# Kacper as my mentor

Dedicated to Professor

**Kacper Zalewski**

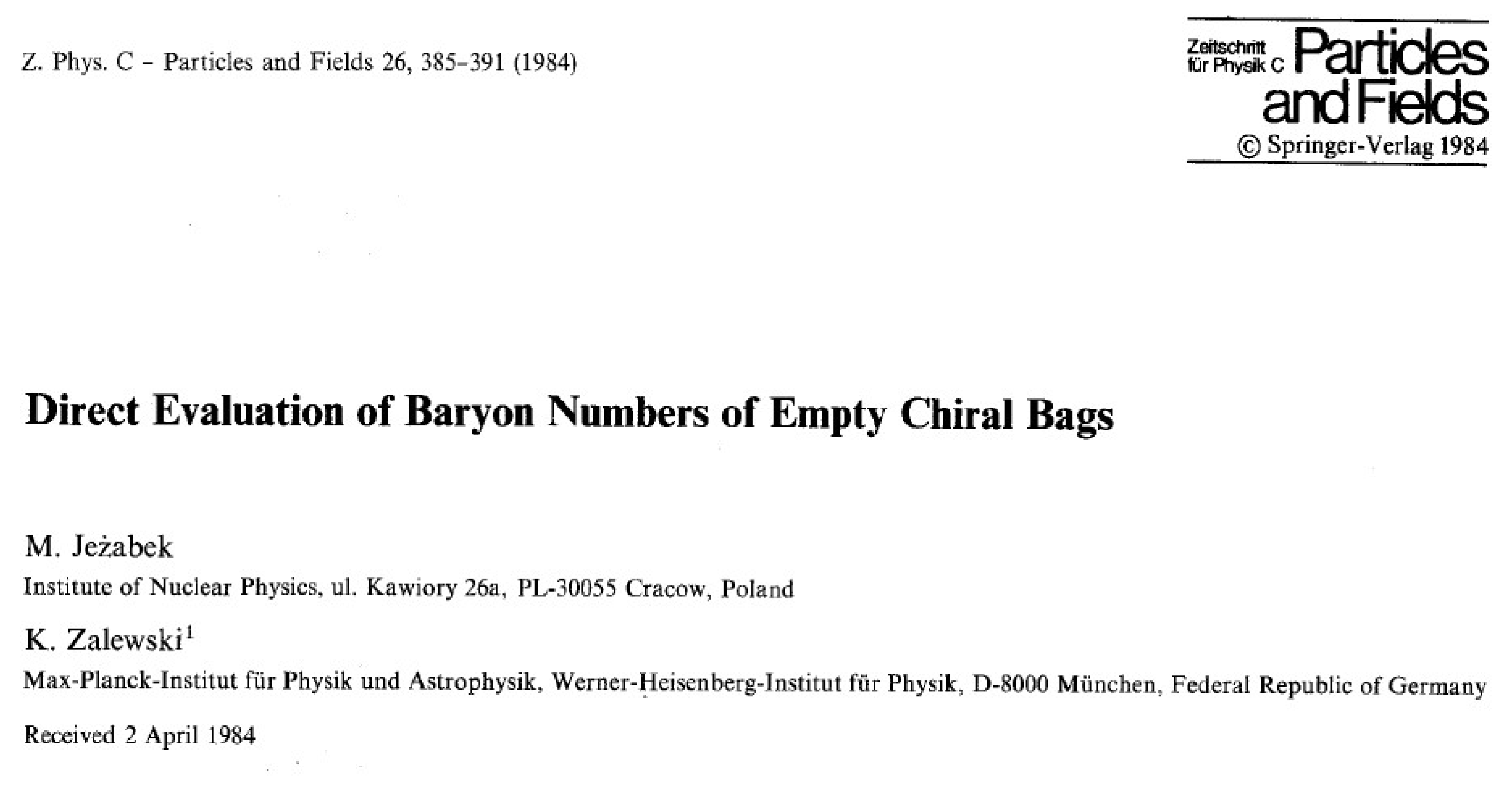
on His 85th birthday

**Marek Jeżabek**

**26th Cracow Epiphany Conference**
**07.01.2020**

# Content

1. Fermion numers of chiral bags
2. Annihilation and leading baryons in scattering on nuclei



Z. Phys. C – Particles and Fields 26, 385–391 (1984)

Zeitschrift für Physik C Particles and Fields

# Direct Evaluation of Baryon Numbers of Empty Chiral Bags

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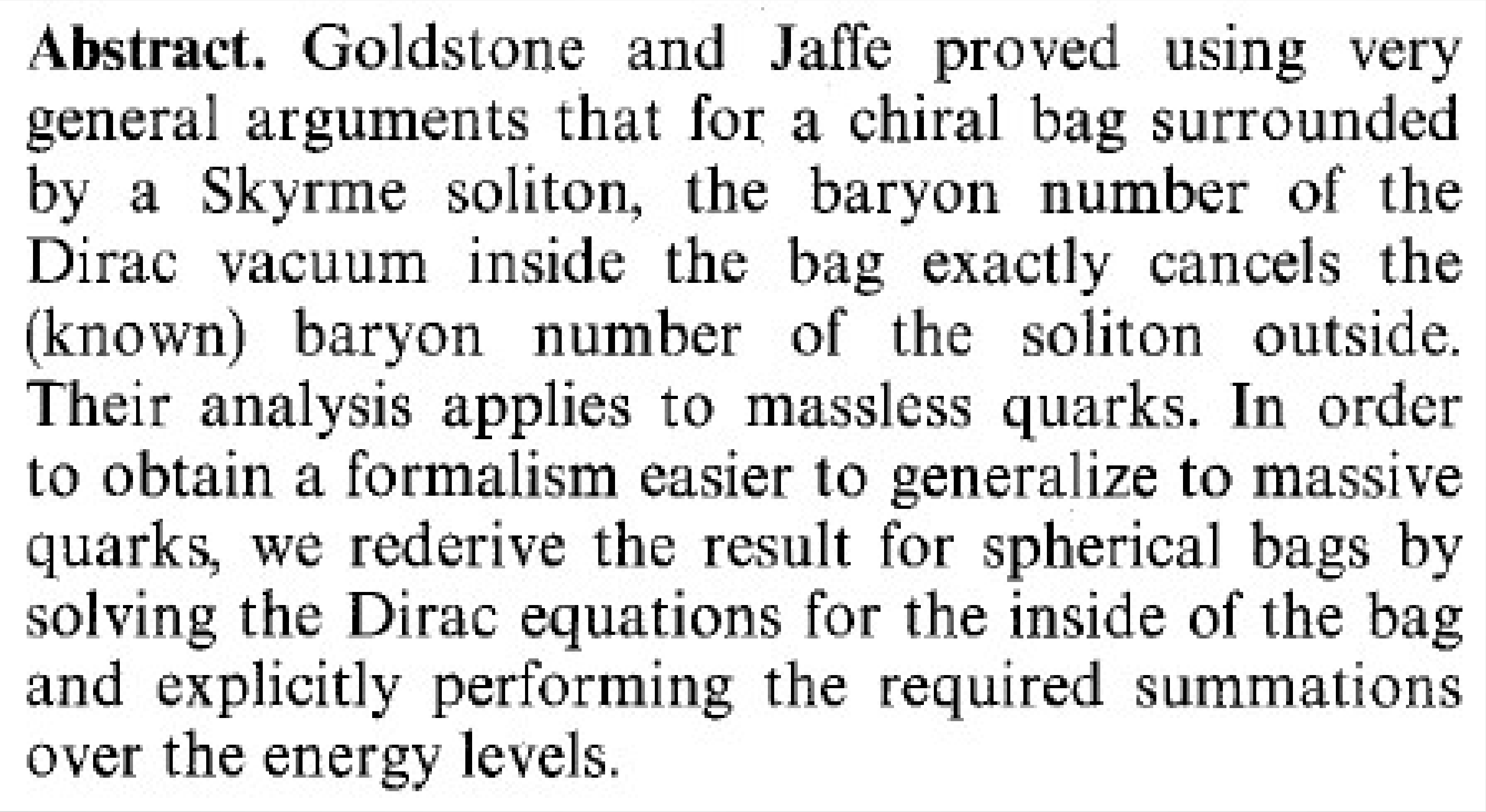
Received 2 April 1984



**Abstract.** Goldstone and Jaffe proved using very general arguments that for a chiral bag surrounded by a Skyrme soliton, the baryon number of the Dirac vacuum inside the bag exactly cancels the (known) baryon number of the soliton outside. Their analysis applies to massless quarks. In order to obtain a formalism easier to generalize to massive quarks, we rederive the result for spherical bags by solving the Dirac equations for the inside of the bag and explicitly performing the required summations over the energy levels.

# Chiral bags

Dirac lagrangian for fermions in the bag, the Skyrme lagrangian for the pion cloud outside the bag, and the interaction between fermionic and bosonic fields at the surface of the bag:

$$S = \int_{\text{in}} d^4x(i\bar{\psi}\hat{\partial}\psi - \mathscr{B}) + \int_{\text{out}} d^4x \mathscr{L}_{\text{Sk}} - \int_{\text{surf}} d\Sigma \delta_{\text{surf}}(\bar{\psi}_{\text{R}} U \psi_{\text{R}} + \bar{\psi}_{\text{L}} U^{\dagger} \psi_{\text{L}}).$$

$$\mathscr{L}_{\text{Sk}} = \frac{F_{\pi}^2}{16} \operatorname{Tr}(\partial_{\mu} U \partial^{\mu} U^{\dagger}) + \frac{1}{32e^2} \operatorname{Tr}[(\partial_{\mu} U) U^{\dagger}, (\partial_{\nu} U) U^{\dagger}]^2,$$

Skyrme's soliton: static hedgehog ansatz

$$U_0(\boldsymbol{r}) = \exp\{i\theta(X)\vec{\tau} \cdot \hat{\boldsymbol{n}}\}$$

$$\varrho_{\text{Sk}}(r) = \frac{2\sin^2\theta}{\pi}\theta'$$

$$\theta(0) = -\pi$$

$$\theta(\infty) = 0.$$

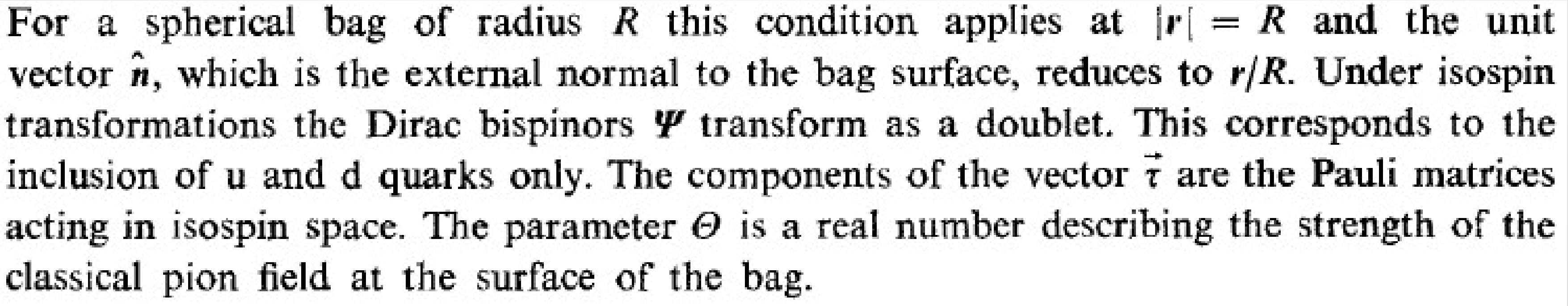
# Boundary condition at the surface of a spherical bag for isodublet of massless Dirac fields *:

$$-i\vec{\gamma}\cdot\hat{\boldsymbol{n}}\Psi(\boldsymbol{r}) = \exp\left(i\Theta\vec{\tau}\cdot\hat{\boldsymbol{n}}\gamma_5\right)\Psi(\boldsymbol{r}).$$

Symmetry $SU_2$:

$$\boldsymbol{K} = \boldsymbol{I} + \boldsymbol{J} = \boldsymbol{I} + \boldsymbol{L} + \boldsymbol{S},$$

*



For a spherical bag of radius $R$ this condition applies at $|\boldsymbol{r}| = R$ and the unit vector $\hat{\boldsymbol{n}}$, which is the external normal to the bag surface, reduces to $\boldsymbol{r}/R$. Under isospin transformations the Dirac bispinors $\Psi$ transform as a doublet. This corresponds to the inclusion of u and d quarks only. The components of the vector $\vec{\tau}$ are the Pauli matrices acting in isospin space. The parameter $\Theta$ is a real number describing the strength of the classical pion field at the surface of the bag.

# Discrete spectrum of energy: n, K, M, $\kappa$, P, $\varepsilon$

($SU_2$ : K= 0,1,2 … ; -K $\leq$ M $\leq$ K) - degenerate: M

Equations for the energy levels:

$$x = |E|R.$$

K = 0

$$(1+\sin\Theta)\sin x+\cos\Theta\cos x-\frac{1}{x}\cos\Theta\sin x=0$$

K > 0

$$[j_{K-1}(x)j_{K+1}(x)-j_K^2(x)]\cos\Theta-j_K(x)\,[j_{K-1}(x)-j_{K+1}(x)]$$
$$-\frac{\sin\Theta}{2K+1}j_K(x)\,[j_{K-1}(x)+j_{K+1}(x)]=0.$$

S = 1 – 1 + 1 – 1 + 1 … = ?

S = 1 – (1 – 1 + 1 – 1 + 1 - …) = 1 – S

$$2S = 1 \quad \Longrightarrow \quad S = \frac{1}{2}$$

Poisson summation:

$$S = \lim_{q \to 1^-} \sum_{n=0}^{n=\infty} (-q)^n =$$

$$\lim_{q \to 1^-} \frac{1}{1+q} = \frac{1}{2}$$

# *Spectral asymmetry for quarks in chiral bags*

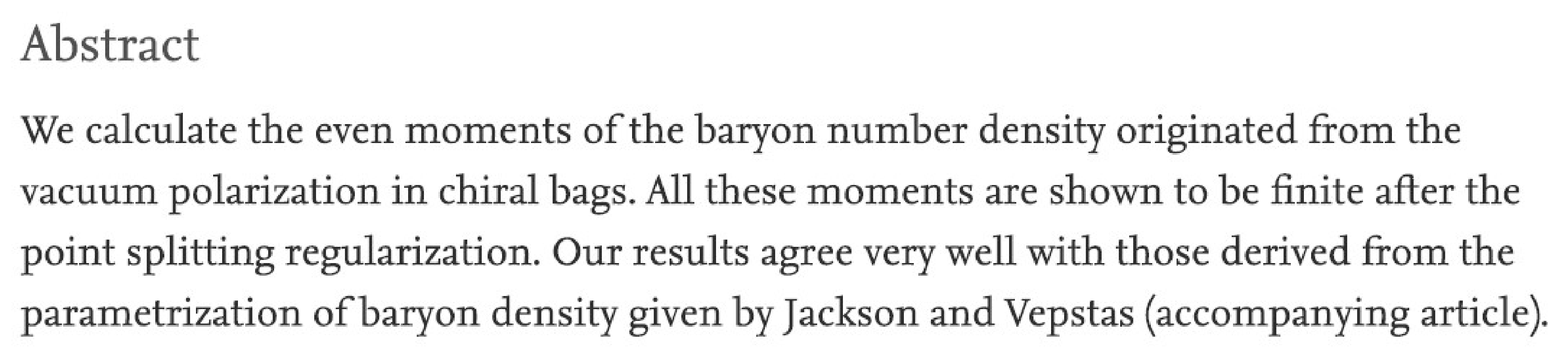
$$B_{\rm vac} = -\tfrac{1}{2} \lim_{t \to 0^+} \sum_E \kappa \exp(-t|E|).$$

$$B(\Theta) = \frac{1}{\pi}(\Theta - \sin\Theta\cos\Theta), \qquad -\frac{\pi}{2} < \Theta < \frac{\pi}{2}$$

$$B(\pi + \Theta) = B(\Theta) = -B(-\theta)$$

# *On the distribution of baryon number in chiral bags*

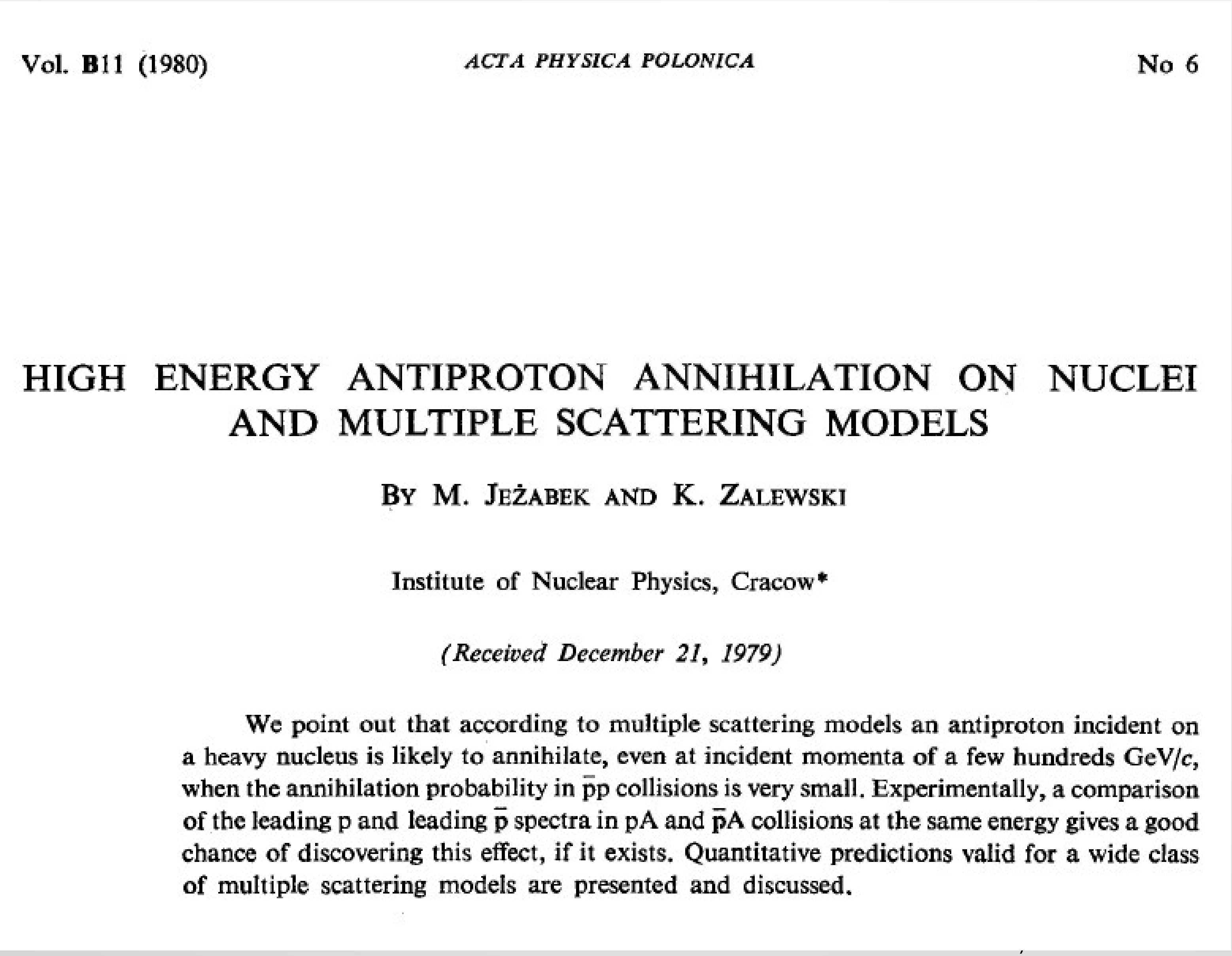
K.J. Heller and MJ, Nucl. Phys. A 481 (1988) 679
(Received 7 December 1987)



## Abstract

We calculate the even moments of the baryon number density originated from the vacuum polarization in chiral bags. All these moments are shown to be finite after the point splitting regularization. Our results agree very well with those derived from the parametrization of baryon density given by Jackson and Vepstas (accompanying article).

Important steps:
K.J. Heller, MJ and M.A. Nowak, Z. Phys. C 30 (1986) 483;
MJ, Acta Phys. Polon. B 19 (1988) 33 (Received April 6, 1987)



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# HIGH ENERGY ANTIPROTON ANNIHILATION ON NUCLEI AND MULTIPLE SCATTERING MODELS

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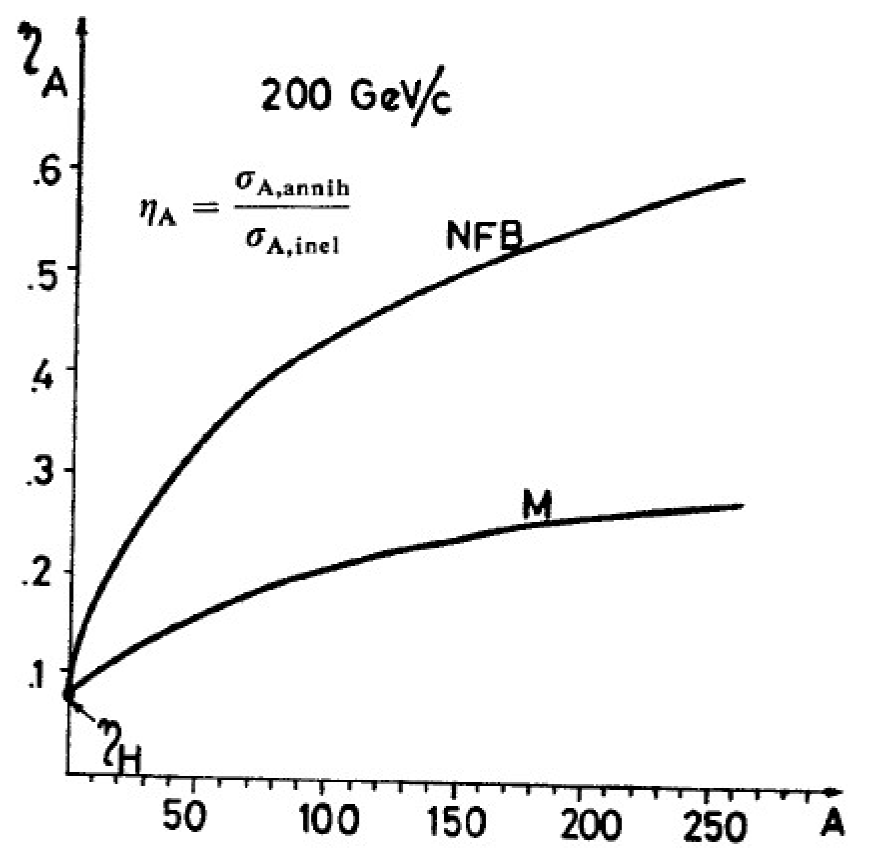
*(Received December 21, 1979)*

We point out that according to multiple scattering models an antiproton incident on a heavy nucleus is likely to annihilate, even at incident momenta of a few hundreds GeV/$c$, when the annihilation probability in $\bar{p}p$ collisions is very small. Experimentally, a comparison of the leading p and leading $\bar{p}$ spectra in pA and $\bar{p}A$ collisions at the same energy gives a good chance of discovering this effect, if it exists. Quantitative predictions valid for a wide class of multiple scattering models are presented and discussed.



A.Białas, M.Błeszyński, W.Czyż, Nucl.Phys. B111, 461 (1976)

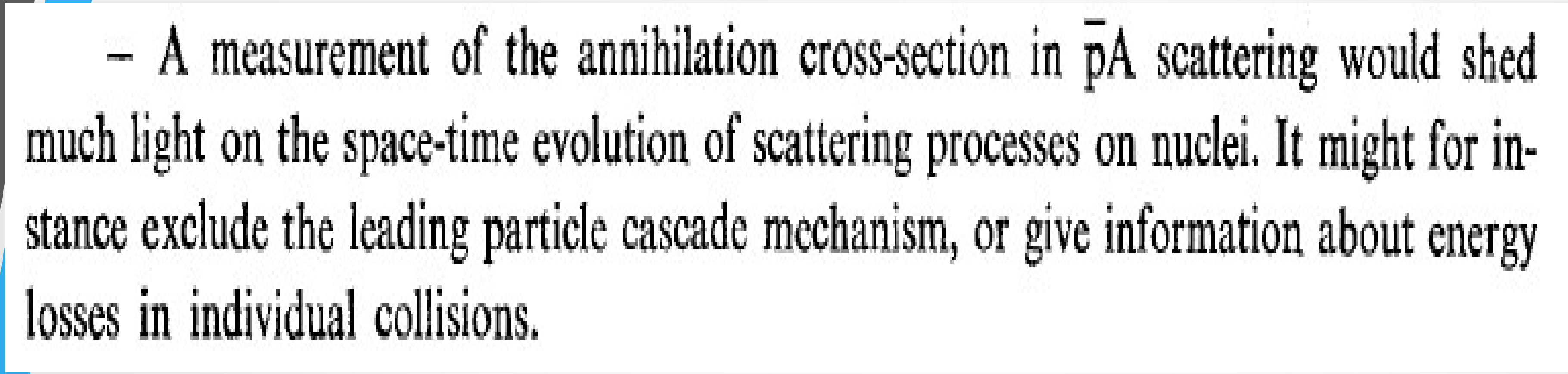
$$\sigma_{A,R}(b) = 1-[1-\tilde{\sigma}_R(b)]^A,$$

$$\tilde{\sigma}_R(b) = \int d^2s\,\sigma_{H,R}(s-b)\int dz\,\varrho_A(s,z),$$

## Energy dependence:

$$\sigma_{H,\mathrm{annih}} = 61\ \mathrm{mb}\ P_{\mathrm{lab}}^{-0.61},$$

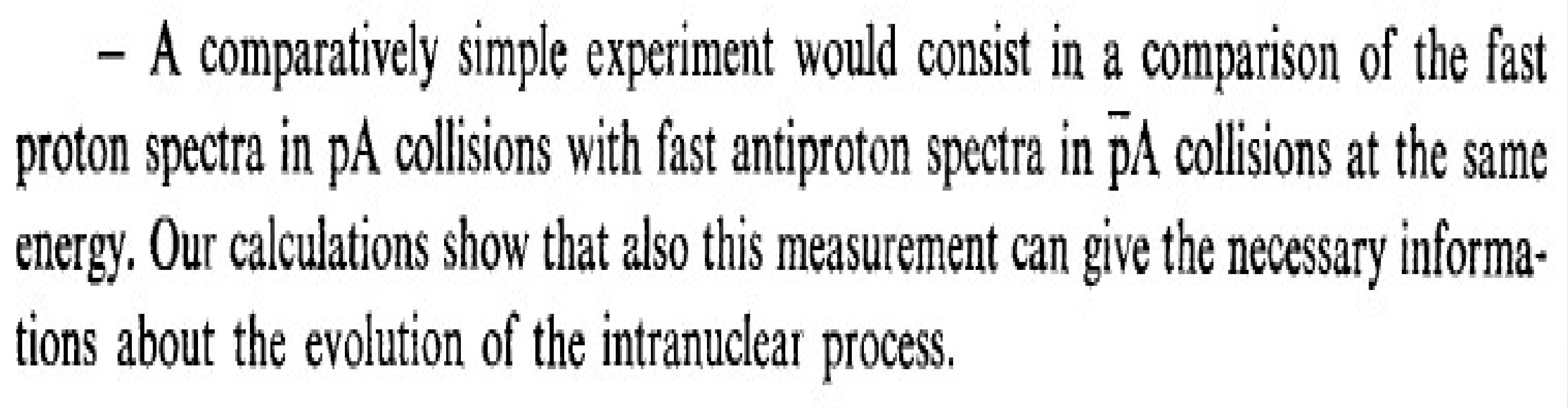
We point out that according to multiple scattering models an antiproton incident on a heavy nucleus is likely to annihilate, even at incident momenta of a few hundreds GeV/c, when the annihilation probability in $\bar{p}p$ collisions is very small.



– A measurement of the annihilation cross-section in $\bar{p}A$ scattering would shed much light on the space-time evolution of scattering processes on nuclei. It might for instance exclude the leading particle cascade mechanism, or give information about energy losses in individual collisions.

**40 Years Later: $\sigma_{annih}$ not measured, LPC ruled out**

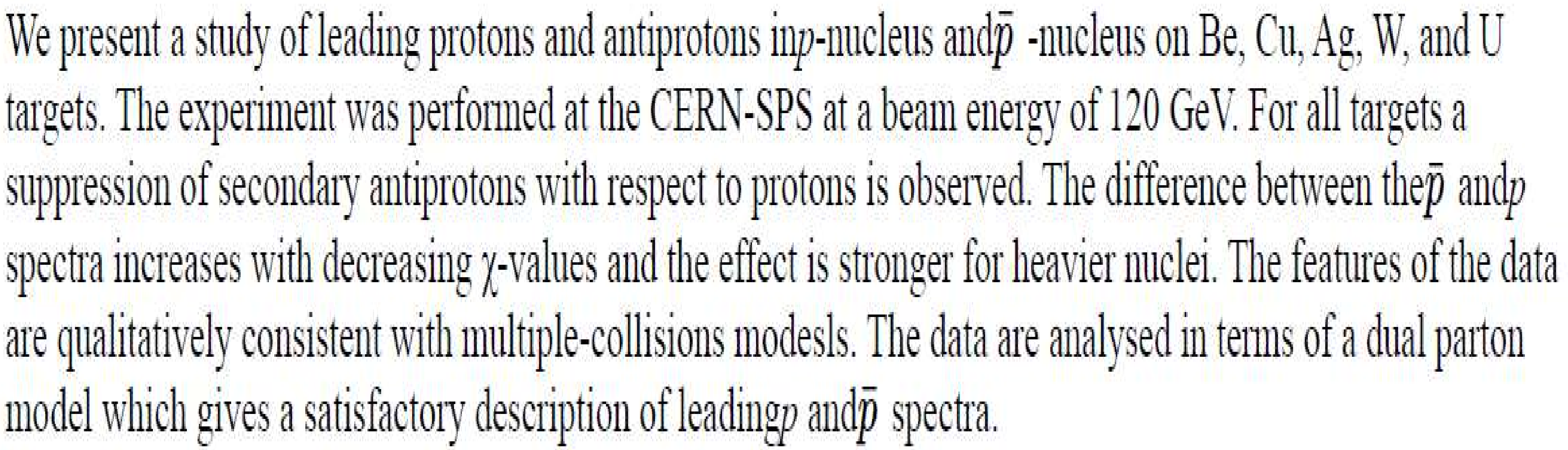
- hard processes (e.g. Drell-Yan:T.Jaroszewicz&MJ,1980)
- p spectra in pA collisions (A.Białas, W.Czyż, K.Zalewski…; DPM: A.Capella, A.Krzywicki, J. Tran Tranh Van… )



– A comparatively simple experiment would consist in a comparison of the fast proton spectra in pA collisions with fast antiproton spectra in $\bar{p}$A collisions at the same energy. Our calculations show that also this measurement can give the necessary informations about the evolution of the intranuclear process.

**40 Years Later: Yes!**

# Leading proton and antiproton distributions in proton-nucleus and antiproton-nucleus interactions



We present a study of leading protons and antiprotons in$p$-nucleus and$\bar{p}$ -nucleus on Be, Cu, Ag, W, and U targets. The experiment was performed at the CERN-SPS at a beam energy of 120 GeV. For all targets a suppression of secondary antiprotons with respect to protons is observed. The difference between the$\bar{p}$ and$p$ spectra increases with decreasing $\chi$-values and the effect is stronger for heavier nuclei. The features of the data are qualitatively consistent with multiple-collisions modesls. The data are analysed in terms of a dual parton model which gives a satisfactory description of leading$p$ and$\bar{p}$ spectra.

**Bailey R., … , Różańska M., et al., Z. Phys. C29, 1 (1985);**
**MJ, J. Karczmarczuk, M. Różańska, Z. Phys. C29, 55 (1985)**

# Dual Parton Model for pA inelastic collisions

$n = n_{w,A}$ - number of wounded nucleons in A (participants)

After collision:

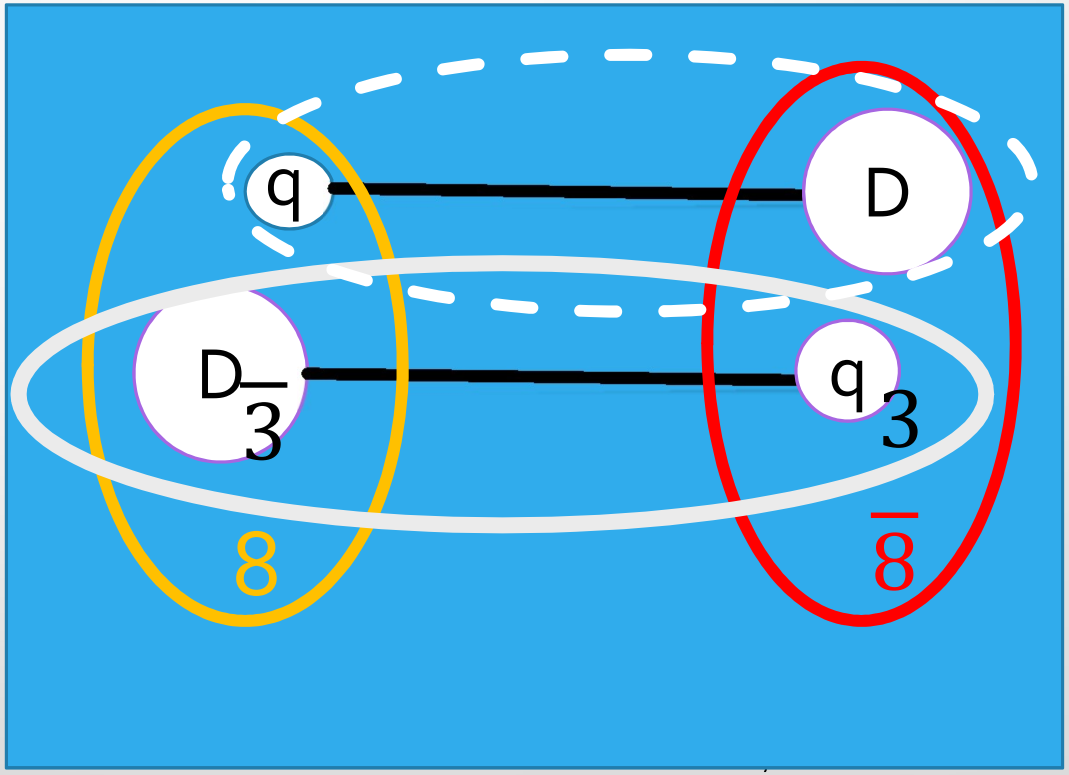
$\Omega = p_1\,\Omega_1 + p_2\,\Omega_2 + p_3\,\Omega_3 + \dots\,;\quad \Omega_n = |\,n\,\rangle\langle\,n\,|\,;$

$|\,n\,\rangle = |\,n\,\rangle_p |\,n\,\rangle_A \quad , \quad \text{where}\ |\,1\,\rangle_p = |\,1\,\rangle_A = |\,\mathrm{Dq}\,\rangle$

For n = 1:

D – valence diquark

q – valence quark



# For n = 2:

$$|\,2>_A = |\,\mathrm{D\ q;\ D\ q} >$$

$$|\,2>_p = |\,\mathrm{D\ q}\ q_s\,\overline{q_s} >$$ where $q_s$ is a sea quark

and four colorless objects are formed

$(\mathrm{D\ q})\ \ (\mathrm{q\ D})\ (q_s\ \mathrm{D})\ (\overline{q_s}\ \mathrm{q})$

and after fragmentation one baryon moves in direction of p (Forwards) and two baryons move in direction of A (Backwards)

⇨ no transfer of baryon number between B and F hemispheres

# Is it possible that

$\Omega_2^f$ = (1-c) $\Omega_2$ + c $\Omega_2'$

$\Omega_2'$ = $|2'><2'|$

$|2'> = |q\ q\ q>_p\ |\ D\ D\ D>_A$ ?

Yes, for 10 - $\overline{10}$ color configuration.

(q D) (q D) (q D)

← ← ←

After fragmentation three baryons in backward hemisphere! $\Delta B_{F\rightarrow B}$ = 1.

A similar mechanism in $\overline{\mathrm{p}}$ inelastic scattering on two wounded nucleons in a nucleus may lead to baryon number annihilation.

Dear Kacper

Happy Birthday !