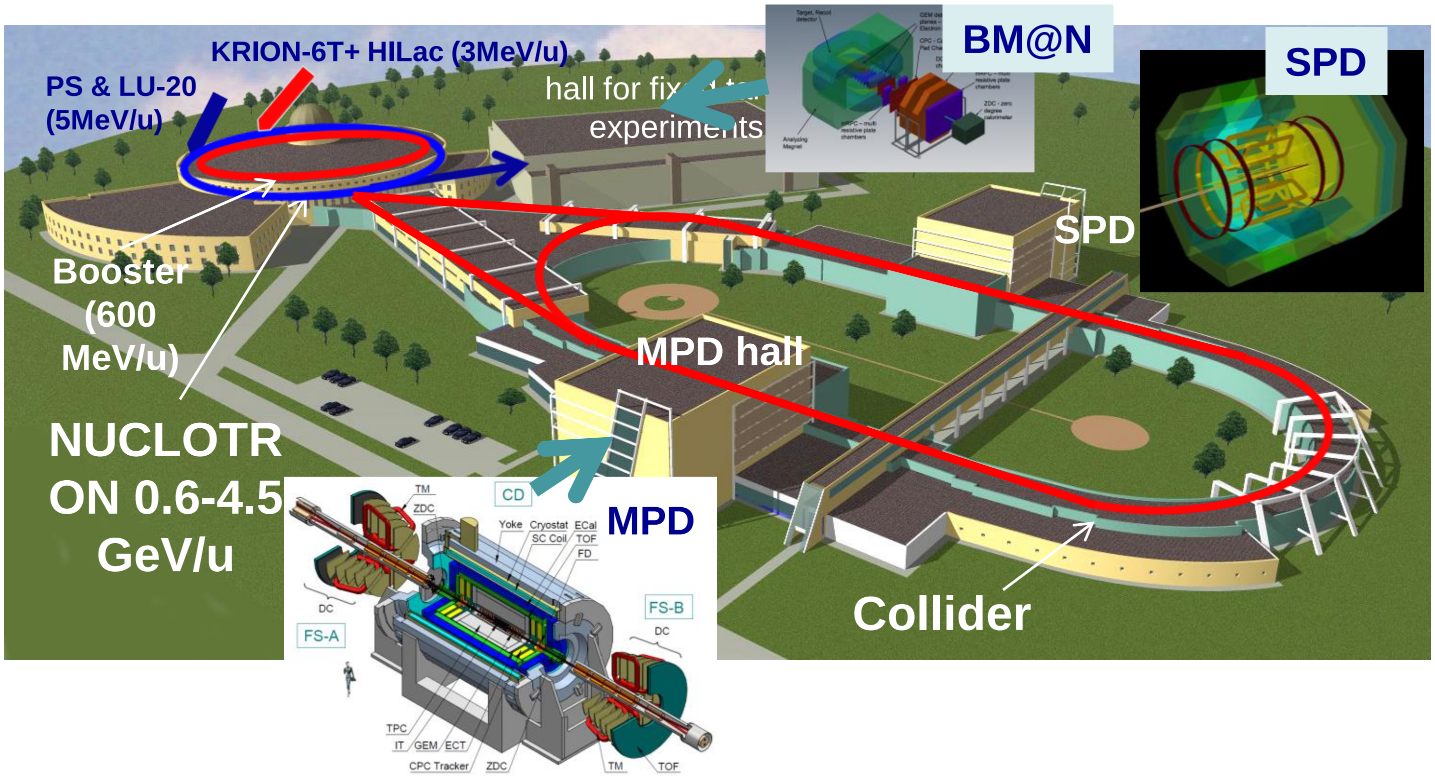
“The Nonperturbative laws of QCD in Experiments (Part I)”

S.S. Shimanskiy (JINR, Dubna)

The NICA complex

existing facilities

to be constructed



SPD project preparation

- Formal JINR project for the SPD design *(i.e. for preparation of the Technical Design Report, TDR)* and submission of the project to the PAC for Particle Physics:
  - status report (Jan. 2018);
  - submission to the PAC in Nov. 2018 for the PAC meeting in Jan. 2019, i.e. complete draft must be ready beginning of October 2018;
- Expressions of Interest by the interested institutes are expected at this stage
- Editorial Board will be set up very soon → first draft to be ready by middle of September!

HIGH p_T ISSUES at SPD

1. Diquark properties.

2. The Confinement laws.

3. Nature of the spin effects.

4. The Deuteron spin structure.

5. FSI (with s,c-quarks participation).

6. Nature of CsDBM.

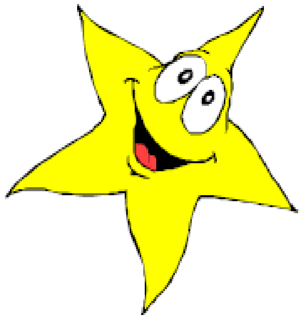
7. np dilepton production anomaly.

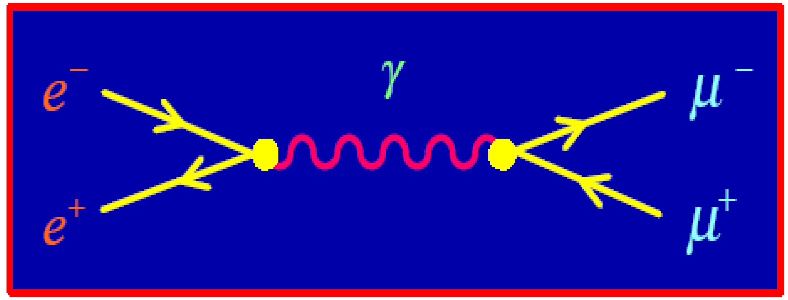
8. Exotic states.

9. Subthreshold J/Ψ production.

…

Successful Theory

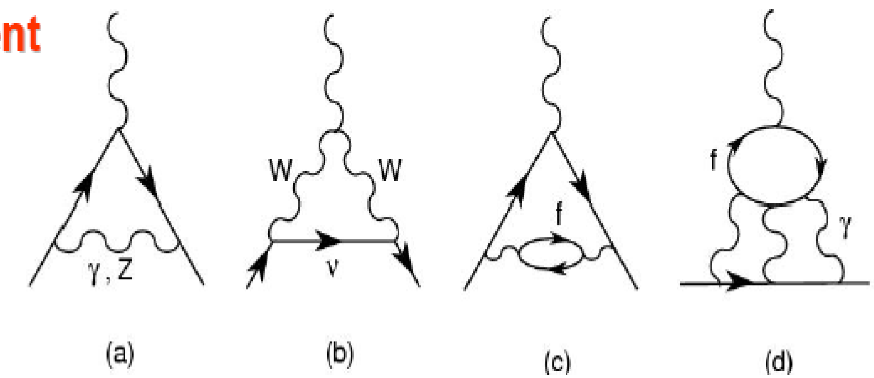




Anomalous Magnetic Moment

$$\mu_l \equiv g_l \frac{e}{2\,m_l}$$

$$a_l \equiv \frac{1}{2}\,(g_l - 2)$$



$a_e = (115\,965\,218.69 \pm 0.41) \times 10^{-11}$ ➡ $\alpha^{-1} = 137.035\,998\,76 \pm 0.000\,000\,52$

➡ $a_\mu^{\text{th}} = (116\,591\,803 \pm 94) \times 10^{-11}$ [Exp: $(116\,592\,030 \pm 80) \times 10^{-11}$]

Nuclei and NN-interaction

1937: Theory of nuclear forces (H. Yukawa)

Existence of a new light particle ("meson") as the carrier of nuclear forces

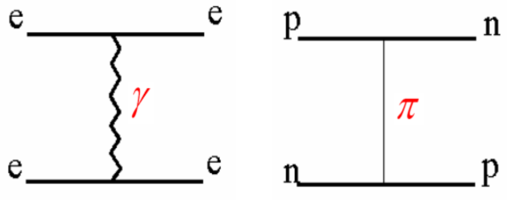
$$U_{я}(r) \sim \frac{e^{-(mc/\hbar)r}}{r}$$

Hideki Yukawa

Relation between interaction radius and meson mass *m*:

$$R_{\text{int}} = \frac{\hbar}{mc} \Rightarrow$$

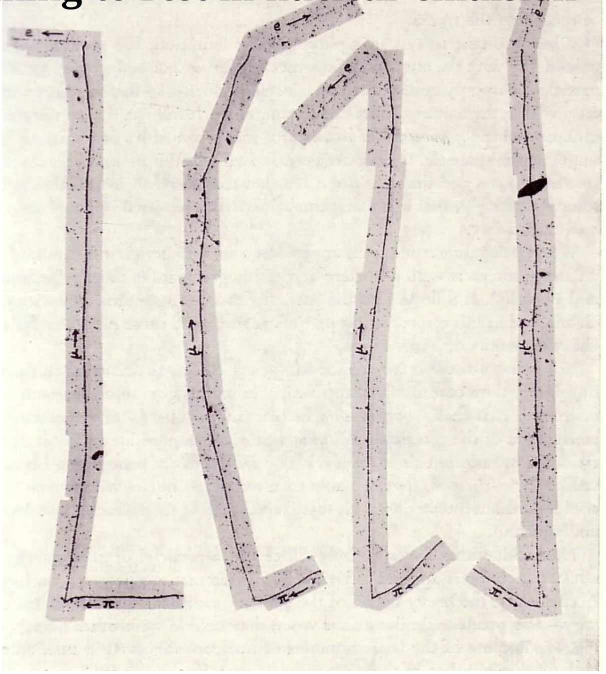
$mc^2 \approx 200$ MeV for $R_{\text{int}} \approx 10^{-13}$ cm



1947: Discovery of the π - meson (the "real" Yukawa particle)

Observation of the $\pi^+ \to \mu^+ \to e^+$ decay chain in nuclear emulsion exposed to cosmic rays at high altitudes

Four events showing the decay of a π^+ coming to rest in nuclear emulsion



$m_\pi = 139.57$ MeV/c^2 ; spin = 0

Dominant decay mode: $\pi^+ \to \mu^+ + \nu$

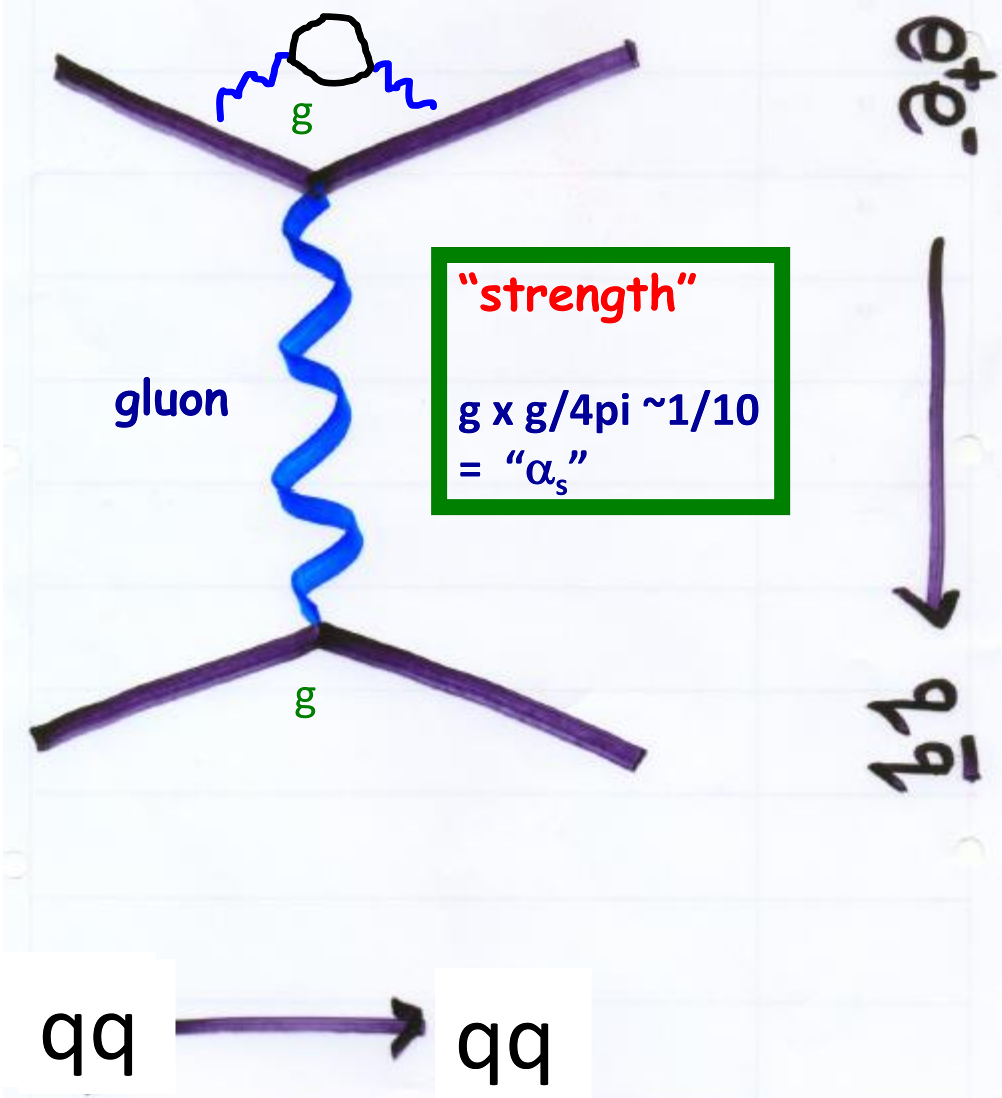
(and $\pi^- \to \mu^- + \nu$)

Mean life at rest: $\tau_\pi = 2.6 \times 10^{-8}$ s = 26 ns

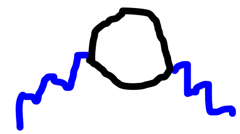
F. Close

Quark Interaction - QCD

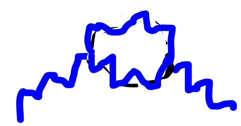
Feynman diagrams for chromomagnetic interaction



Like QED, QCD has

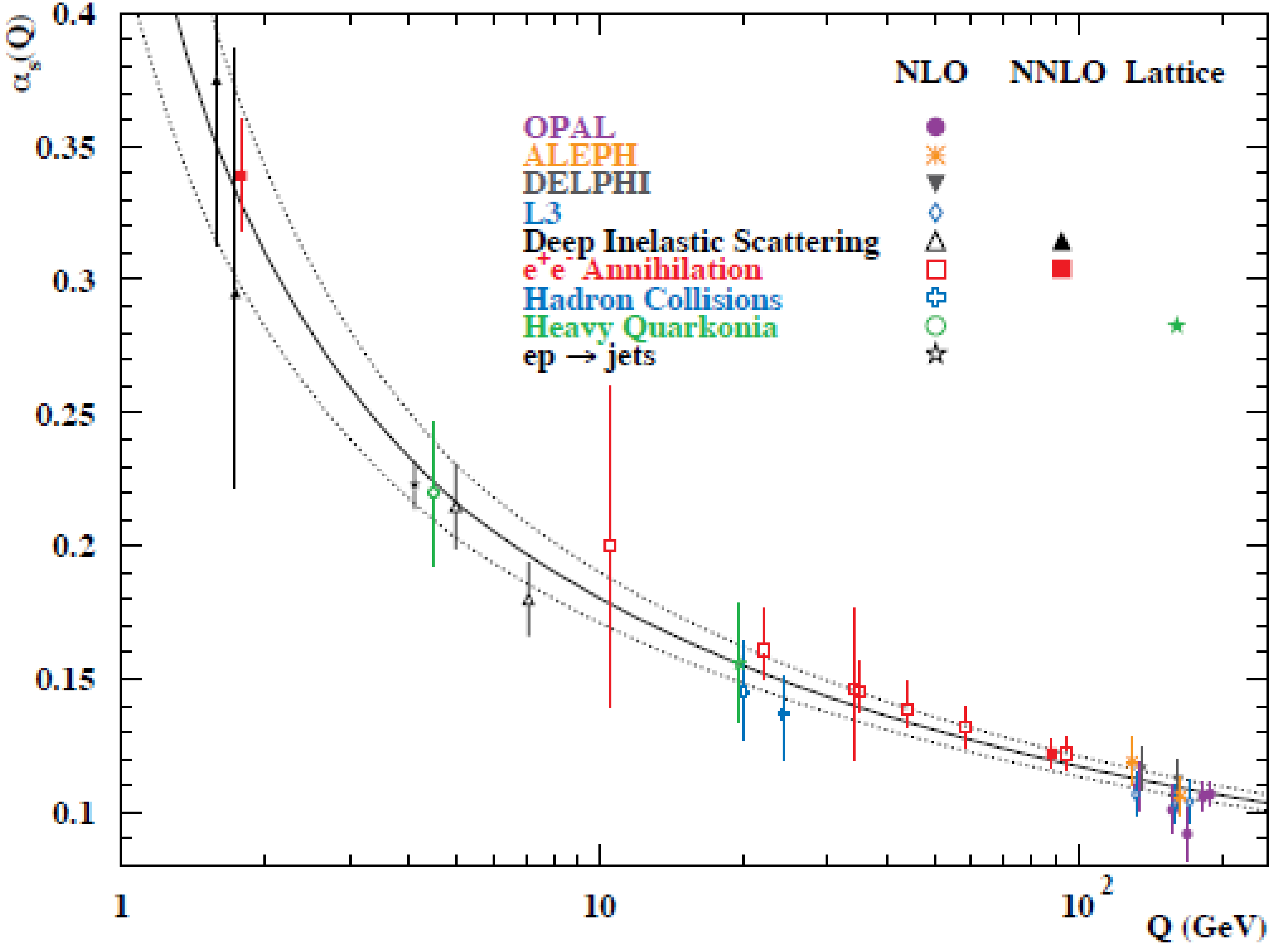


and also



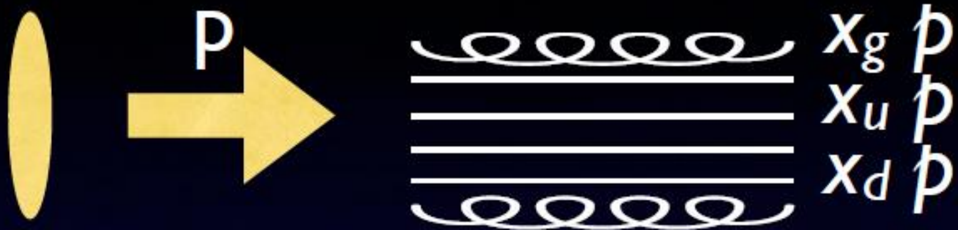
"α_s" falls with p
= is big at small p
"STRONG" force
= small at large p
"pQCD" in HEPhys

α_s constant of the strong interaction



Parton Distribution Function

PDF



$0 < x < 1$

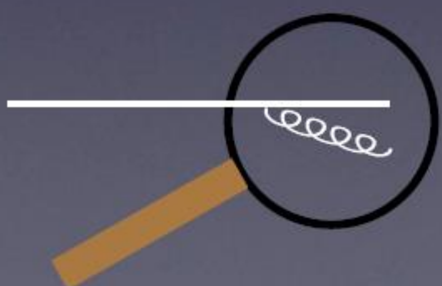
probability to find a "parton" i of momentum $x\,p$

parton distribution function $f_i(x_i)$

p p collision = sum of parton-parton collision

$$\sigma = \int_0^a dx_1 \int_0^1 dx_2 f_i(x_1) f_i(x_2) \sigma(ij \to X)$$

but if you look closely (high Q^2), partons split further

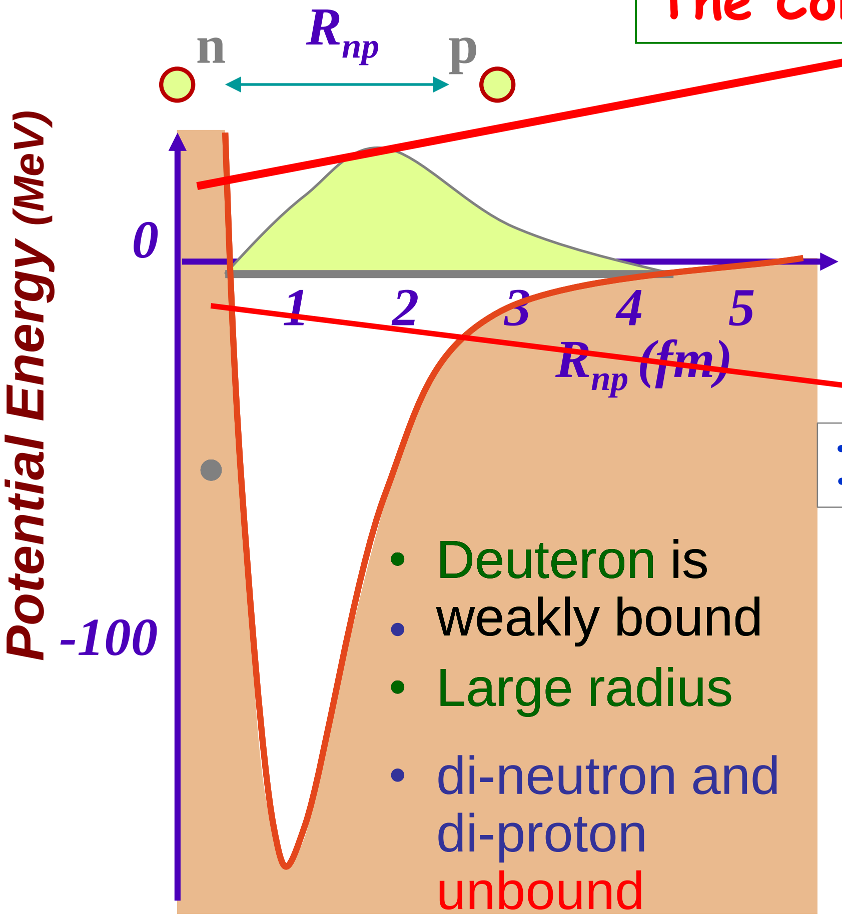


DGLAP equation

$$\frac{df_i(x)}{dQ^2} = \int_x^1 dx' f_j(x') P(j \to i + X)$$

Let us look at the nucleon-nucleon interaction:

The Cold High Dense Nuclear Matter



Internal momentum ≥ 250 MeV/c

- Deuteron is
- weakly bound
- Large radius
- di-neutron and di-proton unbound

DEUTERON STATIC PROPERTIES FROM NN-POTENTIALS

Таблица 1: Статические свойства дейтрона

	$E_D(MeV)$	$P_D(\%)$	$< r_D^2 >^{1/2} (fm)$	$Q(fm^2)$	$\eta = \frac{A_D}{A_S}$	$f_{\pi NN}^2$	$\mu_D(n.m)$
Exp.	2.224579(9)	–	1.9560(68)	0.2859(3)	0.0271(4)	0.0776(9)	0.857406(1)
MU	2.2246	6.78	1.9611	0.2860	0.0271	0.07745	0.843
Paris	2.2250	5.77	1.9716	0.2789	0.0261	0.078	0.853
RHC	2.2246	6.50	1.9602	0.2770	0.0259	0.0757	0.840
RSC	2.2246	6.47	1.9569	0.2796	0.0262	0.0757	0.843
Bonn	2.225	4.58	1.86	0.2856	0.0267	–	–

Table 1: Deuteron properties in the dressed bag model.

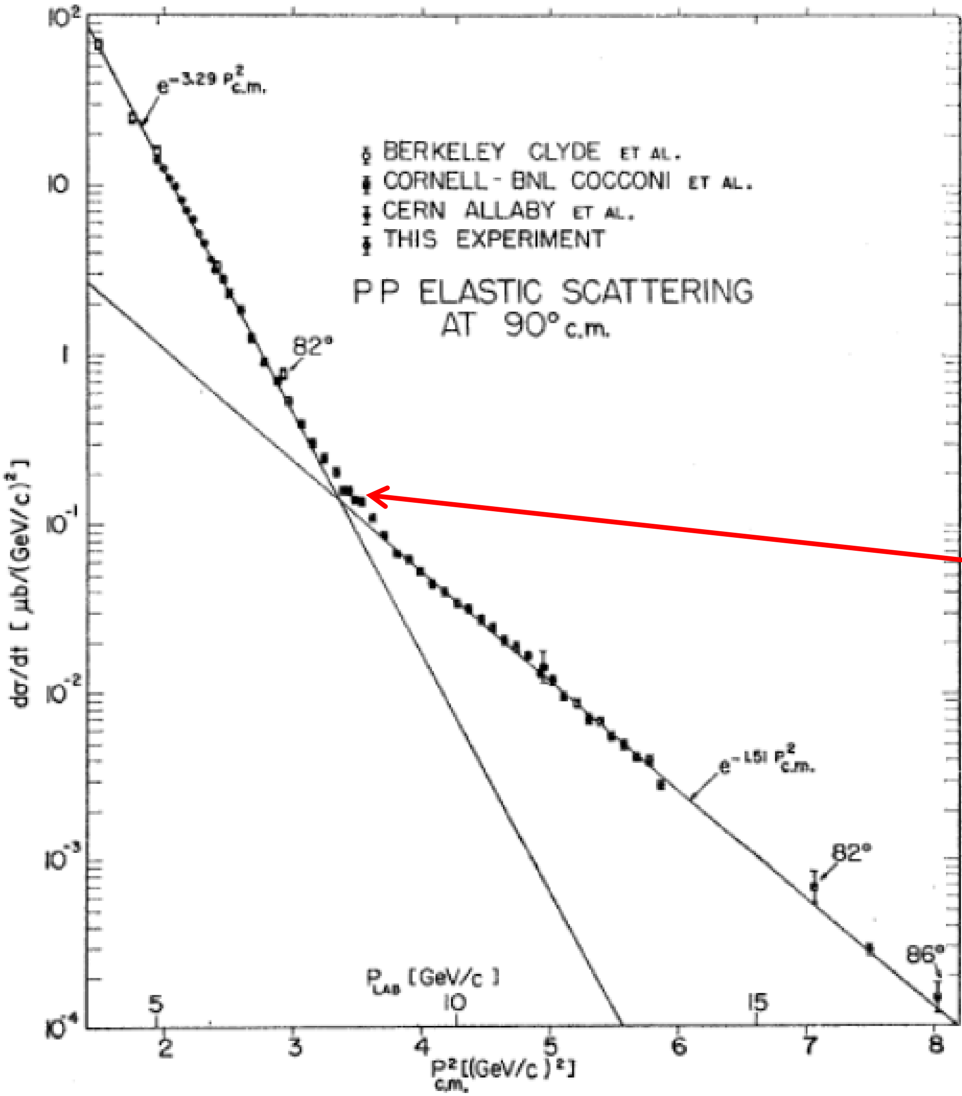
Model	E_d(MeV)	$P_D(\%)$	r_m(fm)	$Q_d(\text{fm}^2)$	$\mu_d\,(\mu_N)$	$A_S(\text{fm}^{-1/2})$	$\eta(D/S)$
RSC	2.22461	6.47	1.957	0.2796	0.8429	0.8776	0.0262
Moscow 99	2.22452	5.52	1.966	0.2722	0.8483	0.8844	0.0255
Bonn 2001	2.224575	4.85	1.966	0.270	0.8521	0.8846	0.0256
DBM (1) $P_{\text{in}} = 3.66\%$	2.22454	5.22	1.9715	0.2754	0.8548	0.8864	0.0259
DBM (2) $P_{\text{in}} = 2.5\%$	2.22459	5.31	1.970	0.2768	0.8538	0.8866	0.0263
experiment	2.224575		1.971	0.2859	0.8574	0.8846	0.0263

“SPIN PROBLEMS” and NN-interaction

Слева направо: Степан Шиманский, Алан Криш, Александр Нагайцев, Рихард Ледницки, Владимир Ладыгин.

pp -> pp (90^0)

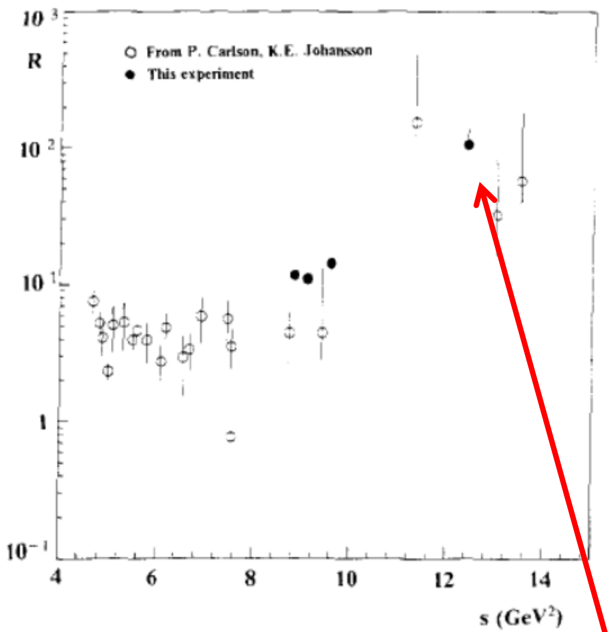
C.W. Akerlof et al., Phys.Rev., vol.159, N5, 1138-1149, 1967



Krisch A. and Leksin G. - non pointlike structure of nucleon

p_T ~ 2 GeV/c

$p\bar{p}$



$$R = \frac{\sigma(pp \to pp)}{\sigma(\bar{p}p \to \bar{p}p)}(90^o\, c.m.)$$

p_T ~ 2 GeV/c region

Cross-sections at 90 degrees

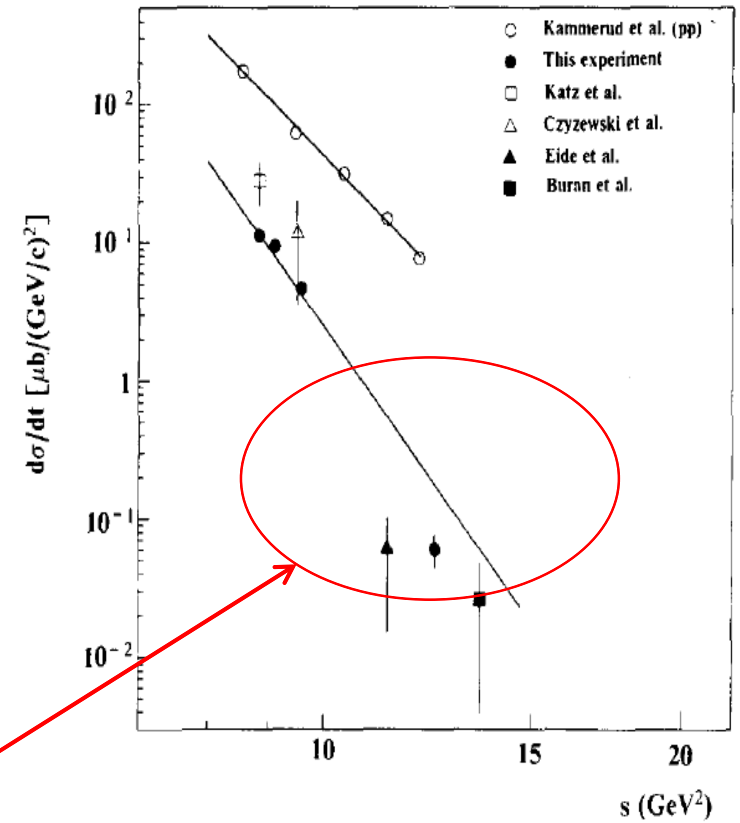


Fig. 3. The p$\bar{p}$ and pp elastic differential cross sections at 90° CM as function of the square of the CM energy, s. Open circles are pp data from ref. [6]. These data fit well to the drawn curve proportional to s^{-9}. The remaining points are p$\bar{p}$ data. Shaded from this experiment. Otherwise 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.

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

2-SPIN PROTON-PROTON ELASTIC CROSS SECTIONS

12 GeV ZGS

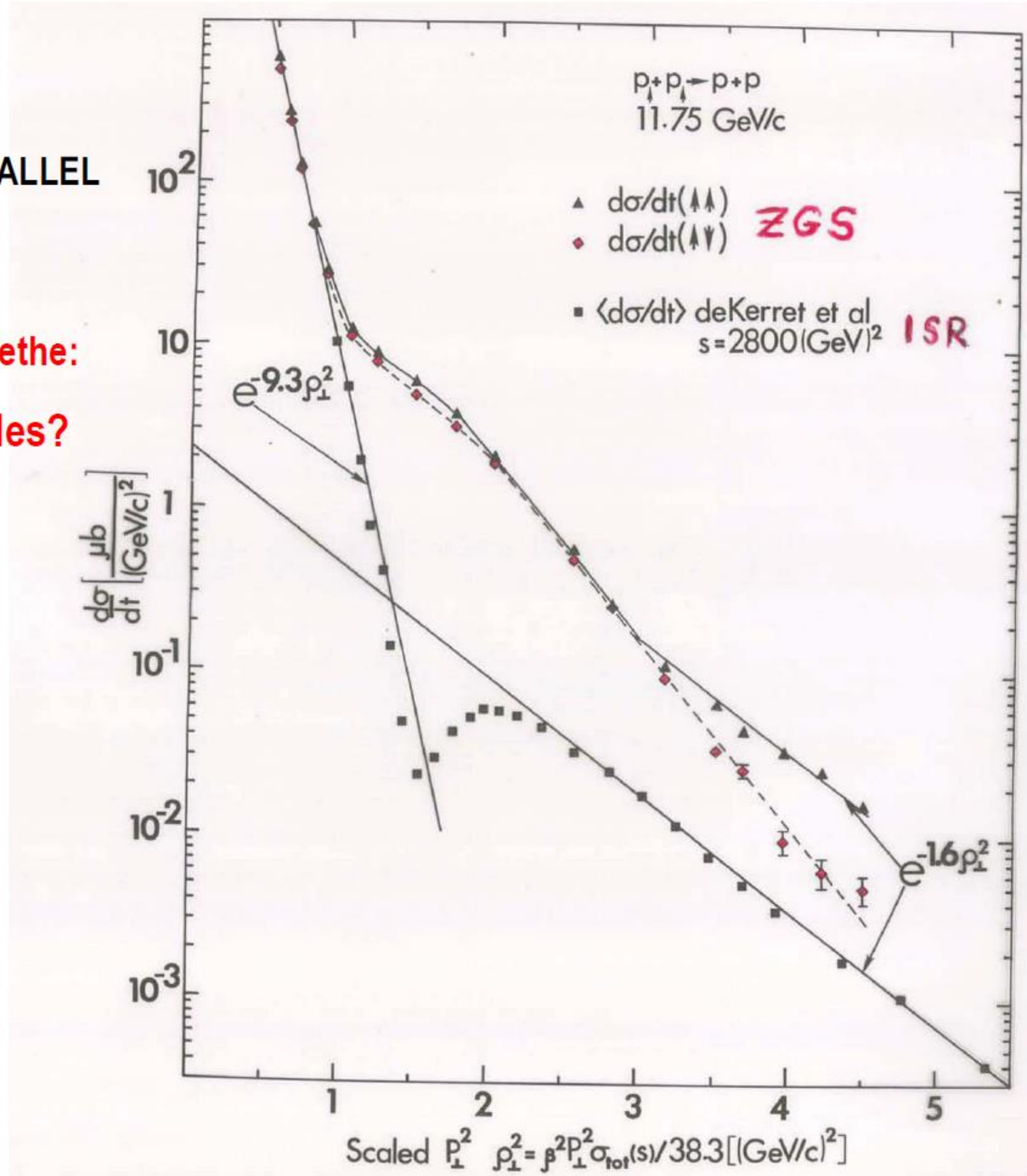
1977-1978

SPINS PARALLEL 4X SPINS ANTIPARALLEL

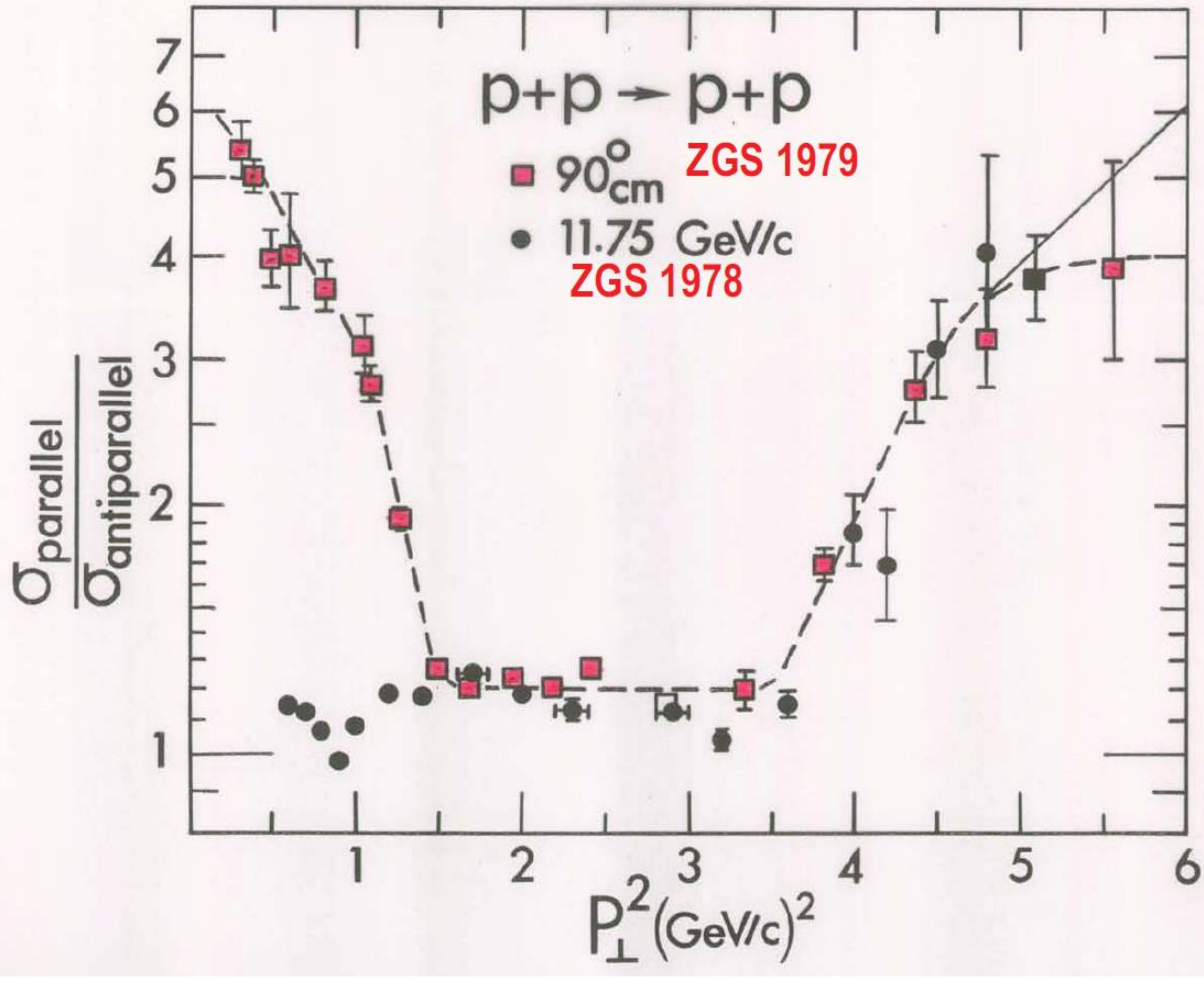
TOTALLY UNEXPECTED

Questions by Profs. Weisskopf & Bethe:

High P_T or 90^o_{cm} Identical Particles?



Answer to Questions by Profs. Weisskopf & Bethe



Spin-Spin Forces in 6-GeV/c Neutron-Proton Elastic Scattering

D. G. Crabb, P. H. Hansen, A. D. Krisch, T. Shima, and K. M. Terwilliger
Randall Laboratory of Physics, The University of Michigan, Ann Arbor, Michigan 48109

and

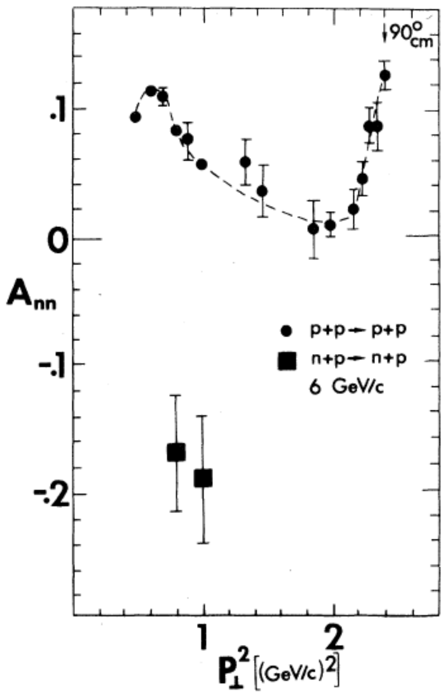


FIG. 2. The spin-spin correlation parameter, A_{nn}, for pure-initial-spin-state nucleon-nucleon elastic scattering at 6 GeV/c is plotted against the square of the transverse momentum. The proton-proton and neutron-proton data are quite different.

This large negative A_{nn} for n-p elastic scattering is quite unexpected. No theoretical models predicted this effect, although a very recent constituent-interchange model[12] predicts $A_{nn} = -44\%$. This may support the suggestion that large spin effects are related to the composite nature of the nucleon.[12,13] An earlier Regge-model prediction[14] is inconsistent with our data. It seems somewhat surprising that A_{nn} is so large at a $P_\perp^2$ of only 1 (GeV/c)^2.

[12]G. R. Farrar, S. Gottlieb, D. Sivers, and G. H. Thomas, Phys. Rev. D 20, 202 (1979).

AGS 1985-1990 A_n

PERTURBATIVE QCD ⇒

$A_n = 0$ at HIGH $P_\perp^2$ and HIGH ENERGY

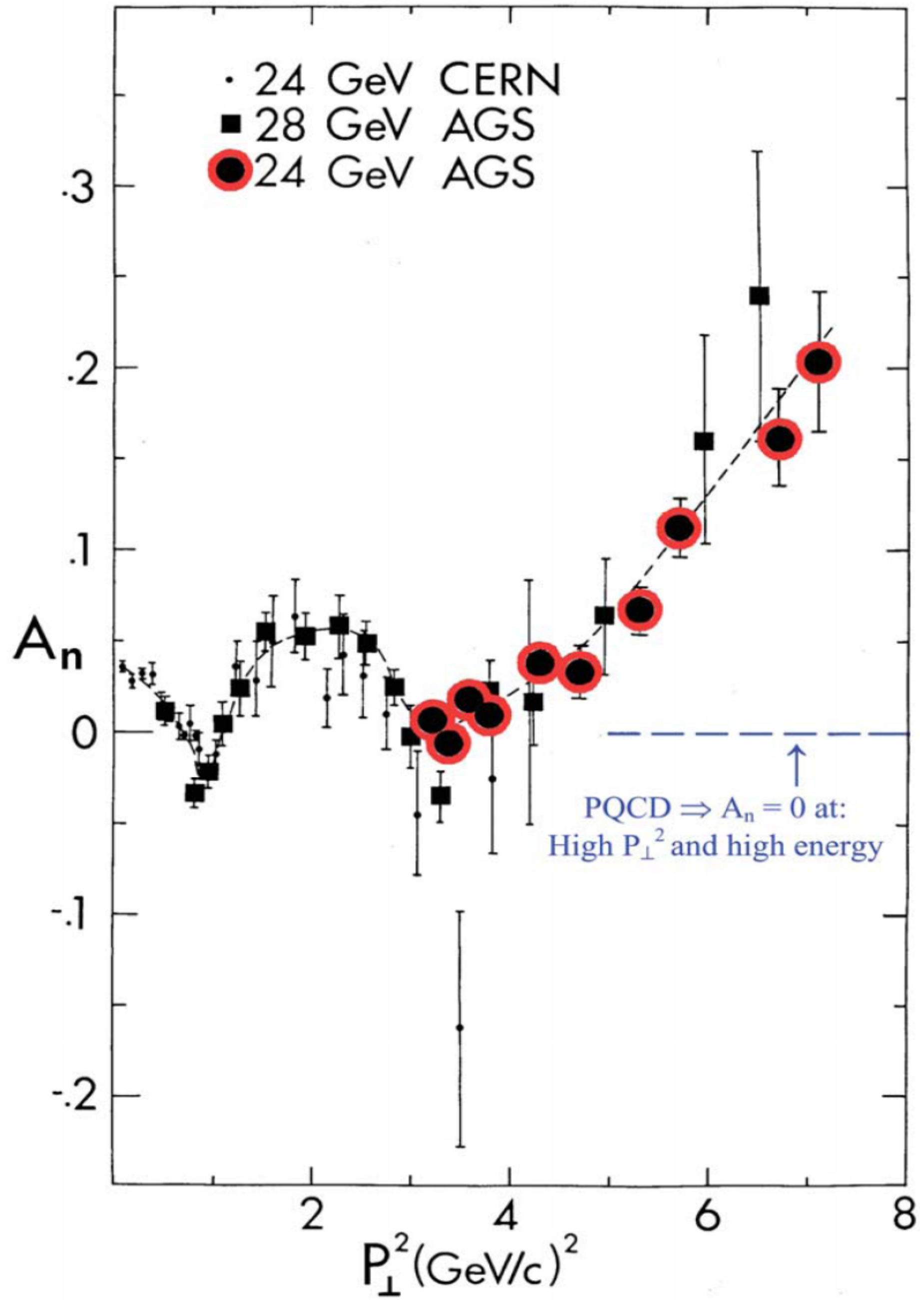
$A_n \neq 0$ ⇒

PROBLEM with PQCD?

NO MODEL can EXPLAIN ALL HIGH-$P_\perp^2$ SPIN EFFECTS (A_n & A_{nn})

GOAL

MEASURE A_n (and A_{nn}) up to $P_\perp^2 = 12\ (GeV/c)$



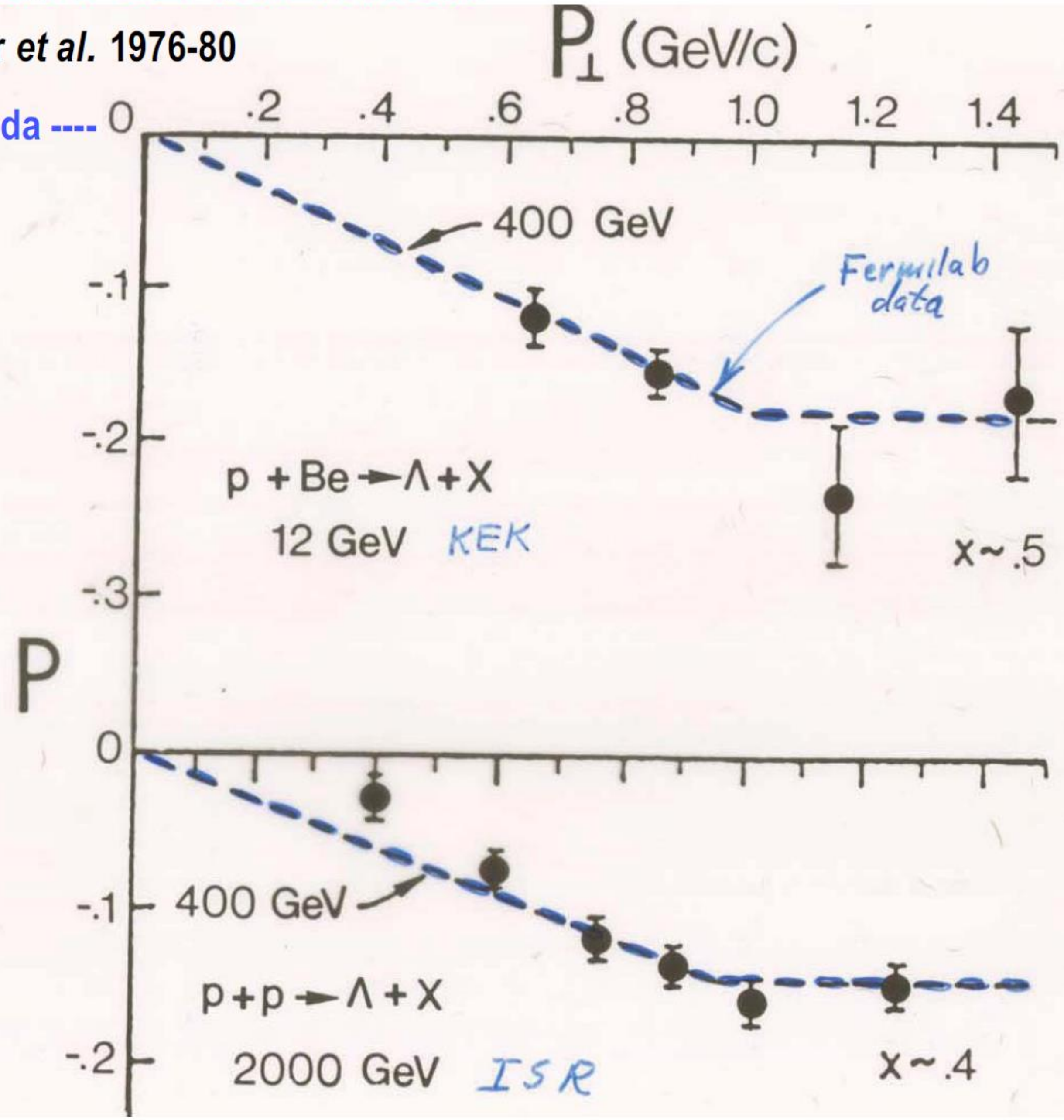
INCLUSIVE HYPERON POLARIZATION

Devlin, Pondrum, Bunce, Heller *et al.* 1976-80

Fermilab 400 GeV p+p -> Lambda ----

Plot by Heller ~1980

with KEK & ISR data



P ~ 15-20 %

QCD says P ~ 0

INCLUSIVE PION PRODUCTION

200 GeV Polarized Proton Beam

from Polarized Hyperon Decay

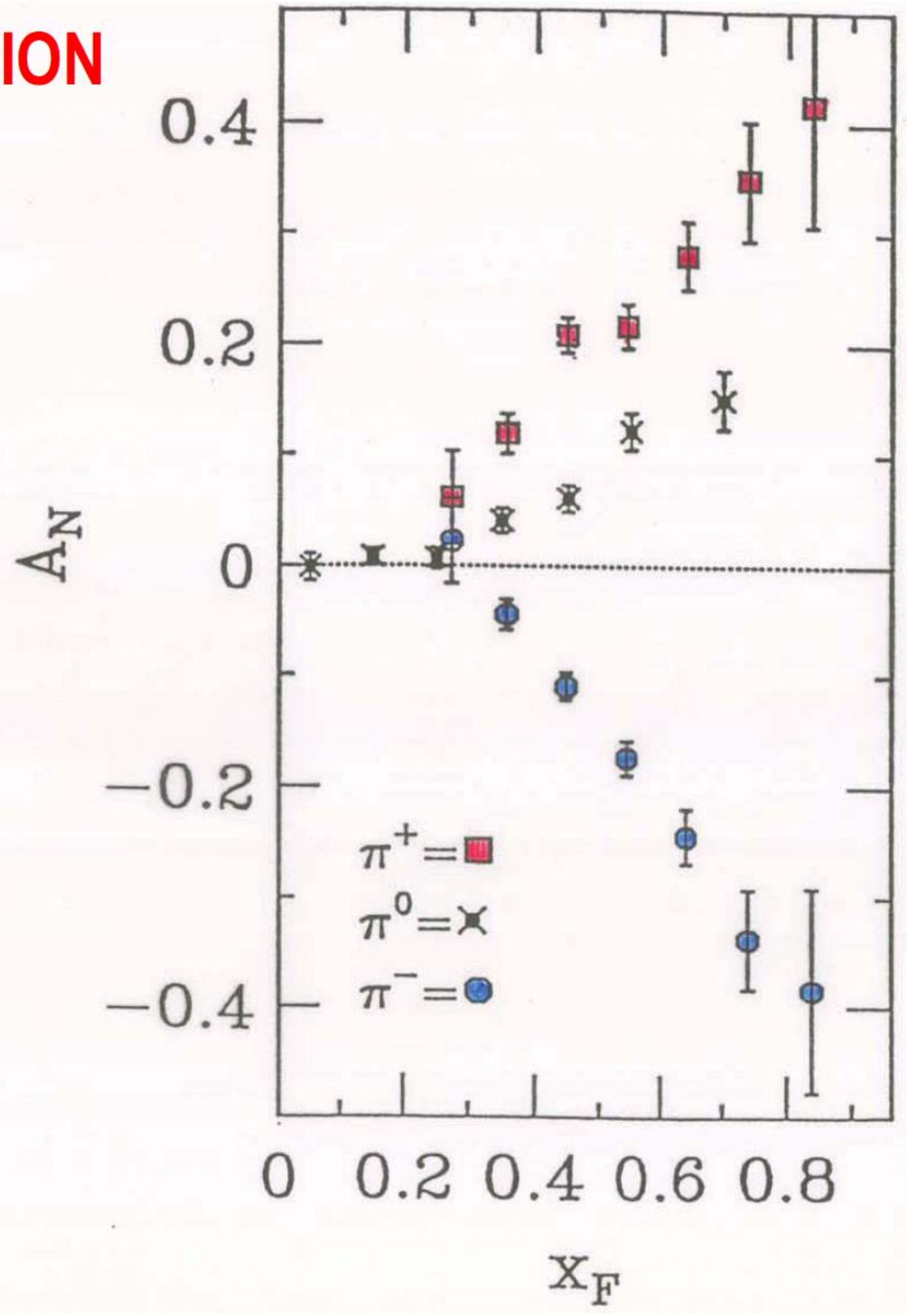
1990s Fermilab E-704

Yokosawa *et al*.

Phys Lett B264, 462 (1991)

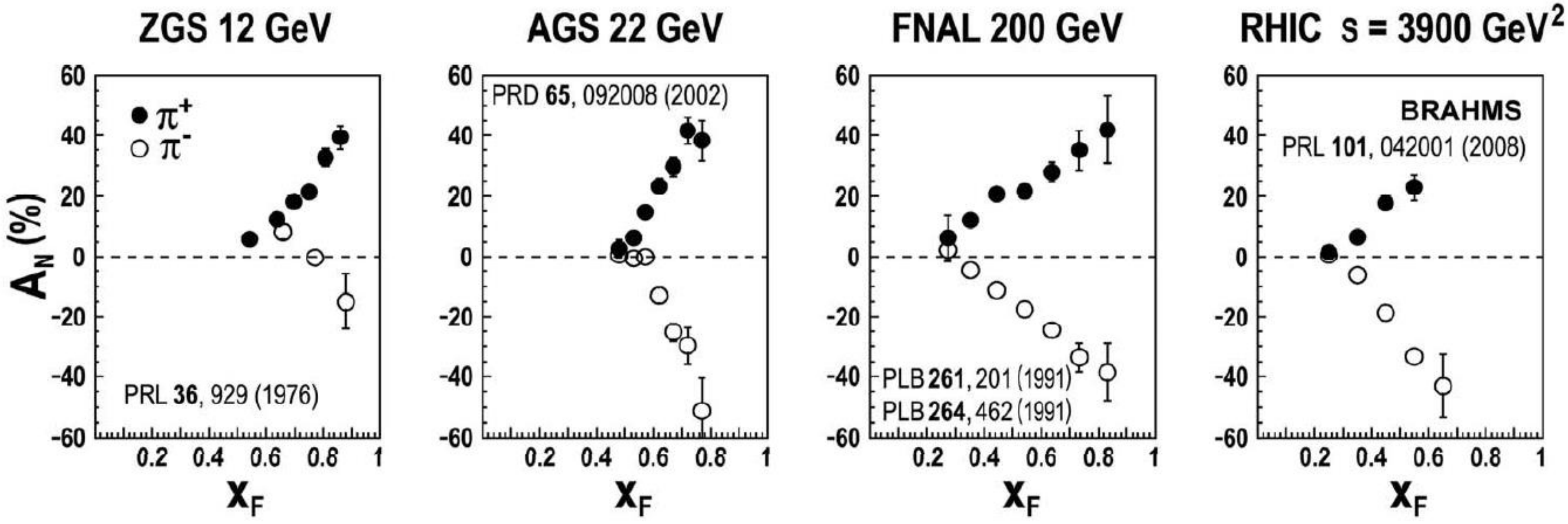
A_n ~ 40%

QCD said A_n ~ 0



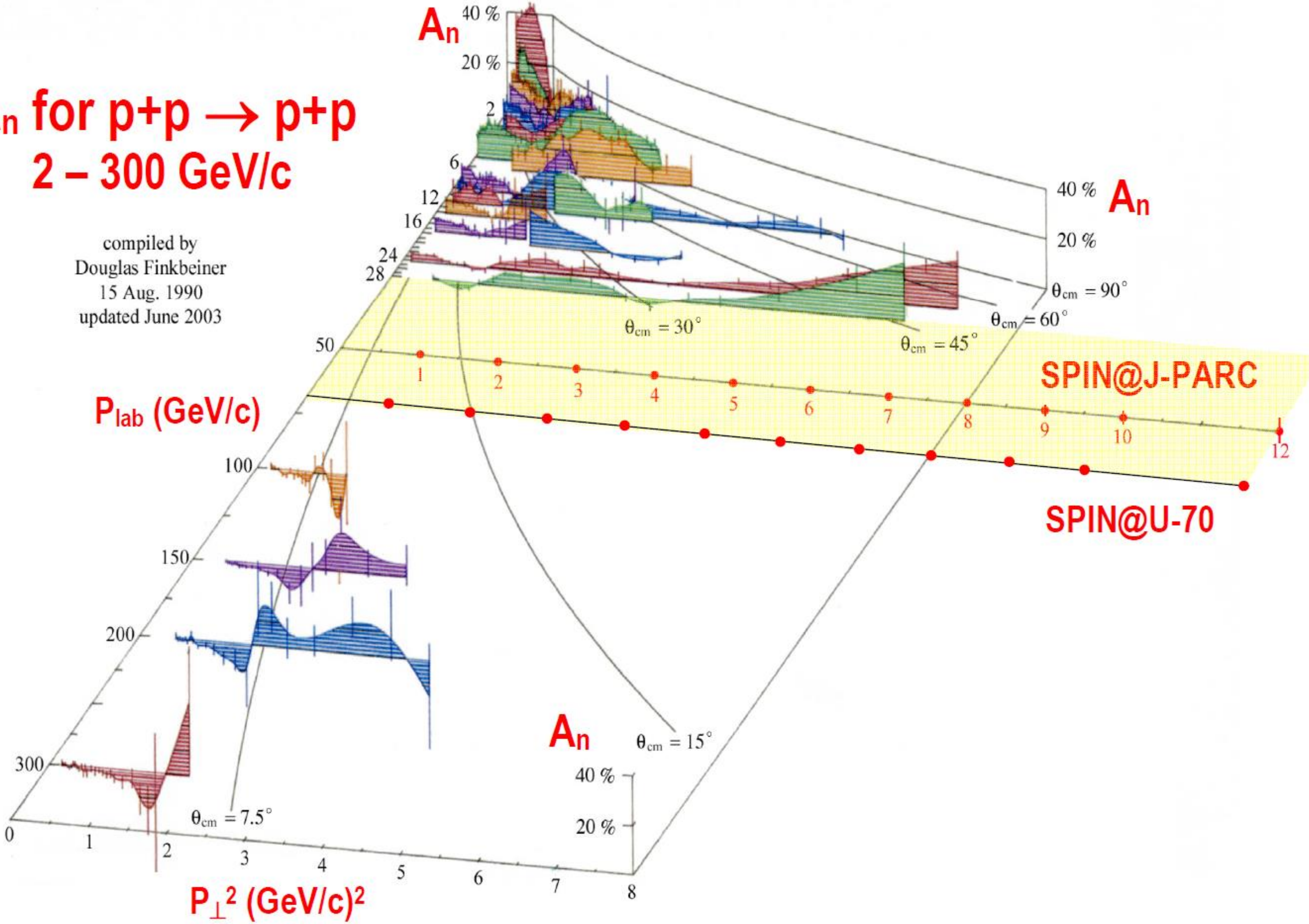
INCLUSIVE PION ASYMMETRY IN PROTON-PROTON COLLISIONS

C. Aidala SPIN 2008 Proceeding and CERN Courier June 2009



A_n for p+p → p+p
2 – 300 GeV/c

compiled by
Douglas Finkbeiner
15 Aug. 1990
updated June 2003



DIQUARK

Volume 8, number 3 PHYSICS LETTERS 1 February 1964

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

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

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 (qqq), $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assuming that the lowest baryon configuration (qqq) 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**.

that it would never have been detected. A search for stable quarks of charge $-\frac{1}{3}$ or $+\frac{2}{3}$ and/or stable di-quarks of charge $-\frac{2}{3}$ or $+\frac{1}{3}$ or $+\frac{4}{3}$ at the highest energy accelerators would help to reassure us of the non-existence of real quarks.

Reviews of Modern Physics, Vol. 65, No. 4, October 1993

Diquarks

Mauro Anselmino and Enrico Predazzi

Dipartimento di Fisica Teorica, Università di Torino and Istituto Nazionale di Fisica Nucleare, Sezione di Torino, I-10125 Torino, Italy

Svante Ekelin

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Sverker Fredriksson

Department of Physics, Luleå University of Technology, S-97187 Luleå, Sweden

D. B. Lichtenberg

Department of Physics, Indiana University, Bloomington, Indiana 47405

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.

ЯДЕРНАЯ ФИЗИКА, 2011, том 74, № 3, с. 438–446

ЭЛЕМЕНТАРНЫЕ ЧАСТИЦЫ И ПОЛЯ

QUARK–DIQUARK SYSTEMATICS OF BARYONS: SPECTRAL INTEGRAL EQUATIONS FOR SYSTEMS COMPOSED BY LIGHT QUARKS

A. V. Anisovich, V. V. Anisovich*, M. A. Matveev, V. A. Nikonov, A. V. Sarantsev, T. O. Vulfs

Petersburg Nuclear Physics Institute, Russian Academy of Sciences, Gatchina
Received May 7, 2010; in final form, August 30, 2010

How Often Do Diquarks Form? A Very Simple Model

Richard F. Lebed*
Department of Physics, Arizona State University, Tempe, Arizona 85287-1504, USA
(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.

DIQURK DYNAMIC

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^o-hyperons with large $p_\perp$ in pp-collisions is discussed in the framework of a dominatiing scalar (ud)-diquark nucleon model. The necessity of making allowance for higher twists-diguarks for explaining strong scaling breaking in p/π^+ ratio is shown. The approximate equation $\Lambda/p \simeq k^+/\pi^+$ 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

pp -> p+X, pp -> pp+X

V.T. Kim (1987)

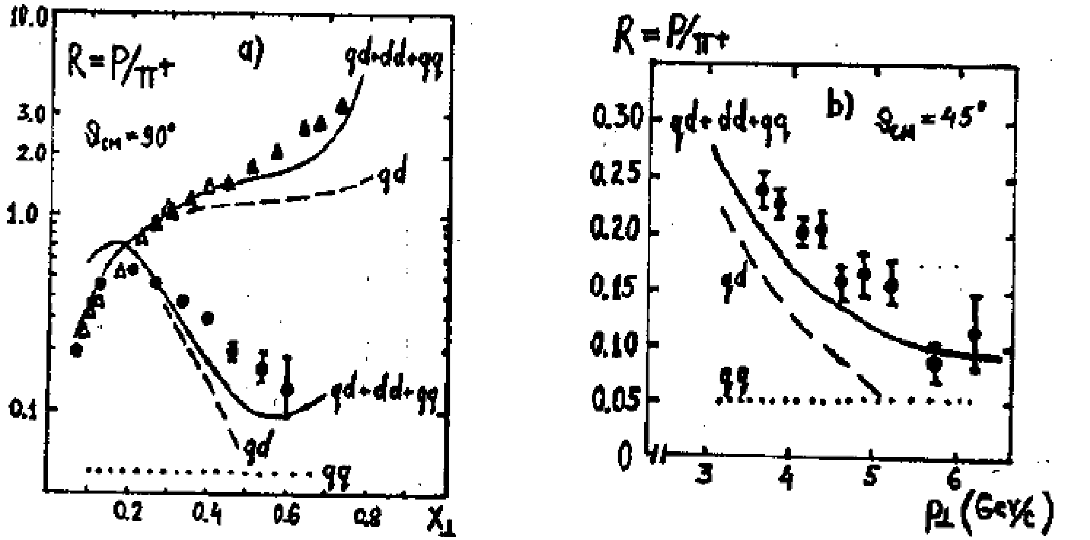


Fig. 1. $R = P/\pi^+$ -ratio in pp-collisions. a) $\vartheta_{cM} = 90°$: ● – FNAL data /16/ at $\sqrt{s} = 23.4$ GeV (E_L = 300 GeV); Δ , ▲ – IHEP (Serpukhov) data/19,20/ at $\sqrt{s}$ = 11.5 GeV (E_L = 70 GeV). b) $\vartheta_{cM} = 45°$: ● – ISR CERN data /18/ at $\sqrt{s}$ = 62 GeV ($E_L \simeq$ 1900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

The result of calcuations of $pp \to ppX$ 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.

arXiv:1007.4705v5 [hep-ph] 25 Sep 2010
&Phys.Rev. C83 (2011) 054606
Carlos Granados and Misak Sargsian

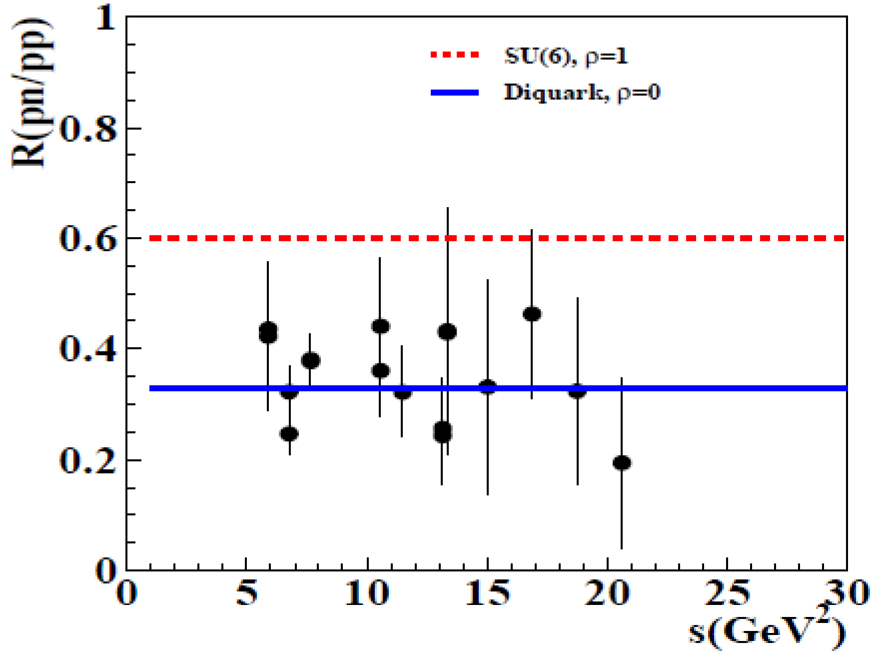


FIG. 2: (Color online) Ratio of the $pn \to pn$ to $pp \to pp$ elastic differential cross sections as a function of s at $\theta^N_{c.m.} = 90^0$.

EXOTICS

Status of the pentaquark problem

- 1st relatively certain theoretical suggestion of mass ~1530 MeV and width < 15 MeV :

  Diakonov, Petrov, Polyakov, Z.Phys., A**359** (1997) 305.

- Experiment : about ten papers with positive evidences;

  about ten papers with negative results

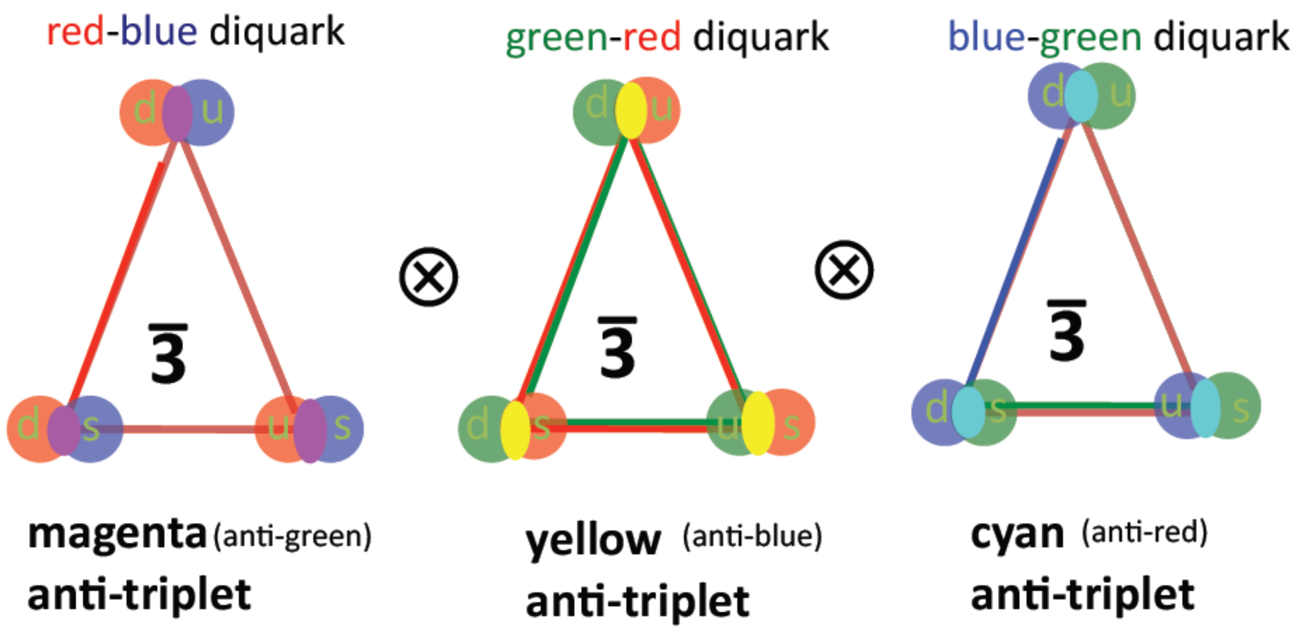
  (some of them with higher statistics).

- Common opinion and PDG position (since edition of 2008) :

  Pentaquark is dead !

  (Note, at the same time, great enthusiasm in searches for tetraquarks !)

multiquark states from diquarks & diantiquarks



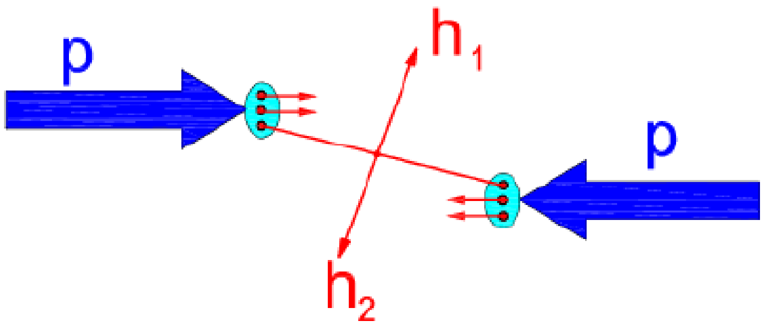
magenta-cyan-yellow
color singlet 5-q state

magenta-cyan-yellow
color singlet 6-q state

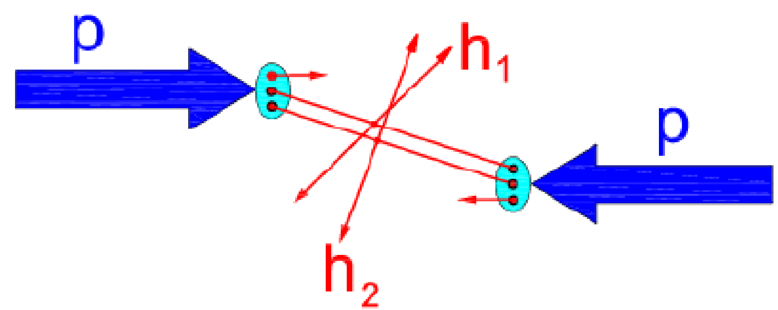
green-magenta (anti-green)
color singlet 4-q state

"exotic" hadrons that particle theorists love

Way to resolve these problems MPI and Exclusive reaction



а



б

NN Elastic scattering with polarized deuteron beams :

$p\uparrow + p\uparrow \to p + p$ for calibration

$p\uparrow + n\uparrow \to p + n$

$n\uparrow + n\uparrow \to n + n$

} New data!

By the way we will have the counting rules verification!

pd, nd and dd – too!

Exclusive NN study at $x_T \sim 1$

$$N\uparrow + N\uparrow \to BB + MM$$

B (p,n,Λ, Δ...), M (π, K , ...)

Mechanisms of hyperons polarization

$$N\uparrow N\uparrow \to NN$$

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

$$N\uparrow N\uparrow \to BB + \pi\pi(KK)$$

$$N\uparrow N\uparrow \to \Delta\Delta$$

Detail vertexes studies and spin structure of the interaction vertex:

$q + (q) - (quark - quark)$

$q + (qq) - (quark - diquark)$

$(qq) + (qq) - (diquark - diquark)$

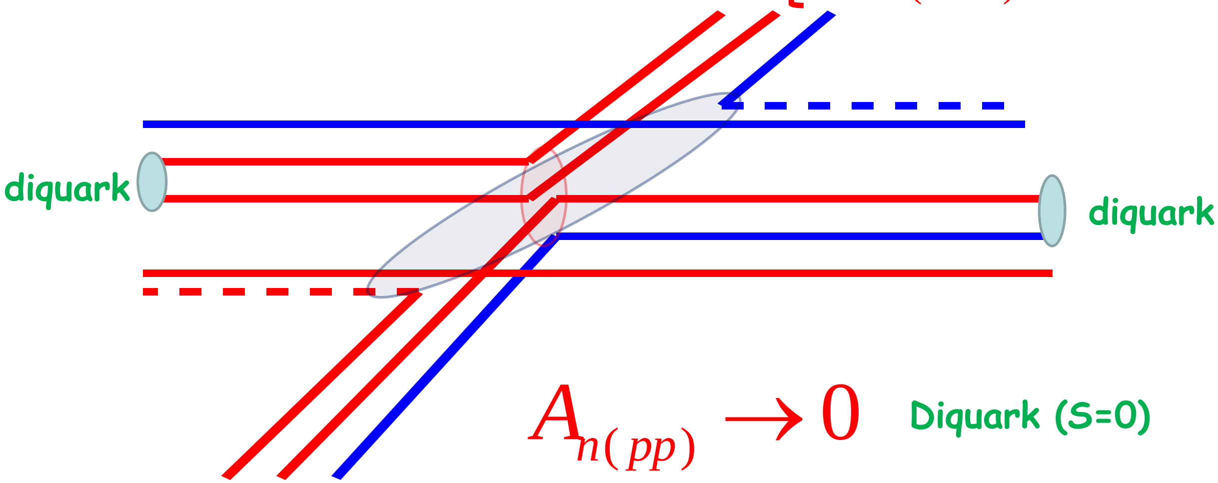
High p_T exclusive reactions -> MPI

$$p\uparrow + p\uparrow \rightarrow B + B + M\overline{M}$$

$$p\uparrow + p\uparrow \rightarrow p + p + \pi^0\pi^0(\pi^+\pi^-)$$

$$R = \frac{N(\pi^+\pi^-)}{N(\pi^0\pi^0)} = \frac{2}{7}$$ Without diquark

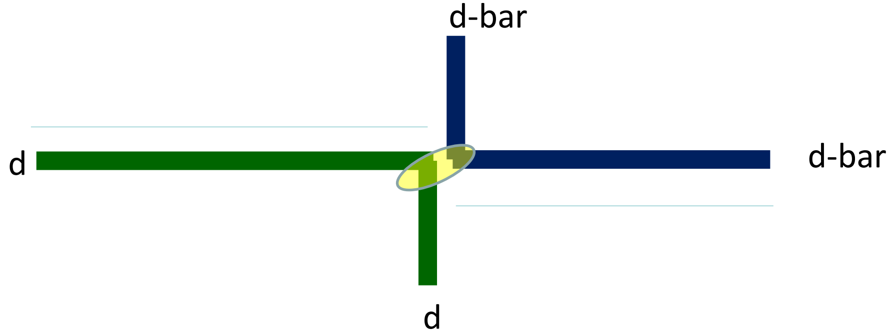
$$R = \frac{N(\pi^+\pi^-)}{N(\pi^0\pi^0)} \rightarrow 0$$ diquark



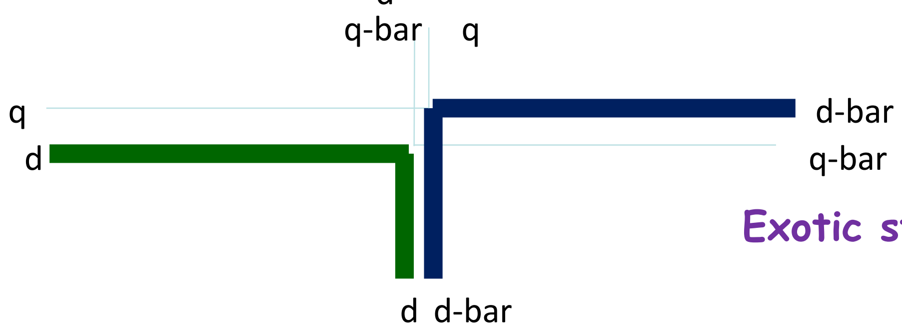
$$A_{n(pp)} \rightarrow 0$$ Diquark (S=0)

Exotic states production

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



Diquark proof

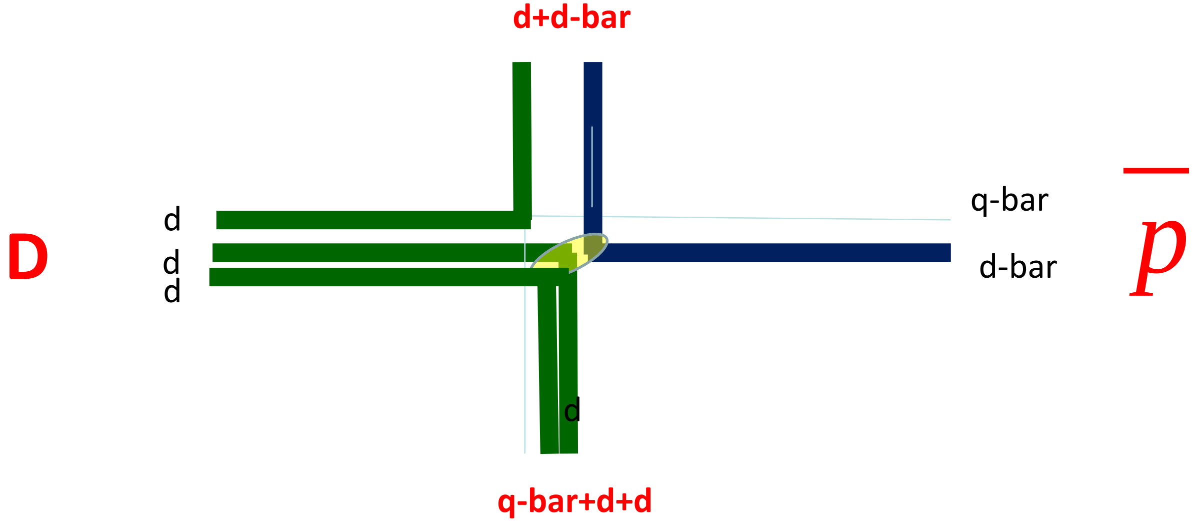


Exotic states production

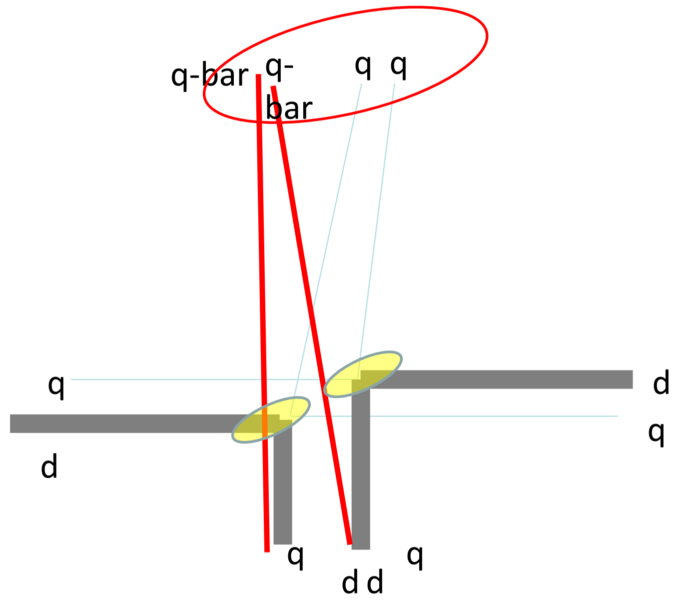
Kim's-bar mechanisms

Exotic states production

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

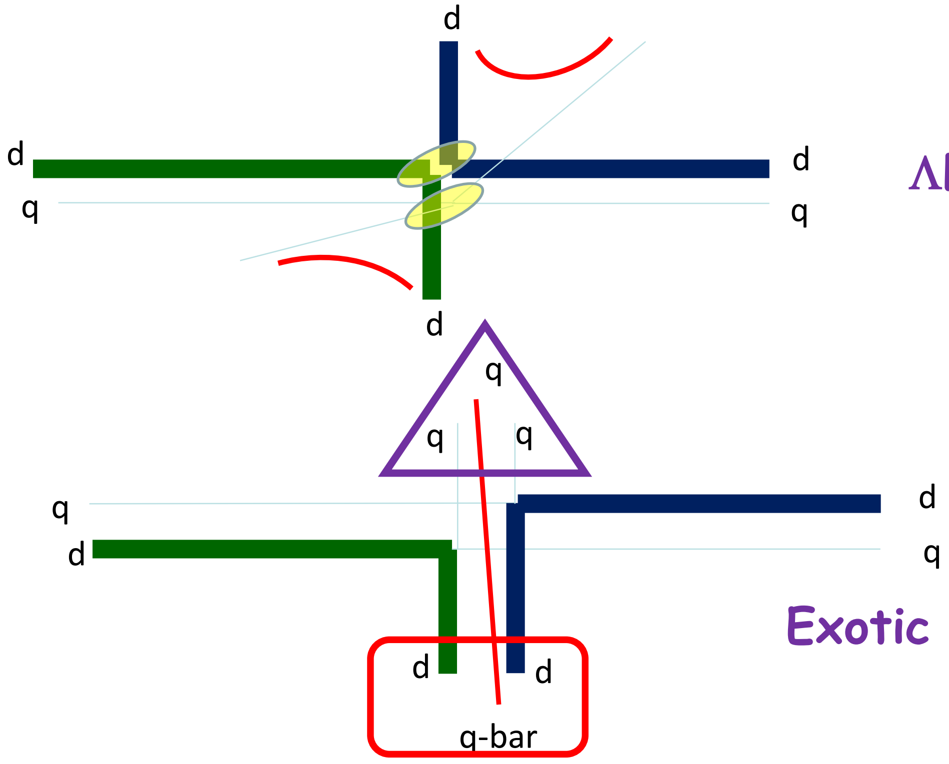


pp - reactions with diquarks and тетракварки



Kim's mechanisms

pp - reactions with pentaquarks production and …



ΛK - interaction

Exotic states production

The Counting Rules

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 ($\theta_{cm} > 40°$) reaction at large momentum transfers $Q = \sqrt{-t}$:

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

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

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

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

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

$$a + b \Rightarrow c + d$$

S. J. Brodsky and G. R. Farrar, Phys. Rev. Lett. **31**, 1153 (1973).

$$\frac{d\sigma}{dt}(a + b \Rightarrow c + d) = \frac{f(t/s)}{s^{n-2}}$$

$s \to \infty$

t/s fixed

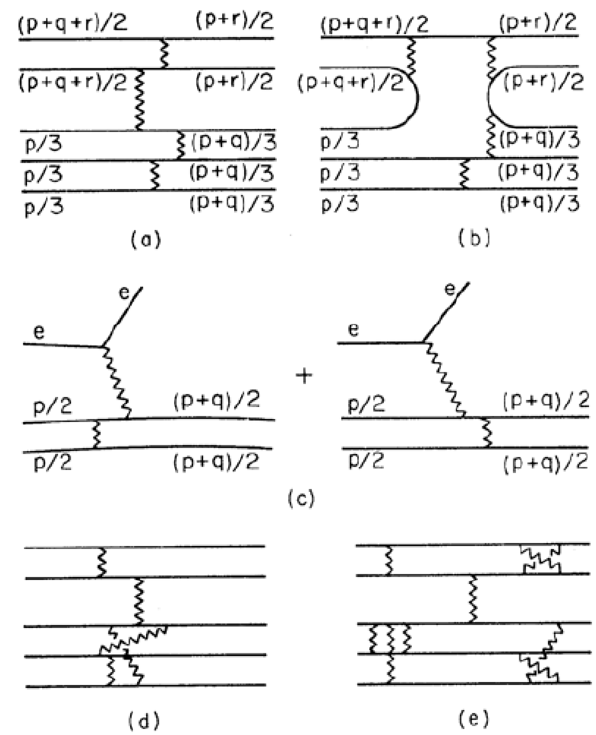


FIG. 1. Typical Born diagrams for large-momentum-transfer elastic scattering in the quark picture. (a) $\pi p \to \pi p$ (quark scattering), (b) $\pi p \to \pi p$ (quark interchange), (c) $e\pi \to e\pi$, (d) an irreducible loop diagram, (e) a reducible loop diagram.

$p + p \Rightarrow p + p$	s^{10}
$p + p \Rightarrow d + \pi^+$	s^{12}
$d + d \Rightarrow d + d$	s^{22}
$d + d \Rightarrow {}^3He + n$	s^{22}
$d + d \Rightarrow t + p$	s^{22}

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

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

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

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 $\epsilon\sim0$. 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 $p_\perp^2\sim\infty$, $\epsilon\to0$, and fixed $\theta_{\text{c.m.}}$ 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	$\frac{d\sigma}{d^3p/E}$ $(\theta\sim90°)$
$M+B\to M+X$	$M+B\to M+B^*$ $(n=10)$	$M+q\to M+q$	$(p_\perp^2)^{-4}\epsilon^3$
		$\bar q+B\to M+qq$	$(p_\perp^2)^{-6}\epsilon^1$
		$M+B\to M+B^*$	$(p_\perp^2)^{-8}\epsilon^{-1}$
$B+B\to B+X$	$B+B\to B+B^*$ $(n=12)$	$B+q\to B+q$	$(p_\perp^2)^{-6}\epsilon^3$
		$(qq)+(qq)\to B+q$	$(p_\perp^2)^{-6}\epsilon^3$
		$B+(qq)\to B+qq$	$(p_\perp^2)^{-8}\epsilon^1$
		$B+B\to B+B^*$	$(p_\perp^2)^{-10}\epsilon^{-1}$
	$B+B\to B+B^*+M^*$ $(n=14)$	$q+q\to B+\bar q$	$(p_\perp^2)^{-4}\epsilon^7$
		$q+(qq)\to B+M^*$	$(p_\perp^2)^{-6}\epsilon^5$
		$(qq)+B\to B+M^*+qq$	$(p_\perp^2)^{-10}\epsilon^1$
		$B+B\to B+B^*+M^*$	$(p_\perp^2)^{-12}\epsilon^{-1}$
$B+B\to M+X$	$B+B\to M+B^*+B^*$ $(n=14)$	$q+(qq)\to M+B^*$	$(p_\perp^2)^{-6}\epsilon^5$
		$q+B\to q\,(\to M+q)+B^*$	$(p_\perp^2)^{-6}\epsilon^5$
		$q+B\to M+q+B^*$	$(p_\perp^2)^{-8}\epsilon^3$
		$(qq)+B\to M+B^*+qq$	$(p_\perp^2)^{-10}\epsilon^1$
		$B+B\to M+B^*+B^*$	$(p_\perp^2)^{-12}\epsilon^{-1}$
	$B+B\to M+M^*+B^*+B^*$ $(n=16)$	$M+q\to M+q$	$(p_\perp^2)^{-4}\epsilon^9$
		$q+q\to\bar q\,(\to M+\bar q)+B^*$	$(p_\perp^2)^{-4}\epsilon^9$
		$q+q\to M+B^*+\bar q$	$(p_\perp^2)^{-6}\epsilon^7$
		$M+B\to M+B^*$	$(p_\perp^2)^{-8}\epsilon^5$
	$B+B\to M+M^*+M^*+B^*+B^*$ $(n=18)$	$q+\bar q\to M+M^*$	$(p_\perp^2)^{-4}\epsilon^{11}$
		$q+M\to q\,(\to M+q)+M^*$	$(p_\perp^2)^{-4}\epsilon^{11}$
$B+B\to\bar B+X$	$B+B\to\bar B+B^*+B^*+\overline{B^*}$ $(n=18)$	$q+q\to B^*+\bar q\,(\to\bar B+qq)$	$(p_\perp^2)^{-4}\epsilon^{11}$
		$q+q\to B^*+\bar B+qq$	$(p_\perp^2)^{-8}\epsilon^7$
		$q+(qq)\to\bar B+B^*+B^*$	$(p_\perp^2)^{-10}\epsilon^5$

S.J. Brodsky, J.F.Gunion

SLAC-PUB-1806
August 1976
(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	

SLAC-PUB-9281
July 2002

Perspectives on Exclusive Processes in QCD*

Stanley J. Brodsky

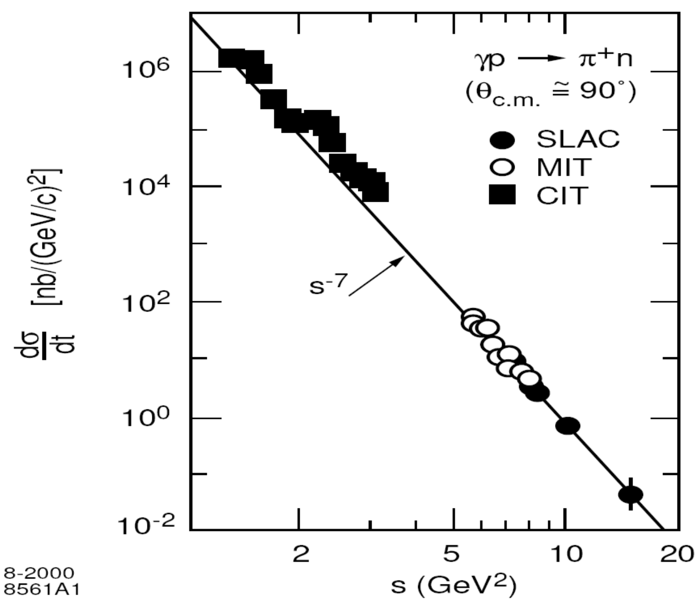


Figure 5: Comparison of photoproduction data with the dimensional counting power-law prediction. The data are summarized in Anderson *et al.*[70]

Shimanskiy S.S.

Comparison of 20 exclusive reactions at large t

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

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

TABLE V. The scaling between E755 and E838 has been measured for eight meson-baryon an 2 baryon-baryon interactions at $\theta_{\text{c.m.}} = 90°$. The nominal beam momentum was 5.9 GeV/c and 9. GeV/c for E838 and E755, respectively. There is also an overall systematic error of $\Delta n_{\text{syst}} = \pm 0.$ from systematic errors of ±13% for E838 and ±9% for E755.

No.	Interaction	Cross section E838	Cross section E755	n-2 $(\frac{d\sigma}{dt} \sim 1/s^{n-2}$
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

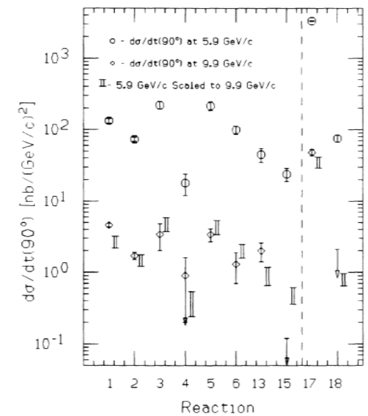


FIG. 26. The scaling between E755 and E838 has been calculated for eight meson-baryon and 2 baryon-baryon interactions at $\theta_{\text{c.m.}} = 90°$. The beam momentum for E838 was 5.9 GeV/c, corresponding to $s = 11.9$ GeV^2 for meson-baryon reactions and $s = 12.9$ GeV^2 for baryon-baryon reactions.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

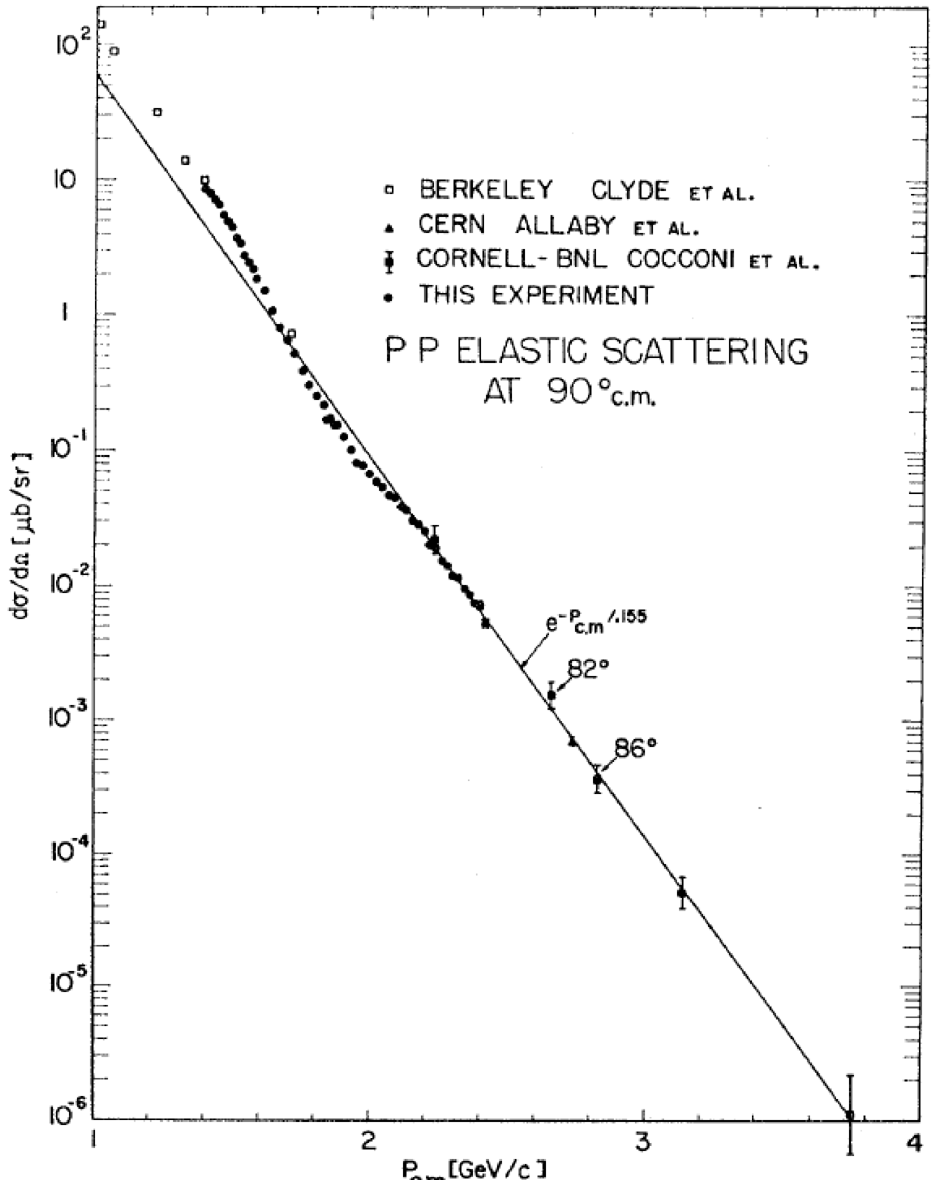


FIG. 9. Plot of $d\sigma/dt$ versus $\beta^2 P_\perp{}^2$ for all high-energy proton-proton elastic scattering. Other data (Refs. 13, 20, 22, 23), are also plotted. The lines drawn are straight line fits to the data.

SLAC – PUB – 4749
October 1988
(M)

ANTIPROTON ANNIHILATION IN QUANTUM CHROMODYNAMICS*

STANLEY J. BRODSKY

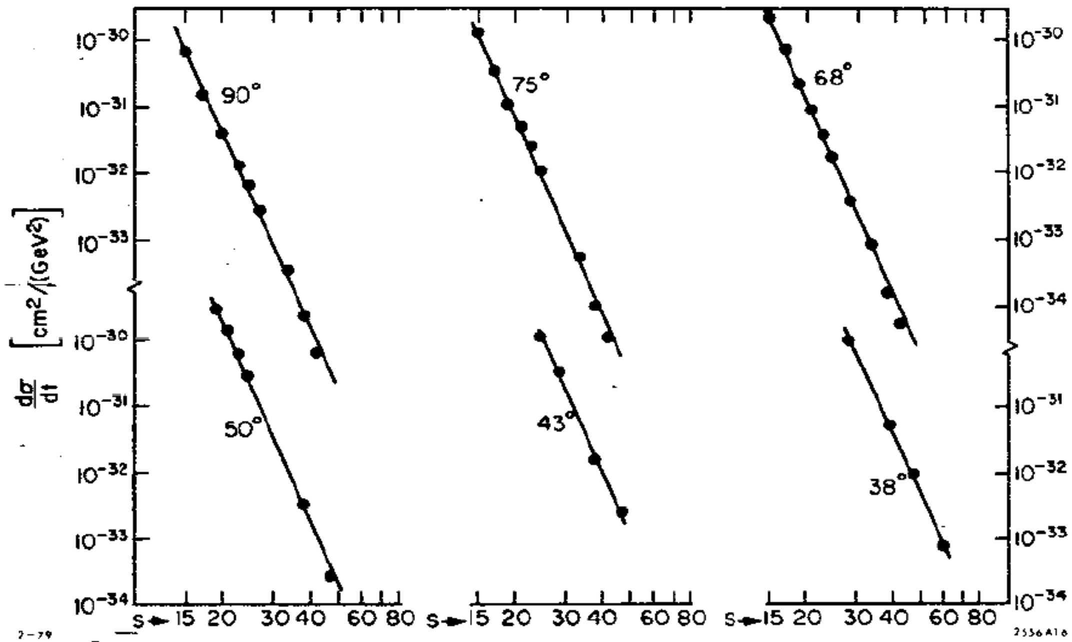


Fig. 16. Test of fixed θ_{CM} scaling for elastic pp scattering. The best fit gives the power $N = 9.7 \pm 0.5$ compared to the dimensional counting prediction N=10. Small deviations are not readily apparent on this log-log plot. The compilation is from Landshoff and Polkinghorne.

Shimanskiy S.S.

«ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА»,
1984, ТОМ 15, ВЫП. 6

УДК 539.12.172

МНОГОКВАРКОВЫЕ СИСТЕМЫ В ЯДЕРНЫХ ПРОЦЕССАХ

В. В. Буров, В. К. Лукьянов, А. И. Титов

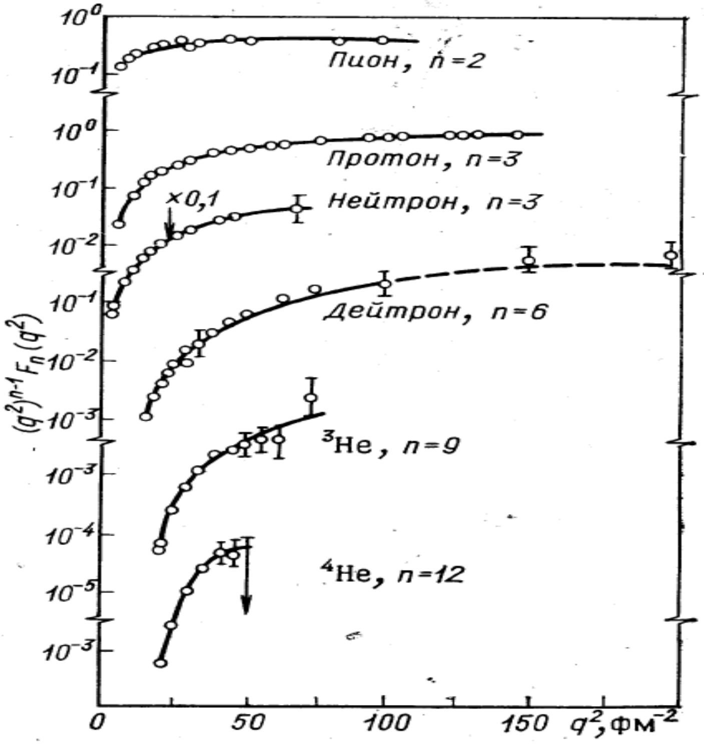
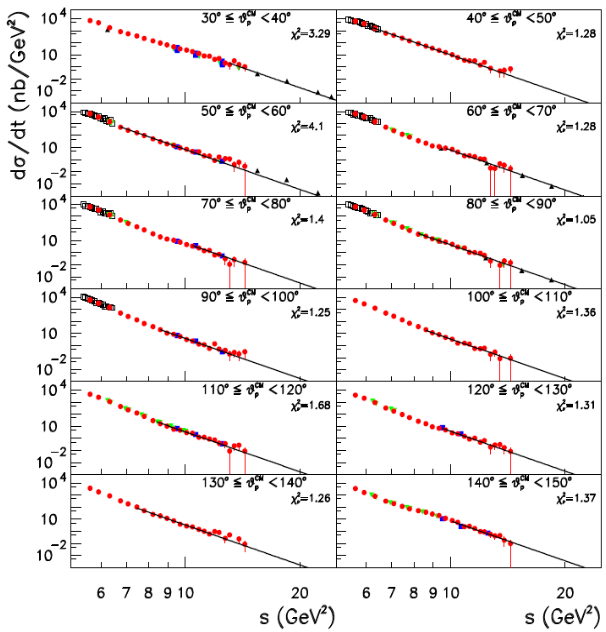


Рис. 5. Зависимость экспериментальных упругих формфакторов пиона, протона, нейтрона, дейтрона, ядер ^{3}He, ^{4}He [20, 21], умноженных на $(q^2)^{n-1}$, от q^2. Линии проведены по точкам



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

The way the differential large angle $2 \to 2$ particle scattering cross sections should scale with energy (momentum transfer) was envisaged by the so-called "quark counting rules" [26].

$$\frac{d\sigma}{dt} = \frac{f(\Theta)}{s^{K-2}}; \qquad \frac{t}{s} = \text{const},$$

with K the number of *elementary fields* (quarks, photons, leptons, etc.) among / inside the initial and final particles.

For example, in the case of the deuteron break-up by a photon, $\gamma + D \to p + n$, we have $K = 1 + 6 + 6 = 13$ (a photon and 6 quarks inside the initial deuteron and another 6 in the final proton and neutron). So, the differential cross section is expected to fall with s, *asymptotically*, as $s^{-11} = E_{\text{c.m.}}^{-22}$.

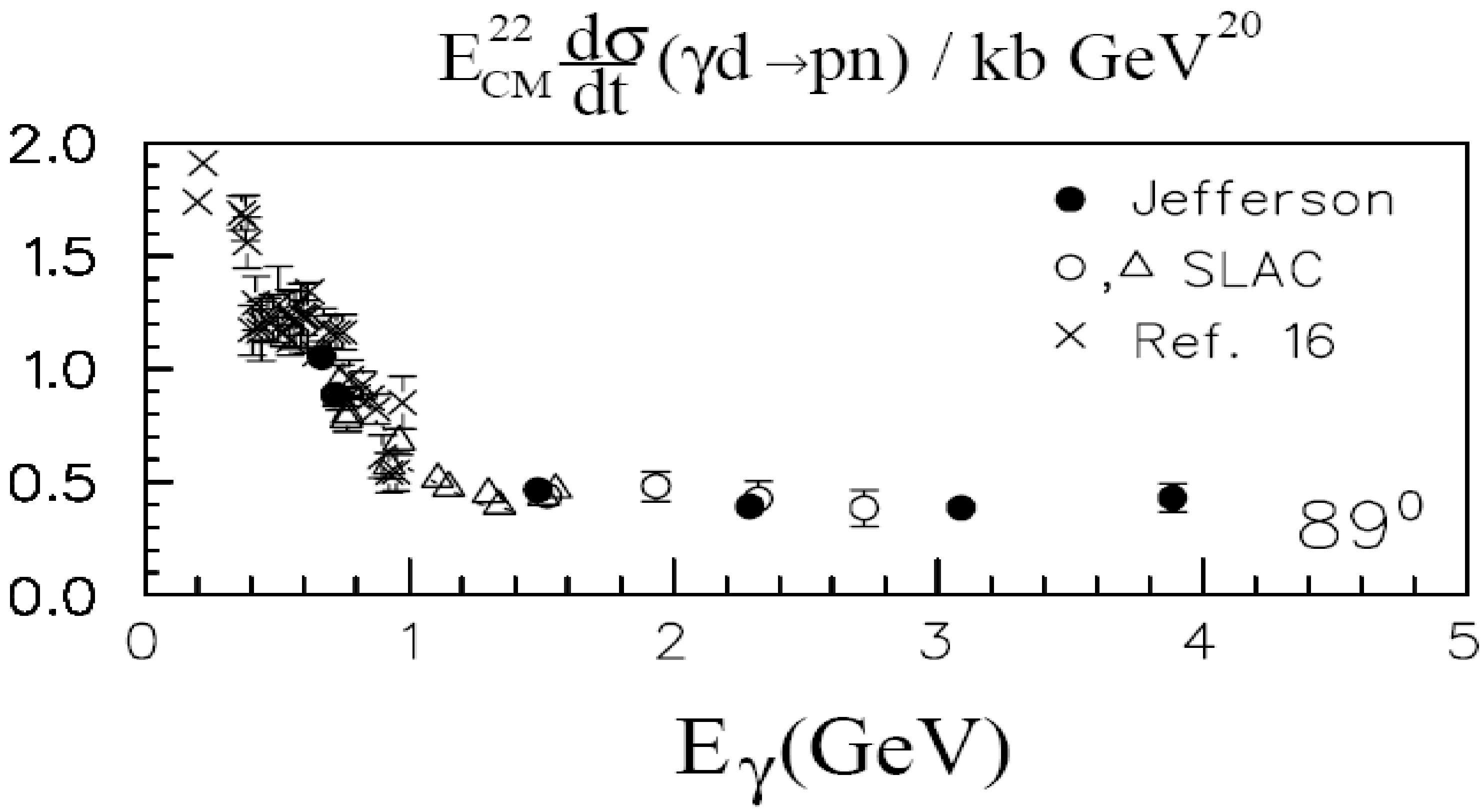


Fig. 1: Large angle γ-disintegration of a deuteron [28].

Eur. Phys. J. A 8, 423–428 (2000)

THE EUROPEAN PHYSICAL JOURNAL A

Measurement of the cross-section asymmetry of deuteron photodisintegration process by linearly polarized photons in the energy range $E_\gamma = 0.8$–1.6 GeV

F. Adamian[1], A. Aganiants[1], Yu. Borzunov[2], S. Chumakov[2], N. Demekhina[1], G. Frangulian[1], L. Golovanov[2], V. Grabski[1,a], A. Hairapetian[1], H. Hakobyan[1], I. Keropian[1], I. Lebedev[1], Zh. Manukian[1], N. Moroz[2], G. Movsesian[1], E. Muradian[1], A. Oganesian[1], R. Oganezov[1], Yu. Panebratsev[2], M. Rekalo[3], S. Shimanski[2], A. Sirunian[1], H. Torosian[1], A. Tsvenev[2], H. Vartapetian[1], and V. Volchinski[1]

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Communicated by B. Povh

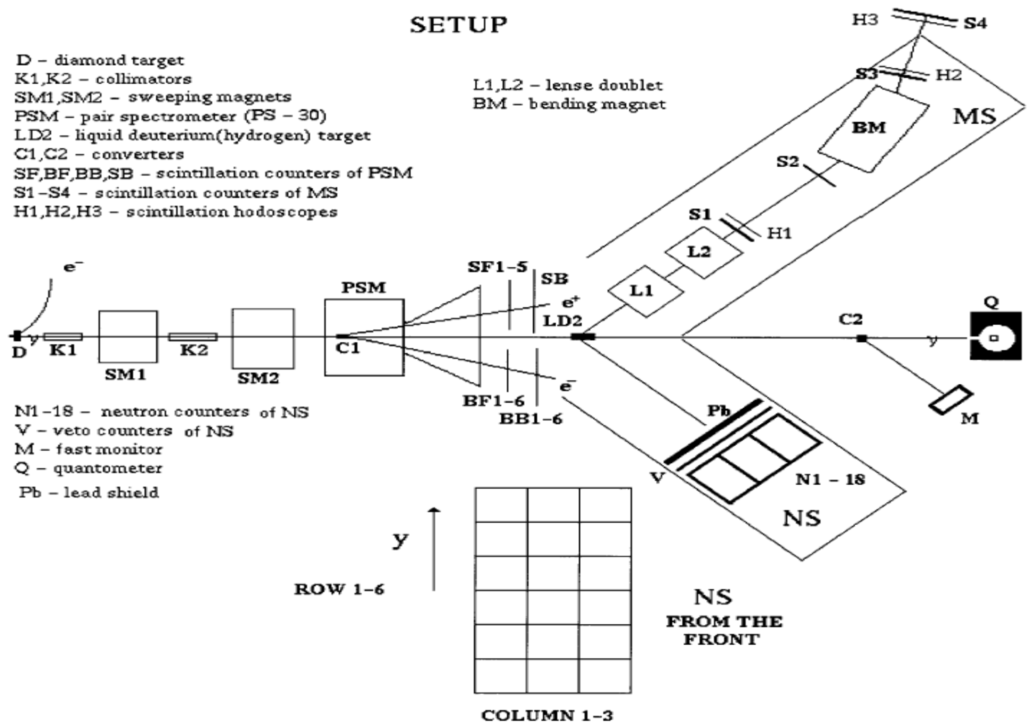

Fig. 2. Experimental Setup. In the frame, the neutron spectrometer NS-18 from the front.

$$\Sigma(\theta) = (d\sigma_{||} - d\sigma_T)/(d\sigma_{||} + d\sigma_T)$$

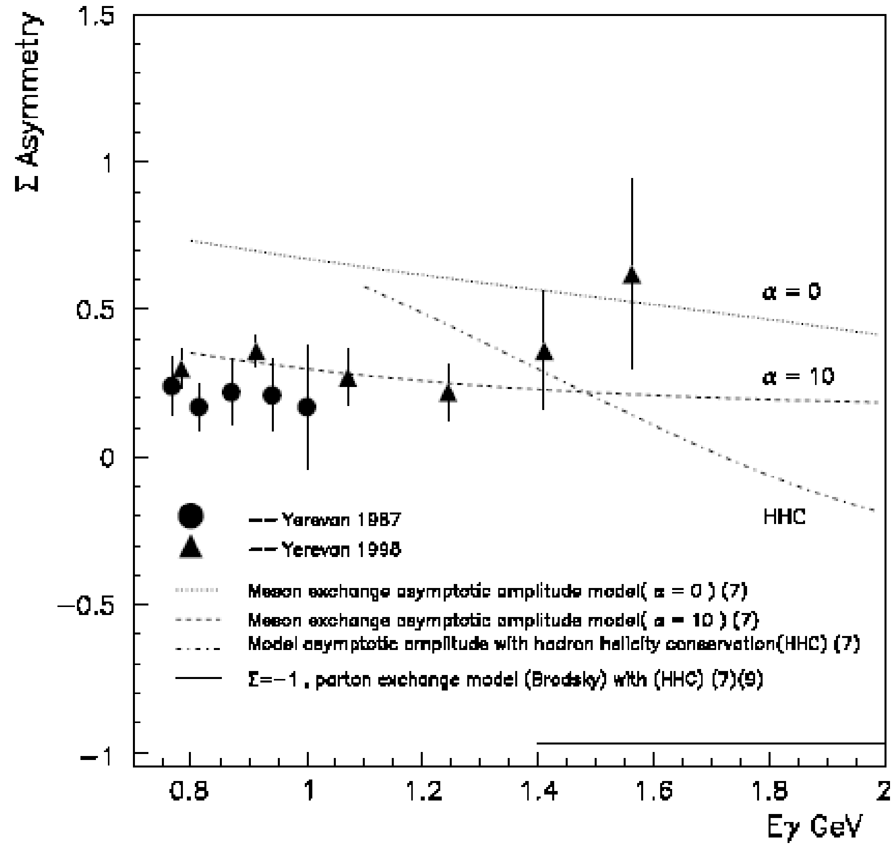

Fig. 8. The energy dependence of the cross-section asymmetry Σ for $\theta_p = 90°$ in the cms.

Pis'ma v ZhETF, vol. 81, iss. 7, pp. 387 – 390

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

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Submitted 11 January 2005
Resubmitted 28 February 2005

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

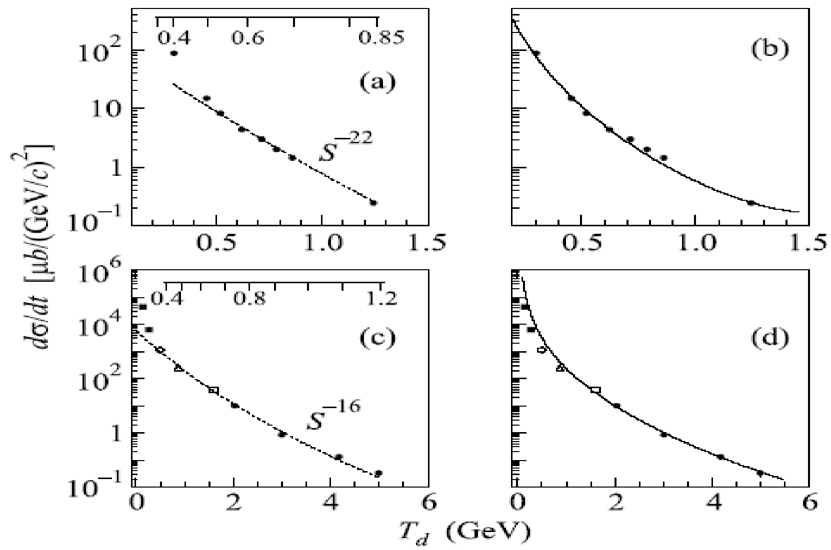


Fig.2. The differential cross section of the $dd \to n\,^3\mathrm{He}$ and $dd \to p\,^3\mathrm{H}$ reactions at $\theta_{cm} = 60^o$ (a), (b) and $dp \to dp$ at $\theta_{cm} = 127^o$ (c), (d) versus the deuteron beam kinetic energy. Experimental data in (a), (b) are taken from [20]. In (c), (d), the 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

Deuteron structure

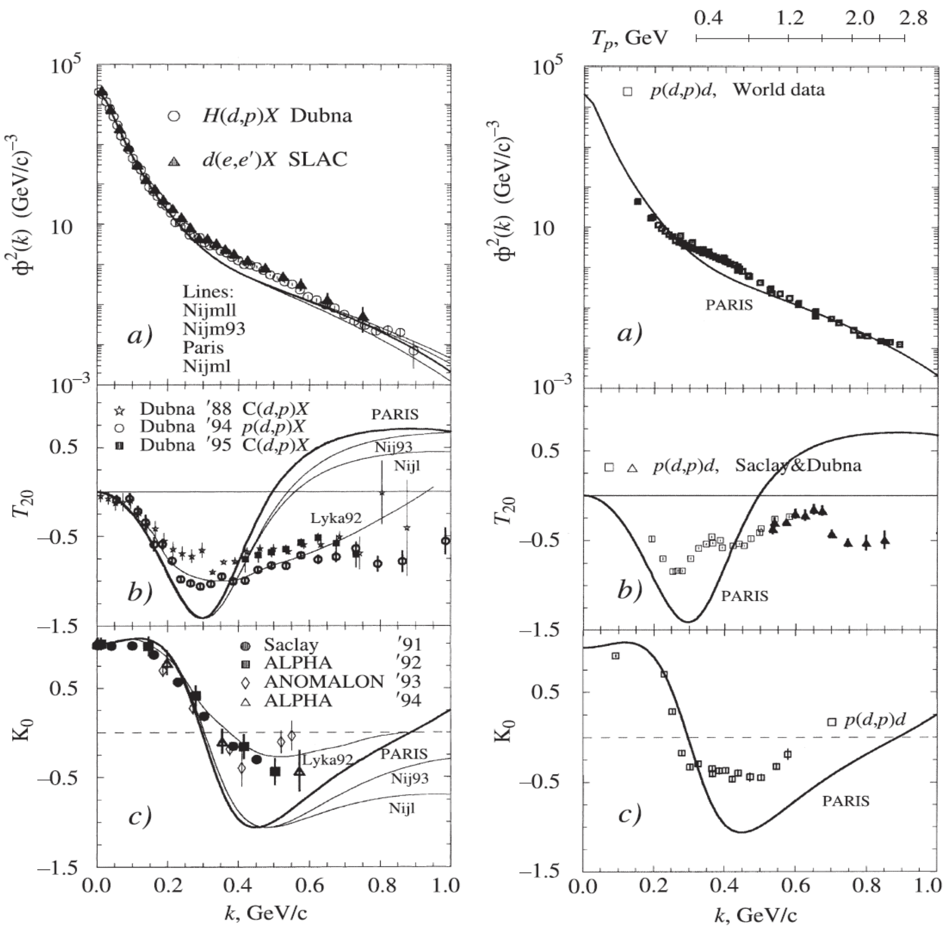
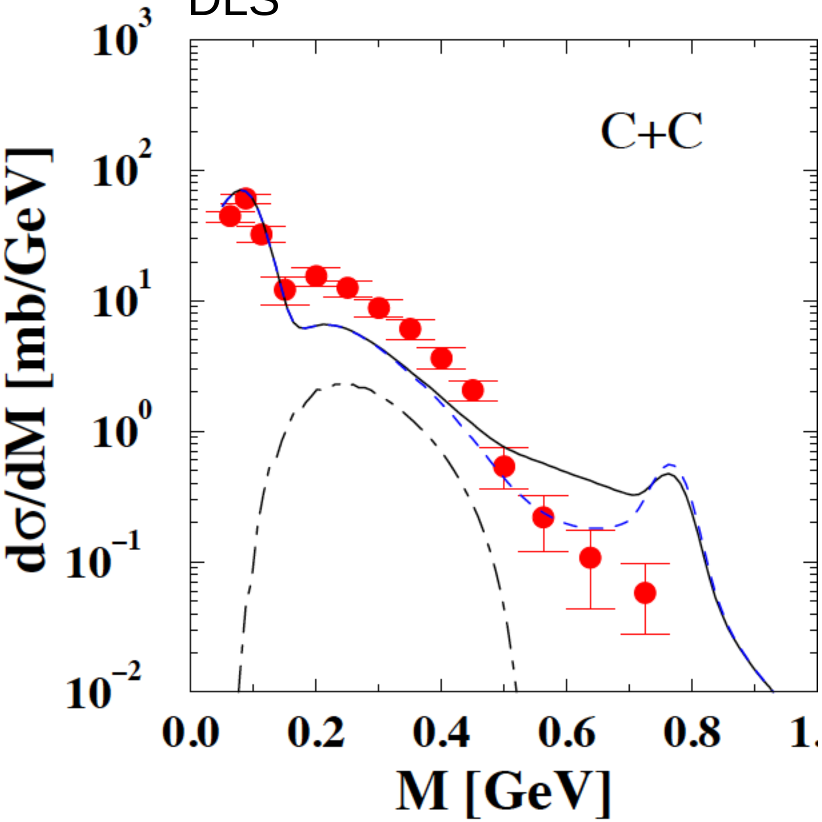


Рис. 5. Сводка данных экспериментов по фрагментации (слева) и упругому рассеянию «назад» (справа) поляризованных и неполяризованных дейтронов

np - puzzle of dilepton production

Столкновения легких ядер при энергии 1 ГэВ/нуклон

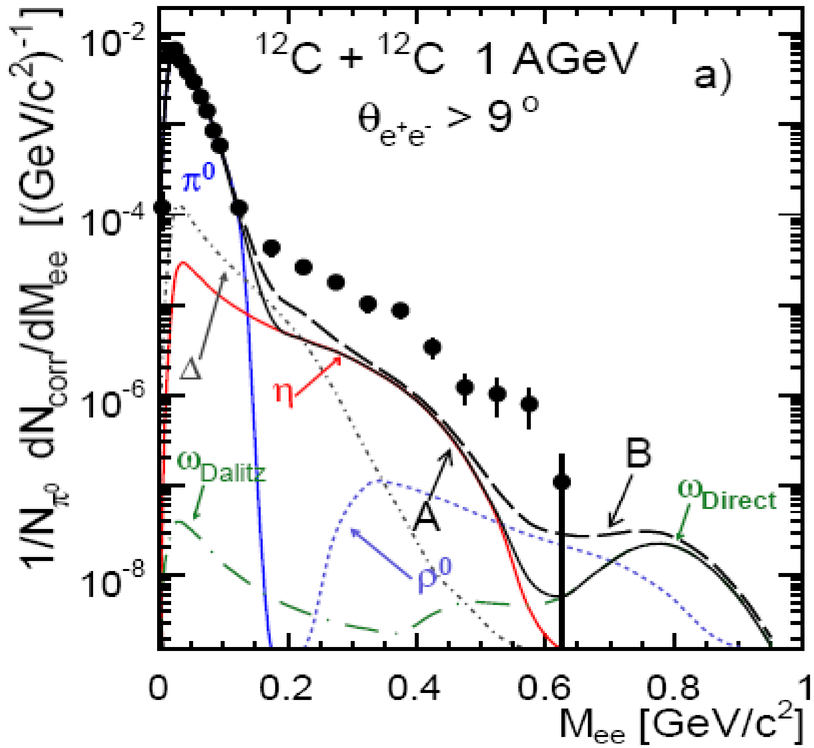
DLS



R. J. Porter *et al.*,
Phys. Rev. Lett. 79 (1997) 1229.

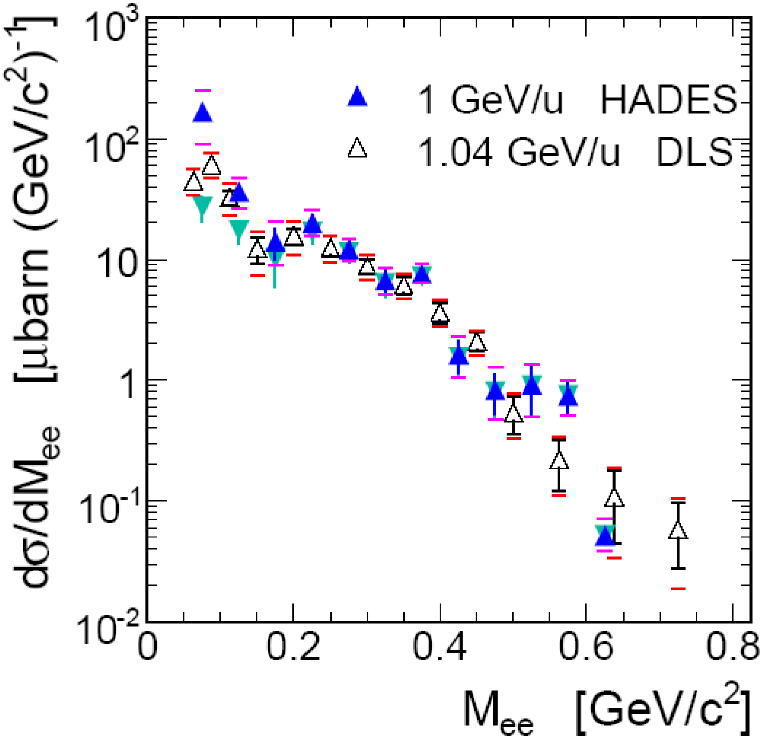
K. Shekhter et al.
Phys. Rev. C68 (2003) P. 014904.

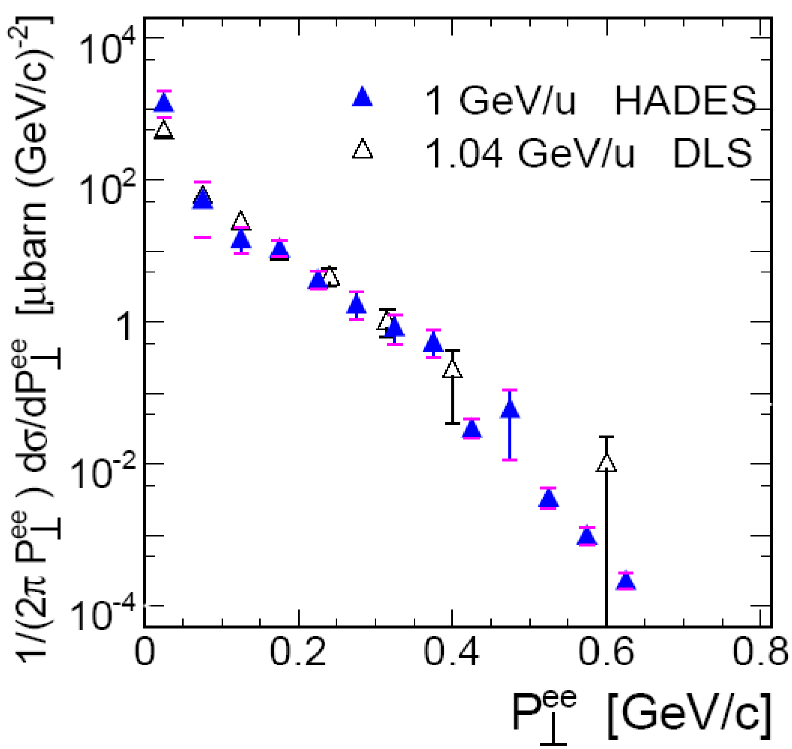
HADES



G. Agakishiev *et al.*,
Phys. Lett. B 663 (2008) 43.

Сравнение данных
DLS – ХАДЕС



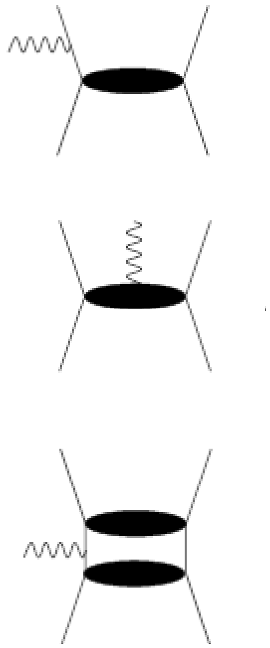


G. Agakishiev *et al.*,
Phys. Lett. B 663 (2008) 43.

n + p bremsstrahlung

Promising candidate: neutron-proton bremsstrahlung

- **Radiation of (virtual) photon in NN scattering**
- **$\sigma_{np} >> \sigma_{pp}$**
- **recent theoretical consideration by L.P. Kaptari and B. Kämpfer, NPA 764 (2006) 338, gives much bigger cross section than previous calculations**
- **no definitive predictions, see also R. Shyam and U. Mosel, PRC 67 (2003) 065202**

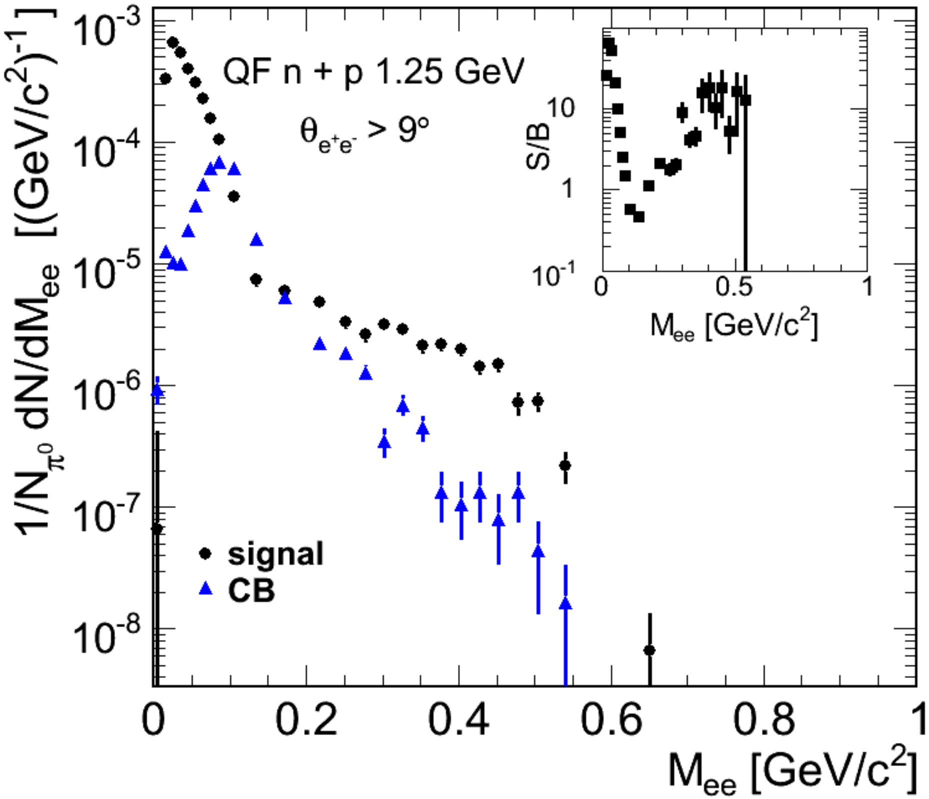


Bottomline:

np-brem *predicted to be* very important process in context of pair production at energies ~1 GeV/u

Need for experimental study

Анализ выхода электрон-позитронных пар



FW (выделение np):

1. $M_{FW} > 0$
2. $1.6 < p < 2.6$ ГэВ/c

Ограничения на пары:

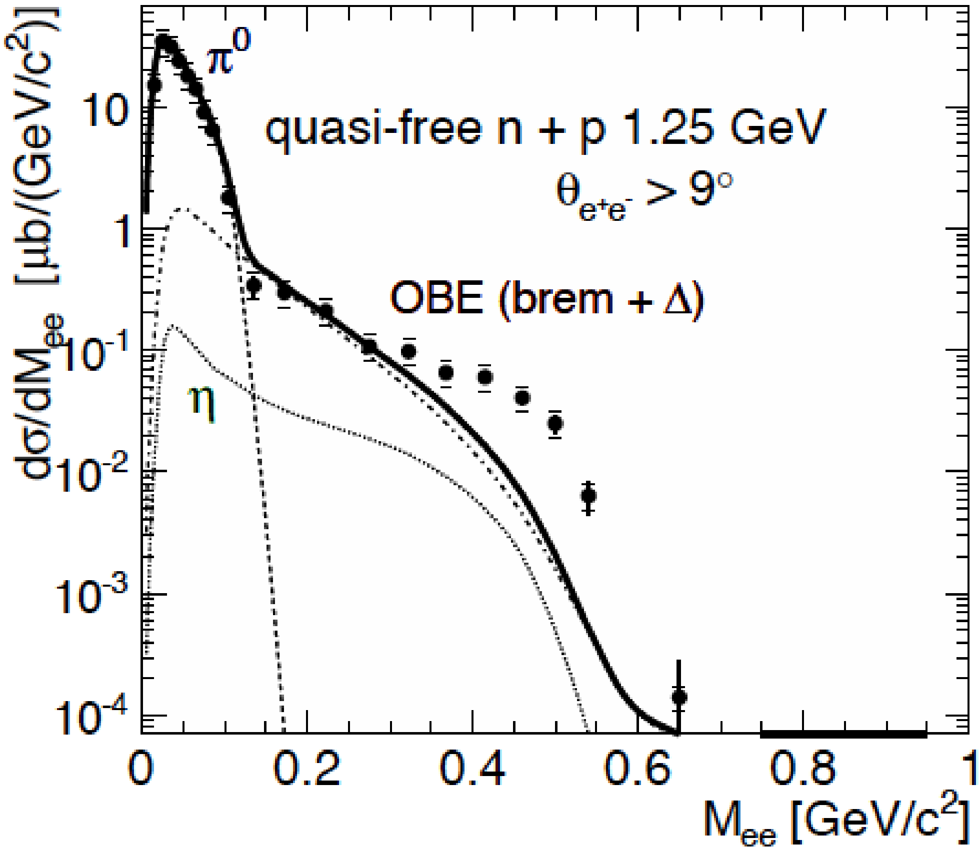
1. no double hit
2. openangle > 9.
3. closestnonfitted cuts
4. RKchi2 < 100000.

Комбинаторный фон:
$(e^+e^+ + e^-e^-)/2$

Корректировка на эффективность регистрации лептонов
(GEANT моделирование)

Абсолютная нормировка
(pp-упругое)

Сравнение экспериментальных данных с модельными расчетами (II)



Теоретические расчеты:

модель однобозонного обмена

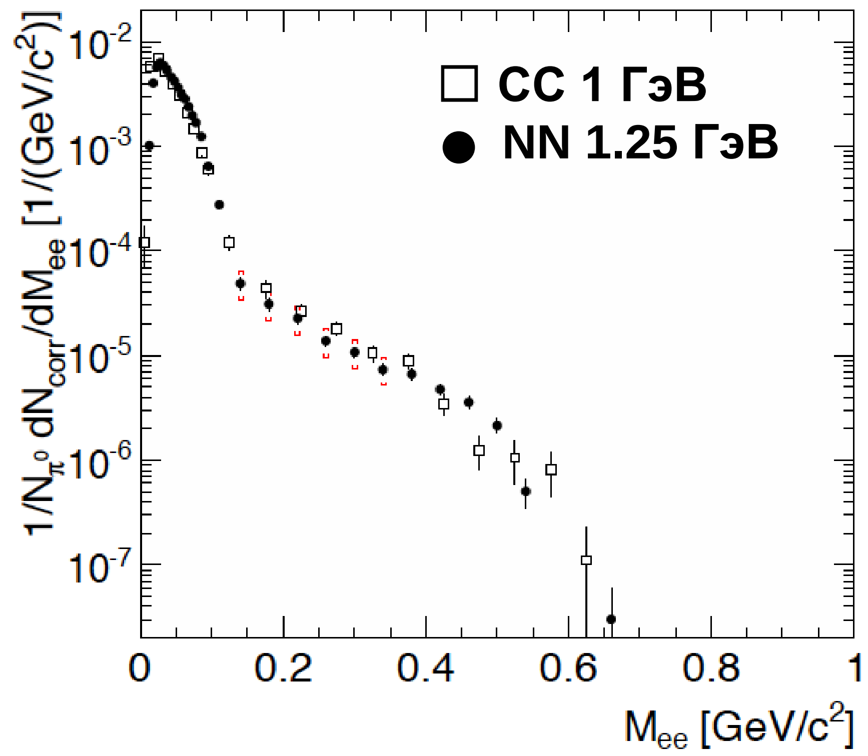
Kaptari L.P, Kampfer B.

Nucl. Phys. 2006. Vol. A764. P. 338

Сравнение выхода e^+e^--пар в нуклон-нуклонных и $^{12}C+^{12}C$ реакциях

$$d\sigma/dM = \frac{(d\sigma/dM)_{np} + (d\sigma/dM)_{pp}}{2}$$

- Вклад η-мезона вычтен из спектров
- Хорошее согласие CC и NN спектров
- Выход в CC обусловлен n+p реакциями



Color Transparency

arXiv:1208.3668v1 [nucl-th] 17 Aug 2012

Gerald A. Miller

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Abstract. Color transparency is the vanishing of nuclear initial or final state interactions involving specific reactions. The reasons for believing that color transparency might be a natural consequence of QCD are reviewed. The main impetus for this talk is recent experimental progress, and this is reviewed briefly.

The basic idea is that some times a hadron is in a color-neutral point-like configuration PLC. If such undergoes a coherent reaction, in which one sums gluon emission amplitudes to calculate the scattering amplitude, the PLC does not interact with the surrounding media. A PLC is not absorbed by the nucleus. The nucleus casts no shadow. This is a kind of quantum mechanical invisibility.

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

Review

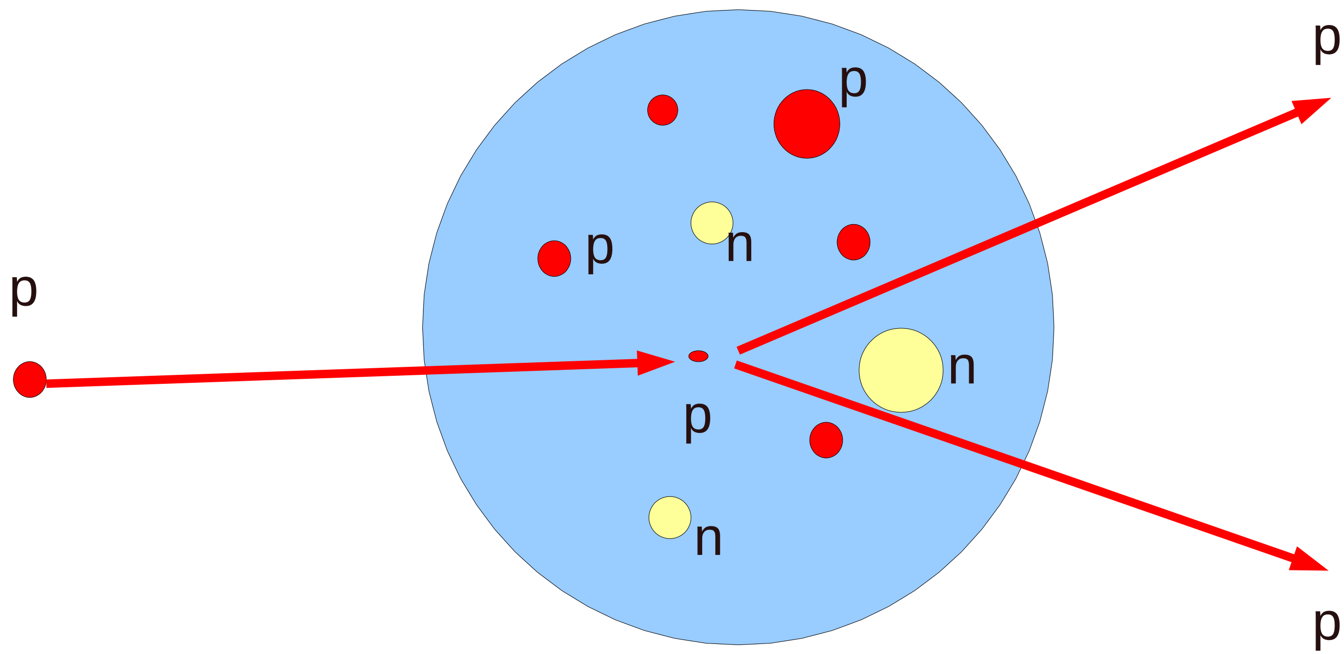
Color transparency: Past, present and future

D. Dutta [a,*], K. Hafidi [b], M. Strikman [c]

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

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

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



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

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

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[2]*Yerevan Physics Institute, Yerevan 375036, Armenia*
[3]*Collider-Accelerator Department, Brookhaven National Laboratory, Upton, New York, 11973*
[4]*Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg 188350, Russia*
[5]*Physics Department, Pennsylvania State University, University Park, Pennsylvania 16801*
[6]*Department of Physics, Kyoto University, Sakyoku, Kyoto, 606-8502, Japan*
[7]*Department of Physics, Mount Holyoke College, South Hadley, Massachusetts 01075*
[8]*J.I.N.R., Dubna, Moscow 141980, Russia*
[9]*Department of Physics, Kent State University, Kent, Ohio 44242*
(Received 20 April 2001; published 6 November 2001)

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.

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

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

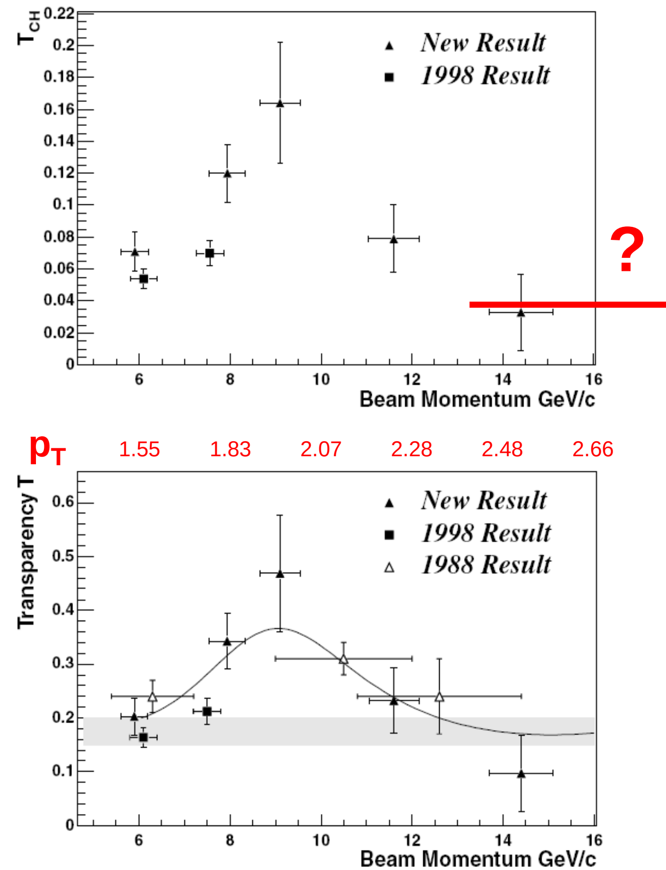

FIG. 2. Top: The transparency ratio T_{CH} as a function of the beam momentum for both the present result and two points from the 1998 publication [3]. Bottom: The transparency T versus beam momentum. The vertical errors shown here are all statistical errors, which dominate for these measurements. The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

Как возникает мистика в научных исследованиях.

Почему «частица Бога» ?

Я.Азимов (ПИЯФ)

В начале 90-х **Ледерман** (NP1988) написал научно-популярную книгу об изучении материи от Демокрита до бозона Хиггса. Она была названа

«Проклятая Частица»

(Goddamn Particle).

(Имелось в виду, что несмотря на все усилия бозон Хиггса уклонялся от наблюдения.)

Издатель отказался выпускать книгу с таким названием: никто не купит. Подумав, он «сократил» название:

Godddamn Particle → **God Particle.**

С этим названием книга вышла в 1993 г. и вызвала ажиотаж, который продолжается до сих пор.

END