Asymptotic Properties of the Nuclear Matter

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About 15 years ago together with A.M.Baldin we published an article which predicted the particle yield as a result of nuclei interactions at high energy.

At present the corresponding experimental data have started to appear up to the LHC energy. In this talk I will give a comparison of predictions made many years ago with the latest experimental data.

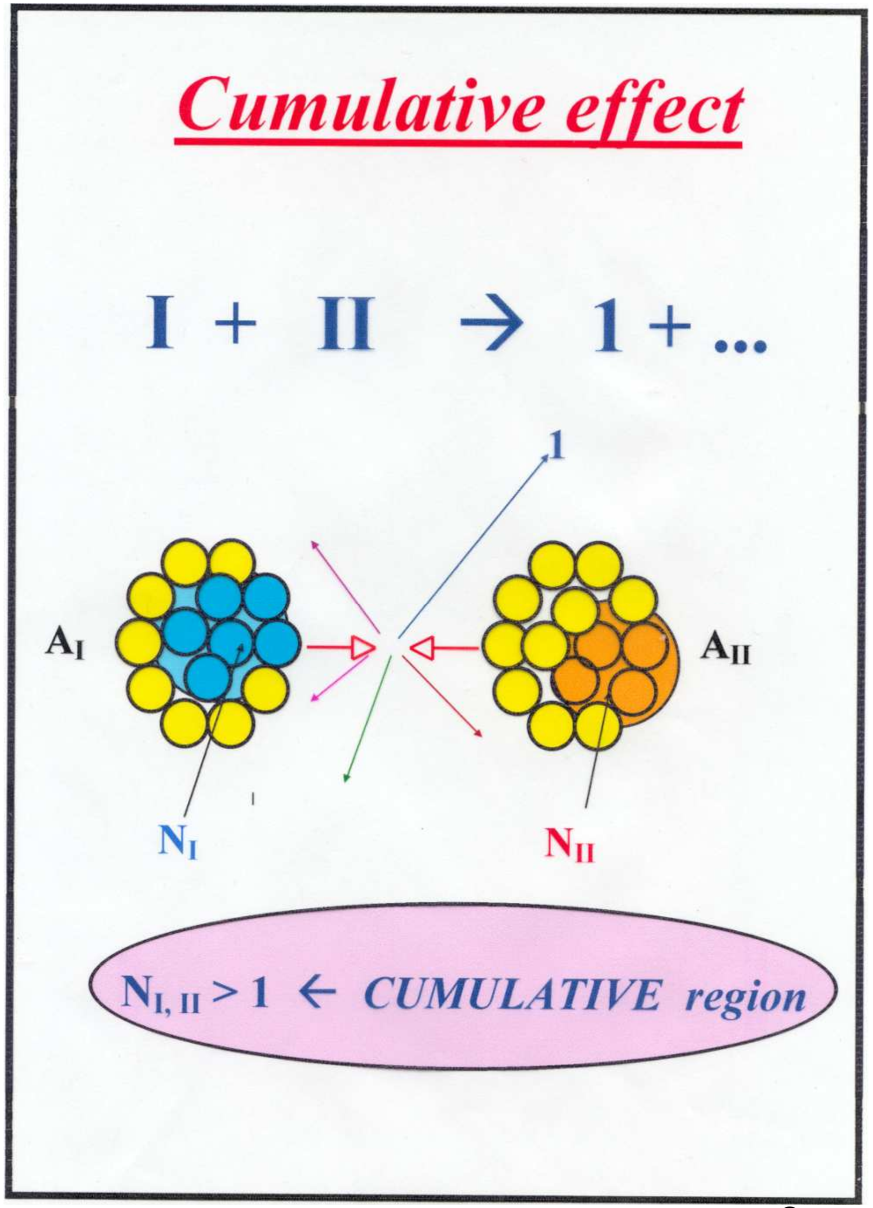
$I + II \rightarrow 1 + \ldots$

More than one nucleon of nucleus I takes part in the interaction (A.M.Baldin)

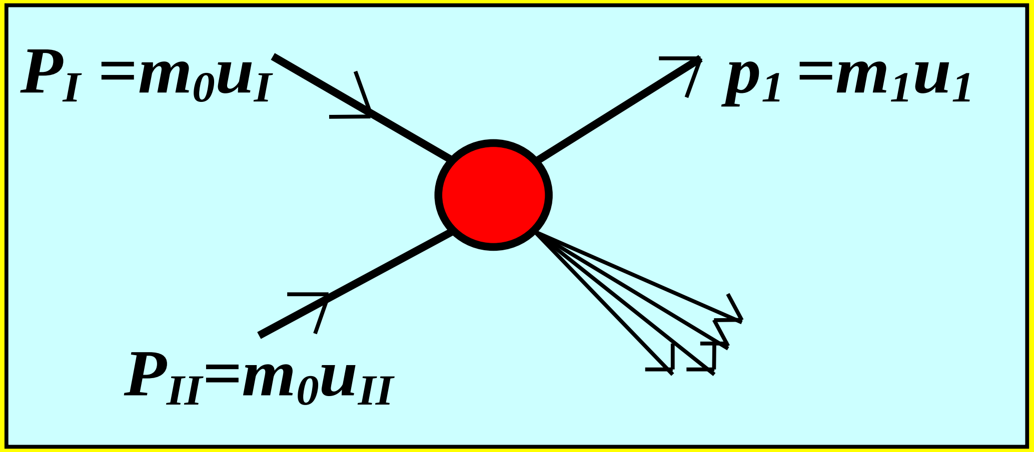
The value $N_I = \lambda A_I$, the effective number of nucleons inside nucleus I participating in the collisions, is called the *cumulative number*

$$0 \leq N_I \leq A_I$$

Cumulative region → $N_I > 1$



$$I + II \rightarrow 1 + \ldots$$



$$(N_I P_I + N_{II} P_{II} - p_1)^2 = (N_I m_0 + N_{II} m_0 + \Delta)^2$$

Δ is the mass of the particle providing conservation of the baryon number, strangeness and other quantum numbers

Using the principle of symmetries, in particular, symmetries of the solutions, allowed A.M.Baldin to enter the self-similarity parameter of Π for the nucleus interaction:

$$\boldsymbol{\Pi = min[\tfrac{1}{2}\sqrt{(u_I N_I + u_{II} N_{II})^2}],}$$

where N_I and N_{II} are cumulative numbers for nuclei I and II, and u_I and u_{II} are 4-velocities of these nuclei.

A.M.Baldin, A.A.Baldin. Phys. Particles and Nuclei, v.29, No.3 (1988) p.232.

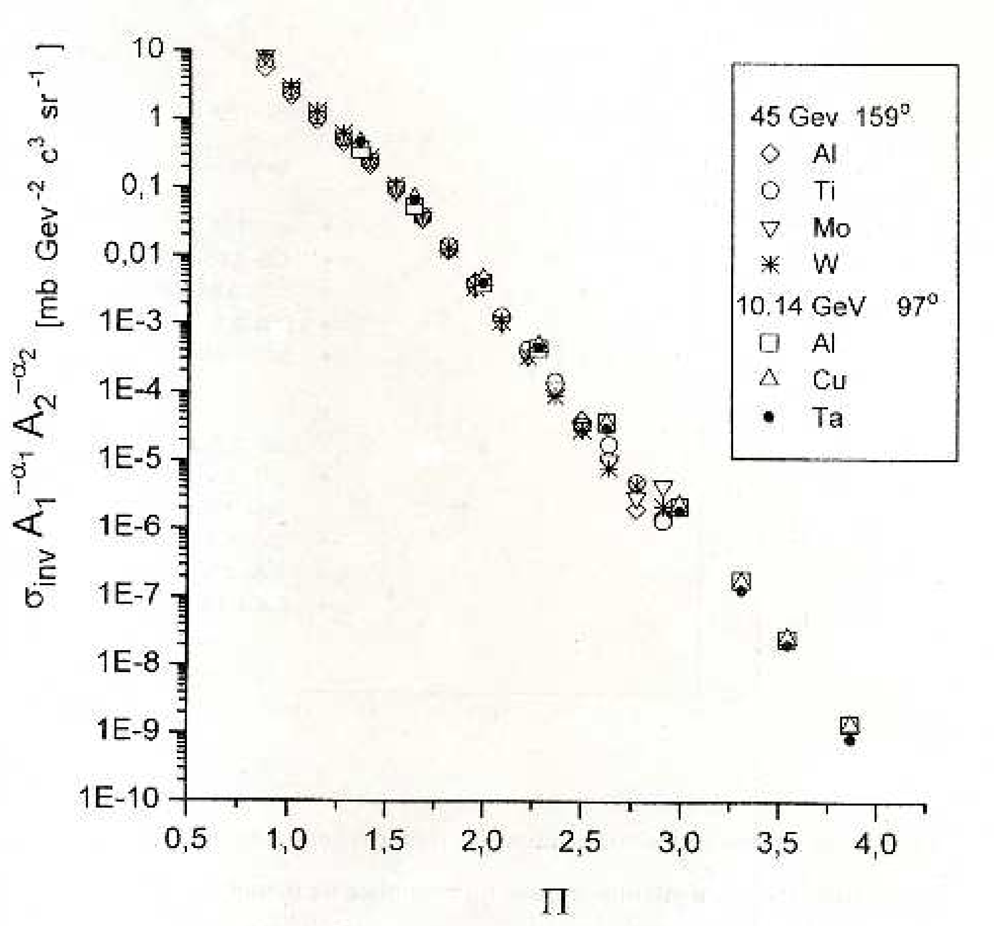
A.M.Baldin, A.I.Malakhov, and A.N.Sissakian. Physics of Particles and Nuclei, Vol.32. Suppl. 1, 2001, pp.S4-S30.

In this case the invariant cross-sections of the output inclusive particles of different types at nucleus interactions with atomic numbers A_I and A_{II}, are described by universal dependence in a broad energy range and different atomic numbers of colliding nuclei:

$$\boldsymbol{Ed^3\sigma/dp^3 = C_1 A_I^{\alpha(N_I)}\ A_{II}^{\alpha(N_{II})}\ exp\,(-\Pi/C_2)},$$

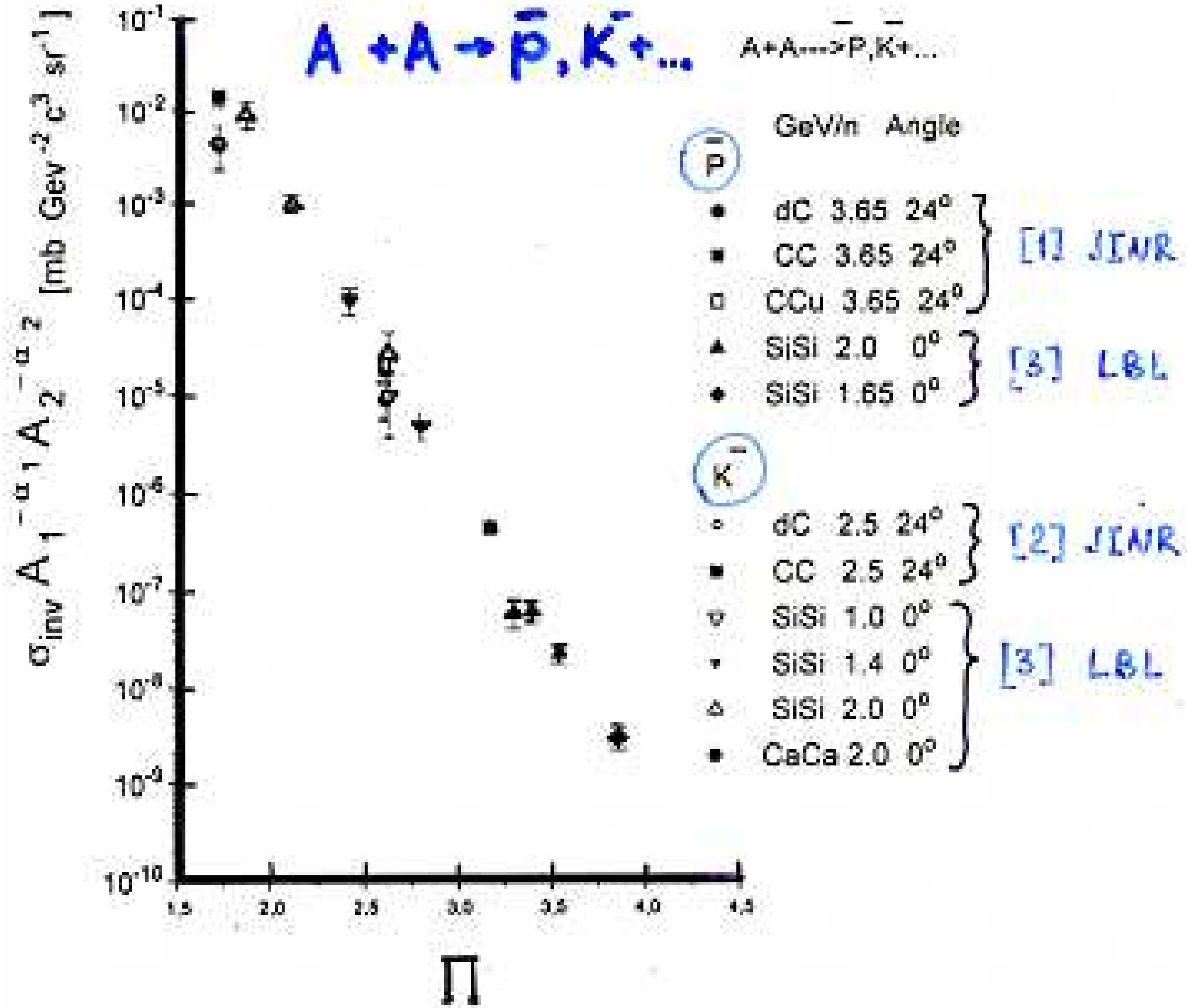
where $\alpha(N_I) = 1/3 + N_I/3, \quad \alpha(N_{II}) = 1/3 + N_{II}/3,$

$$C_1 = 1.9\cdot 10^4 mb\ GeV^{-2} c^3 st^{-1} \text{ и } C_2 = 0.125 \pm 0,002$$

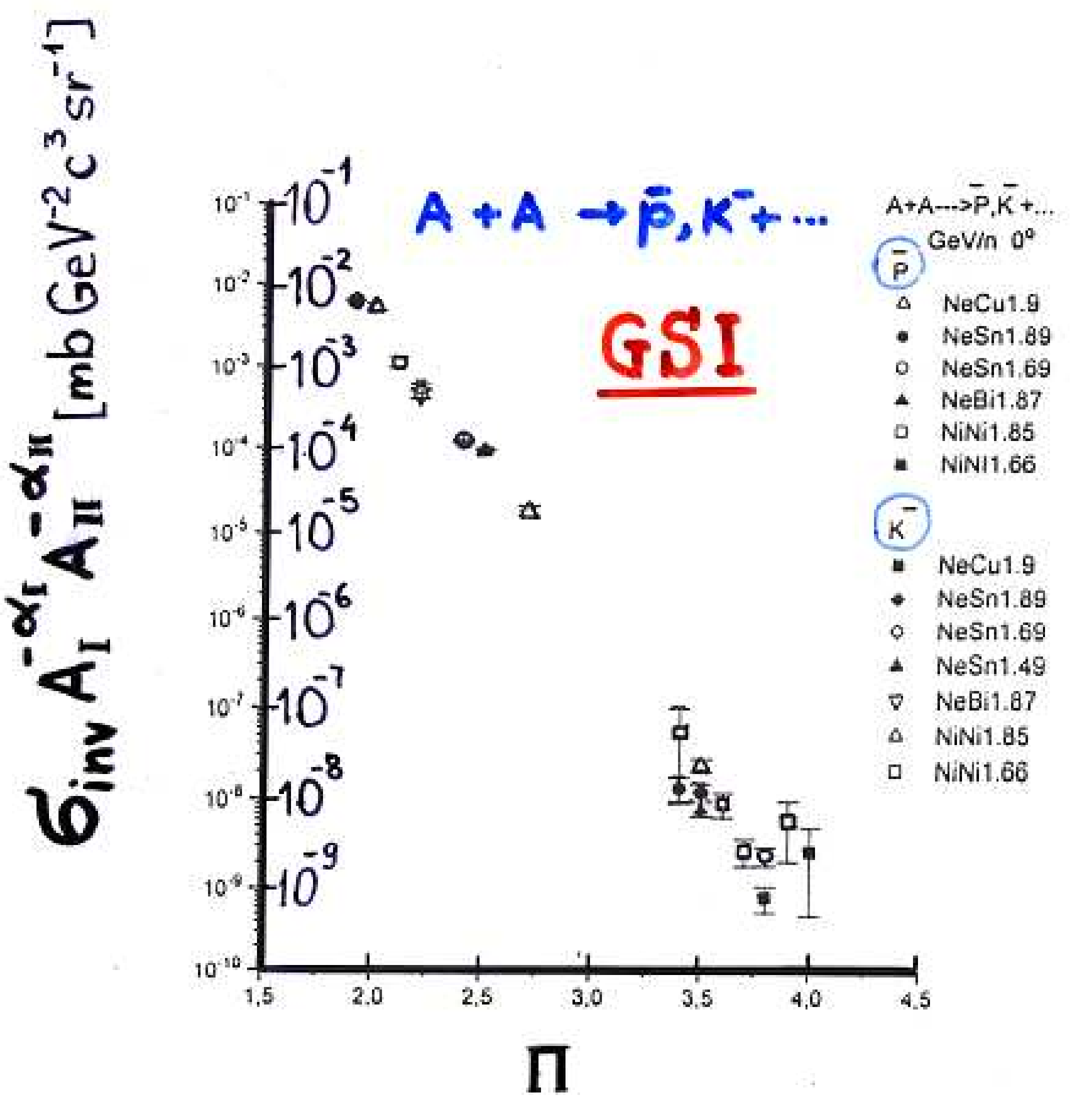


The experimental data on cumulative pion production were obtained at the ITEP and IHEP accelerators in dependence on similarity parameter Π. The experimental data are normed on A dependences.

A.M.Baldin, A.A.Baldin. Phys. Particles and Nuclei, v.29, No.3 (1988) p.232.



A.M.Baldin, A.A.Baldin. Phys. Particles and Nuclei, v.29, No.3 (1988) p.232.

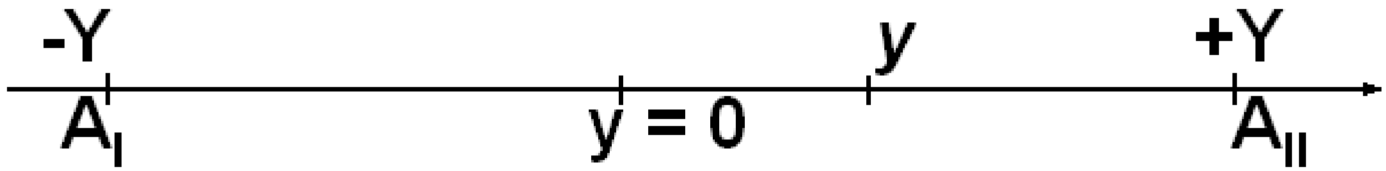


A.M.Baldin, A.A.Baldin. Phys. Particles and Nuclei, v.29, No.3 (1988) p.232.

$$\Pi^{min} \Rightarrow d\Pi/dN_I = 0; \quad d\Pi/dN_{II} = 0$$

In the central rapidity region ($y = 0$)

$$(u_1 u_I) = (u_1 u_{II})$$



$$N_I = N_{II} =$$

$$N = [1 + \sqrt{1 + (\Phi_\delta/\Phi^2)}]\Phi,$$

where

$$\Phi = (1/m_0)[m_T chY + \Delta](½\, sh^2Y)$$

$$\Phi_\delta = (\Delta^2 - m_1^2)(4m_0^2\, sh^2Y)$$

and

$$\Pi^{min} = N \cdot chY$$

$$\Pi_{min} = \min\left[1/2\sqrt{(u_I N_I + u_{II} N_{II})^2}\right]$$

$$(N_I m_0 u_I + N_{II} u_{II} m_0 - m_1 u_1)^2 = (N_I m_0 + N_{II} m_0 + \Delta)^2$$

$$N_I \cdot N_{II} - \Phi_I N_I - \Phi_{II} N_{II} = \Phi_\delta ,$$

$$\Phi_I = [(m_1/m_0)\cdot(u_I u_1) + \Delta/m_0]/[(u_I u_{II}) - 1]$$

$$\Phi_{II} = [(m_1/m_0)\cdot(u_{II} u_1) + \Delta/m_0]/[(u_I u_{II}) - 1]$$

$$\Phi_\delta = (\Delta^2 - m_1^2)/[2m_0^2((u_I u_{II}) - 1)].$$

$$[(N_I/\Phi_{II}) - 1]\cdot[(N_{II}/\Phi_I) - 1] = 1 + [\Phi_\delta/(\Phi_I \cdot \Phi_{II})]$$

$$d\Pi/dN_I = 0 , \quad d\Pi/dN_{II} = 0.$$

$$F_I = [(N_I/\Phi_{II}) - 1] , \qquad F_{II} = [(N_{II}/\Phi_I) - 1].$$

$$F_I \cdot F_{II} = 1 + \Phi_\delta/(\Phi_I \cdot \Phi_{II}) = \alpha$$

$$d\Pi/dF_I = 0 , \quad d\Pi/dF_{II} = 0.$$

$$4\Pi^2 = N_I^2 + N_{II}^2 + 2N_I \cdot N_{II} \cdot (u_I u_{II})$$

$$4\Pi^2 = (F_I + 1)^2 \Phi_{II}^2 + (F_{II} + 1)^2 \Phi_I^2 + 2\Phi_I \cdot \Phi_{II} \cdot (F_I + 1) \cdot (F_{II} + 1) \cdot (u_I u_{II})$$

$$F_{II} = \alpha/F_I \qquad d(4\Pi^2)/dF_I = 0$$

$$F_I^4 + F_I^3[1 + (u_I u_{II})/z] - (\alpha/z) \cdot F_I \cdot [(u_I u_{II}) + (1/z)] - \alpha^2/z^2 = 0$$

$z = \Phi_{II}/\Phi_I$

$I \leftrightarrow II$: $z \rightarrow (1/z)$; $F_I \rightarrow (\alpha/F_{II})$.

$$F_{II}^4 + F_{II}^3[1 + (u_I u_{II})z] - z \cdot \alpha \cdot F_{II} \cdot [z + (u_I u_{II})] - \alpha^2 z^2 = 0.$$

In the central rapidity region $(u_1 u_I) = (u_1 u_{II}) \rightarrow \quad z = 1 \rightarrow$

$$F_I = F_{II}, \ \Phi_I = \Phi_{II} = \Phi$$

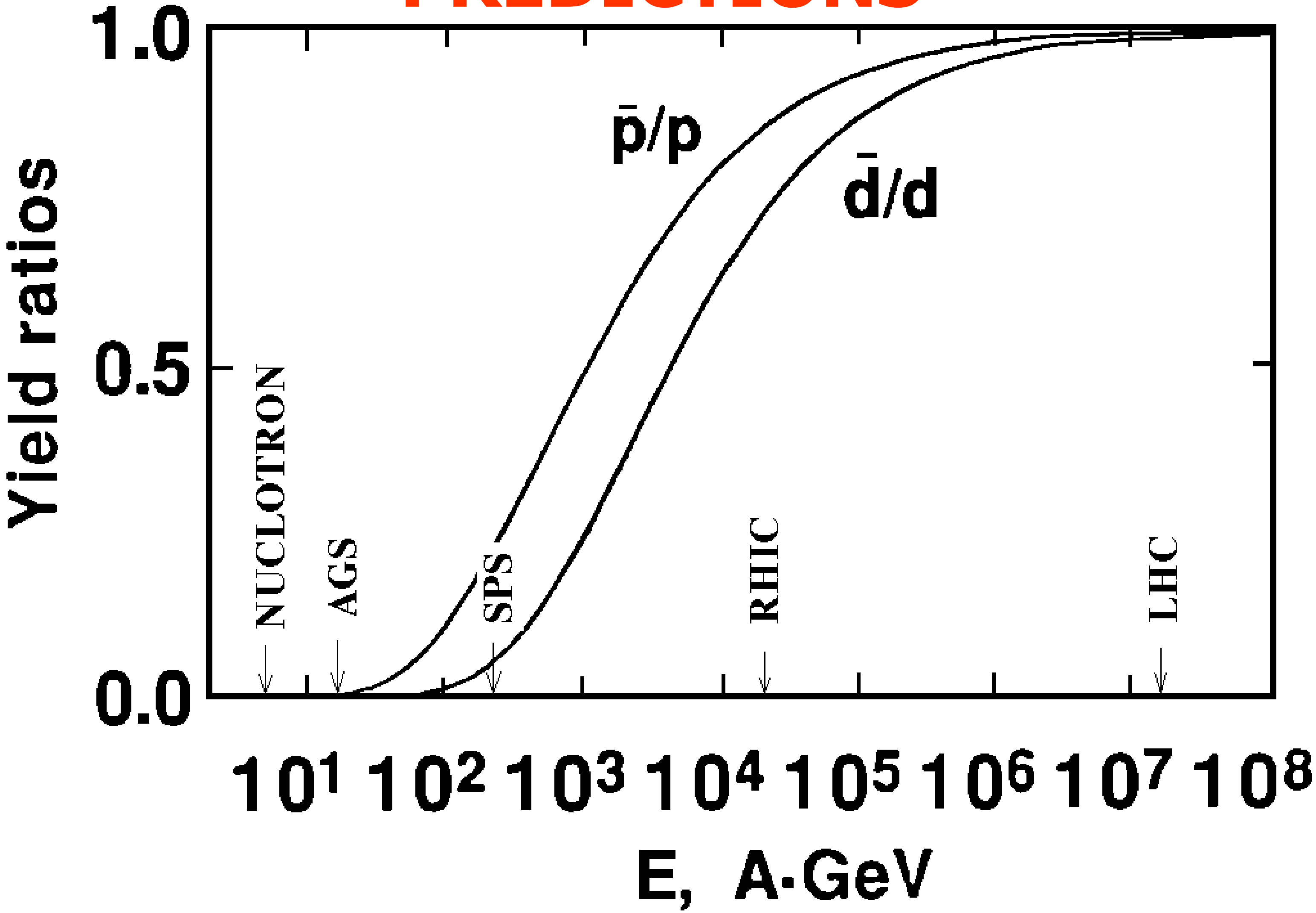
$$F_I = F_{II}, \ (N_I/\Phi - 1) = (N_{II}/\Phi - 1), \ N_I = N_{II} = N$$

$$F^2 = \alpha , \ F_I = F_{II} = \sqrt{\alpha} = \sqrt{1 + (\Phi_\delta/\Phi^2)}$$

$$N_I = N_{II} = N = (1+F)\cdot\Phi = [1 + \sqrt{1 + (\Phi_\delta/\Phi^2)}]\cdot\Phi$$

Baldin A.M., Malakhov A.I.
JINR Rapid Communications,
No.1(87)-98, 1998, pp.5-12.

PREDICTIONS



Asymptotics

$$s/(2m_I m_{II}) \approx (u_I u_{II}) = ch2Y \to \infty$$

$$\Pi_\infty^{min} = (m_T/2m_0)[1+ \sqrt{1+(\Delta^2-m_1^2)/m_T^2}$$

$$N_\infty \to 0$$

The analytical representation for Π leads to the following conclusions:

- There is the limit value of Π at high energies
- The ratio of particle to antiparticle and nucleus to antinucleus production cross-section goes to the unit while energy rising
- The effective number of nucleons involved in the reaction decreases with collision energy increasing
- Probability of observation of antinuclei and fragments in the central rapidity region is small

$$\text{Ratio} = \frac{C_1 \cdot A_I^{\alpha(N_I)} \cdot A_{II}^{\alpha(N_{II})} \cdot \exp\left(-\frac{\Pi_1}{C_2}\right)}{C_1 \cdot A_I^{\alpha(N_I)} \cdot A_{II}^{\alpha(N_{II})} \cdot \exp\left(-\frac{\Pi_2}{C_2}\right)} = \exp\left(-\frac{\Pi_1 - \Pi_2}{C_2}\right)$$

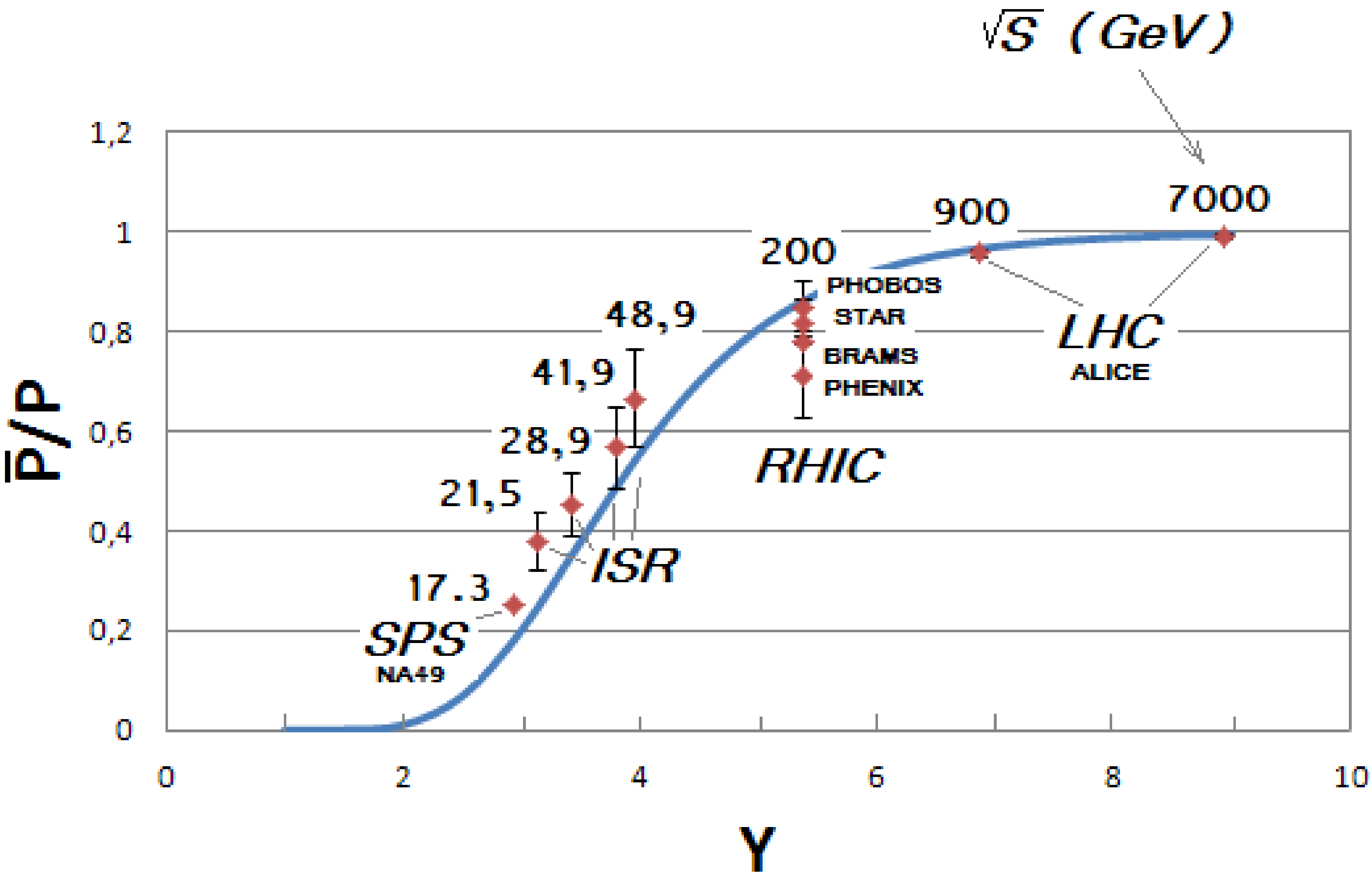
For baryon $\longrightarrow$ $\Pi_1 = \left[\frac{m_{1T}}{m_0} chY - \frac{m_1}{m_0}\right] \frac{chY}{sh^2 Y}$

For antibaryon $\longrightarrow$ $\Pi_2 = \left[\frac{m_{1T}}{m_0} chY + \frac{m_1}{m_0}\right] \frac{chY}{sh^2 Y}$

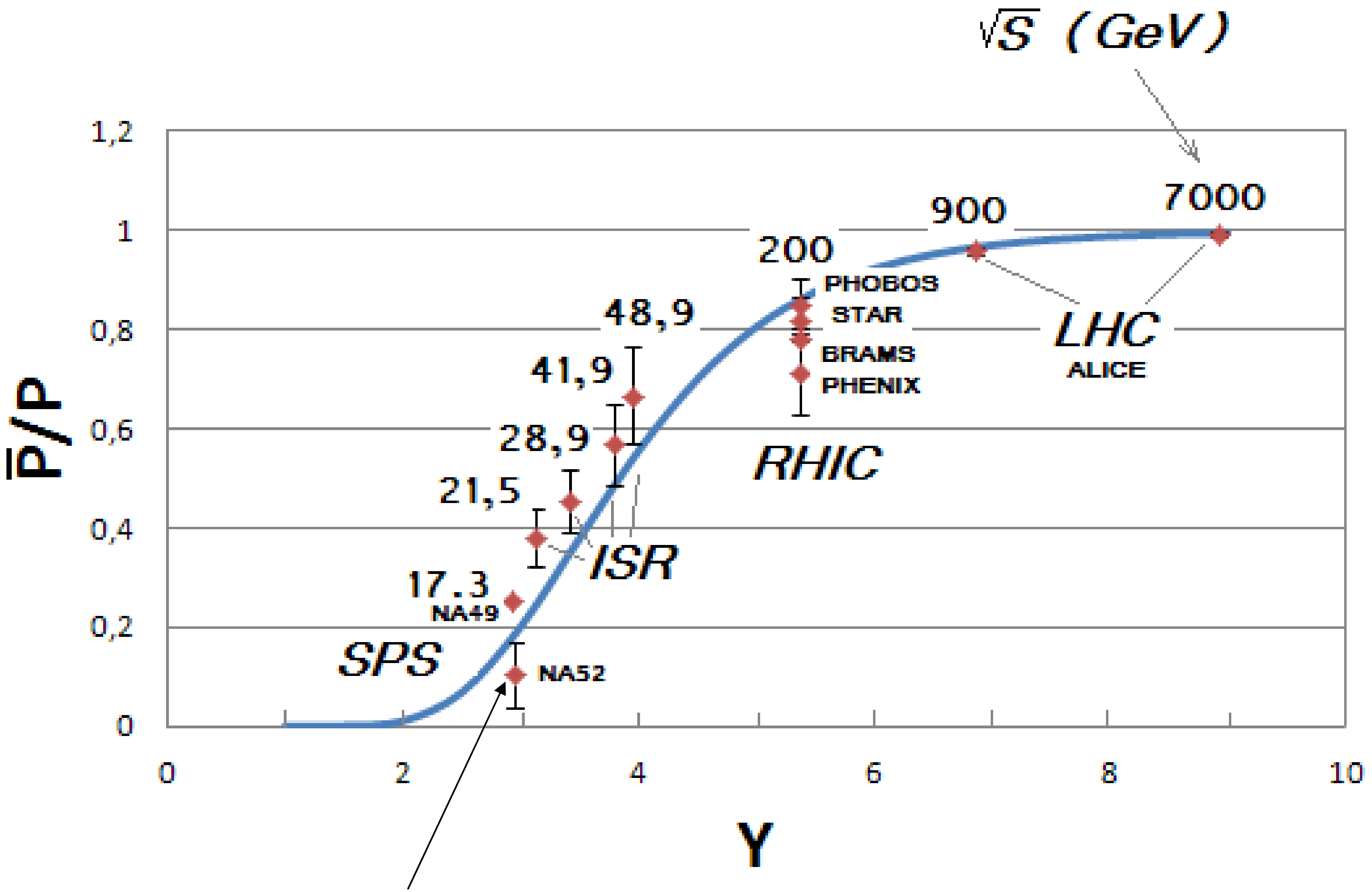
$$\Pi_1 - \Pi_2 = \left[\cancel{\frac{m_{1T}}{m_0} chY} - \frac{m_1}{m_0}\right] \frac{chY}{sh^2 Y} - \left[\cancel{\frac{m_{1T}}{m_0} chY} + \frac{m_1}{m_0}\right] \frac{chY}{sh^2 Y} = -2 \frac{m_1}{m_0} \frac{chY}{sh^2 Y}$$

$$\boxed{\Pi_1 - \Pi_2 = -2 \frac{m_1}{m_0} \frac{chY}{sh^2 Y}}$$

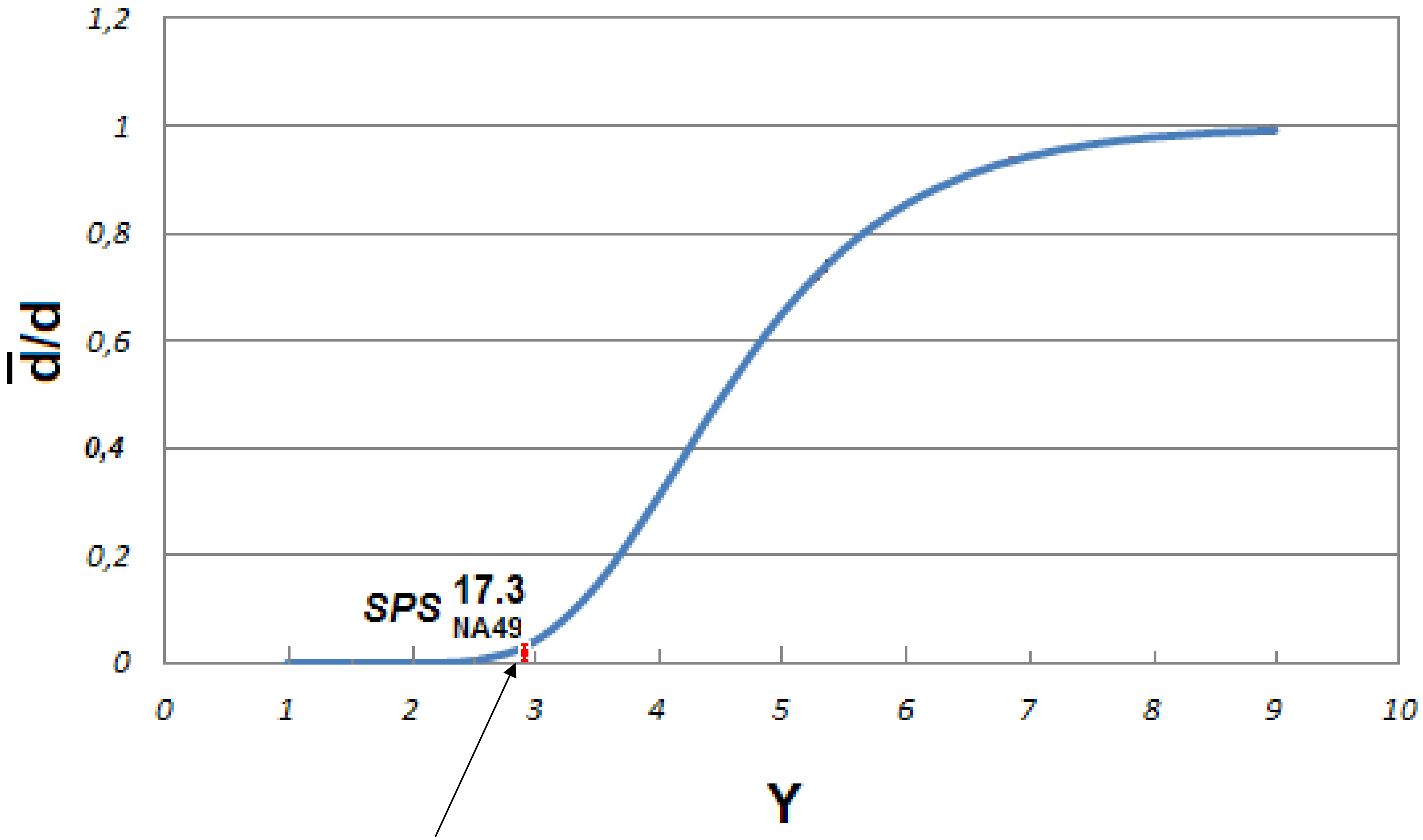
$$\textbf{Ratio (Antibaryon/baryon)} = \exp\left(-2 \frac{m_1}{m_0} \frac{chY}{sh^2 Y} \right)$$



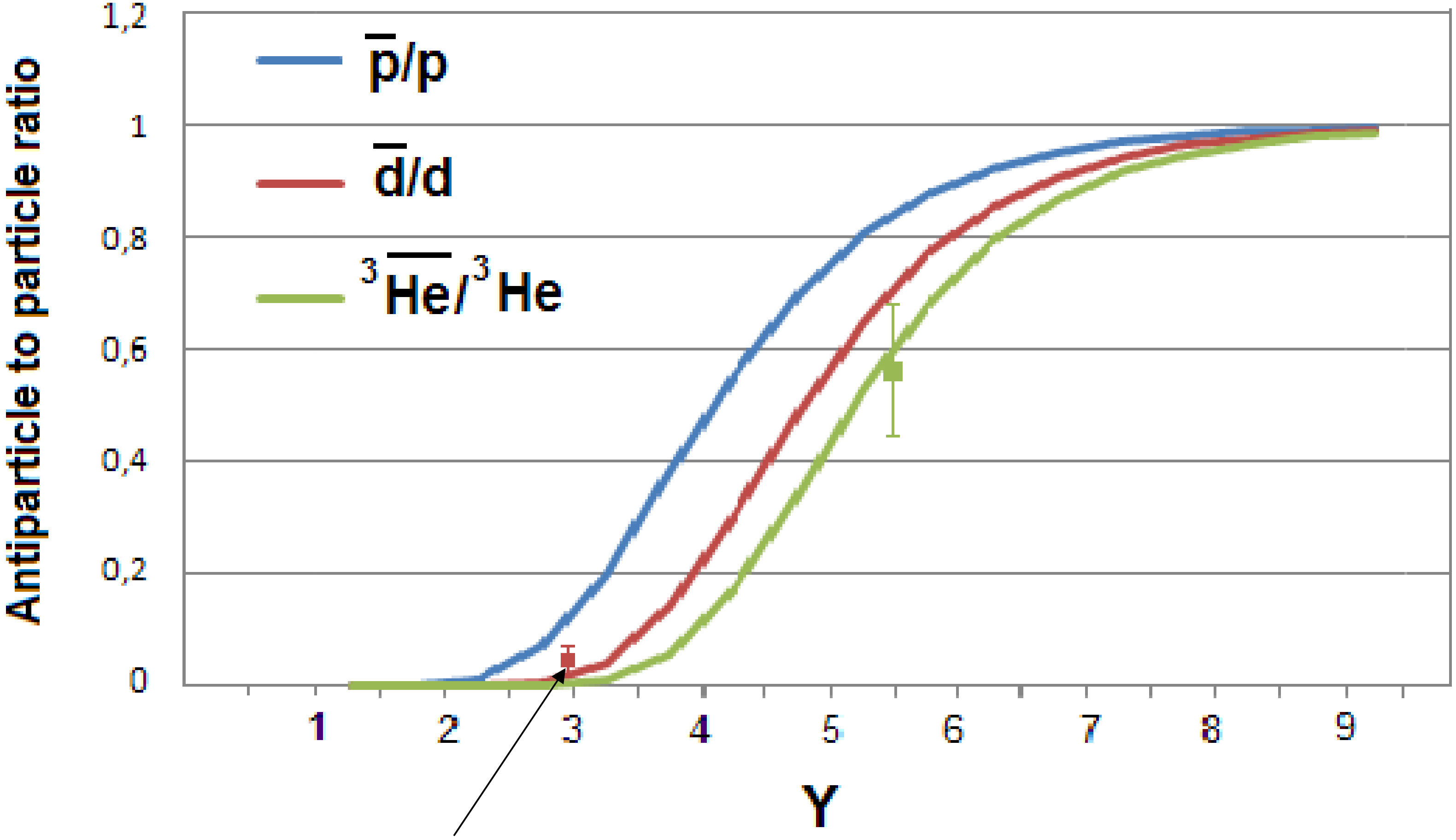
◆ — Nuclear Physics A 859(2011) 63-72.
http://hepdata.cedar.ac.uk/view/p7907.



Nuclear Physics A610 (1996) 306c-316c (SPS, NA52).



Physical Review C 85 (2012) 044913 (SPS, NA49).



Physical Review C 85 (2012) 044913 (SPS, NA49).

Conclusion

The description of the nuclear interactions in the four-velocity space and introduction of the self-similarity parameter allows one to predict the secondary particles production in a wide energy range from several GeV to the LHC energy with a good accuracy.

Thank you for the attention!