"Anti-p p interactions in the region x_T~1:the questions and the solutions at PANDA"

S.S. Shimanskiy (VBLHEP)

13.01.2010

Plan

1. Counting rules

2. p_T~2 GeV/c anomaly

In 1973 were published two artiles :

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

$$A + B \to C + D$$

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

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

$s=(p_A+p_B)^2$ and $t=(p_A-p_C)^2$,

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

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 $s \to \infty$, fixed-t/s predictions are $(d\sigma/dt)_{\pi p \to \pi p} \sim s^{-8}$, $(d\sigma/dt)_{pp \to pp} \sim s^{-10}$, $(d\sigma/dt)_{\gamma p \to \pi p} \sim s^{-7}$, $(d\sigma/dt)_{\gamma p \to \gamma p} \sim s^{-6}$, $F_\pi(q^2) \sim (q^2)^{-1}$, and $F_{1p}(q^2) \sim (q^2)^{-2}$. We show that such scaling laws are characteristic of renormalizable field theories satisfying certain conditions.

Our central result for exclusive scattering[1] is

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

($s \to \infty$, 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-

[1]This 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. Kiskis for bringing this work to our attention.

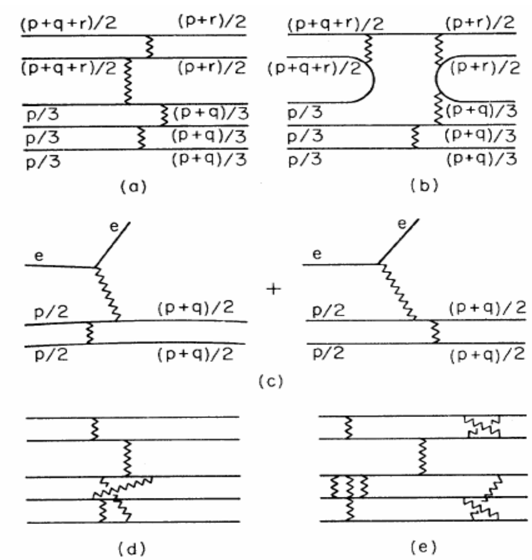

FIG. 1. Typical Born diagrams for large-momentum-transfer elastic scattering in the quark picture. (a) $\pi p \to \pi p$ (quark scattering), (b) $\pi p \to \pi p$ (quark interchange), (c) $e\pi \to e\pi$, (d) an irreducible loop diagram, (e) a reducible loop diagram.

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(M)

ANTIPROTON ANNIHILATION IN QUANTUM CHROMODYNAMICS*

STANLEY J. BRODSKY

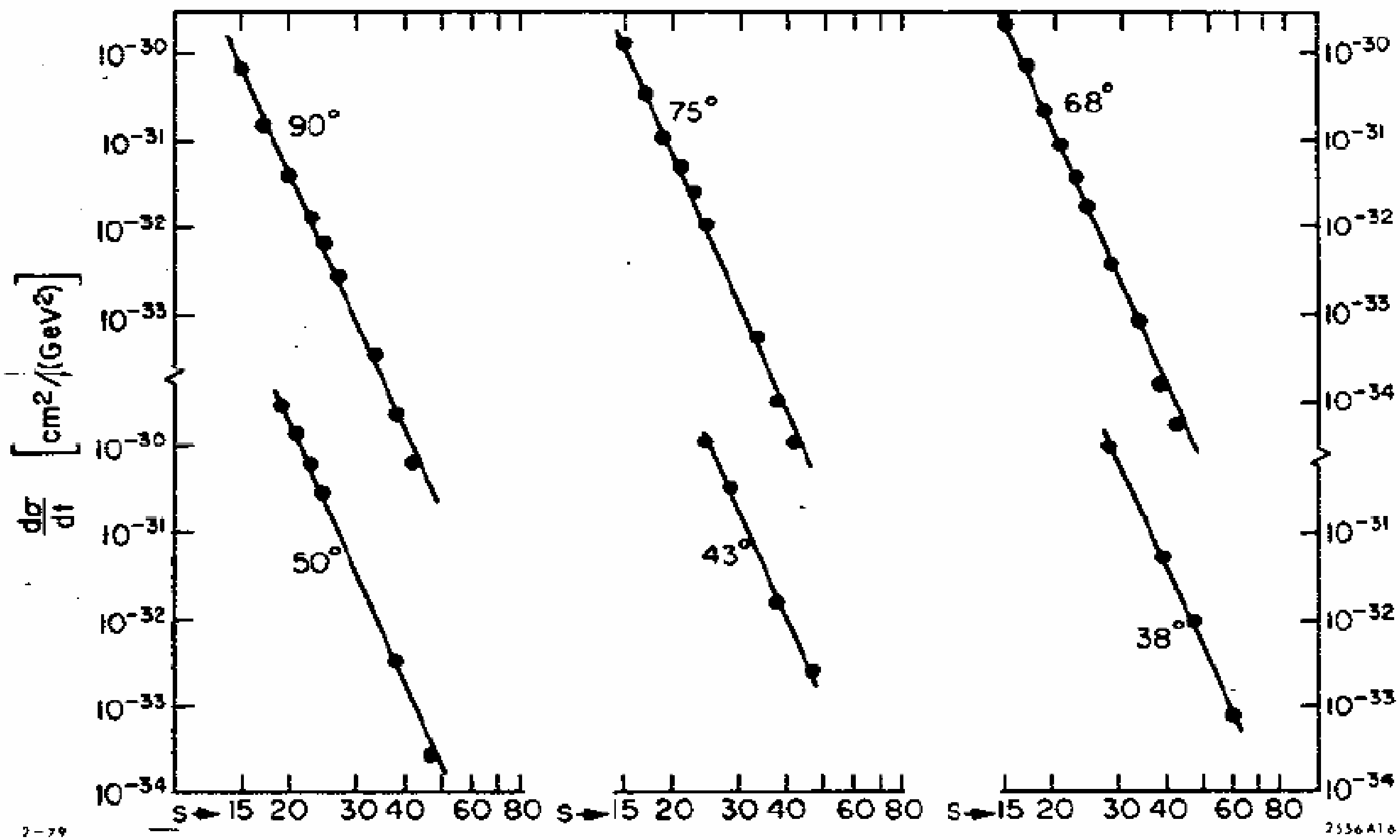
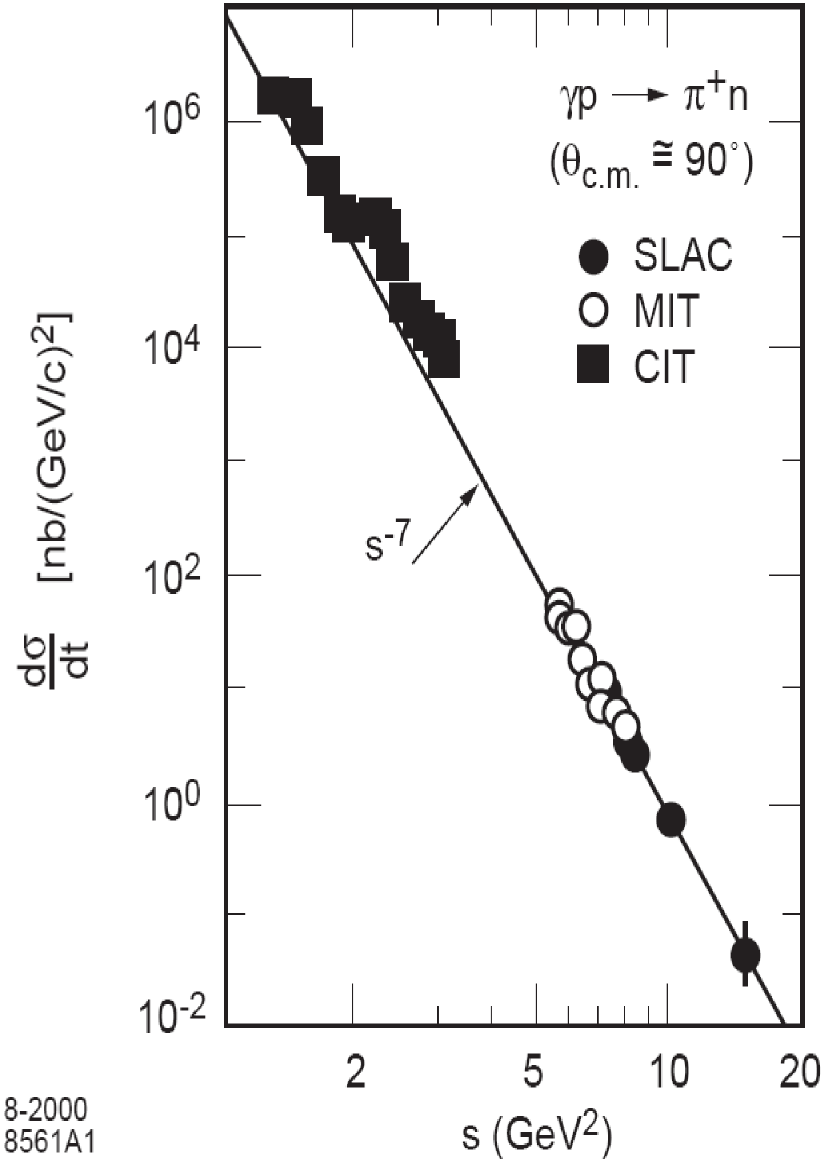


Fig. 16. Test of fixed θ_{CM} scaling for elastic pp scattering. The best fit gives the power $N = 9.7 \pm 0.5$ compared to the dimensional counting prediction N=10. Small deviations are not readily apparent on this log-log plot. The compilation is from Landshoff and Polkinghorne.



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Asymptotic form factors of hadrons and nuclei and the continuity of particle and nuclear dynamics

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The large-q^2 behavior of the elastic form factor of a hadron or nucleus is related by dimensional counting to the number of its elementary constituents. Using the framework of a scale-invariant quark model, dimensional-scaling predictions are derived for the $B(q^2)/A(q^2)$ ratio in the Rosenbluth formula, multiple-photon-exchange corrections, and the mass parameters which control the onset of the asymptotic power law in the meson, nucleon, and deuteron form factors. A simple "democratic chain" model predicts that for large q^2, $F(q^2) \propto (1 - q^2/m_n{}^2)^{1-n}$, where $m_n{}^2$ is proportional to the number of constituents n. In the case of nuclear targets (or systems with several scales of compositeness), we also define the "reduced" form factor $f_A(q^2) = F_A(q^2)/\Pi_{i=1}^A F_i(q_i{}^2)$ in order to remove the minimal falloff of F_A due to the nucleon form factors at $q_i{}^2 = (m_i{}^2/M_A{}^2)q^2$. Dimensional counting predicts $(q^2)^{A-1}f_A(q^2) \to$ const. A systematic comparison of the data for π, p, n, and deuteron form factors with the dimensional-scaling quark-model predictions is given. Predictions are made for the large-spacelike-q^2 ^{3}He and α-particle form factors. We also relate the deuteron form factor to (off-shell) fixed-angle n-p scattering, and show that the experimental results for $t^5F_d(t)$ are consistent with the magnitude of the s-wave wave function $u'(0)$ obtained from soft-core potentials. The relation of the dynamics of an underlying six-quark state of the deuteron to the nucleon-potential and meson-exchange-current contributions is discussed. The scaling of $q^2 f_d(q^2)$ implies that the nuclear potential (after removing the effects of nucleon structure) displays the scale-invariant behavior of a theory without a fundamental length scale. Predictions are also given for the structure functions, fragmentation, and large-angle scattering of a nucleus.

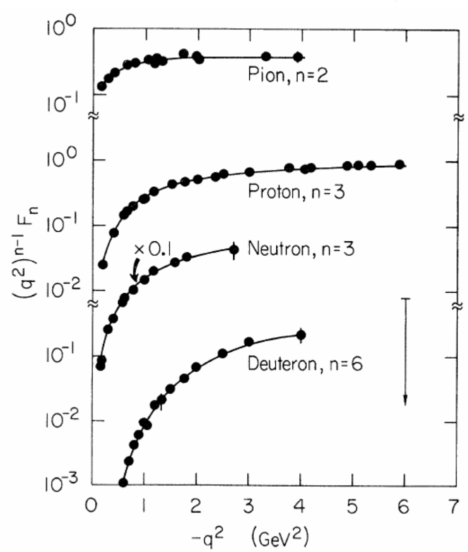

FIG. 1. Elastic electromagnetic form factors of hadrons for large spacelike q^2 in terms of the dimensional-scaling quark model. The curves simply connect the data points. (The neutron data have been multiplied by 0.1.)

Light-Front QCD*

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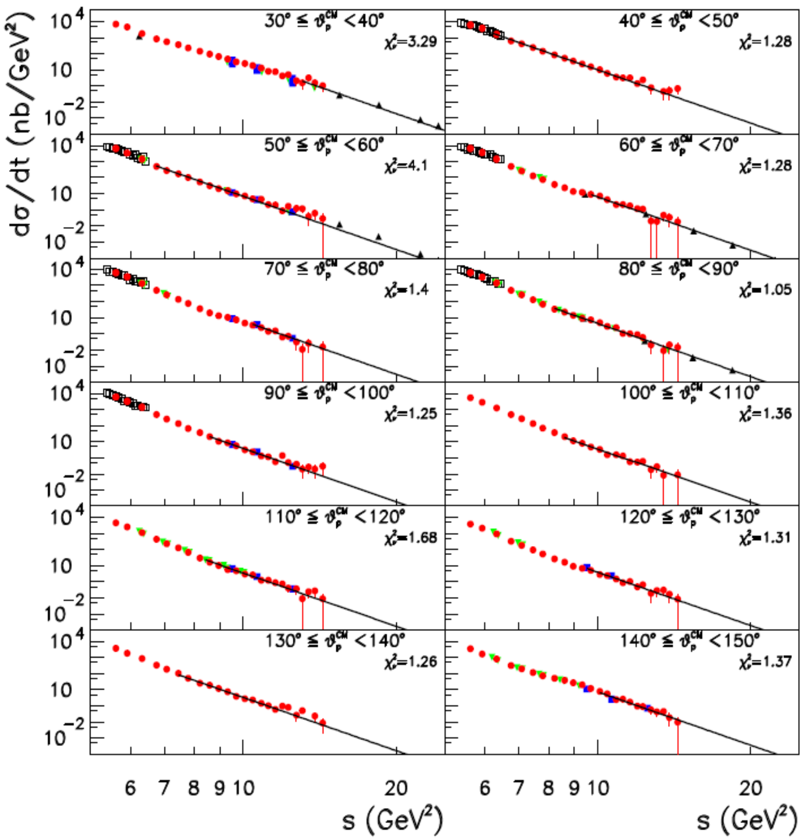
Stanley J. Brodsky



$s^{11}\frac{d\sigma}{dt}(\gamma d \to pn) \sim$ 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^2_ν value of the fit. From Ref. [160].

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Indication of asymptotic scaling in the reactions $dd \to p^3$H, $dd \to n^3$He and $pd \to pd$

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It is shown that the differential cross sections of the reactions $dd \to n^3$He and $dd \to p^3$H measured at c.m.s. scattering angle $\theta_{cm} = 60°$ 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 $dp \to dp$ scattering at $\theta_{cm} = 125-135°$ follows the scaling regime $\sim s^{-16}$ at beam energies 0.5–5 GeV. These data are parameterized here using the Reggeon exchange.

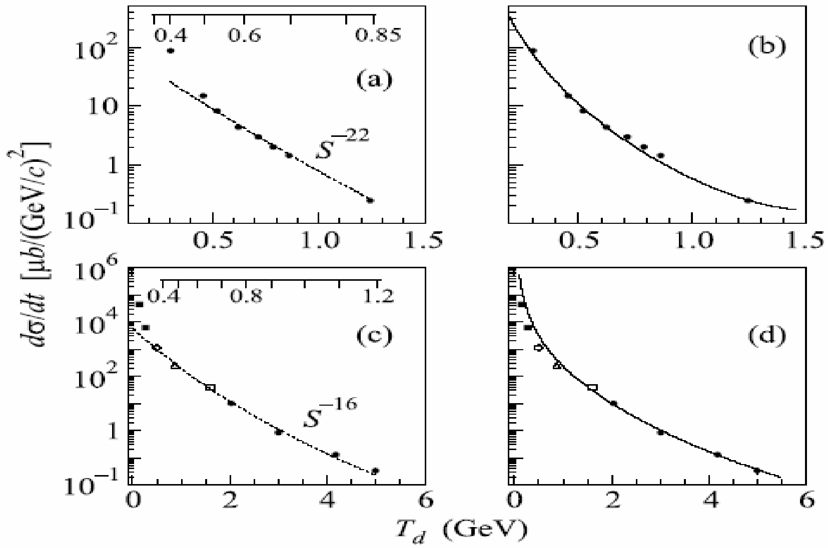

Fig.2. The differential cross section of the $dd \to n^3$He and $dd \to p^3$H reactions at $\theta_{cm} = 60^o$ (a), (b) and $dp \to dp$ at $\theta_{cm} = 127^o$ (c), (d) versus the deuteron beam kinetic energy. Experimental data in (a), (b) are taken from [20]. In (c), (d), the experimental data (black 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) – $C_1 = 1.9\,\mathrm{GeV}^2$, $R_1^2 = 0.2\,\mathrm{GeV}^{-2}$, $C_2 = 3.5$, $R_2^2 = -0.1\,\mathrm{GeV}^{-2}$; (d) – $C_1 = 7.2\,\mathrm{GeV}^2$, $R_1^2 = 0.5\,\mathrm{GeV}^{-2}$, $C_2 = 1.8$, $R_2^2 = -0.1\,\mathrm{GeV}^{-2}$. The upper scales in (a) and (c) show the relative momentum q_{pn} (GeV/c) in the deuteron for the ONE mechanism

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Comparison of 20 exclusive reactions at large t

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TABLE IV. Cross sections at 90 degrees and 5.9 GeV/c incident beam momentum. Reaction number refers to Fig. 27. The values represent interpolations where the range spans 90°.

Number	Reaction	Cross section [nb/(GeV/c)^2]
1	$\pi^+ p \to p\pi^+$	132 ± 10
2	$\pi^- p \to p\pi^-$	73 ± 5
3	$K^+ p \to pK^+$	219 ± 30
4	$K^- p \to pK^-$	18 ± 6
5	$\pi^+ p \to p\rho^+$	214 ± 30
6	$\pi^- p \to p\rho^-$	99 ± 13
7	$K^+ p \to pK^{*+}$	$291 + 47 - 130$
8	$K^- p \to pK^{*-}$	$15 + 10 - 13$
9	$K^- p \to \pi^- \Sigma^+$	50 ± 21
10	$K^- p \to \pi^+ \Sigma^-$	4 ± 3
11	$K^- p \to \Lambda \pi^0$	< 80
12	$\pi^- p \to \Lambda K^0$	< 5
13	$\pi^+ p \to \pi^+ \Delta^+$	45 ± 10
14	$\pi^- p \to \pi^- \Delta^+$	20 ± 11
15	$\pi^- p \to \pi^+ \Delta^-$	24 ± 5
16	$K^+ p \to K^+ \Delta^+$	< 230
17	$pp \to pp$	3300 ± 40
18	$\bar{p}p \to p\bar{p}$	75 ± 8
19	$\bar{p}p \to \pi^+ \pi^-$	7 ± 3
20	$\bar{p}p \to K^+ K^-$	2 ± 2

TABLE V. The scaling between E755 and E838 has been measured for eight meson-baryon and 2 baryon-baryon interactions at $\theta_{\text{c.m.}} = 90°$. 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 ±13% for E838 and ±9% for E755.

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

Unified description of inclusive and exclusive reactions at all momentum transfers*

R. Blankenbecler and S. J. Brodsky

$$E\,\frac{d\sigma}{d^3p}\,(A+B\to C+X)\to(p_T{}^2)^{-N}\,f\!\left(\frac{\mathfrak{M}^2}{s},\frac{t}{s}\right)$$

and[5,6]

$$\frac{d\sigma}{dt}\,(A+B\to C+D)\to(p_T{}^2)^{-N}\,f\!\left(\frac{t}{s}\right)$$

The entire kinematic range of high-energy inclusive reactions is illustrated on the Peyrou plot of Fig. 1. As usual we define

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

$$u=(p_B-p_C)^2,\quad \mathfrak{M}^2=(p_A+p_B-p_C)^2,$$

and

$$\epsilon=\mathfrak{M}^2/s\cong(1-p_{\rm c.m.}/p_{\rm max})\ ,$$

$$x_T=p_T/p_{\rm max},\quad x_L=p_L/p_{\rm max}\simeq(t-u)/s\,.$$

TABLE I. The expected dominant subprocesses for selected hadronic inclusive reactions at large transverse momentum. The second column lists the important exclusive processes which contribute to each inclusive cross section at $\epsilon\sim 0$. The basic subprocesses expected in the CIM, and the resulting form of the inclusive cross section $Ed\sigma/d^3p\sim(p_\perp{}^2)^{-N}\epsilon^P$ for $p_\perp{}^2\sim\infty$, $\epsilon\to 0$, and fixed $\theta_{\rm c.m.}$ are given in the last columns. The subprocesses that have the dominant $p_\perp$ dependence at fixed ϵ are underlined. For some particular final-state quantum numbers, the above powers of ϵ should be increased.

Inclusive process	Exclusive-limit channel	Subprocesses	$\frac{d\sigma}{d^3p/E}$ $(\theta\sim 90°)$
$M+B\to M+X$	$M+B\to M+B^*$ $(n=10)$	$\underline{M+q\to M+q}$	$(p_\perp{}^2)^{-4}\epsilon^3$
		$\bar q+B\to M+qq$	$(p_\perp{}^2)^{-6}\epsilon^1$
		$M+B\to M+B^*$	$(p_\perp{}^2)^{-8}\epsilon^{-1}$
$B+B\to B+X$	$B+B\to B+B^*$ $(n=12)$	$\underline{B+q\to B+q}$	$(p_\perp{}^2)^{-6}\epsilon^3$
		$\underline{(qq)+(qq)\to B+q}$	$(p_\perp{}^2)^{-6}\epsilon^3$
		$\underline{B+(qq)\to B+qq}$	$(p_\perp{}^2)^{-8}\epsilon^1$
		$B+B\to B+B^*$	$(p_\perp{}^2)^{-10}\epsilon^{-1}$
	$B+B\to B+B^*+M^*$ $(n=14)$	$\underline{q+q\to B+\bar q}$	$(p_\perp{}^2)^{-4}\epsilon^7$
		$q+(qq)\to B+M^*$	$(p_\perp{}^2)^{-6}\epsilon^5$
		$(qq)+B\to B+M^*+qq$	$(p_\perp{}^2)^{-10}\epsilon^1$
		$B+B\to B+B^*+M^*$	$(p_\perp{}^2)^{-12}\epsilon^{-1}$
$B+B\to M+X$	$B+B\to M+B^*+B^*$ $(n=14)$	$\underline{q+(qq)\to M+B^*}$	$(p_\perp{}^2)^{-6}\epsilon^5$
		$q+B\to q\,(\to M+q)+B^*$	$(p_\perp{}^2)^{-6}\epsilon^5$
		$q+B\to M+q+B^*$	$(p_\perp{}^2)^{-8}\epsilon^3$
		$(qq)+B\to M+B^*+qq$	$(p_\perp{}^2)^{-10}\epsilon^1$
		$B+B\to M+B^*+B^*$	$(p_\perp{}^2)^{-12}\epsilon^{-1}$
	$B+B\to M+M^*+B^*+B^*$ $(n=16)$	$\underline{M+q\to M+q}$	$(p_\perp{}^2)^{-4}\epsilon^9$
		$q+q\to\bar q\,(\to M+\bar q)+B^*$	$(p_\perp{}^2)^{-4}\epsilon^9$
		$q+q\to M+B^*+\bar q$	$(p_\perp{}^2)^{-6}\epsilon^7$
		$M+B\to M+B^*$	$(p_\perp{}^2)^{-8}\epsilon^5$
	$B+B\to M+M^*+M^*+B^*+B^*$ $(n=18)$	$\underline{q+\bar q\to M+M^*}$	$(p_\perp{}^2)^{-4}\epsilon^{11}$
		$\underline{q+M\to q\,(\to M+q)+M^*}$	$(p_\perp{}^2)^{-4}\epsilon^{11}$
$B+B\to\bar B+X$	$B+B\to\bar B+B^*+B^*+\bar B^*$ $(n=18)$	$\underline{q+q\to B^*+\bar q\,(\to\bar B+qq)}$	$(p_\perp{}^2)^{-4}\epsilon^{11}$
		$q+q\to B^*+\bar B+qq$	$(p_\perp{}^2)^{-8}\epsilon^7$
		$q+(qq)\to\bar B+B^*+B^*$	$(p_\perp{}^2)^{-10}\epsilon^5$

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(T/E)

RECENT DEVELOPMENTS IN THE THEORY OF LARGE TRANSVERSE MOMENTUM PROCESSES*

TABLE I

Scaling Predictions for $E\, d\sigma/d^3p = C\, p_T^{-n}(1-x_T)^F$

Large p_T Process	Leading CIM Subprocess	Predicted	Observed (CP)[3]
		n//F	n//F
$pp \to \pi^+ X$	$qM \to q\pi^+$	8//9	8.5//8.8
π^-	$qM \to q\pi^-$	8//9	8.9//9.7
K^+	$qM \to qK^+$	8//9	8.4//8.8
K^-	$qM \to qK^-$	8//13	8.9//11.7
	$q\bar{q} \to K^+K^-$	8//11	
$pp \to pX$	$q(qq) \to Mp$	12//5	11.7//6.8
	$qB \to qp$	12//7	
$pp \to \bar{p}X$	$q\bar{q} \to B\bar{p}$	12//11	8.8//14.2
	$qM \to qM$	8//15	
$\pi p \to \pi X$	$q\bar{q} \to M\pi$	8//5	
	$qM \to q\pi$	8//7	
	$q(qq) \to B\pi$	12//3	
	$\pi q \to \pi q$	8//3	

p_T~2 GeV/c anomaly

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Elastic Proton-Proton Scattering at 90° and Structure within the Proton*

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The differential cross section for proton-proton elastic scattering at 90° in the center-of-mass system was measured at laboratory momenta ranging from 5.0 to 13.4 GeV/c. Fifty-one measurements were made at momentum intervals of 100 or 200 MeV/c. The extracted proton beam of the ZGS impinged upon a CH_2 target. The two scattered protons were detected by two spectrometers consisting of magnets and scintillation counter telescopes in coincidence. The incident beam flux was measured by radiochemical analysis of the CH_2 targets. The experiment showed no evidence for any $S=0$, $T=1$ dibaryon resonances in the 3300–5200-MeV mass range. It also yielded some information about the validity of the statistical model and the analyticity of the scattering amplitude. The most interesting result of the experiment was a sharp break in the fixed-angle cross section. This may be evidence for the existence of two inner regions of the proton with radii 0.51±.02 and 0.34±.02 F.

S.S.Shimanskiy

TABLE I. Proton-proton elastic scattering cross sections at 90° in the center-of-mass system.

$P_{c.m.}^2$ $(GeV/c)^2$	P_0 (GeV/c)	$(d\sigma/d\Omega)_{c.m.}$ (μb/sr)	$(d\sigma/dt)_{c.m.}$ μb/$(GeV/c)^2$	Error in $d\sigma/d\Omega$ & $d\sigma/dt$ %
1.946	5.0	8.51	13.74	2.9
1.993	5.1	7.90	12.45	3.3
2.039	5.2	7.09	10.93	3.1
2.086	5.3	6.49	9.77	3.6
2.132	5.4	5.53	8.15	3.1
2.178	5.5	4.90	7.07	3.4
2.223	5.6	4.47	6.32	3.1
2.270	5.7	3.72	5.15	3.3
2.316	5.8	3.37	4.57	3.3
2.363	5.9	2.74	3.64	3.5
2.409	6.0	2.44	3.18	3.1
2.456	6.1	2.19	2.80	3.7
2.503	6.2	1.83	2.30	3.7
2.595	6.4	1.50	1.82	3.7
2.686	6.6	1.07	1.25	4.7
2.779	6.8	0.796	0.900	4.7
2.873	7.0	0.645	0.706	4.1
2.965	7.2	0.515	0.546	4.0
3.059	7.4	0.386	0.396	4.8
3.151	7.6	0.305	0.304	5.4
3.247	7.8	0.253	0.245	4.5
3.338	8.0	0.217	0.204	4.5
3.386	8.1	0.169	0.157	3.9
3.434	8.2	0.172	0.157	4.4
3.480	8.3	0.154	0.139	3.8
3.527	8.4	0.153	0.136	4.6
3.618	8.6	0.127	0.110	4.6
3.713	8.8	0.103	0.0871	4.8
3.806	9.0	0.0809	0.0667	4.6
3.897	9.2	0.0780	0.0629	4.3
3.992	9.4	0.0676	0.0532	5.3
4.084	9.6	0.0589	0.0453	4.9
4.178	9.8	0.0536	0.0403	4.7
4.272	10.0	0.0468	0.0344	4.9
4.364	10.2	0.0441	0.0318	4.8
4.461	10.4	0.0386	0.0272	4.7
4.554	10.6	0.0356	0.0246	4.8
4.644	10.8	0.0303	0.0205	4.9
4.739	11.0	0.0284	0.0188	5.5
4.831	11.2	0.0255	0.0166	5.4
4.924	11.4	0.0202	0.0129	5.4
5.018	11.6	0.0190	0.0119	5.2
5.112	11.8	0.0153	0.00940	5.4
5.208	12.0	0.0143	0.00862	5.4
5.299	12.2	0.0118	0.00699	5.3
5.392	12.4	0.0116	0.00676	5.4
5.490	12.6	0.00953	0.00545	6.3
5.579	12.8	0.00867	0.00488	5.7
5.674	13.0	0.00739	0.00409	5.9
5.770	13.2	0.00722	0.00393	7.1
5.861	13.4	0.00525	0.00281	5.7

Spin Correlations, QCD Color Transparency, and Heavy-Quark Thresholds in Proton-Proton Scattering

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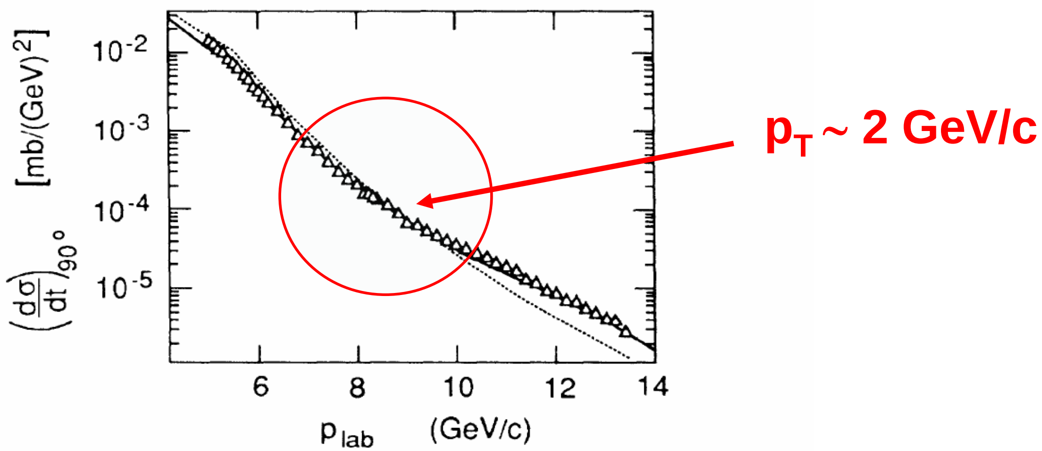

FIG. 1. Prediction (solid curve) for $d\sigma/dt$ compared with the data of Akerlof *et al.* (Ref. 16). The dotted line is the background PQCD prediction.

[16]K. Abe *et al.*, Phys. Rev. D **12**, 1 (1975), and references therein. The high-energy data for $d\sigma/dt$ at $\theta_{c.m.}=\pi/2$ are from C. W. Akerlof *et al.*, Phys. Rev. **159**, 1138 (1967); G. Cocconi *et al.*, Phys. Rev. Lett. **11**, 499 (1963); J. V. Allaby *et al.*, Phys. Lett. **23**, 389 (1966).

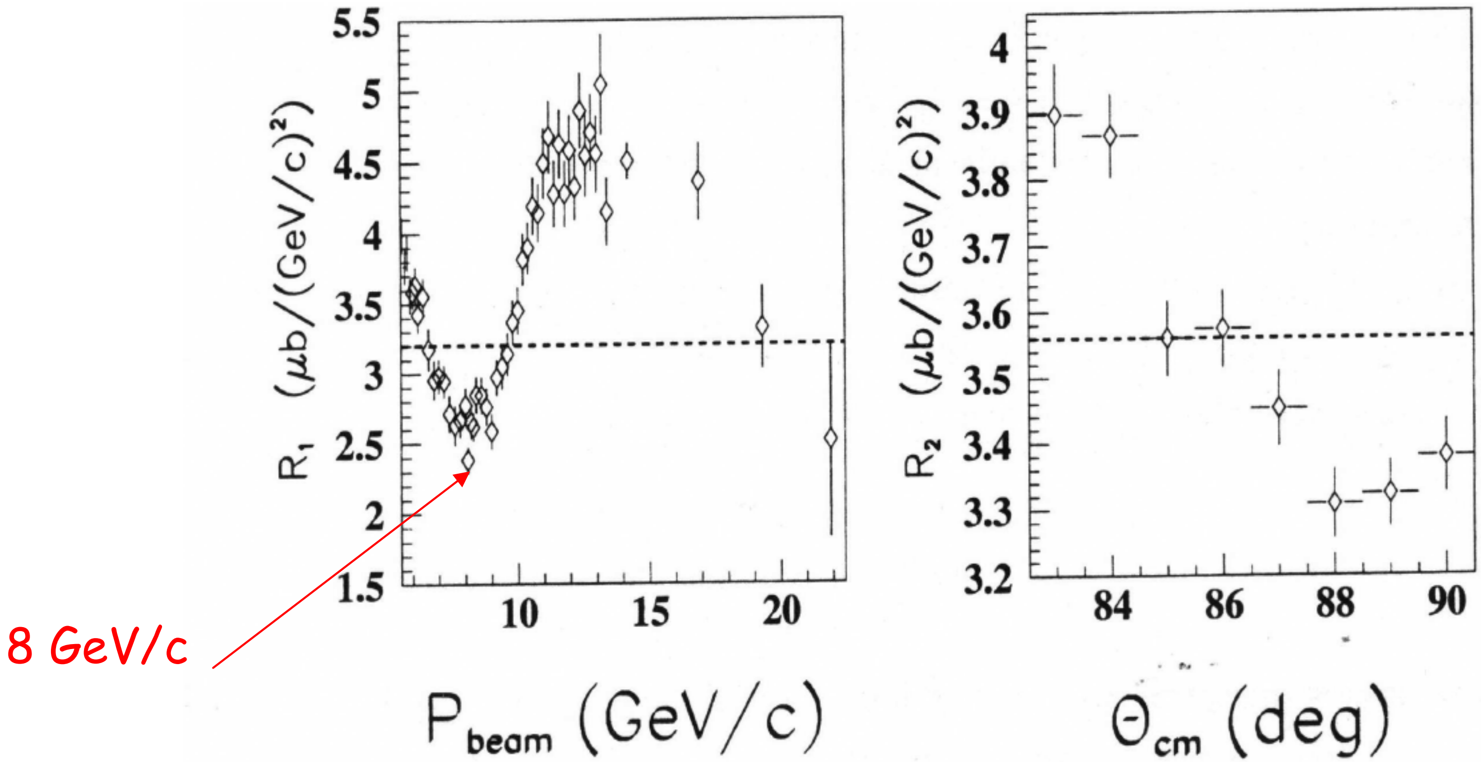

Figure 1.2: Scaled $pp \to pp$ differential cross sections. The dashed lines represent perfect scaling. Their vertical position is arbitrary. **Left** - $R_1 = ((\frac{s}{s_0})^{10} \frac{d\sigma}{dt}(pp))^{-1}$ ($s_0 = 13\ GeV^2$) at $\theta_{cm} = 90^0$ versus incoming momentum. Data are from Ref. [19]. **Right** - $R_2 = (1 - \cos^2\theta_{cm})^{4\gamma} \frac{d\sigma}{dt}(pp)$ ($\gamma = 1.6$) at $p_{lab} = 5.9$ GeV/c versus θ_{cm}. Data are from Ref. [17].

E2-85-537

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HARD HADRON-NUCLEUS PROCESSES AND MULTIQUARK CONFIGURATIONS IN NUCLEI

V. Conclusion

The analysis of the inclusive large $x_\perp$ meson production in the hard hadron processes on nuclei has allowed one to understand the relative contribution of multiple rescattering processes and the existence of multiquark fluctons in the nucleus in dependence on $x_\perp$ the multiple rescattering processes are dominating at $x_\perp < 0.7 \div 0.8$ whereas at larger $x_\perp$ the mechanism of hard scattering on fluctons is dominating. The model of multiple rescattering in which the multiple soft collisions suggested in this paper are taken into account before the hard collision allows one to describe the multiple rescattering processes inside the nucleus correctly.

The flucton model succesfully used earlier for the description of the cumulative production and EMC-effect with such parameters is applied for the description of anomalous phenomena in the large $p_\perp$ processes in nuclei.

PHYSICAL REVIEW D VOLUME 23, NUMBER 3 1 FEBRUARY 1981

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

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The energy dependence of the spin-parallel and spin-antiparallel cross sections for $p_\uparrow + p_\uparrow \to p + p$ 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 $P_\perp^2$.

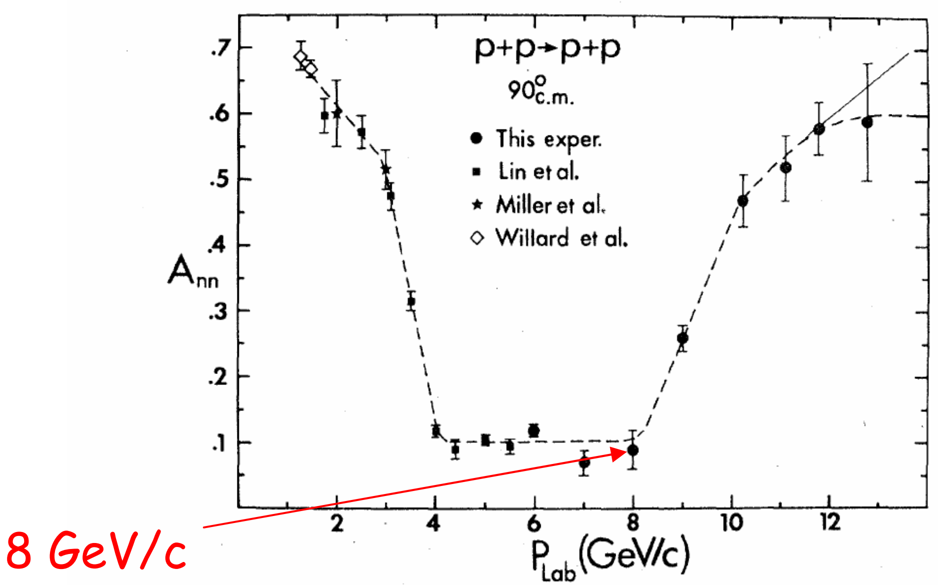


FIG. 2. Plot of the spin-spin correlation parameter A_{nn} for $p+p\to p+p$ at $90°_{c.m.}$ as a function of incident beam momentum. The dashed and solid lines are hand-drawn possible fits.

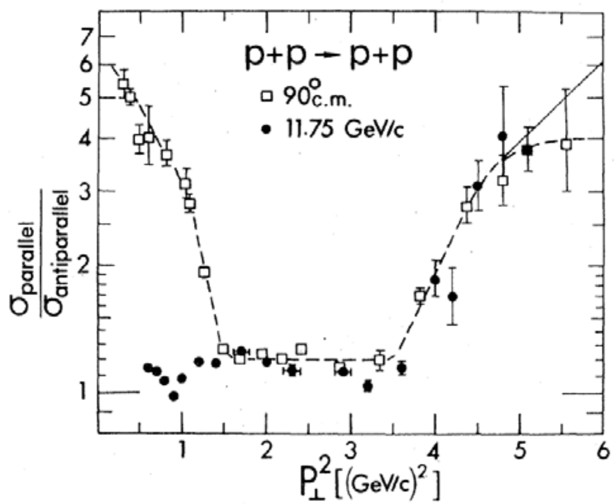
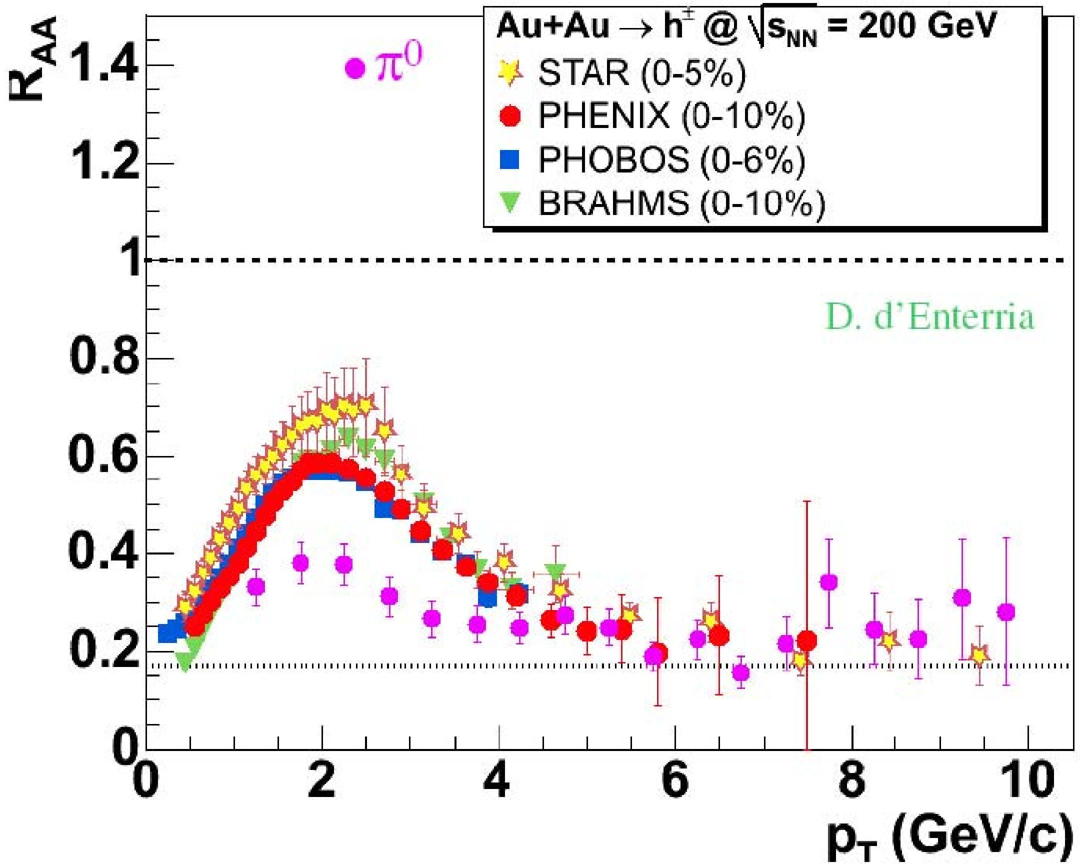


FIG. 3. Plot of the ratio of the spin-parallel to spin-antiparallel differential cross sections, as a function of $P_\perp^2$, for p-p elastic scattering. The squares are the fixed-angle data at $90°_{c.m.}$, with the incident energy varied. The circles are data (Refs. 5, 11) with the momentum held fixed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

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

$\bar{p}p$ - data in the $x_T \sim 1$ region

QCD with and in nuclei: color transparency and short-range correlations in nuclei - theory, observations, directions for further studies

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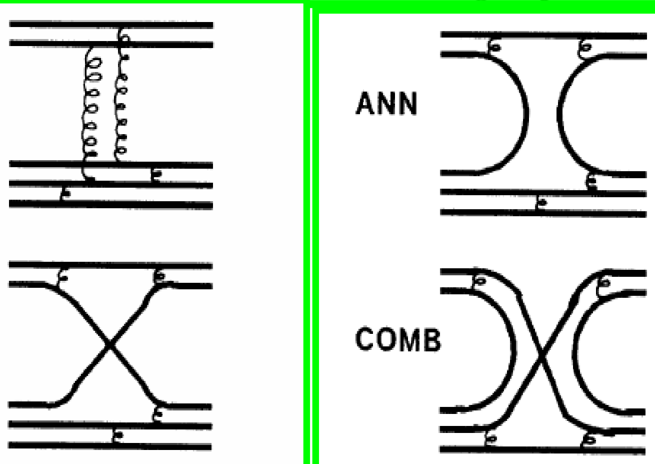
PANDA meeting, March 2009

Abstract

We summarize basic theoretical ideas which let to the observation of the short-range correlations (SRC) in nuclei using hard probes and outline directions for probing quark-gluon structure of SRCs. Implications of the observations of color transparency for processes involving pions are reviewed. Open questions and directions for further studies of color transparency phenomena using hadronic projectiles are presented using as an example the PANDA detector at FAIR.

Key words: short-range correlations, color transparency
PACS: 25.30.-c, 25.40.-h, 24.85.+p

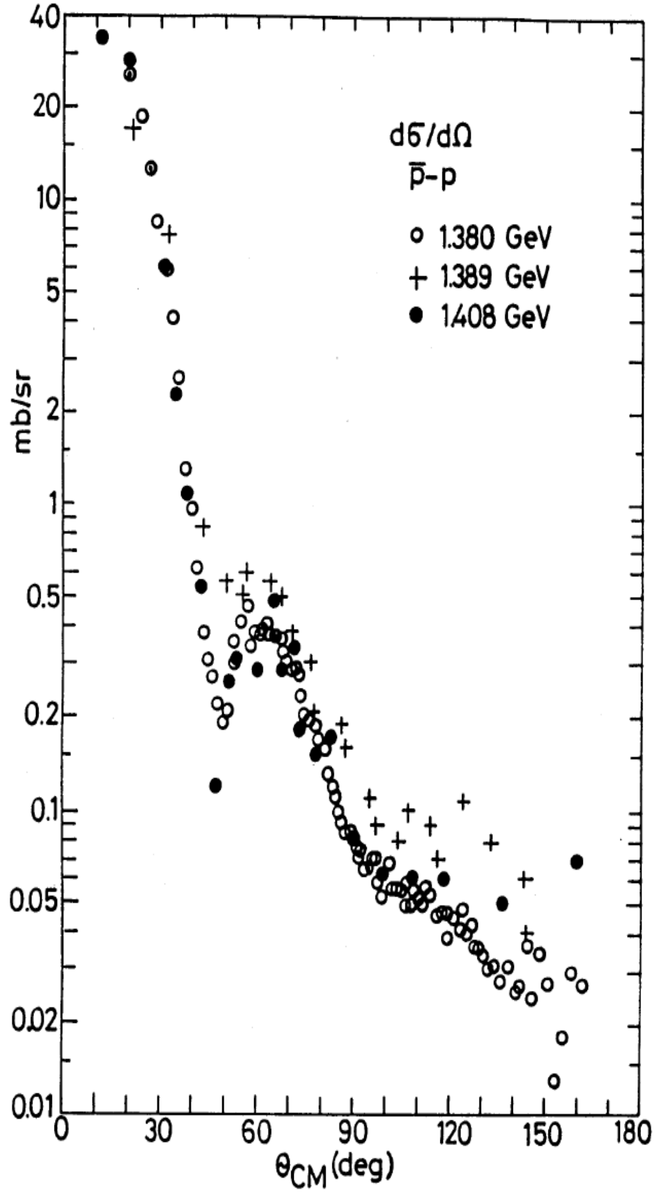
Farrar has expressed meson-baryon scattering amplitudes as a sum of terms involving valence quark scattering amplitudes [17]. The amplitudes can be subdivided into four basic categories, shown in Fig. 1, which are described by pure gluon exchange (GEX), quark interchange (INT) between the hadrons, quark-antiquark annihilation (ANN) and pair creation, or a combination (COMB) of the above. The quark scattering amplitudes



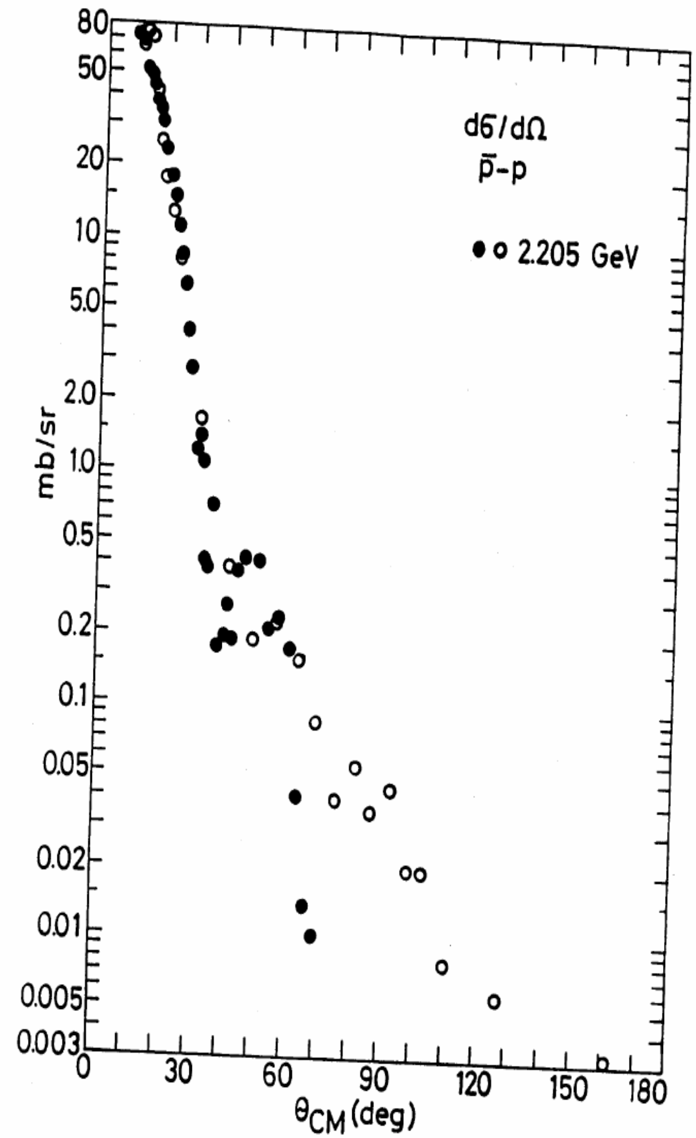
i. Study of the two body processes large angle processes with nucleon targets

Understanding of the large angle exclusive processes: $a + b \rightarrow c + d$ remains one of the challenges for pQCD. Systematic study of a large variety of reactions is available only for incident momentum of 6 and 9.9 GeV/c and below [27]. Analysis [27] found that cross sections of the processes where quark exchanges are allowed are much larger, and the energy dependence is roughly consistent with quark counting rules. Among the biggest puzzles is the ratio of $\theta_{c.m.} = 90^o$ cross sections of $\bar{p}p$ and pp elastic scattering which is below 4% at 6 GeV/c. At face value, it indicates extremely strong suppression of the diagrams with gluon exchanges in t channel, though more systematic, more precise studies are clearly necessary. Another puzzle is the oscillation of the differential cross section of the elastic pp scattering at large t around a smooth quark counting inspired parametrization. Are these oscillations present in any of the $p\bar{p}$ channels?

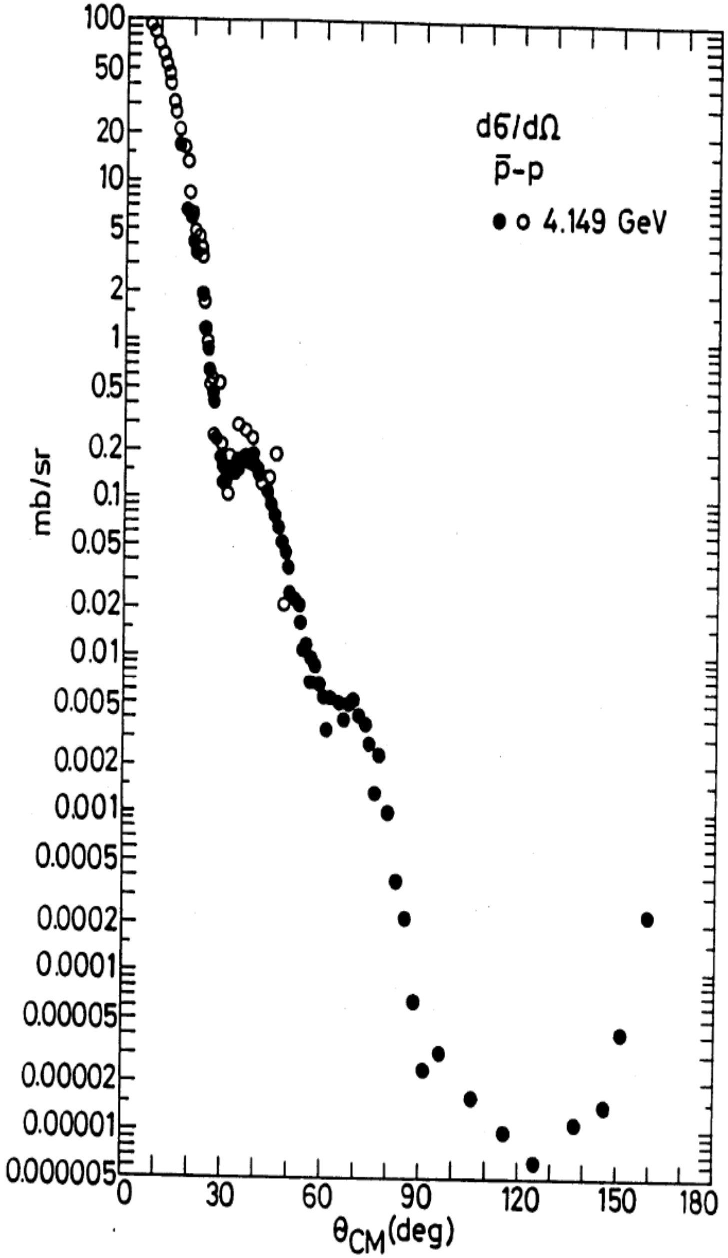
It appears that PANDA will have excellent acceptance for numerous large angle processes - from the simplest processes $p\bar{p} \rightarrow p\bar{p}, \pi\pi, K\bar{K}$ to the processes of production of multi particle states: baryon - antibaryon and meson pairs, etc. In the case of the proton beam the elastic channel is covered reasonably well, though the channels involving Δ-isobars, nonresonance πN production, etc are practically not known. Another gap in the knowledge is pn scattering which could be studied using the ^{2}H pellets. There is a suggestion that the measurement of the pn/pp ratio may provide an insight on the SU(6) structure of the nucleon wave function at large x [28]. Overall, comparing all these channels in pN and $\bar{p}N$ scattering may lead to a break through in understanding hard two body reactions.



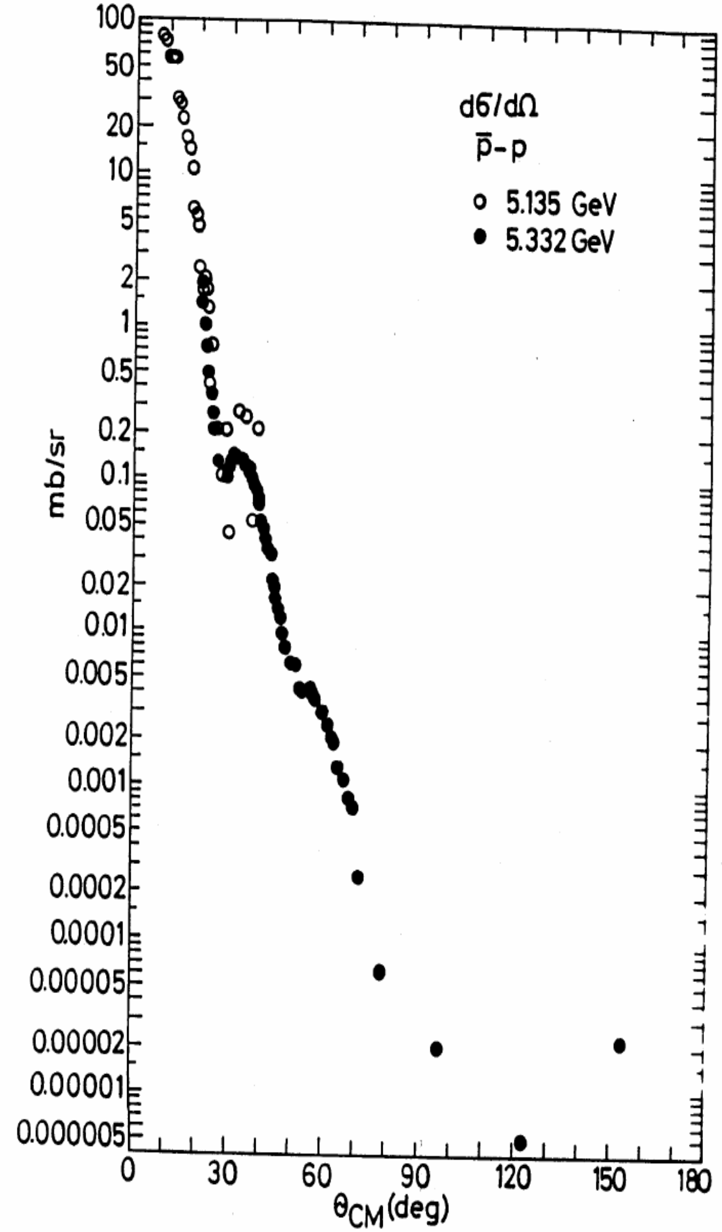
dσ/dΩ
p̄-p
1.380 GeV
1.389 GeV
1.408 GeV
mb/sr
θCM (deg)



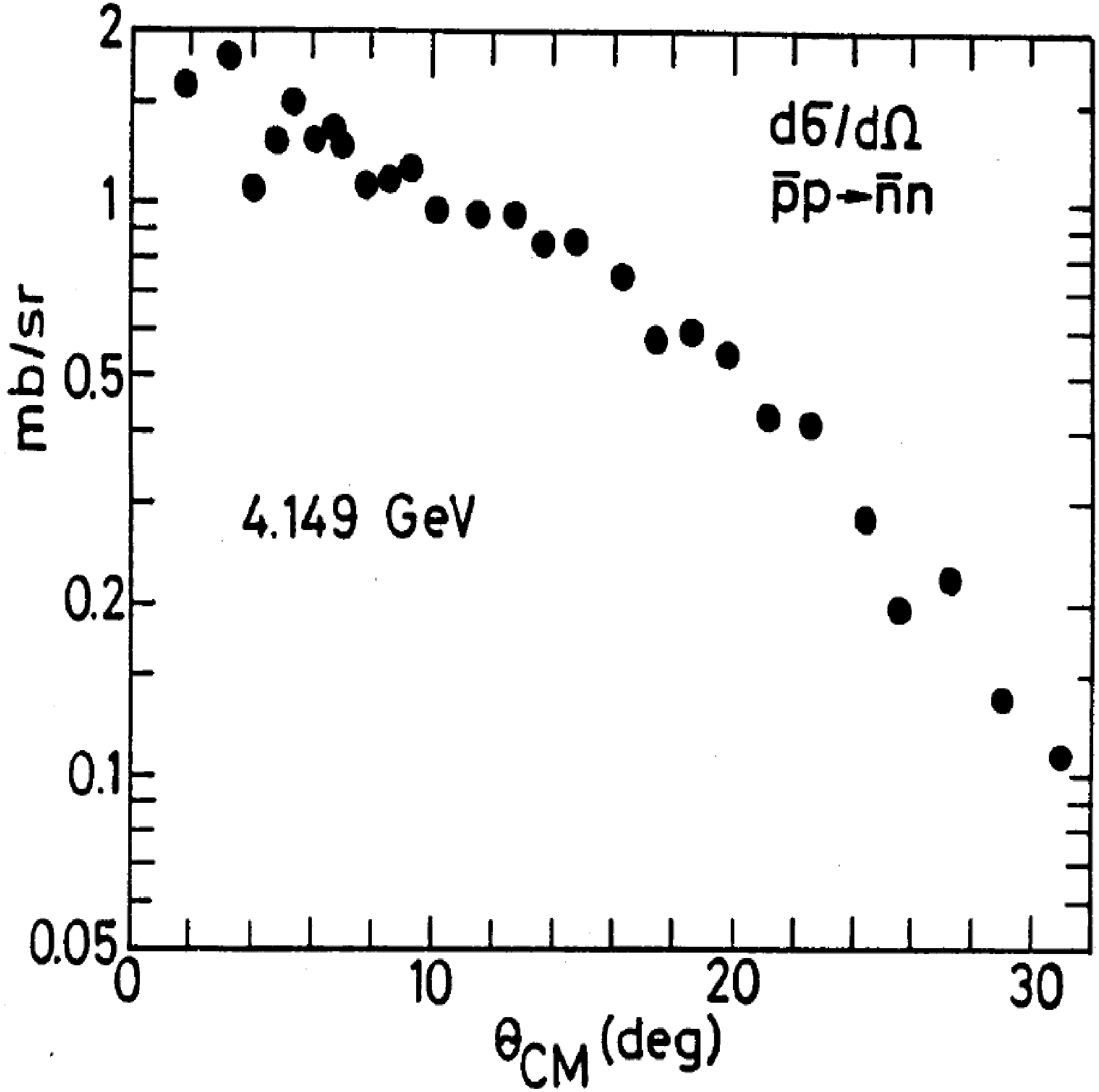
dσ/dΩ
p̄-p
2.205 GeV
mb/sr
θCM (deg)



dσ/dΩ
p̄-p
4.149 GeV
mb/sr
θCM(deg)



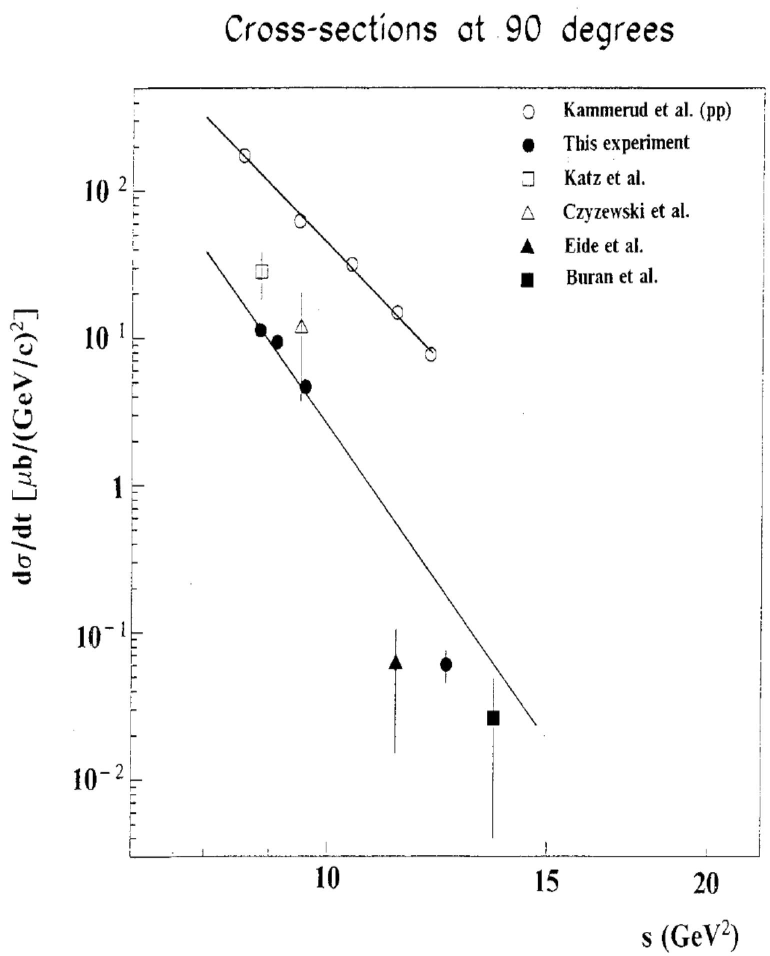
dσ/dΩ
p̄-p
5.135 GeV
5.332 GeV
mb/sr
θCM(deg)



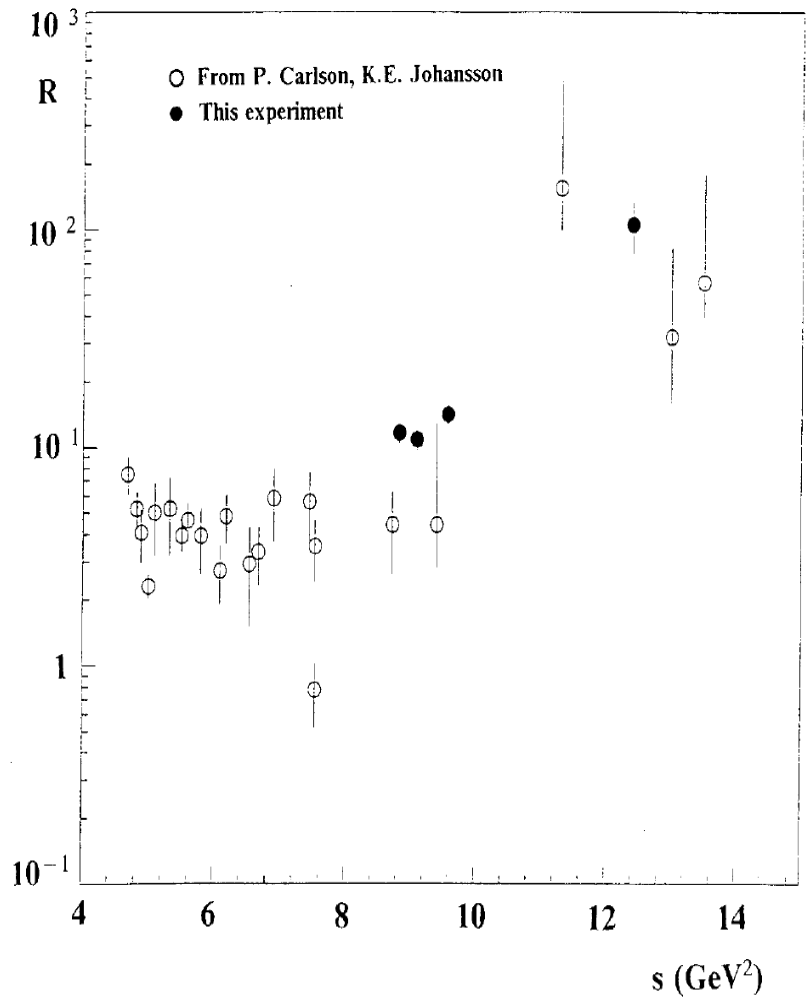
dσ/dΩ
p̄p→n̄n
4.149 GeV
mb/sr
2
1
0.5
0.2
0.1
0.05
0
10
20
30
θ_CM (deg)

PRECISION MEASUREMENTS OF THE ANTIPROTON–PROTON ELASTIC SCATTERING CROSS SECTION AT 90° IN THE INCIDENT MOMENTUM RANGE BETWEEN 3.5 GeV/c AND 5.7 GeV/c

R-704 Collaboration



Ratio between cross-sections

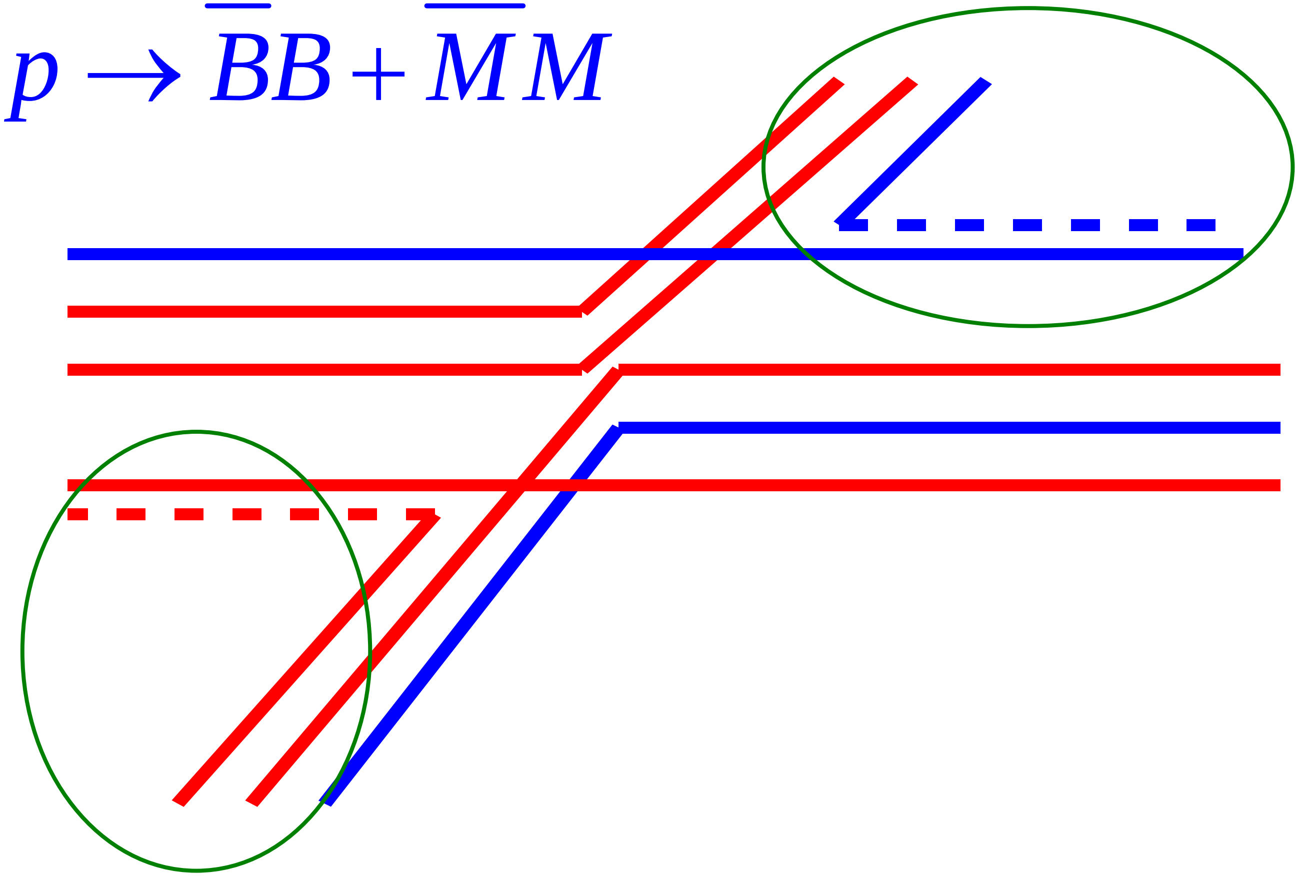


Other reactions

Exclusive reactions as way to resolve questions

B (p, Λ, Δ...), M (π, K , e...)

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



$$\overline{p}p \rightarrow \overline{p}p(\overline{n}n - ?) + \pi\pi(KK)$$

$$\overline{p}p \rightarrow \overline{\Lambda}\Lambda + KK(\pi\pi, \mu\mu)$$

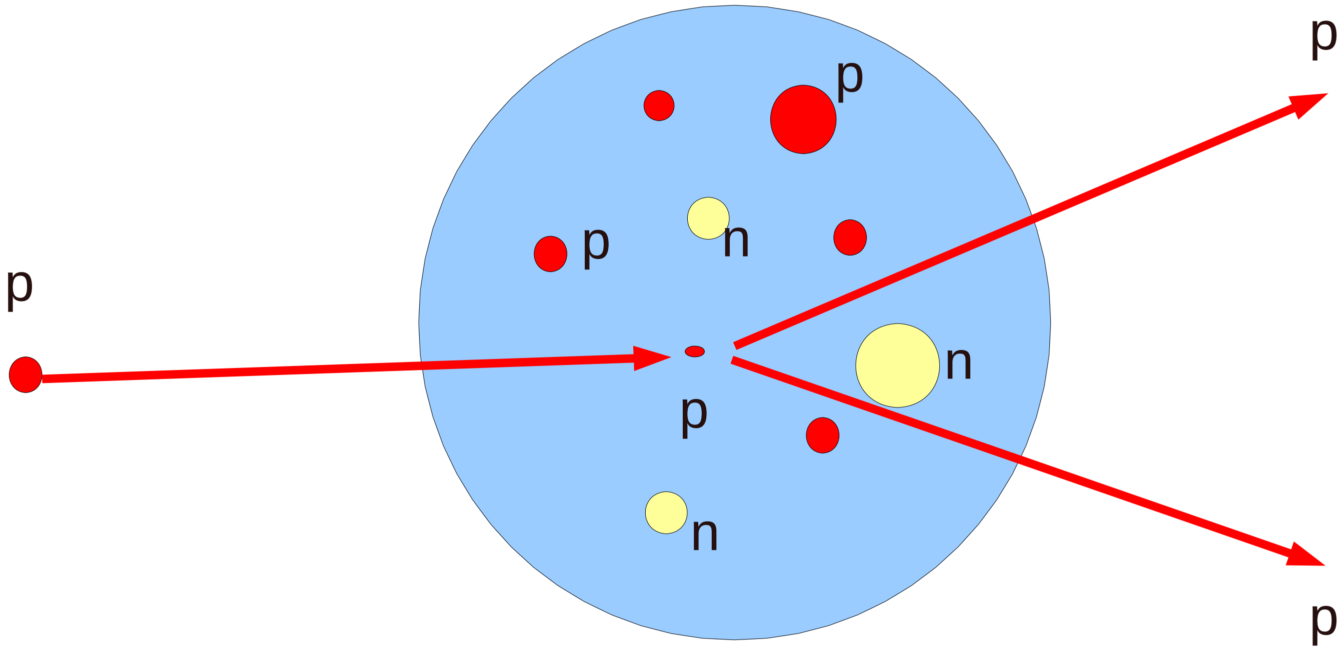
$$\overline{p}p \rightarrow \overline{\Delta}\Delta$$

CT

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

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

$$T = \frac{\frac{d\sigma}{dt}(p + "p" \to p + p)}{Z\frac{d\sigma}{dt}(p + p \to p + p)}$$



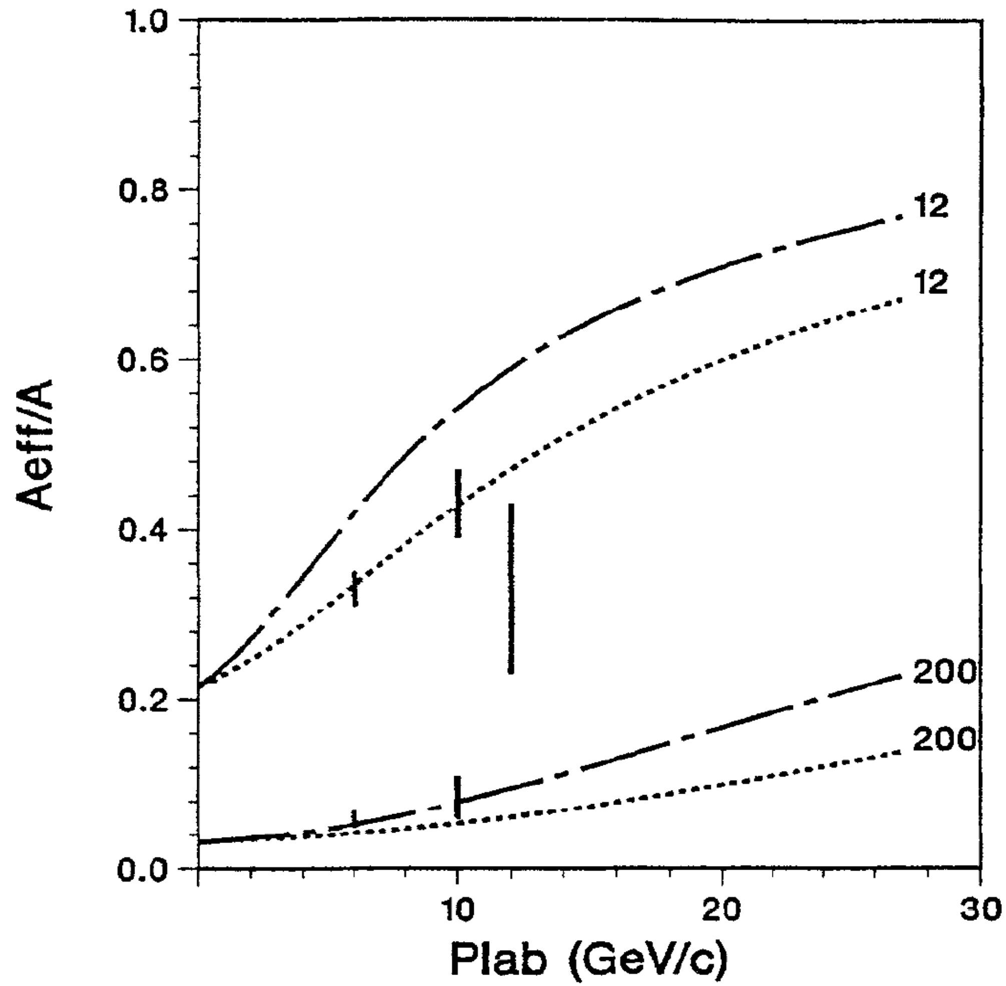


Fig. 3.8. The theoretical predictions of Farrar et al. [51] for $pA \to p'p''(A-1)$. The model predicts a monotonically increasing transparency ratio which is in clear conflict with the data, especially for the Al target (not shown; see Fig. 3.3).

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A relativistic framework to determine the uclear transparency from $A(p,2p)$ reactions

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tract

elativistic framework for computing the nuclear transparency extracted from $2p)$ scattering processes is presented. The model accounts for the initial- and -state interactions (IFSI) within the relativistic multiple-scattering Glauber ap- imation (RMSGA). For the description of color transparency, two existing mod- re used. The nuclear filtering mechanism is implemented as a possible explana- for the oscillatory energy dependence of the transparency. Results are presented he target nuclei ^{7}Li, ^{12}C, ^{27}Al, and ^{63}Cu. An approximated, computationally intensive version of the RMSGA framework is found to be sufficiently accurate he calculation of the nuclear transparency. After including the nuclear filtering color transparency mechanisms, our calculations are in acceptable agreement the data.

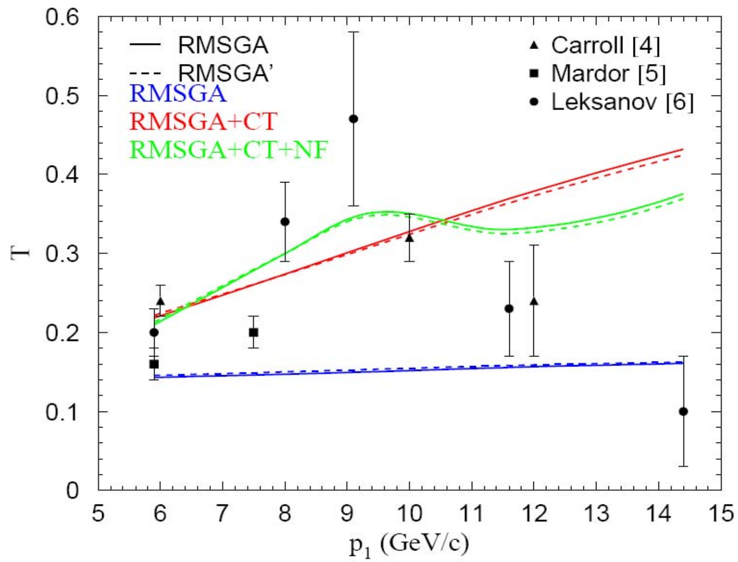

Fig. 1. The nuclear transparency for the ^{12}C$(p,2p)$ reaction as a func the incoming lab momentum p_1. The full RMSGA (solid lines) are comp the RMSGA′ (dashed lines) results. The different curves represent the R RMSGA+CT and RMSGA+CT+NF calculations. The CT effects are cal in the FLFS model [21] with $\Delta M^2 = 0.7$ (GeV/c^2)^2 and the results incluc mechanism of NF are obtained using the positive sign of $\phi(s) + \delta_1$. Data a Refs. [4,5,6].

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

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The transparency of carbon for $(p,2p)$ quasielastic events was measured at beam momenta ranging from 5.9 to 14.5 GeV/c at 90° c.m. The four-momentum transfer squared (Q^2) ranged from 4.7 to 12.7 (GeV/c)^2. We present the observed beam momentum dependence of the ratio of the carbon to hydrogen cross sections. We also apply a model for the nuclear momentum distribution of carbon to obtain the nuclear transparency. We find a sharp rise in transparency as the beam momentum is increased to 9 GeV/c and a reduction to approximately the Glauber level at higher energies.

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

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

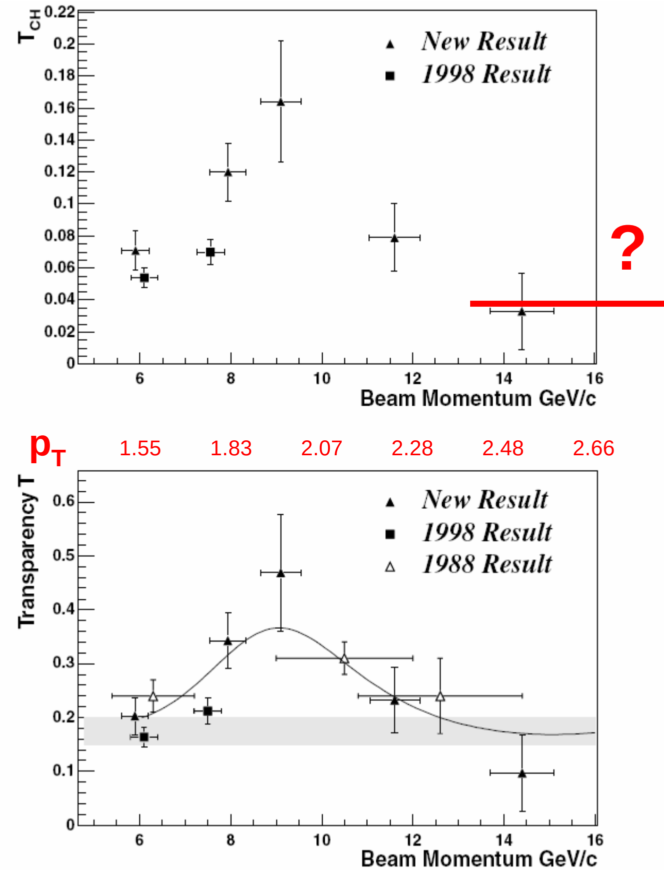

FIG. 2. Top: The transparency ratio $T_{\rm CH}$ as a function of the beam momentum for both the present result and two points from the 1998 publication [3]. Bottom: The transparency T versus beam momentum. The vertical errors shown here are all statistical errors, which dominate for these measurements.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

COLOR TRANSPARENCY

PHYSICAL REVIEW C **70**, 015208 (2004)

VIII. SUGGESTIONS FOR FUTURE EXPERIMENTS

Clearly there remain a number of interesting investigations involving nuclear transparency of protons and other hadrons. A revival of the AGS fixed target program [44], or the construction of the 50-GeV accelerator as part of the J-PARC complex in Japan [55], would provide excellent opportunities to expand the range of these nuclear transparency studies. Some of the remaining questions are the following.

(1) What happens at higher incident momentum? Does nuclear transparency rise again above 20 GeV/c, as predicted in the Ralston-Pire picture [56]?

(2) A-dependent studies in the 12 to 15 GeV/c range; will the effective absorption cross section continue to fall after the nuclear transparency stops rising at ~9.5 GeV/c [56]?

(3) At the higher energy ranges of these experiments the spin effects are expected to be greatly diminished. However, they continue to persist, as shown in both single and double spin measurements [34,57]. So it is important to see, in quasielastic scattering inside a nucleus, whether a relatively pure pQCD state is selected, and if the spin dependent effects are attenuated.

(4) Measurements of nuclear transparency with antiprotons, pions, and kaons will be informative. These particles have widely different cross sections at $90^\circ_{\text{c.m.}}$. For instance, the pp differential cross section at $90^\circ_{\text{c.m.}}$ is 50 times larger than the $\overline{p}p$ differential cross section [19]. How should this small size of the $\overline{p}p$ cross section affect the absorption of $\overline{p}$'s by annihilation?

(5) The production of exclusively produced resonances provides a large testing ground for nuclear transparency effects. This is especially true for those resonances that allow the determination of final state spin orientation, such as ρ's or Λ's [19,36]. Will the interference terms that generate asymmetries disappear for reactions which take place in the nucleus?

(6) Measurements in light nuclei that determine the probability of a second hard scatter after the first hard interaction are an alternative way to study nuclear transparency effects. With the proper kinematics selected, the probability of the second scatter is dependent on the state of the hadrons at the first hard interaction [58].

END