QCD, NUCLEAR PDF and CUMULATIVE PROCESSES

90

A.Efremov, JINR, Dubna, [PLB174(86)319 and hep-ph/9710477]

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- 2. The EMC Effect
- 3. Cumulative Particle Production
- 4. Sea Particles and Multiquarks
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Some short history

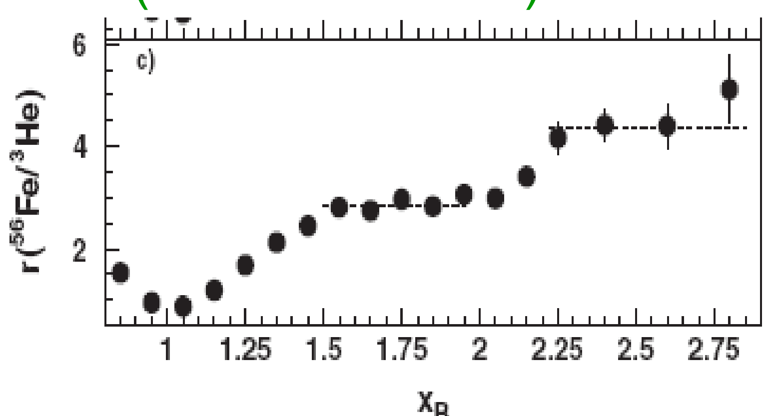
1957-- Leksin G.A. at al. -- Intensive backward protons discovery
1957 -- Mescheryakov M.G. – Intensive knock out of deuterons from nuclei
1957 -- Blokhintsev D.I. – Hypothesis about "fluctons".
1971 -- Baldin, Stavinski at al. – Proposal and discovery of cumulative pions

$$D(5\ GeV/N) + Cu \rightarrow \pi(7\ GeV) + X$$

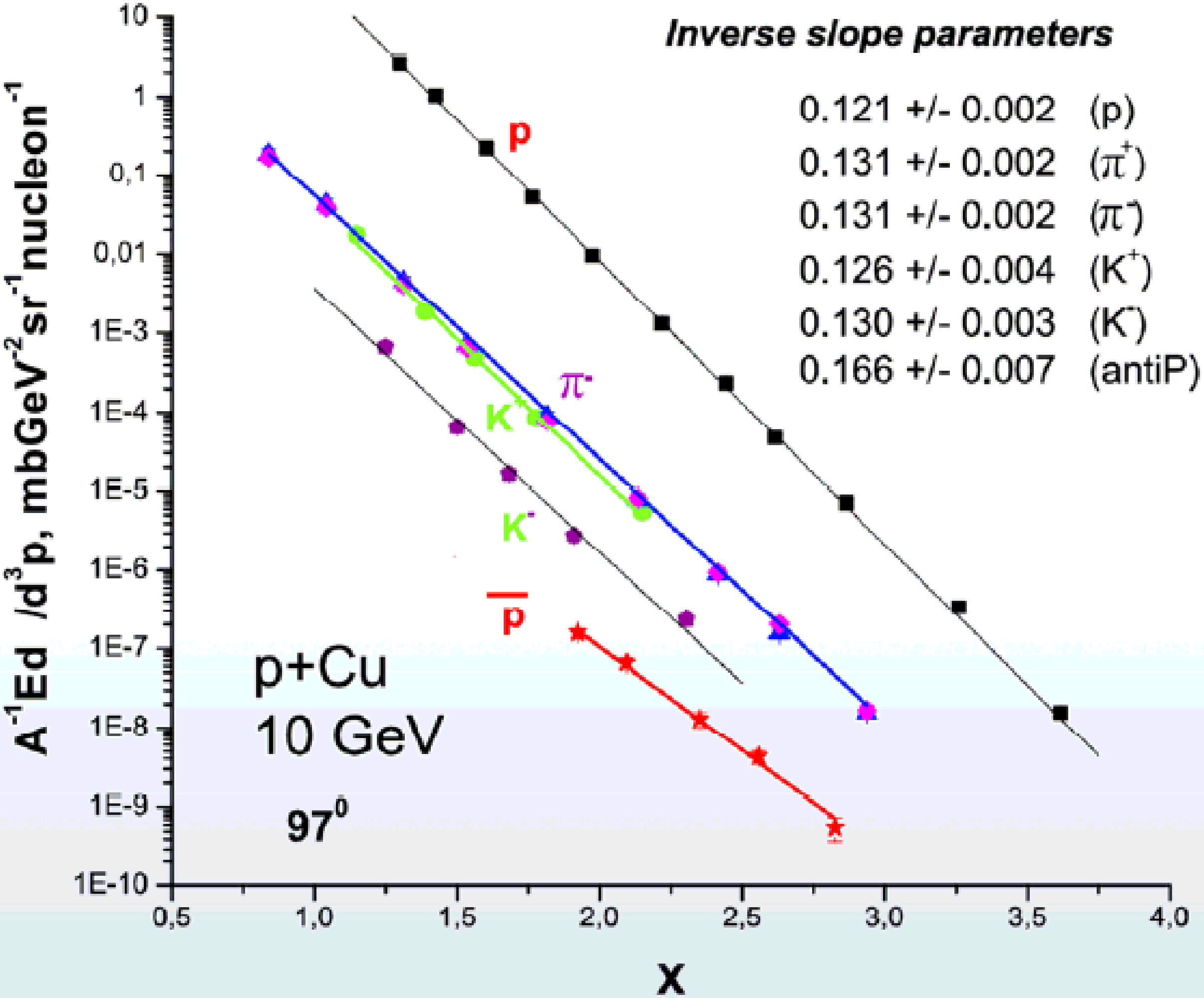
Mid of 70's -- Dubna, ITEP, Erevan -- Intensive experimental studies of cumulative particle production
1976 – AE – Nuclear quark-gluon stricture
1976 – Frankfurt, Strikman – Short range FNC

"Could" and "Hot" models

1983 – EMC collaboration – brings important news -- EMC1-effect
1984 – Savin (BCDMS) – $F_2^A(x)$ beyond $x>1$, in favor of "Could" models
2006 – Egiyan et al. (CLAS e-A→e-X) -- clear step behavior of the ratio



$$R(A, {}^3\mathrm{He}) = \frac{3\sigma_A(Q^2, x_B)}{A\sigma_{^3\mathrm{He}}(Q^2, x_B)}$$

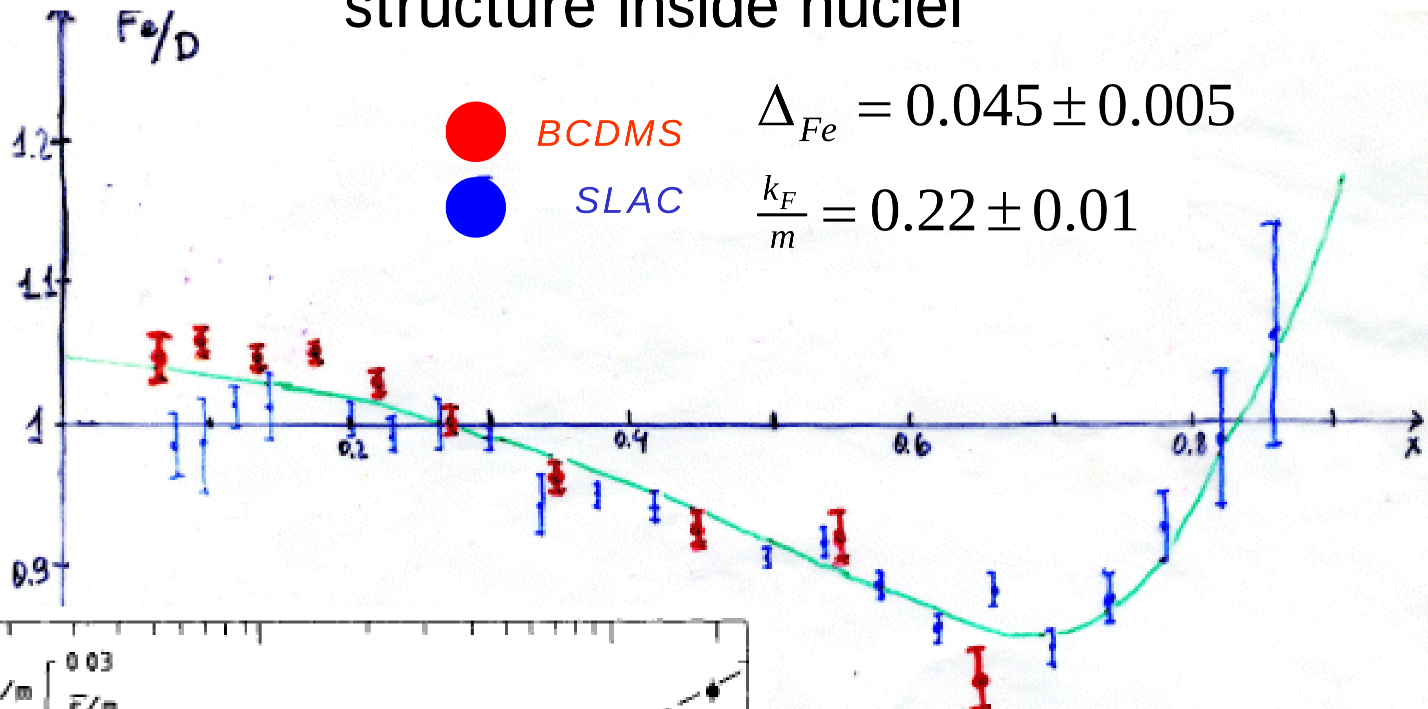


FAS @ ITEP
(Boyarinov et.al
Yad.Fiz 57
(1994) 1452)

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

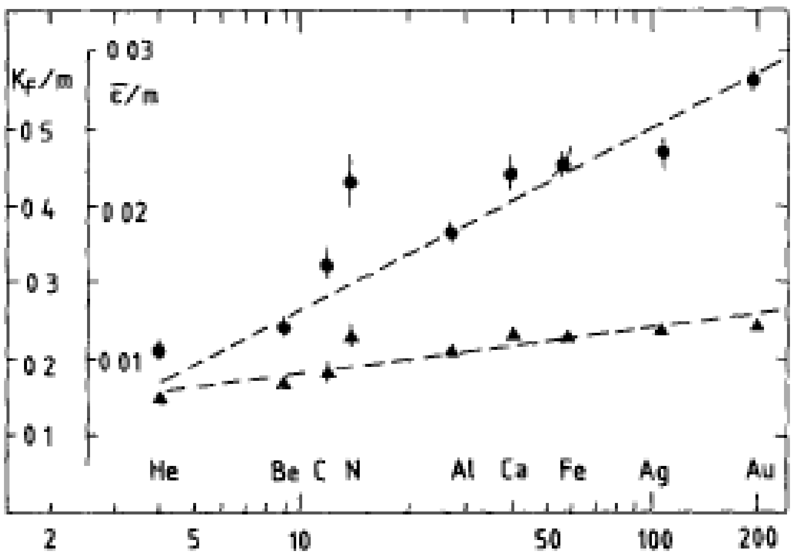
New information from

Nuclear EMC-effect – change of nucleon structure inside nuclei



$$\Delta_{Fe} = 0.045 \pm 0.005$$

$$\frac{k_F}{m} = 0.22 \pm 0.01$$



The A -dependence of the parameters ϵ/m (•) and k_F/m (▲) obtained from SLAC and NA4 (A = 14, 56) data.

1. Nucleon and Nuclear PDF's

QCD evolution equations **do not depend on kind of object**.

$$\frac{\dot{V}_A(n,Q^2)}{V_A(n,Q^2)} = \frac{\dot{V}_N(n,Q^2)}{V_N(n,Q^2)} = \gamma_N(\alpha_S(Q^2)) \qquad \cdot \equiv \frac{d}{d\log Q^2}$$

n - moment number

or

$$V_A(n,Q^2) = T_A^{NS}(n)V_N(n,Q^2) \qquad (1)$$

or

$$xF_{3A} \approx V_A(x,Q^2) = \int_x^A d\alpha\, T_A^{NS}(\alpha) V_N\left(\frac{x}{\alpha}, Q^2\right) \qquad (2)$$

with baryon number sum rule: (All nuclear function here are normalized to A.)

$$\int_0^A d\alpha\, T_A^{NS}(\alpha) = 1$$

Singlet channel (Assume no "primordial" gluon distribution, i.e. all gluons results in QCD evolution.)

$$\Sigma_A(x,Q^2) = \int_x^A d\alpha\, T_A^S(\alpha)\Sigma_N\left(\frac{x}{\alpha},Q^2\right) \qquad (3)$$

$$G_A(x,Q^2) = \int_x^A d\alpha\, T_A^S(\alpha)G_N\left(\frac{x}{\alpha},Q^2\right) \qquad (4)$$

In general, $T^S \neq T^{NS}$ and T^S satisfies energy-momentum sum rule

$$\int_0^A d\alpha\, \alpha T_A^S(\alpha) = \frac{M_A}{AM_N} \approx 1 \qquad (5)$$

Immediate consequence of Eqs. (3,4) $\dfrac{<x_G>_A}{<x_G>_N} = \dfrac{<x_q>_A}{<x_q>_N} = 1$

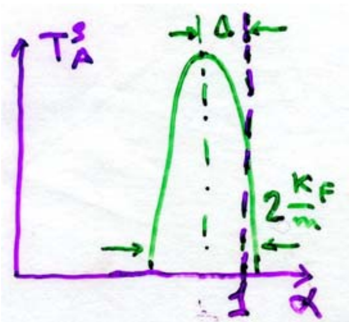
Clearly contradict rescaling hypothesis!

Notice: QCD evolution is leading twist approximation. Nuclear screening (formally, a high twist effect) is not included.

Levin,Ryskin(85), Brodsky,Hoyer(91,92) Indumathi(96)

2. The EMC Effect

T_A is, approximately, an effective distribution of nucleons in nucleus. Concentrated at α =1 (zero internal momentum).
Expanding (1) and (3) around α = 1 one have:



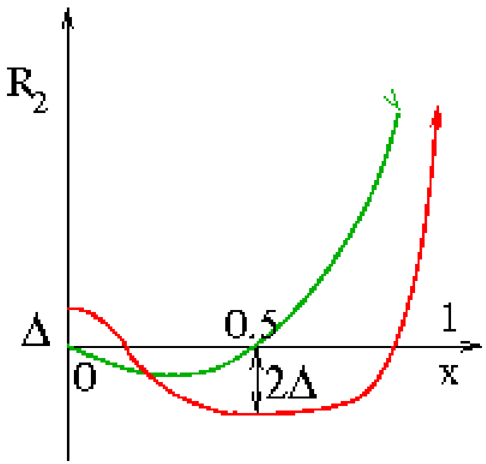
<... > means integration over interval 0 < α < *A*.

$$R = \frac{F_A}{F_N} \simeq < T > + < (1-\alpha)T > x\frac{F_N'}{F_N} \quad (7)$$

$$+ \frac{1}{2} < (1-\alpha)^2 T > x\left(x\frac{F_N''}{F_N} + 2\frac{F_N'}{F_N}\right) + \cdots$$

=-3x/(1-x)

=0 at x=0.5 and F~(1-x)[3]



For ratio of $F_2 \approx \Sigma$

$$< T_A^S > -1 = \Delta_A > 0 \quad \text{or}$$

$$\int_0^A d\alpha \left[T_A^S(\alpha) - T_A^{NS}(\alpha)\right] = \Delta_A > 0 \quad (8)$$

$$\int_0^A d\alpha\, \alpha \left[T_A^S(\alpha) - T_A^{NS}(\alpha)\right] = \delta_A > 0 \quad (9)$$

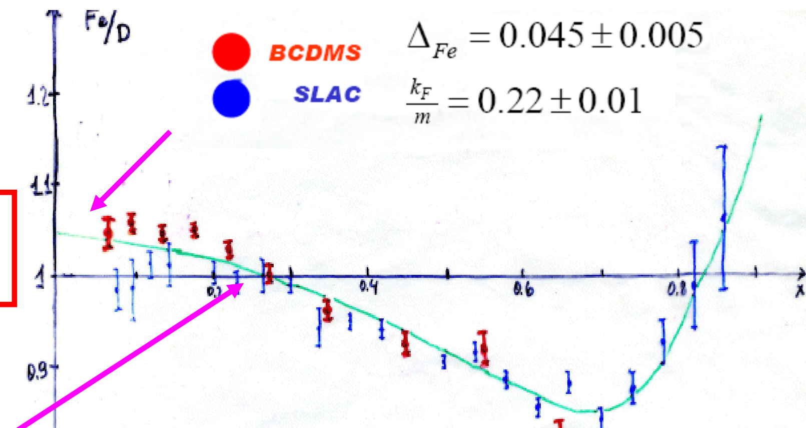
Since $R_3 \approx R_2$ near $x \approx 0.5$ (no sea quarks) $\delta_A \approx \frac{2}{3}\Delta_A$

Conclusions on EMC:

•Effective nucleons" number larger than *A*,

•Valence nucleons carry only a part of total nucleus momentum,

•EMC-effect is result of repumping a part of momentum from valence quarks to sea quarks.



•Immediate consequences:

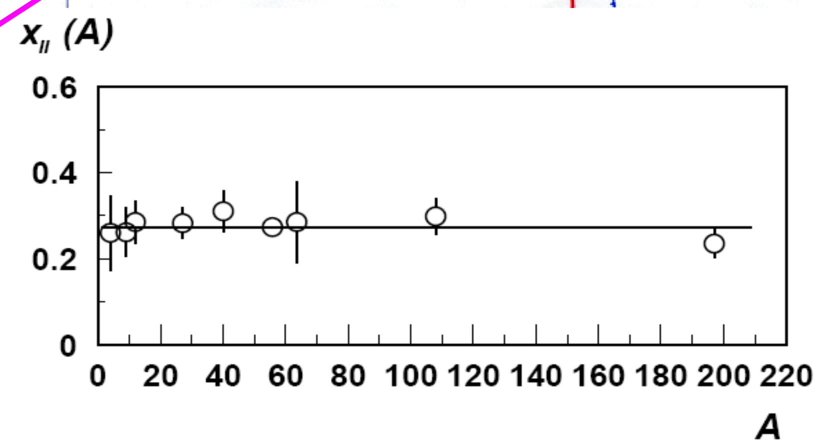
i. $R_2(x \simeq 0) = \int_0^A d\alpha\, T_A^S(\alpha) = 1 + \Delta_A > 1$

Seen by BCDMS, $\Delta_{\rm Fe} = 0.045 \pm 0.005$

(Recall: screening phenomena are disregarded!)

ii. $R_2(x \simeq 0.3) = 1$ independent on A.

Seen by SLAC, BCDMS, EMC.



G.Smirnov, **Phys.Atom.Nucl. 58 (1995) 1613**

iii. Small ($\approx \Delta_A$) but hard "collective" sea

$$O_A(x,Q^2) \equiv \Sigma_A - V_A = \int_x^A d\alpha\, T_A^{NS}(\alpha) O_N\left(\frac{x}{\alpha},Q^2\right) +$$

Internucleon sea

$$+ \int_x^A d\alpha \left[T_A^S(\alpha) - T_A^{NS}(\alpha)\right] \Sigma_N\left(\frac{x}{\alpha},Q^2\right) \qquad (11)$$

Collective nuclear sea O'_A

$$\overline{\alpha}_{O'} = \frac{<\alpha(T_A^S - T_A^{NS})>}{<T_A^S - T_A^{NS}>} = \frac{\delta_A}{\Delta_A} \approx 1 (=2/3$$

Can be seen in excess of hard "sea" particles (***K*⁻, *P̄*, *J/ψ***)

Models: Different ways of repumping: *Llewellin-Smith(83), Ericson,Thomas(83)*

a. Repumping to a heavy components (ρ, ω, *N̄N*-pairs, off-shell π),

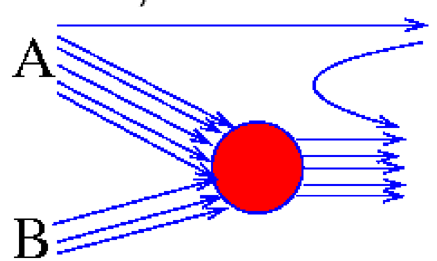
b. Repumping inside each nucleon, *Frakfurt,Strikman(82), Barone at.al., Szwed(83*

c. Repumping inside multiquarks. $\Delta_A \approx p_A \Delta_{6q} + \ldots << \Delta_{6q}$ *Lot of authors*

3. Cumulative Particle Production

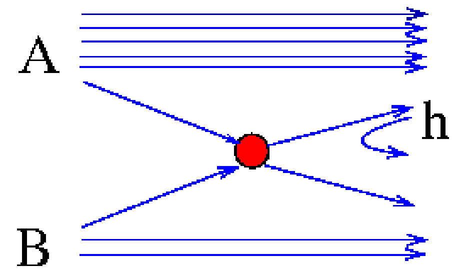
Common property quark-parton models for inclusive production:

$$\frac{\epsilon}{A}\frac{d\sigma}{d^3p} = \rho_{A\to h}(x,y,p_T) = \int_x^A \frac{d\alpha}{\alpha} F_A(\alpha) f_h\left(\frac{x}{\alpha}, y, p_T\right) \qquad (12)$$



($x=u/s$, $y=-t/s$) f_h is model dependent but does not depend on A.

Models:

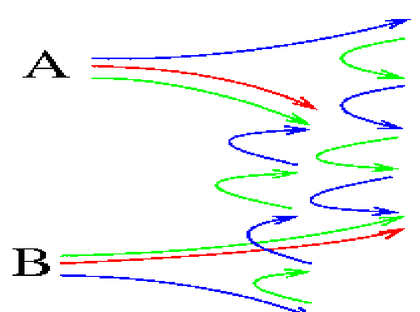


• Limiting fragmentation. Coaliscent:

$r_A \sim F_A$, $f(x/\alpha) \sim \delta(x/\alpha - 1)$

• Hard scattering: $f\left(\frac{x}{\alpha}\right) = \int_{\frac{y}{1-x/\alpha}}^{1} d\beta F_B(\beta) D_h\left(\frac{x}{\alpha} + \frac{y}{\beta}\right) \frac{d\sigma}{dt}\left(p_T, \frac{x}{\alpha}, \frac{y}{\beta}\right)$

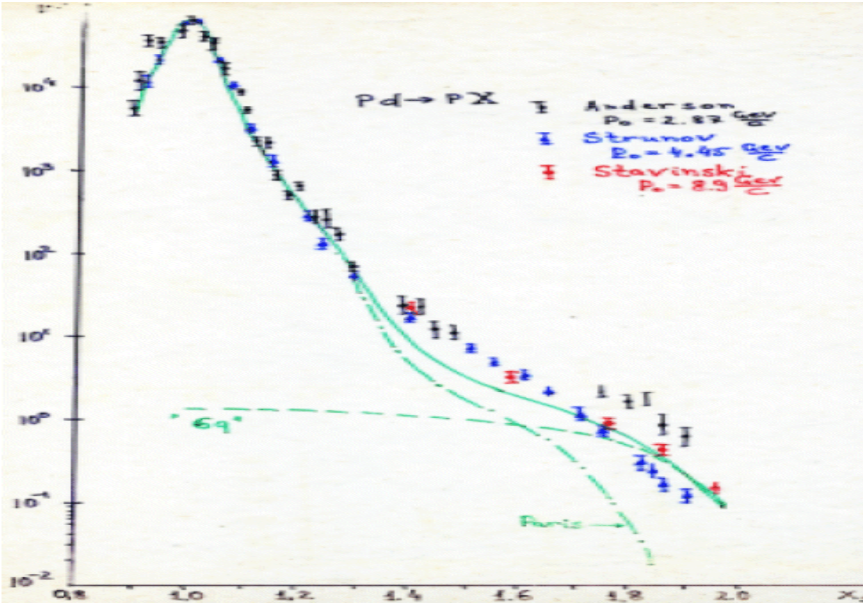
•Dual string: $f\left(\frac{x}{\alpha}\right) = D_h\left(\frac{x}{\alpha} + \frac{y}{\beta}\right)$



Combining (12) with (1,3) one has:

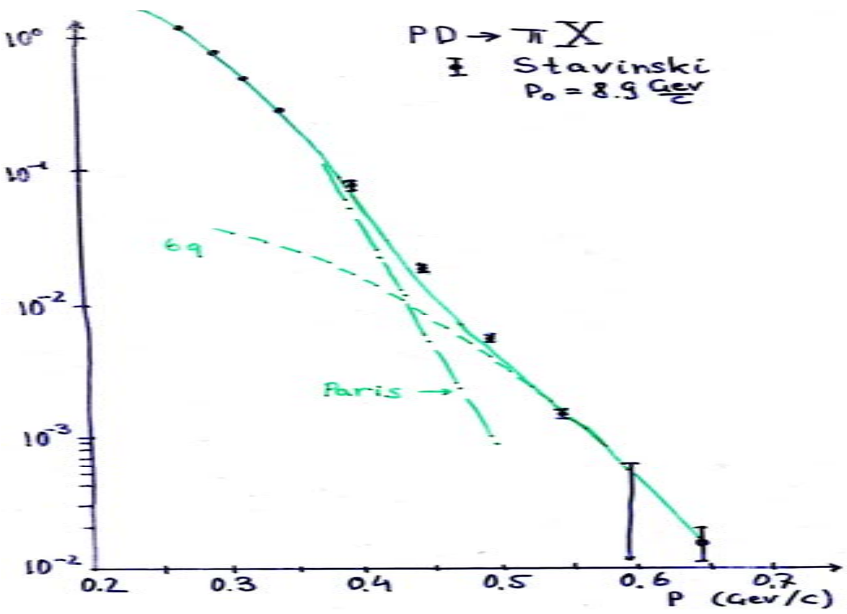
$$\rho_{A\to h}(x,y,p_T) = \int_x^A d\alpha\, N_A(\alpha)\rho_{N\to h}\left(\frac{x}{\alpha},y,p_T\right) + \int_x^A d\alpha\, \tilde{N}_A(\alpha)\rho_{\tilde{N}\to h}\left(\frac{x}{\alpha},y,p_T\right) \quad (13)$$

$$N_A = \frac{1}{2}\left(T_A^S + T_A^{NS}\right) \text{ and } \tilde{N}_A = \frac{1}{2}\left(T_A^S - T_A^{NS}\right)$$

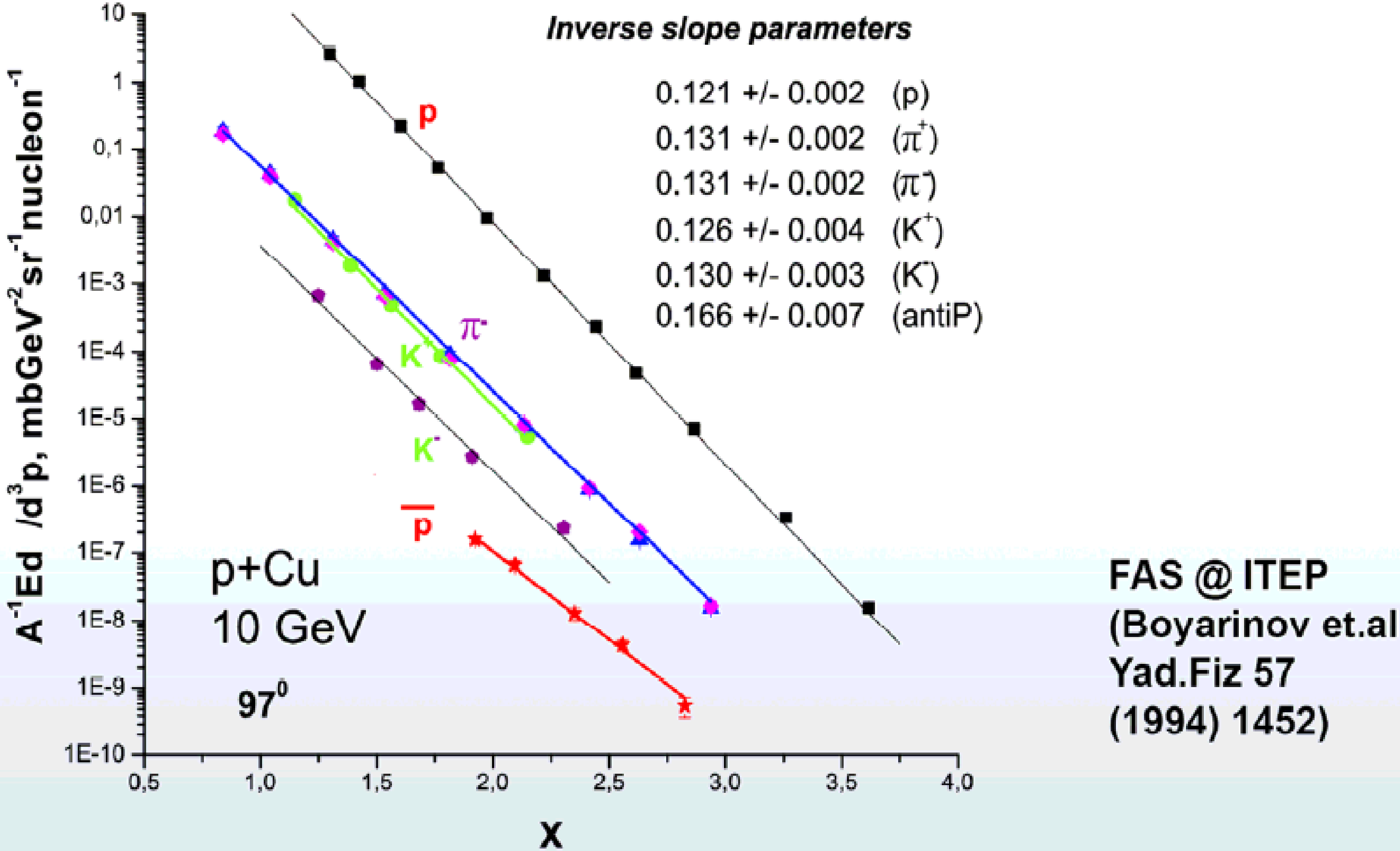


N_A can be found from stripped **cumulative proton** spectrum with $p_T = 0$.

(AE,Kajdalov, et.al.YaF(88,99))



Cumulative ***π*** and ***K⁺*** than determines by (13) with experimental $\rho_{N\text{-->}\pi}$ **with no new parameters!** ($\tilde{N}_A$ term is small).



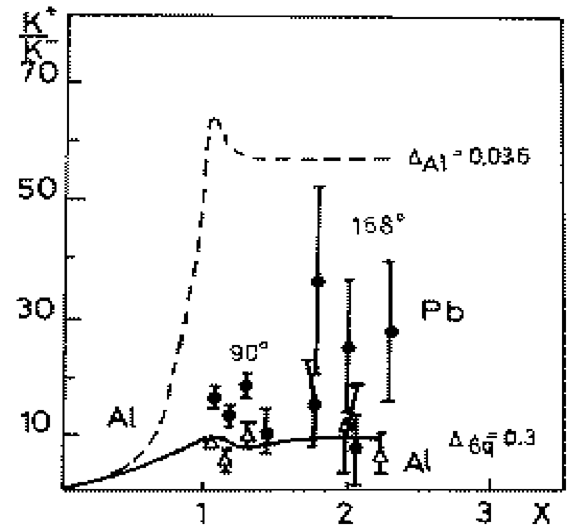
X – minimal target mass [m_N] needed to produce particle

4. Sea Particles and Multiquarks

The most intriguing. Descriminates "6q" and FNC.

$$\boxed{r_A = \frac{K^+}{K^-}} \approx \frac{\int_x^A d\alpha\, N_A(\alpha)\rho_{N\to K^+}(\frac{x}{\alpha})}{\int_x^A d\alpha\, \widetilde{N}_A(\alpha)\rho_{N\to K^+}(\frac{x}{\alpha})} \approx \frac{2}{\Delta_{6q}}$$

$$\left(\text{approximation } \rho_{\widetilde{N}\to K^-} \approx \rho_{N\to K^+} \text{ was used.}\right)$$

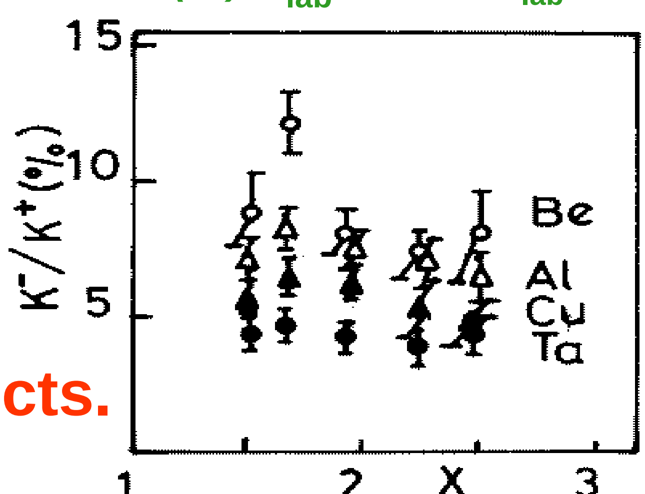


Experiment: r_A const(x) for $1 < x < 2.5$ and surprisingly small compared with expected from EMC-effect

(Baldin at al. (82), E_{lab}=8,9 GeV, θ_{lab}=168°)

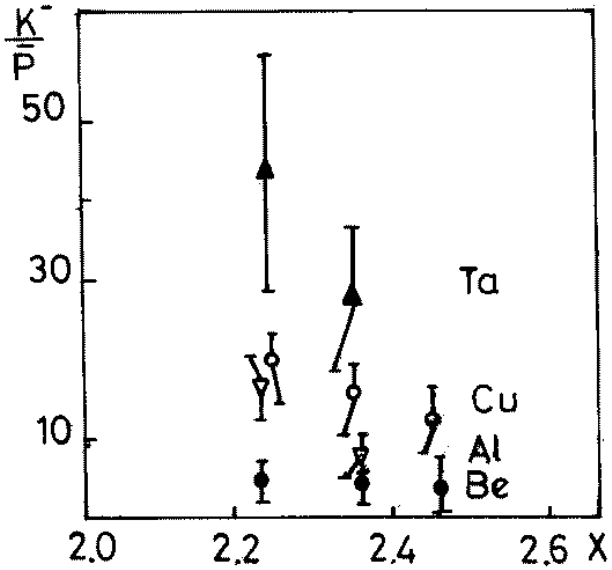
(Boyarinov at al. (89), E_{lab}=10 GeV, θ_{lab}=119°)

Nuclei	Be	Al	Ta	Pb
Δ_A from EMC	0.023	0.036	0.056	0.058
$r_A = (2-\Delta_A)/\Delta_A$	86	55	36	35



Low experimental r_A indicates to "6q"-mechanism of cumulative and EMC-effects.

$\tilde{\mathrm{P}}$ from $\tilde{\mathrm{q}}$: $\frac{K^-}{\tilde{p}} \simeq \frac{D_{\bar{q}\to K^-}}{D_{\bar{q}\to\tilde{p}}} \simeq 10$



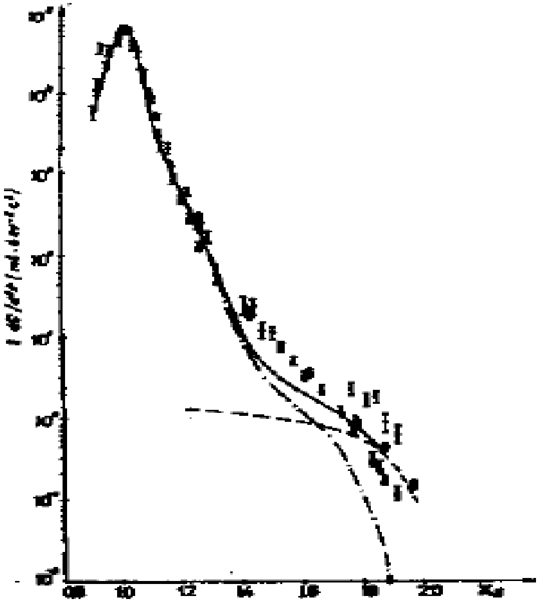
(Boyarinov at al., YaF (91,93), E_{lab}=10 *GeV*, θ_{lab}=119^o and θ_{lab}=97^o*)*

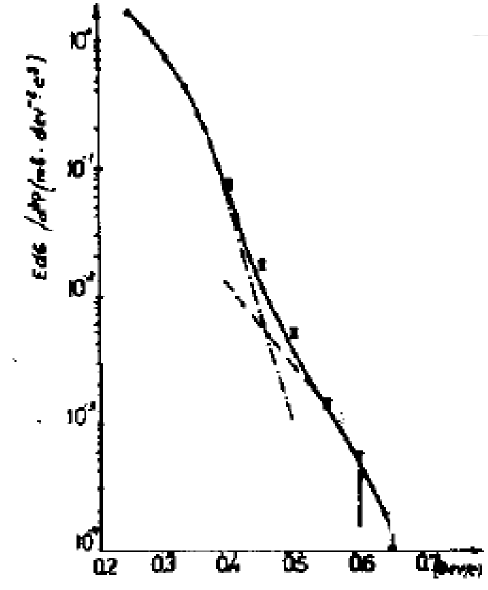
Again in favor of multiquarks!

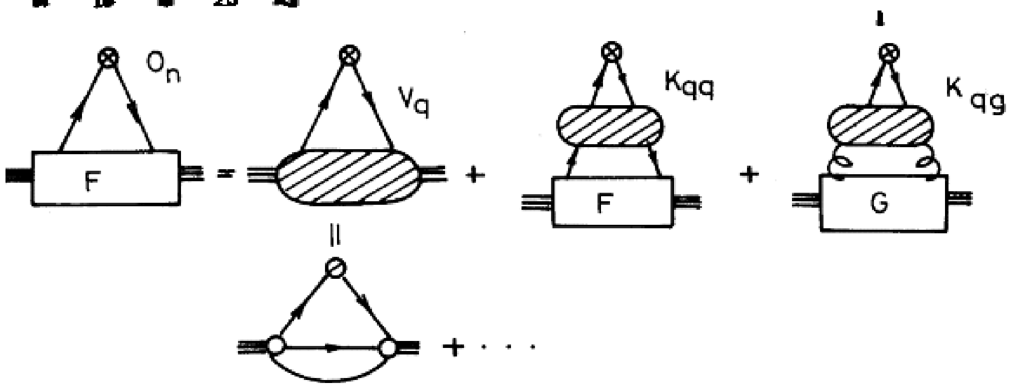
5. Conclusions

- EMC-effect is repumping of valence quarks to sea quarks momentum,
- Small but hard "collective" sea,
- Evidence for multiquark from cumulative K^- and $\tilde{P}$
- Good data for cumulative K^- and $\tilde{\mathrm{P}}$ for deuterium are necessary of the "collective" sea.
- What are the situation with spin PDFs?

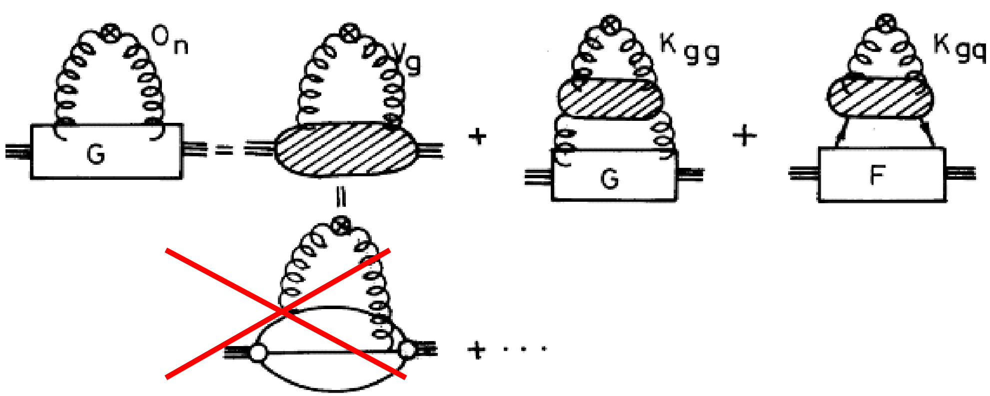
Thanks for attention!







On
F
Vq
Kqq
F
Kqg
G



On
G
Vg
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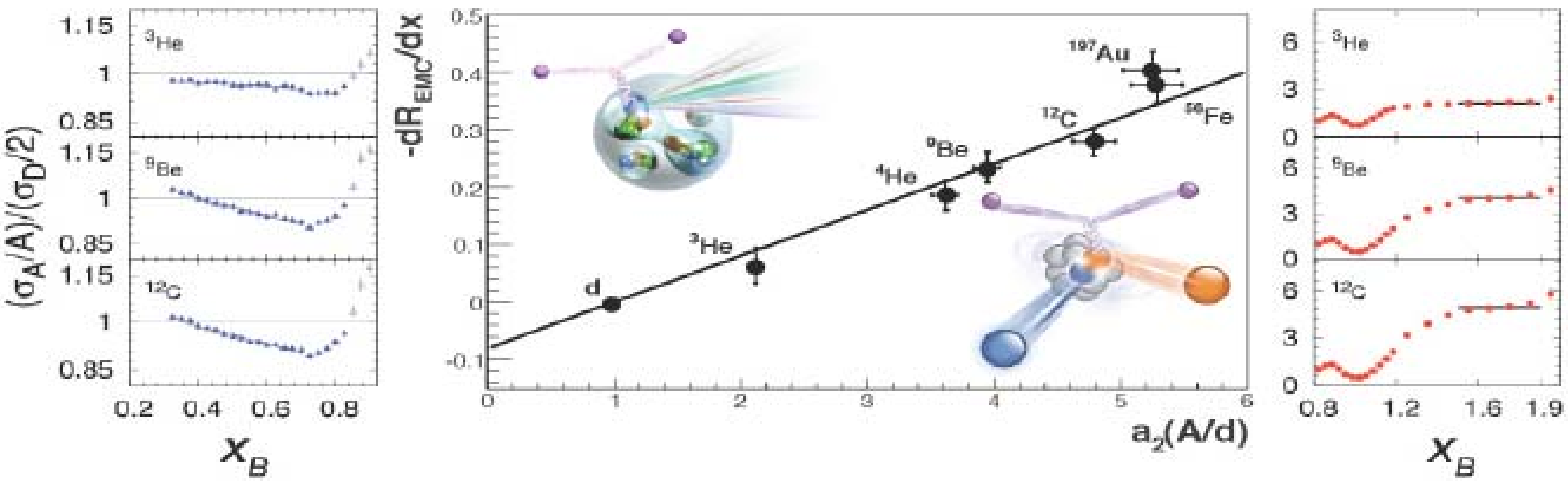
Some recent work at 6 GeV large x....



L.B. Weinstein, et al, Phys.Rev.Lett. 106 (2011) 052301