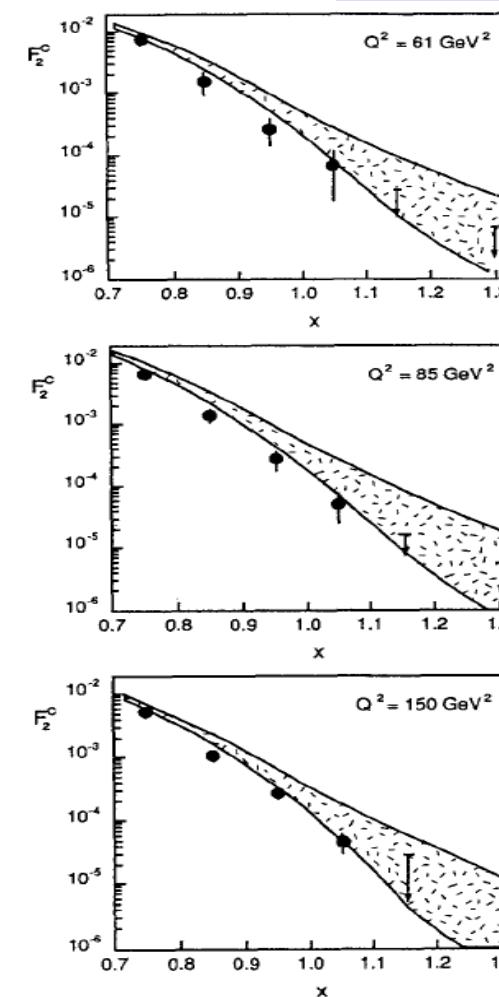


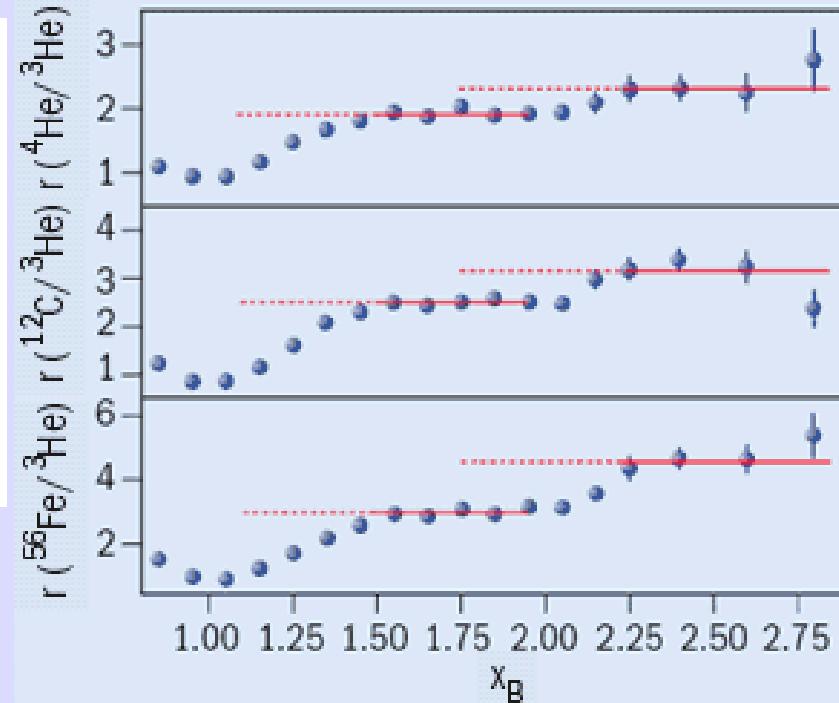
Fig. 7. The nuclear structure function $F_2^C(x)$ as a function of x , at three different values of Q^2 . The hatched regions show the range of predictions of [26]

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

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$$r(A, {}^3\text{He}) = \frac{A(2\sigma_{ep} + \sigma_{en})}{3(Z\sigma_{ep} + N\sigma_{en})} \frac{3\mathcal{Y}(A)}{A\mathcal{Y}({}^3\text{He})} C_{\text{rad}}^A, \quad (2)$$

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_{rad}^A is the ratio of the radiative correction factors for A and ${}^3\text{He}$ ($C_{\text{rad}}^A = 0.95$ and 0.92 for ${}^{12}\text{C}$ and ${}^{56}\text{Fe}$ 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 ${}^4\text{He}$ and 1.18 ± 0.02 for ${}^{56}\text{Fe}$. Fig. 1 shows the resulting ratios integrated over $1.4 < Q^2 < 2.6 \text{ GeV}^2$.



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

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

$$\begin{aligned}
 a_{pp}(^{12}\text{C}) &\approx 4 \pm 2 \% \\
 a_{2N}(^{12}\text{C}) \approx 20 \pm 0.2 \pm 4.1 \% &\longrightarrow a_{pn}(^{12}\text{C}) \approx 12 \pm 4 \% \\
 a_{nn}(^{12}\text{C}) \approx 4 \pm 2 \%
 \end{aligned}$$

^{12}C - structure

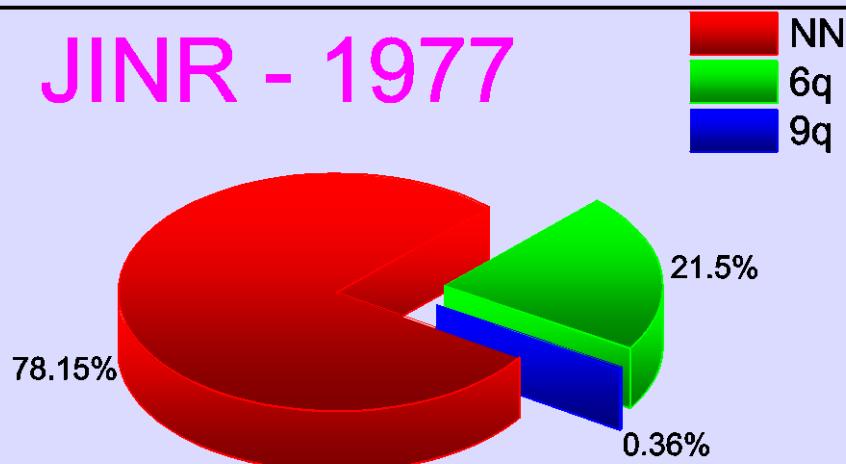
RNP - program at JINR

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

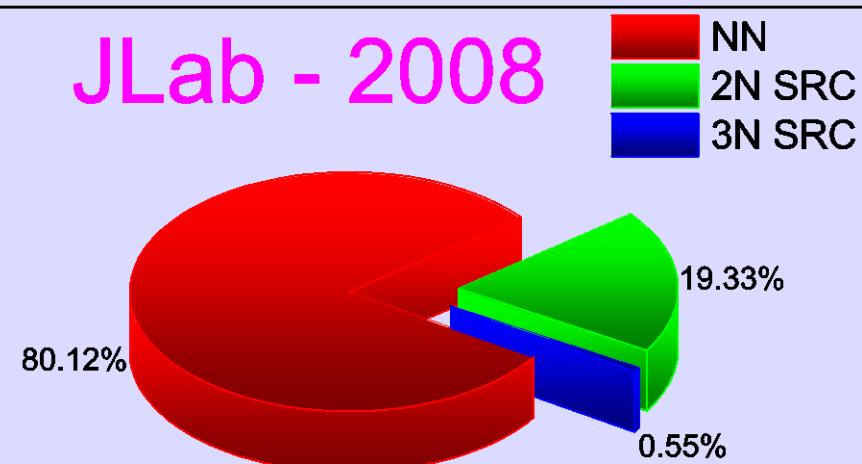
eA - program at JLab

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

JINR - 1977



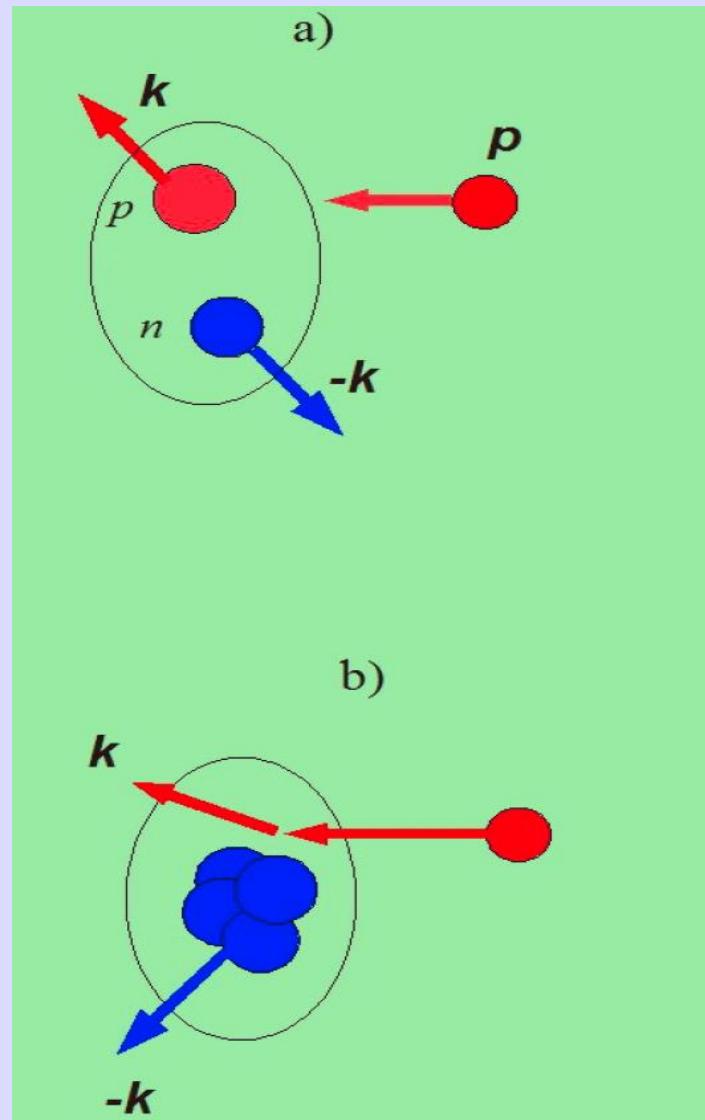
JLab - 2008



Knot out cold dense nuclear configurations

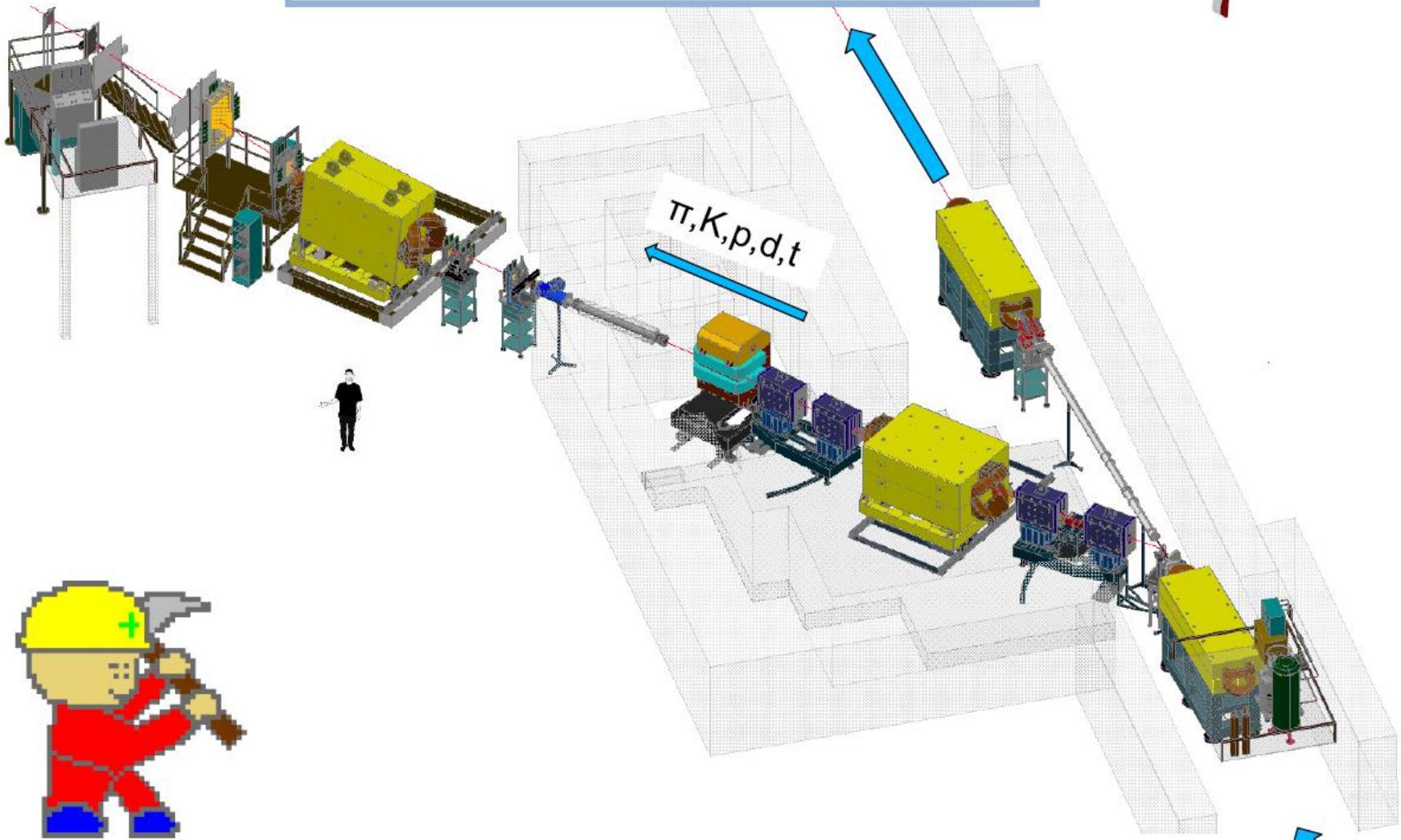
SRC configuration

**M multinucleon(multiquark)
configuration**



**SPIN – narrow acceptance spectrometer,
beam line #8**

Spin



protons
 $10^{12} - 10^{13}/\text{s}$

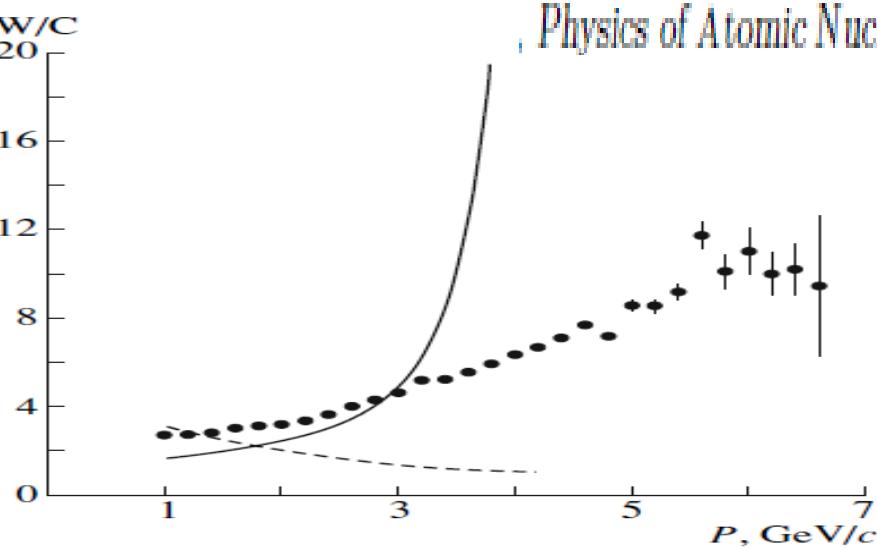
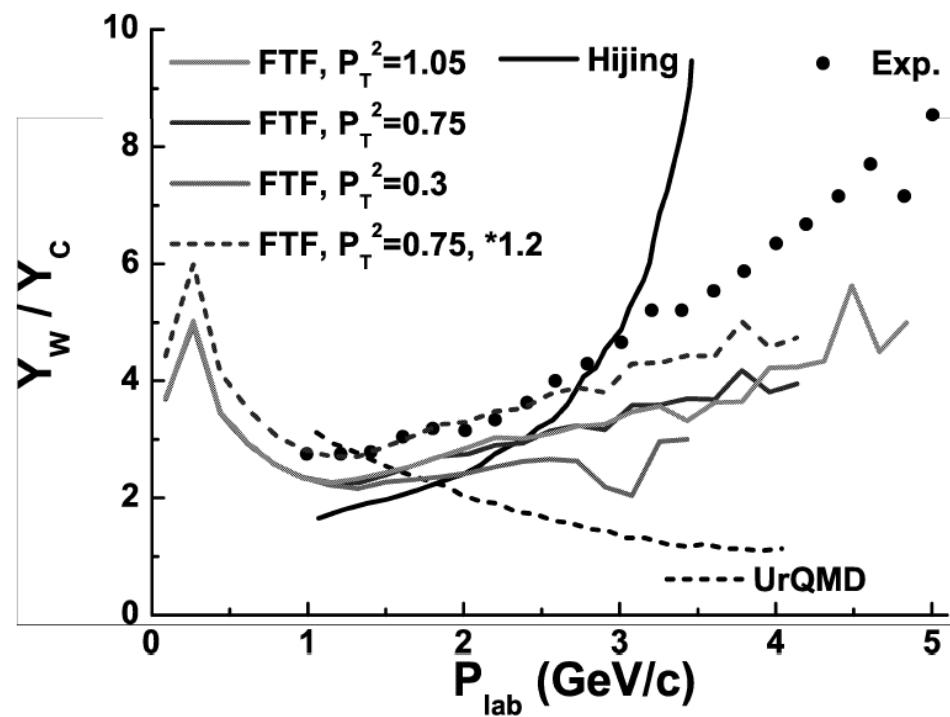


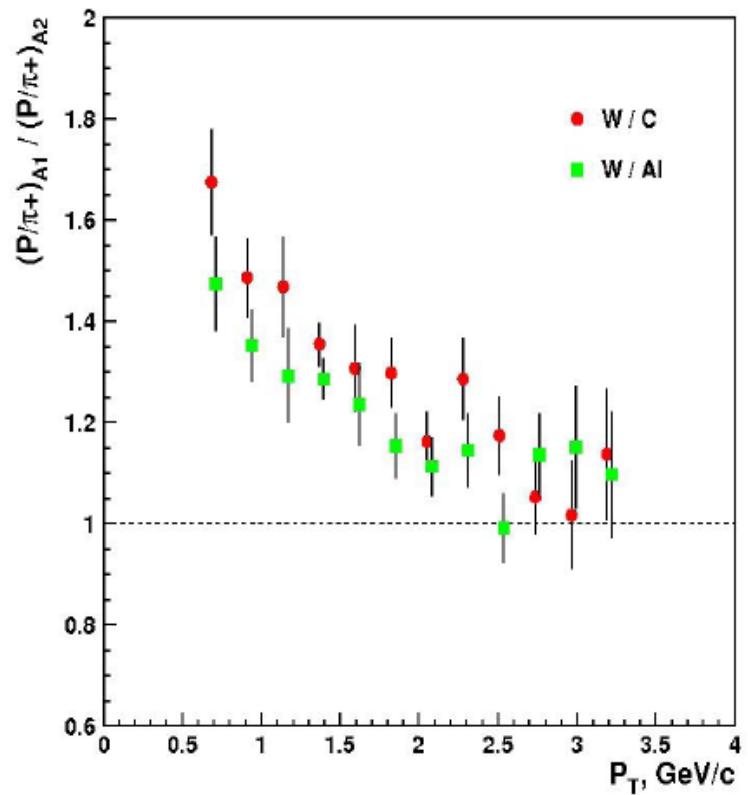
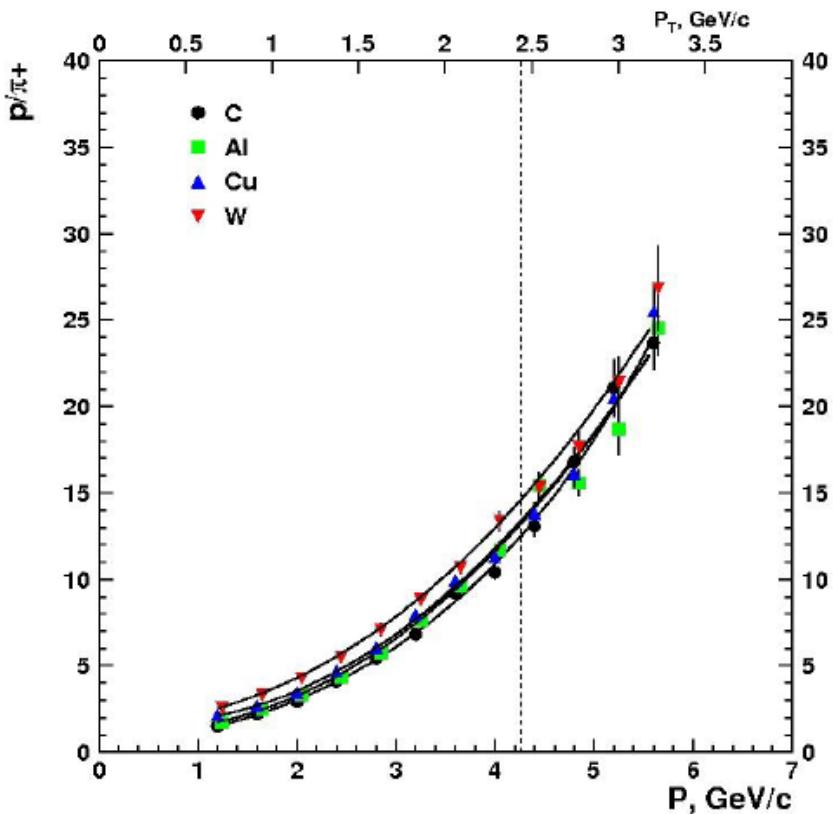
Fig. 4. Ratio of the yields of positively charged particles in proton interactions with tungsten and carbon targets: (points) experimental data, (dashed curve) predictions of the UrQMD model, and (solid curve) predictions of the HIJING model.

Galoyan A. &
Uzhinsky V.
(2016)

SPIN data

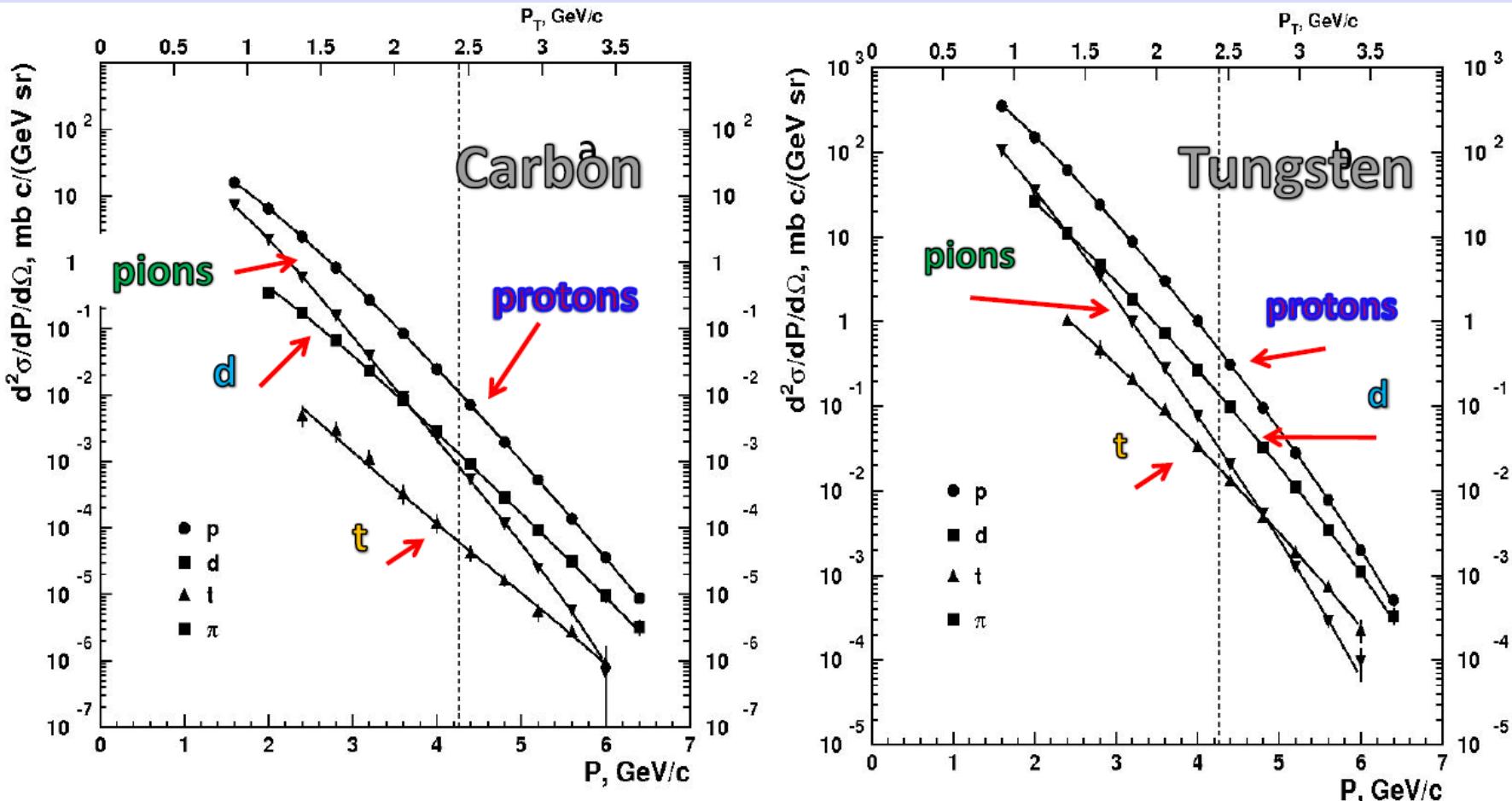


Ratio p/π^+ (2013)



SPIN data

N.N. Antonov et al., JETP Letters, Vol.101, No.10, pp.670-673(2015)



Invariant function found for positive pion, proton, deuteron and triton.

The vertical dashed lines indicate the kinematical limit for elastic nucleon-nucleon scattering. The upper horizontal scale shows values of the transverse momentum p_T .

Particle Production at Large Angles by 30- and 33-Bev Protons Incident on Aluminum and Beryllium*

V. L. FITCH, S. L. MEYER,[†] AND P. A. PIROUÉ

Palmer Physical Laboratory, Princeton University, Princeton, New Jersey

(Received February 12, 1962)

A mass analysis has been made of the relatively low momentum particles emitted from Al and Be targets when struck by 30- and 33-Bev protons. Measurements were made at 90° , 45° , and $13\frac{1}{4}^\circ$ relative to the direction of the Brookhaven AGS proton beam. Magnetic deflection and time-of-flight technique were used to determine the mass of the particles.

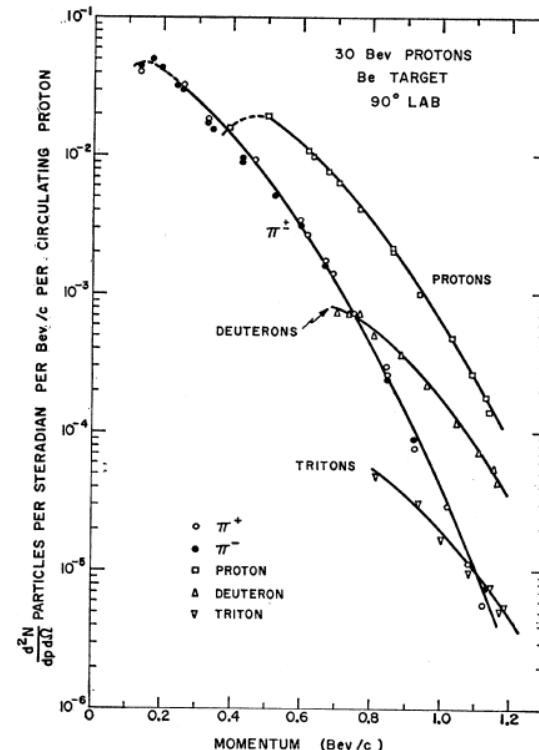


FIG. 2. Momentum spectrum of particles emitted at 90° from a beryllium target struck by 30-Bev protons. The ordinate is the number of particles produced at the target per steradian per Bev/c per circulating proton. The dashed portions of the curves indicate regions where the corrections due to multiple scattering exceed 15%. At the time these data were taken no effort was made to detect He^3 .

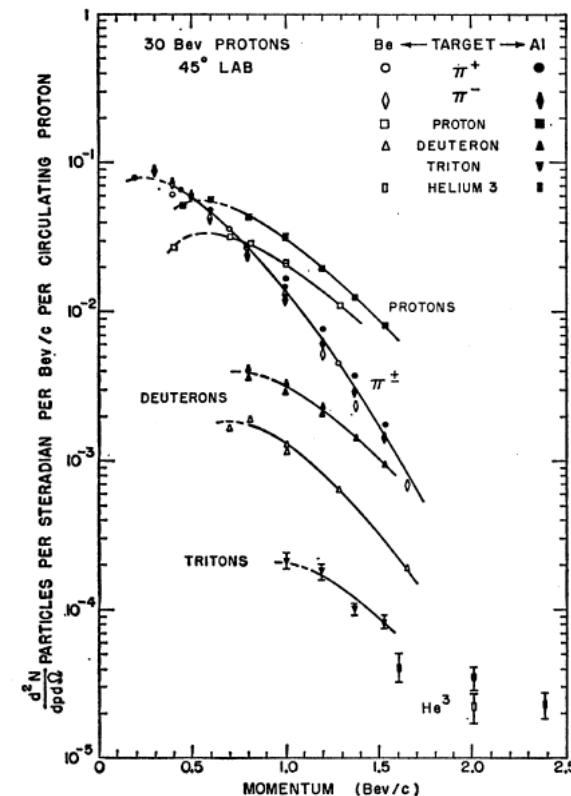
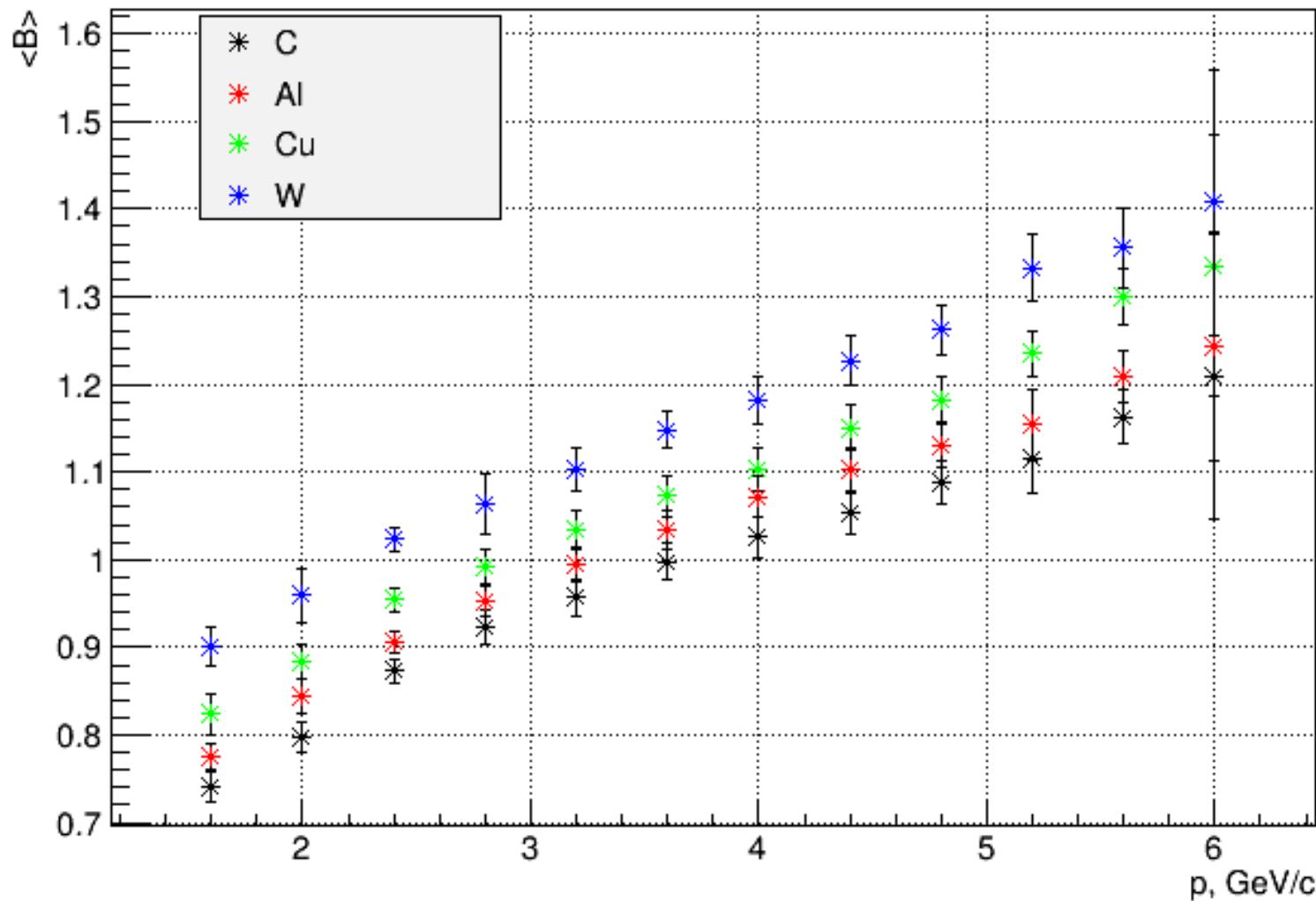


FIG. 3. Momentum spectra of particles emitted at 45° from aluminum and beryllium targets when struck by 30-Bev protons. Tritons from Be were not measured. For general remarks refer to Fig. 2 caption.

Average baryon number $\langle B \rangle$



FIELDS, PARTICLES, AND NUCLEI

Knockout of Deuterons and Tritons with Large Transverse Momenta in pA Collisions Involving 50-GeV Protons

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V. N. Gres'^a, M. A. Ilyushin^a, V. A. Korotkov^a, A. I. Mysnik^a, A. F. Prudkoglyad^a,
A. A. Semak^a, V. I. Terekhov^a, V. Ya. Uglekov^a, M. N. Ukhanov^a,
B. V. Chuiko^{a†}, and S. S. Shimanskii^b

$$\frac{E_d}{\sigma_{inel}} \frac{d^3 \sigma_A}{dp_A^3} = B_A \times \left(\frac{E_p}{\sigma_{inel}} \frac{d^3 \sigma_p}{dp_p^3} \right)^A$$

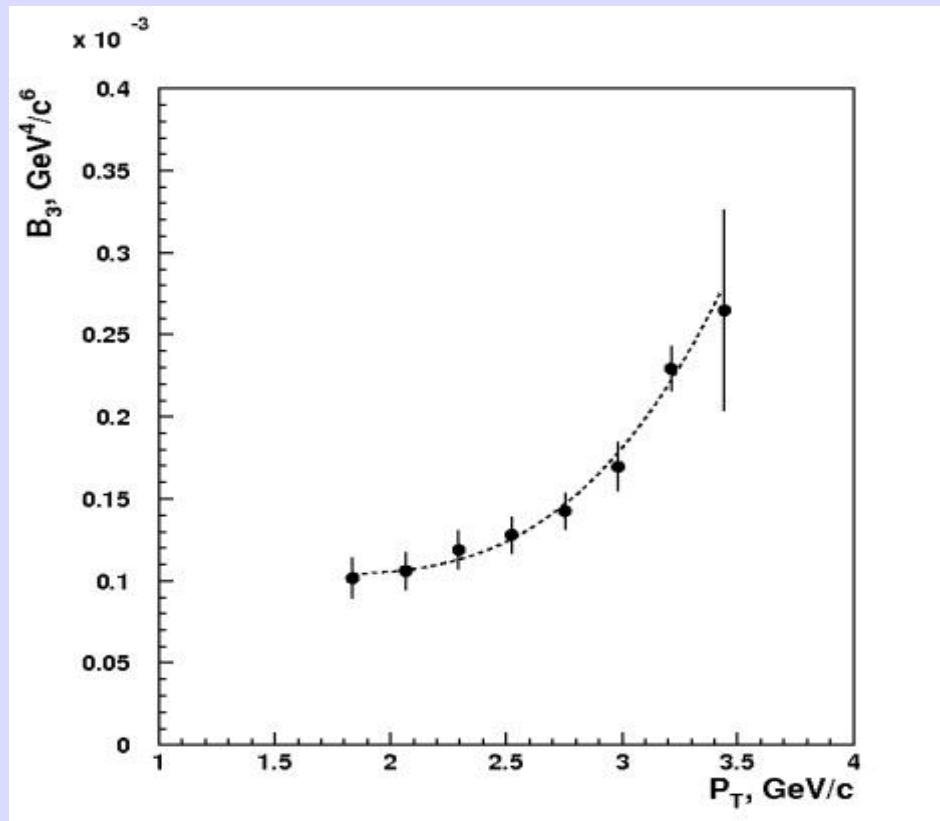
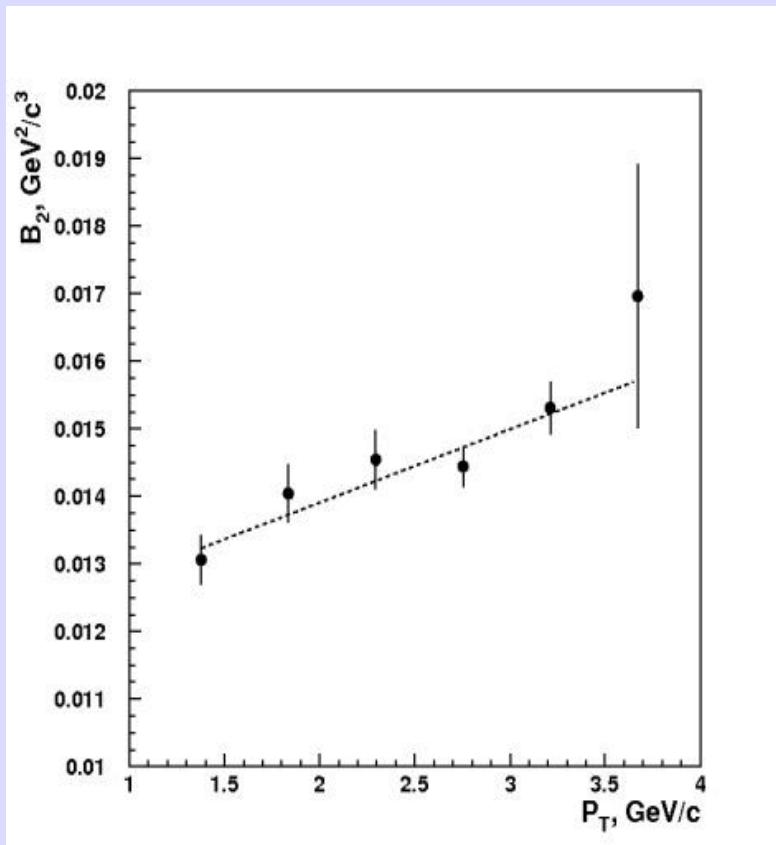
Mean values of the B_2 parameter

Target	C	Al	Cu	W
$B_2 \times 10^2, \text{GeV}^2/c^3$	1.41 ± 0.10	1.56 ± 0.08	1.51 ± 0.07	1.41 ± 0.06

SPIN data

$$B_2 \sim V^{-1}$$

$$B_3 \sim V^{-2}$$



PROSPECTS FOR CONSTITUENT(COLOR) QUARK CONDENSATE OF NUCLEAR MATTER STUDY AT NUCLOTRON AND ...

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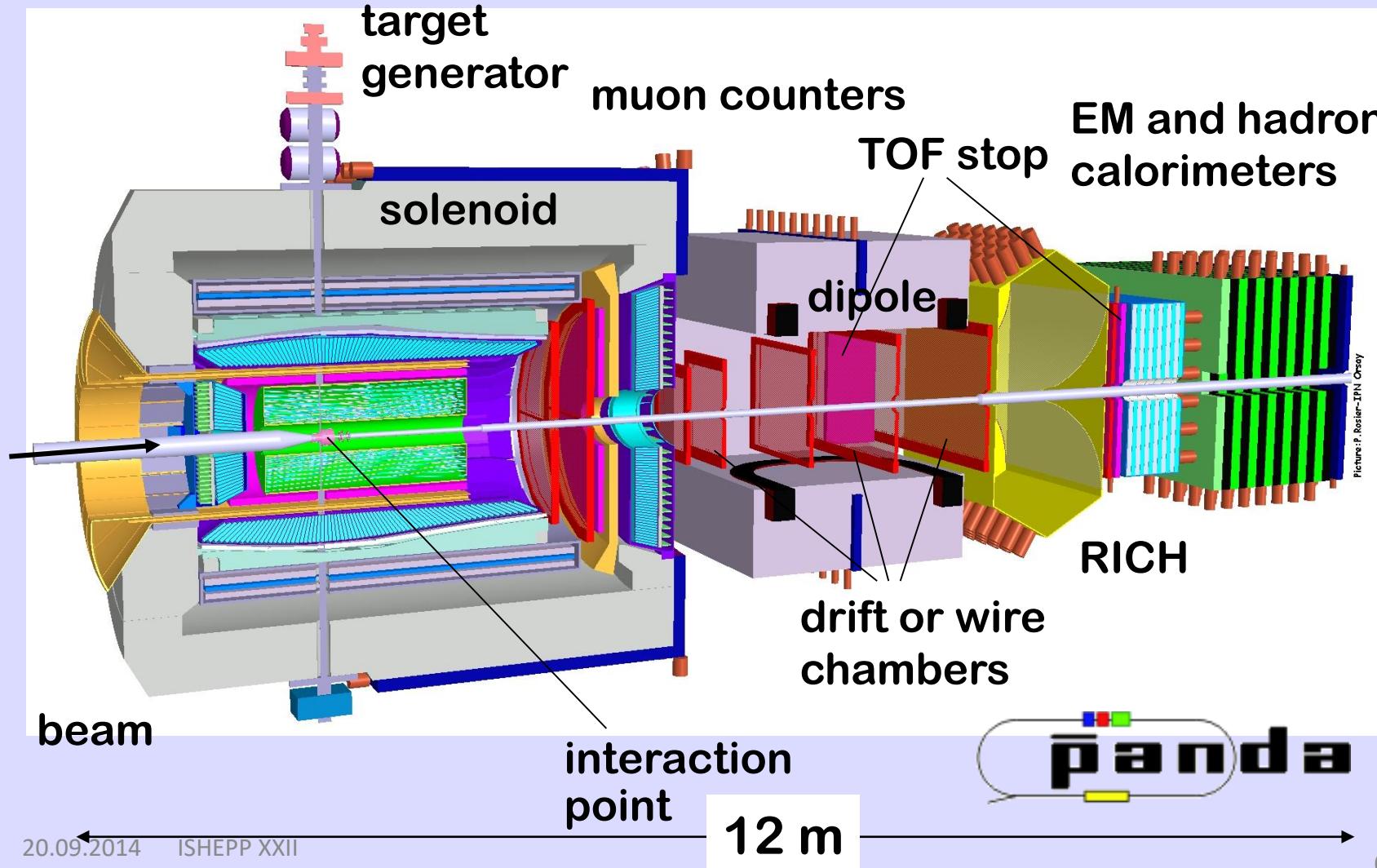
Abstract

In this report will discuss a physical programm to study Constituent(Color) Quark Condensate(CQC) -the state of cold high density nuclear matter. Characteristics of CQC determines properties of matter inside massive stars and nevertheless can be probed in the laboratory experiments. Nowadays studies (cumulative processes and processes in region with $x_T \simeq 1$) have allowed to determine some characteristic properties of CQC. The offered program can advance considerably our understanding of properties of the superdense cold nuclear matter. We are stressing importance to carry out investigations with polarized beams of the lightest nuclei.

CsDBM

1. **Cold** - exists inside ordinary nuclear matter as a quantum component of the wave function (with some probability and life time).
2. **superDense** - several nucleons can be in a volume less than the nucleon volume. The mass will be several nucleon masses. The small size means that the multinucleon(multiquark) configuration seeing as point like objects in processes with high transfer energy.
3. **Baryonic Matter** - enhancement of baryonic states and suppression of sea and gluon degrees of freedom (mesons and antiparticles production).

The PANDA Detector $\bar{p} + p(A) \rightarrow \bar{p}' + \{X\}$



NEWS from Theorists

How Often Do Diquarks Form? A Very Simple Model

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(Dated: June, 2016)

Starting from a textbook result, the nearest-neighbor distribution of particles in an ideal gas, we develop estimates for the probability with which quarks q in a mixed q , \bar{q} gas are more strongly attracted to the nearest q , potentially forming a diquark, than to the nearest \bar{q} . Generic probabilities lie in the range of tens of percent, with values in the several percent range even under extreme assumptions favoring $q\bar{q}$ over qq attraction.

We have seen that the large relative size of the short-distance attraction between quarks in the color-antitriplet channel compared to the attraction between a quark and an antiquark in the color-singlet channel leads inexorably to a given quark being initially attracted to a quark rather than an antiquark a sizeable fraction of the time. We interpret this initial attraction as the seed event in the formation of a compact diquark qq rather than a color-singlet $q\bar{q}$ pair.

Study of the phase diagram of dense two-color QCD within lattice simulation

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In this paper we carry out a low-temperature scan of the phase diagram of dense two-color QCD with $N_f = 2$ quarks. The study is conducted using lattice simulation with rooted staggered quarks. At small chemical potential we observe the hadronic phase, where the theory is in a confining state, chiral symmetry is broken, the baryon density is zero and there is no diquark condensate. At the critical point $\mu = m_\pi/2$ we observe the expected second order transition to Bose-Einstein condensation of scalar diquarks. In this phase the system is still in confinement in conjunction with nonzero baryon density, but the chiral symmetry is restored in the chiral limit. We have also found that in the first two phases the system is well described by chiral perturbation theory. For larger values of the chemical potential the system turns into another phase, where the relevant degrees of freedom are fermions residing inside the Fermi sphere, and the diquark condensation takes place on the Fermi surface. In this phase the system is still in confinement, chiral symmetry is restored and the system is very similar to the quarkyonic state predicted by $SU(N_c)$ theory at large N_c .

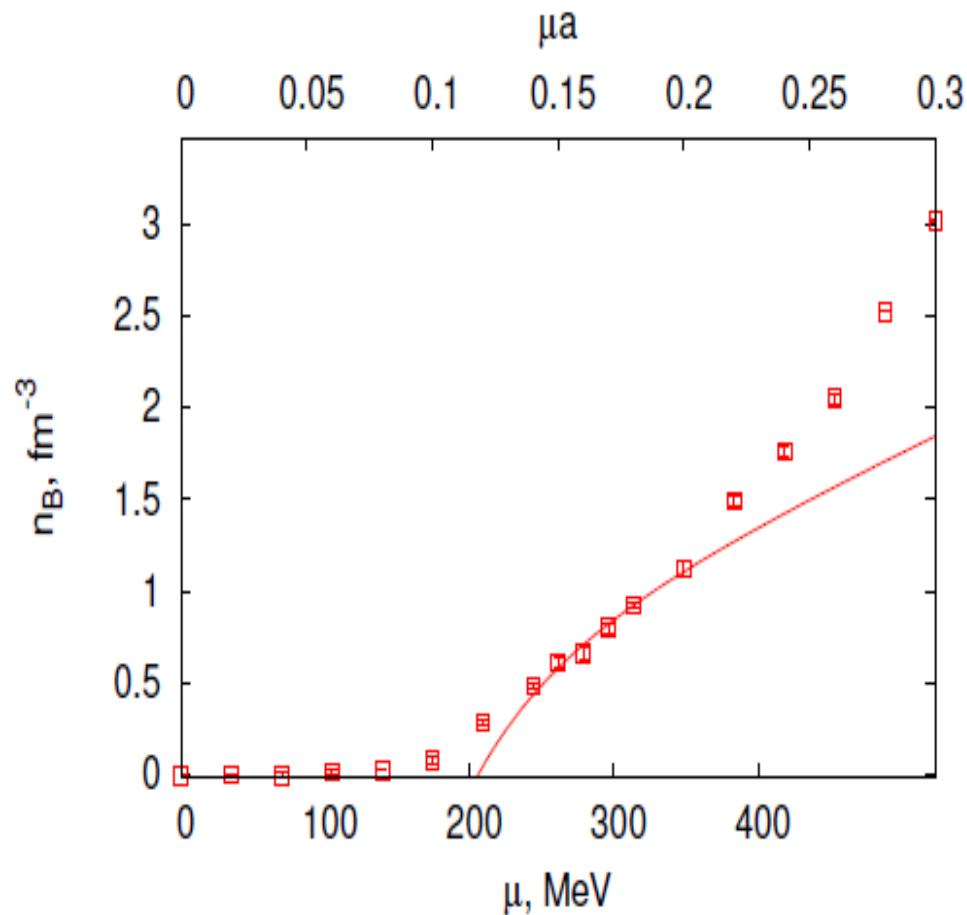


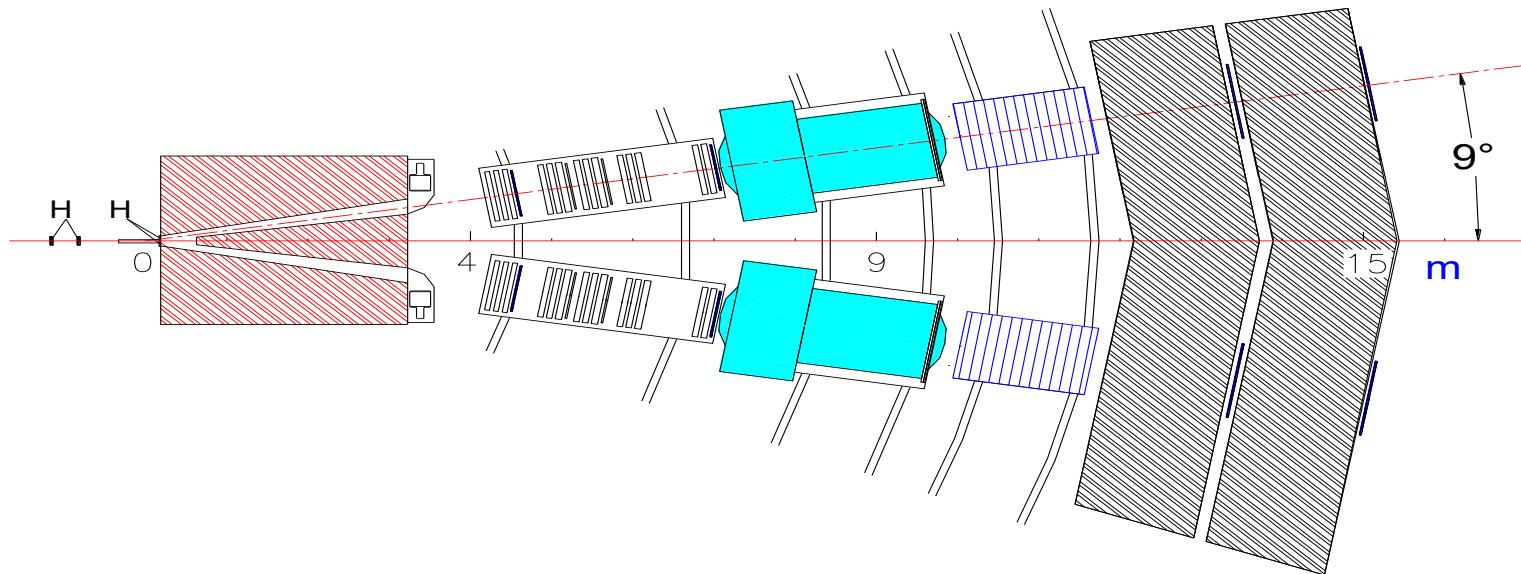
FIG. 10: The baryon density n_B in physical units, as a function of μ . The chemical potential is expressed in physical units (lower scale) and in lattice units (upper scale).

END

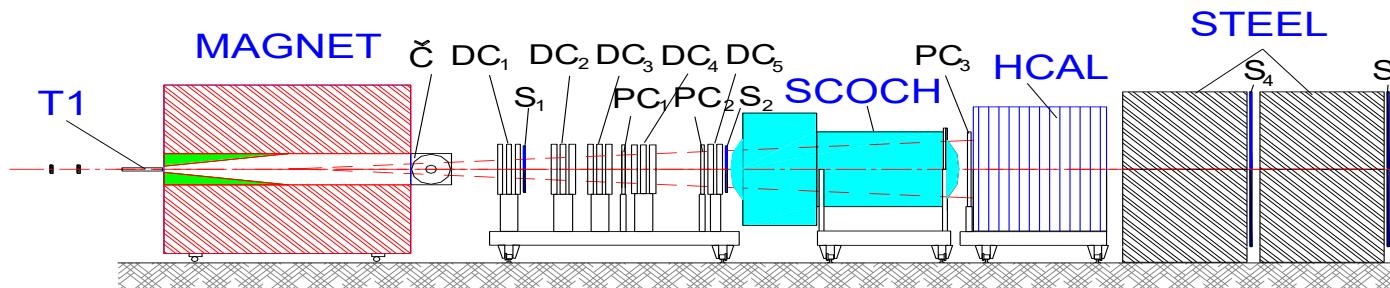
FODS

(proton energy 15-50 GeV and
nuclear beams up to 34 GeV/u)

TOP VIEW



SIDE VIEW (ALONG THE ARM AXIS)



$p_T \sim 2 \text{ GeV}/c$ region

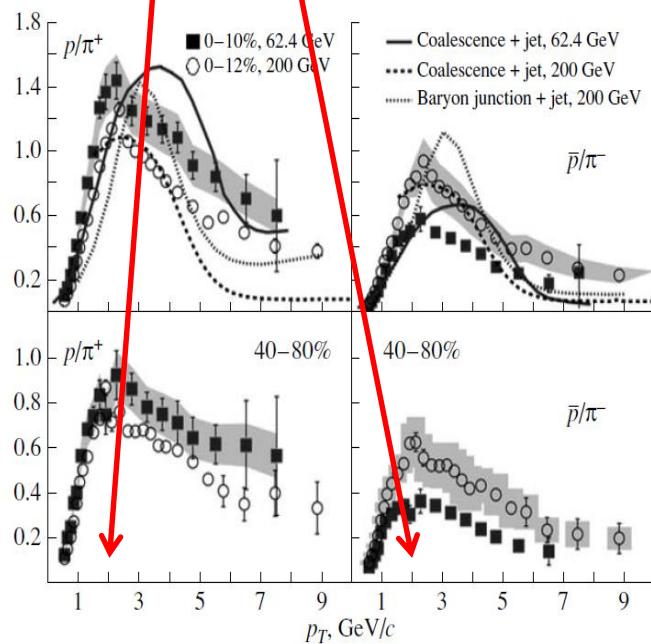


Fig. 3. [10] Ratio of the cross sections for the production of protons and charged pions as a function of the transverse momentum for various degrees of centrality and two beam energies of 62.4 and 200 GeV: (points) results of the STAR experiment and (curves) results of model calculations.

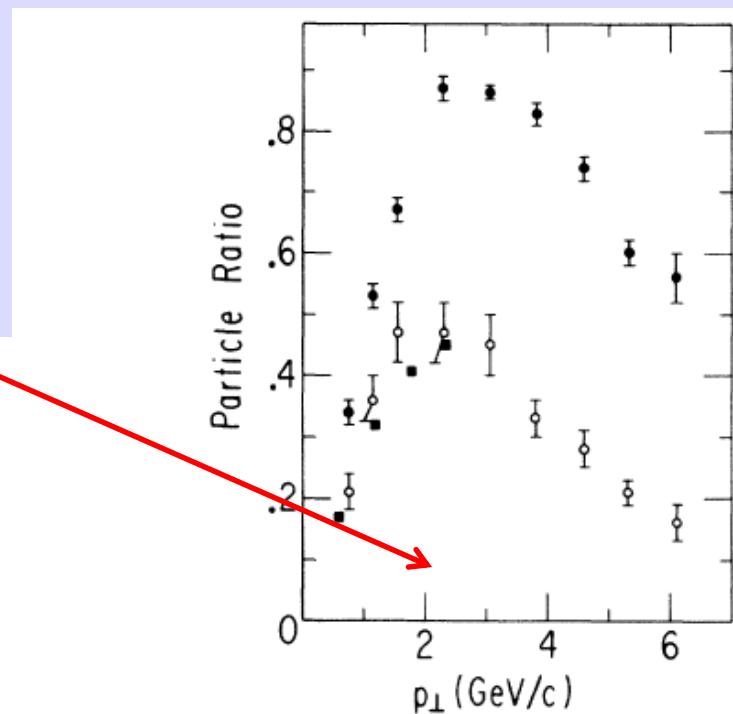
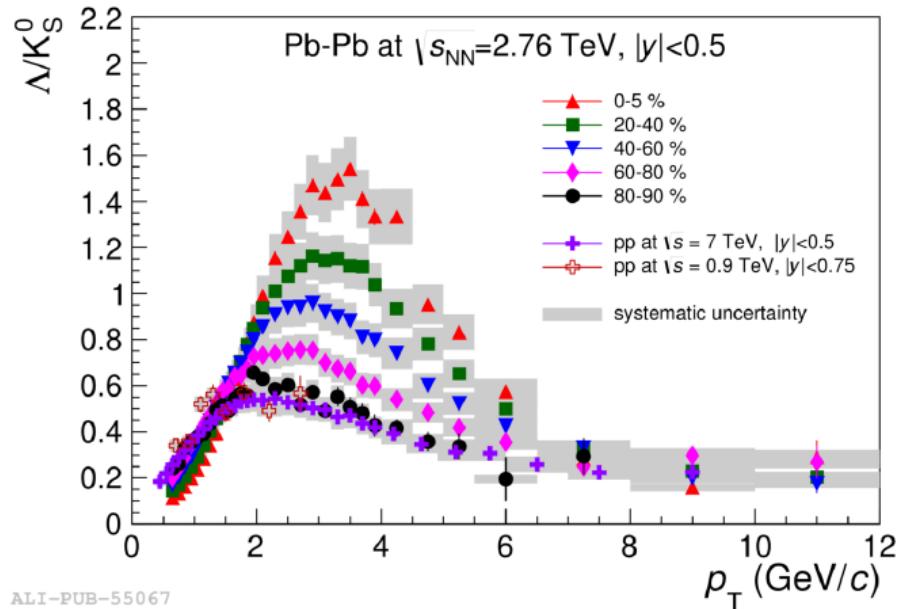
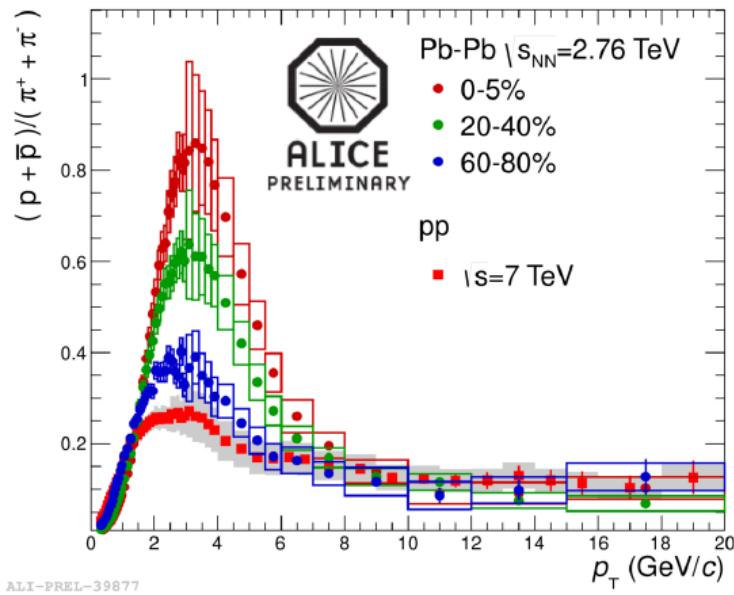


FIG. 20. Comparison of the cross-section ratio p/π^+ measured on tungsten at $\sqrt{s} = 23.7$ GeV (closed circles), with that obtained by extrapolation to $A = 1$ (open circles). Ratios obtained from the British-Scandinavian collaboration (Ref. 23) at $\sqrt{s} = 23.4$ GeV are also plotted (closed squares).



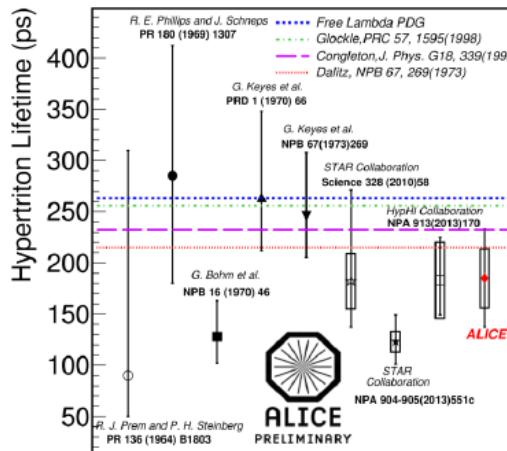
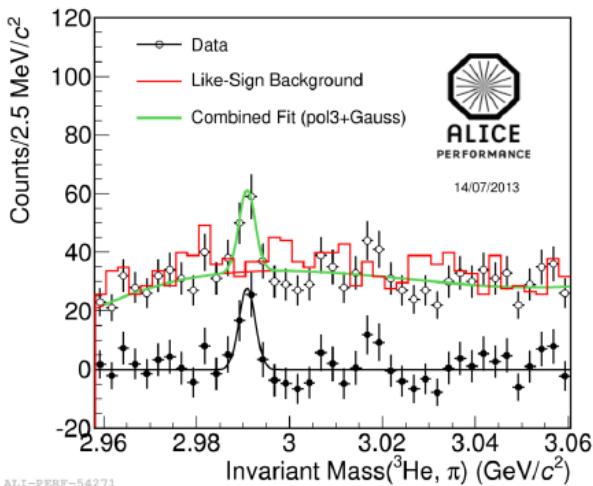
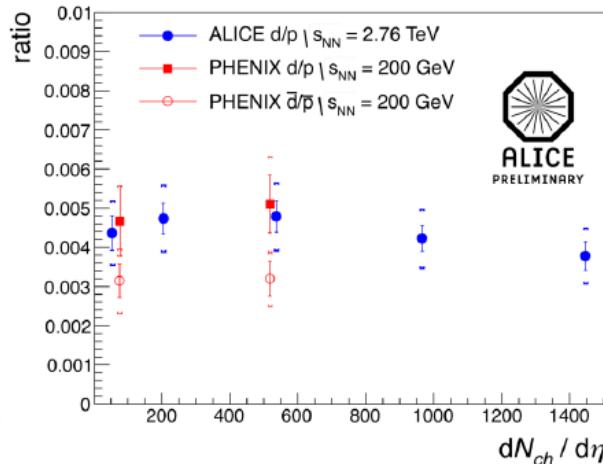
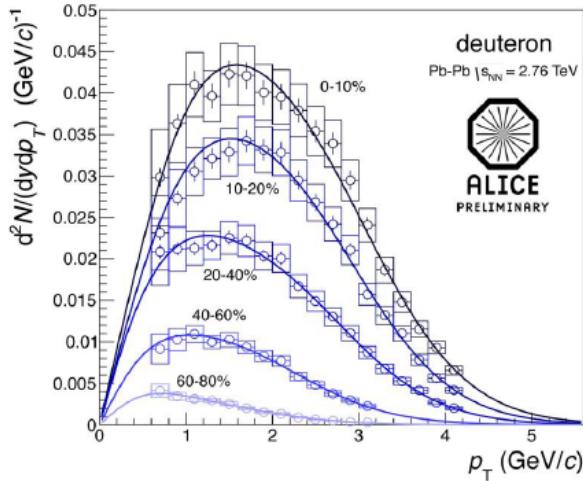
Baryon anomaly in Pb-Pb



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



Nuclei and hyper-nuclei



- Deuterons show hardening with increase of centrality (radial flow).
- d/p ratio does not depend on multiplicity.

- Hypertriton (p, n, Λ) yield is measured in Pb-Pb collisions.
- Production rate of ${}^3\Lambda H$ is described by thermal model.
- Lifetime measured.

High p_T Measurements at the CERN SPS

C. Blume arXiv:nucl-ex/0609022v1 15 Sep 2006

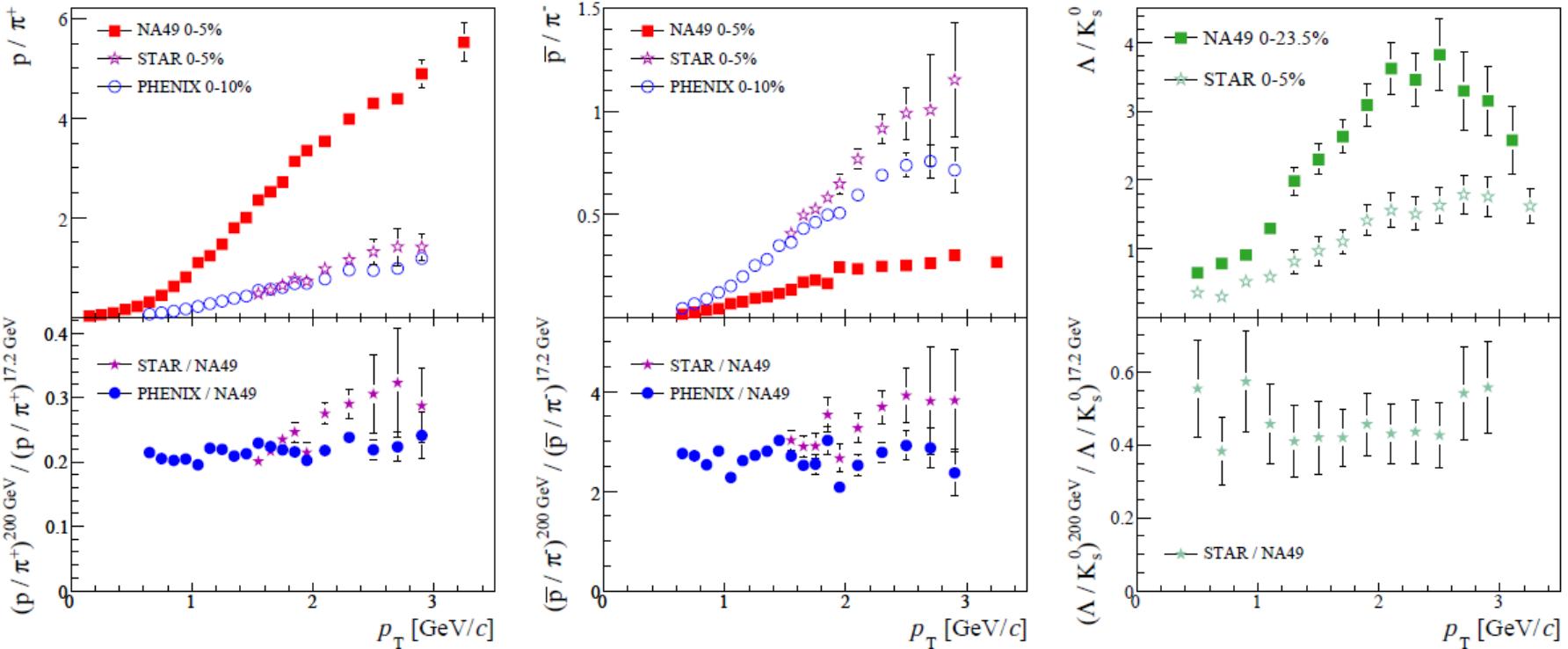


Fig. 6. The baryon/meson ratios as measured by NA49 at $\sqrt{s_{\text{NN}}} = 17.3 \text{ GeV}$ [32], compared to results from RHIC at $\sqrt{s_{\text{NN}}} = 200 \text{ GeV}$ [33,34]. Please note the different scales of the plots.

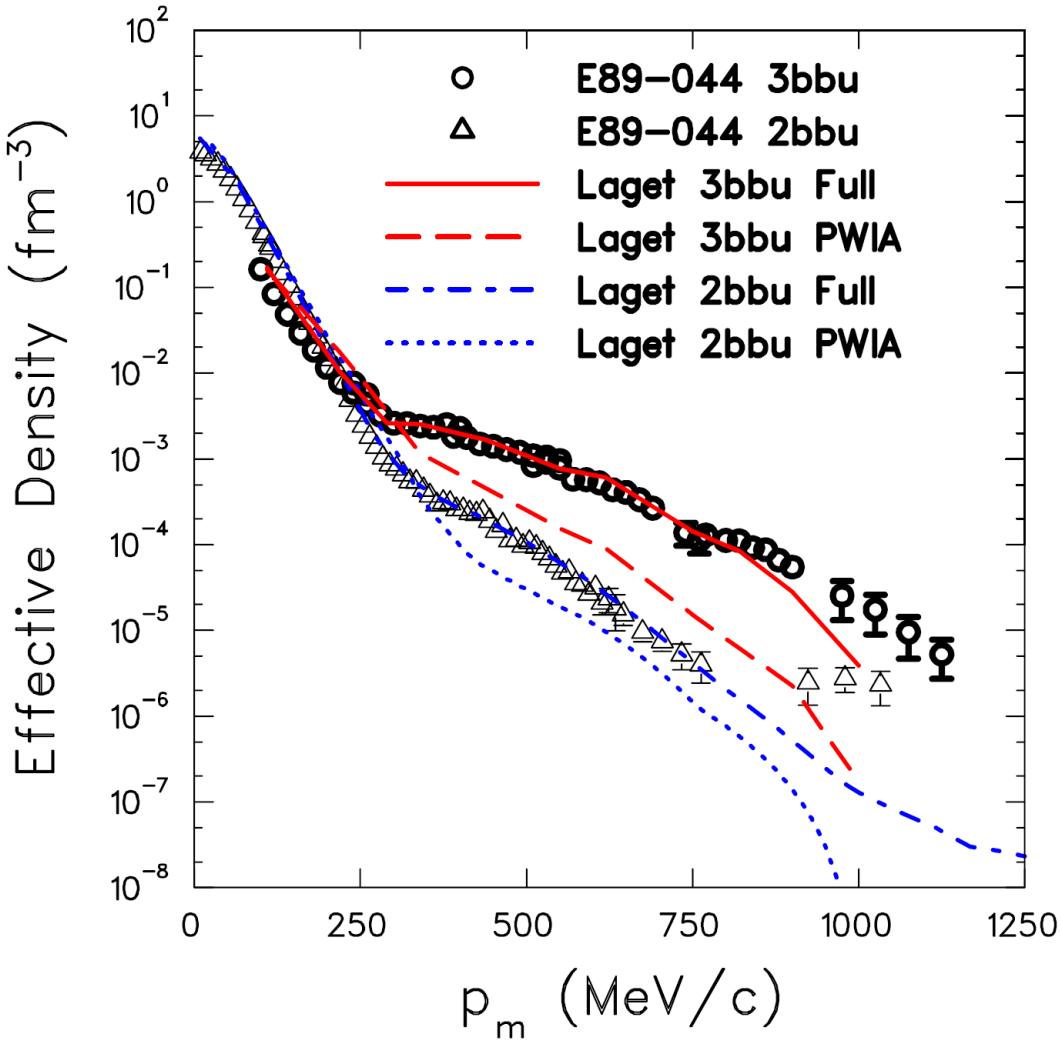
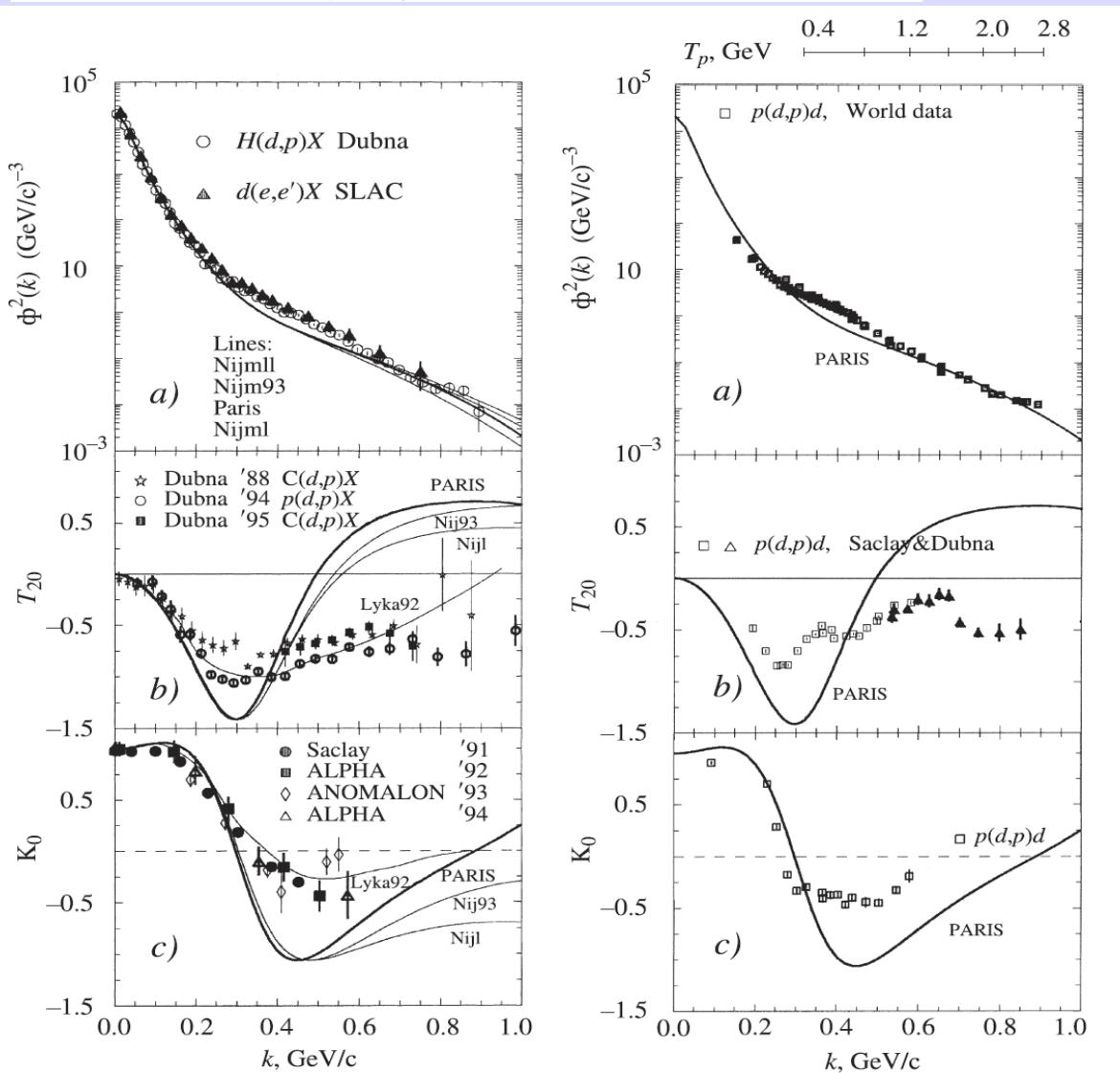


Figure 3. Proton effective momentum density distributions in ${}^3\text{He}$ extracted from ${}^3\text{He}(e, e'p)pn$ three-body break-up (3bbu) is shown as the open black circles and the ${}^3\text{He}(e, e'p)d$ two-body break-up (2bbu) is shown as open black triangles. The three-body break-up (3bbu) 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. Copyright 2005 by the American Physical Society.

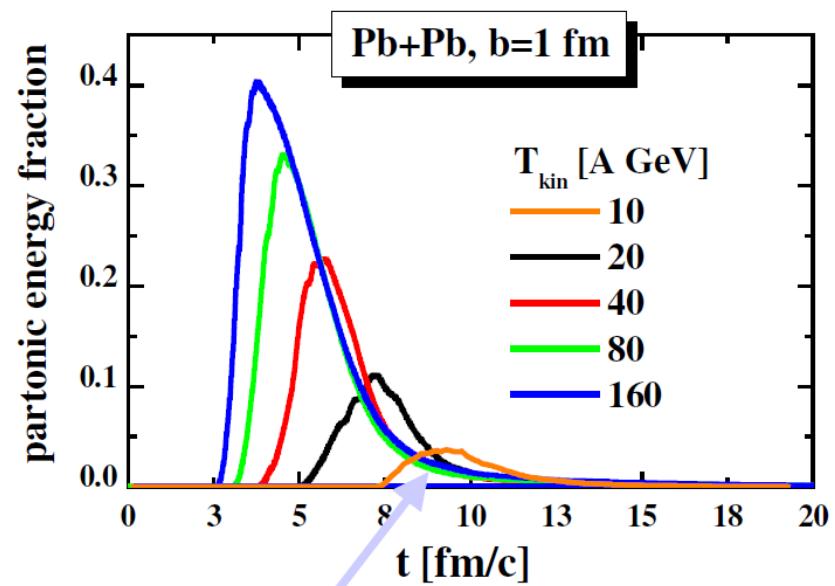
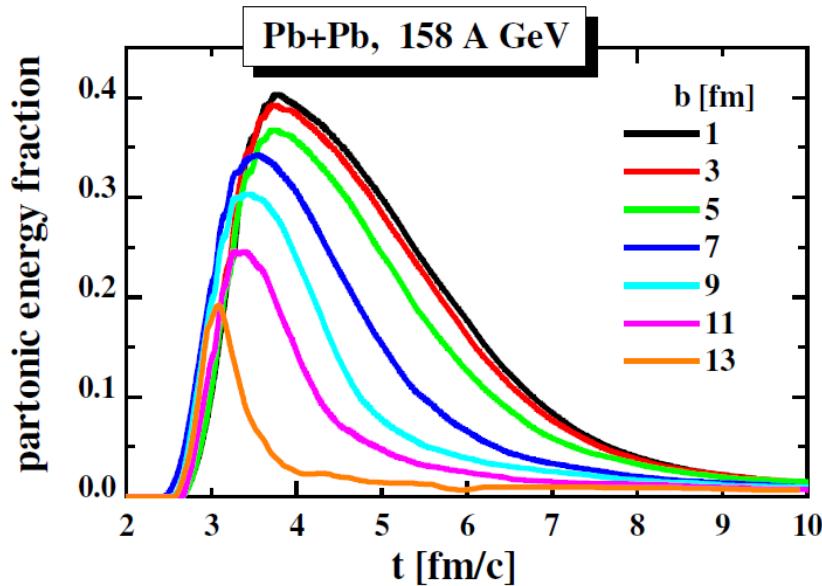
**CURRENT EXPERIMENTS USING POLARIZED
BEAMS OF THE JINR VBLHE ACCELERATOR
COMPLEX**
F. Lehar

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



Partonic phase at SPS/FAIR/NICA energies

partonic energy fraction vs centrality and energy



Dramatic decrease of partonic phase with decreasing energy and centrality