Stopping of
protons in pA collisions at SPS and NICA energies in analytical hydrodynamic model and in SMASH event generator

V.Ermakova, G.Feofilov, V.Sandul, V.Kovalenko, V.Vechernin, A.Puchkov

Saint Petersburg State University (Laboratory of Ultra-High Energy Physics)

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Motivation

Our study is motivated by the first experimental results on pion production and stopping obtained in p-A collisions in E910 experiment at BNL [1]. The effect of stopping is the deceleration of an incident high energy proton traversing the target nucleus. It appears due to the energy losses relevant to the production of secondary particles in the inelastic interactions with nucleons.

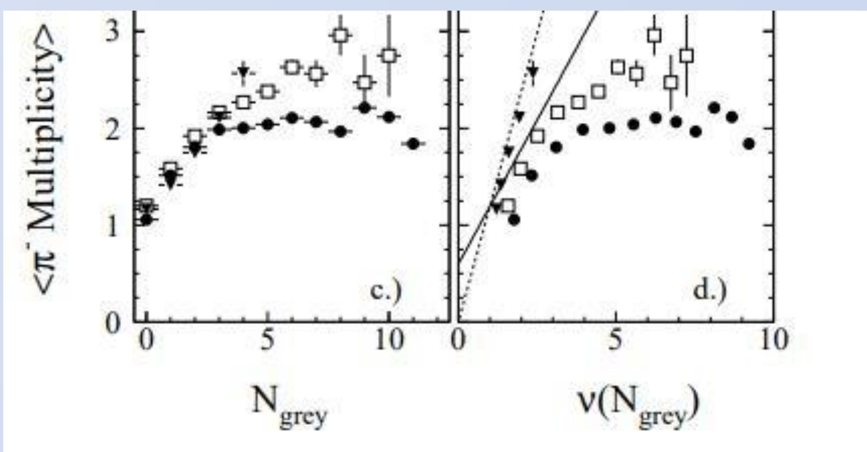

Fig.2. Multiplicity vs. number of "grey nucleons" (N_grey) and number of binary collisions ($\nu(N\_grey)$) in p-A collisions at 18 GeV/c[1]

Our hydrodynamic model of proton stopping

The idea is to treat the target nucleus as a **liquid drop** with momentum tensor

$$T^{\alpha\beta} = \begin{pmatrix} \varepsilon & 0 & 0 & 0 \\ 0 & p & 0 & 0 \\ 0 & 0 & p & 0 \\ 0 & 0 & 0 & p \end{pmatrix}$$

$\varepsilon = \frac{M}{V}$ — M: mass of target; V: volume of target

$p = 0$ — static pressure

In any other system, where liquid moves with the speed v: $T^{ik} = \frac{\varepsilon v^i v^k}{1 - v^2}$ [2] L. D. Landau, E. M. Lifshitz (1986)

Liquid acts on the body with the force $dF^i = T^{ik} df_k$

This force is the same in magnitude for the opposite case when the body moves through the liquid at rest, so that It's projection on z-axis is:

$$\boldsymbol{F = -\frac{1}{1 - v^2}\varepsilon v^2 S}$$

$v = v(t)$ - speed of proton,
S - transverse area of proton

Newton's law for projectile:

$m\vec{a}\gamma + m\vec{v}(\vec{v}\vec{a})\gamma^3 = \vec{F} \Rightarrow v(t)$

Speed of the «stop» V_0 (when become gray) =>

$\boldsymbol{l}$ **– the length of the proton's path in the nucleus => $\boldsymbol{\Omega}$**

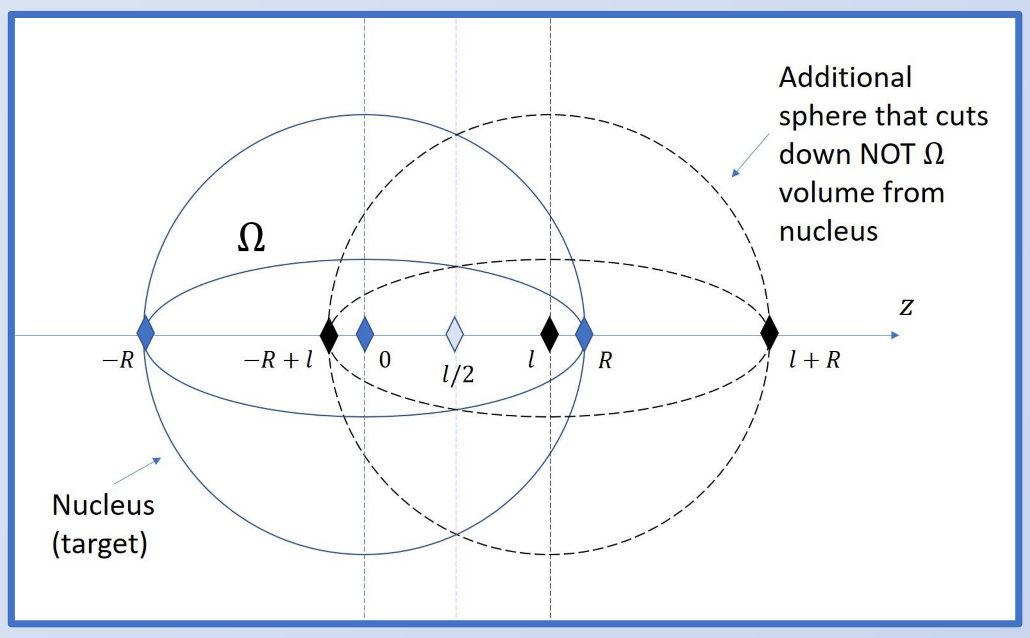

Fig.3. $\Omega = S(R, 0) - S_1(R, l + R)$

◆ $$\sigma_{inel}^{NN} T(b) = \int_{\Omega} \rho(z, \boldsymbol{b_A}) \delta(\boldsymbol{b} - \boldsymbol{b_A}) dz\, d\boldsymbol{b_A} \sigma_{inel}^{NN}$$

- probability to have ONE baryon-baryon inelastic collision when proton and target situated at an impact parameter $\boldsymbol{b}$ relative to each other

◆ $$P(n, b) = C_A^n \left(\sigma_{inel}^{NN} T(b)\right)^n \left(1 - \sigma_{inel}^{NN} T(b)\right)^{A-n}$$

- probability to have n baryon-baryon inelastic collision when proton and target situated at an impact parameter $\boldsymbol{b}$ relative to each other

◆ $$N_{bin}(\boldsymbol{b}) = \sum_{i=1}^{A} nP(n, \boldsymbol{b})$$ [3] Cheuk-Yin Wong (1994)

- average number on inelastic baryon-baryon collisions at an impact parameter $\boldsymbol{b}$

◆ $$N_{ch} = \sum_{i=1}^{N} N_{ch}^{pp}(v_i) * \Delta N_{bin}(v_i|\boldsymbol{b}) * Q^{\sum_{k=1}^{i} \Delta N_{bin}(v_k|\boldsymbol{b})}$$ **!**

- average multiplicity considering acceptance

$$N_{ch}^{pp}(s_{NN}) = a + b * \log(s_{NN}) + c(\log(s_{NN}))^2$$

[4] W.Thomé, K.Eggert, K.Gibini [etc.], (1997)

$\Delta N_{bin}(v_i|\boldsymbol{b})$ - number of binary collisions that happened while proton was decelerating from v_i to v_{i+1}

Q – probability to detect multiplicity that we got from ONE inelastic binary collision.

In fact, this is an integral that was written in a discrete form for better understanding. **!**

Compare with MC event-generators

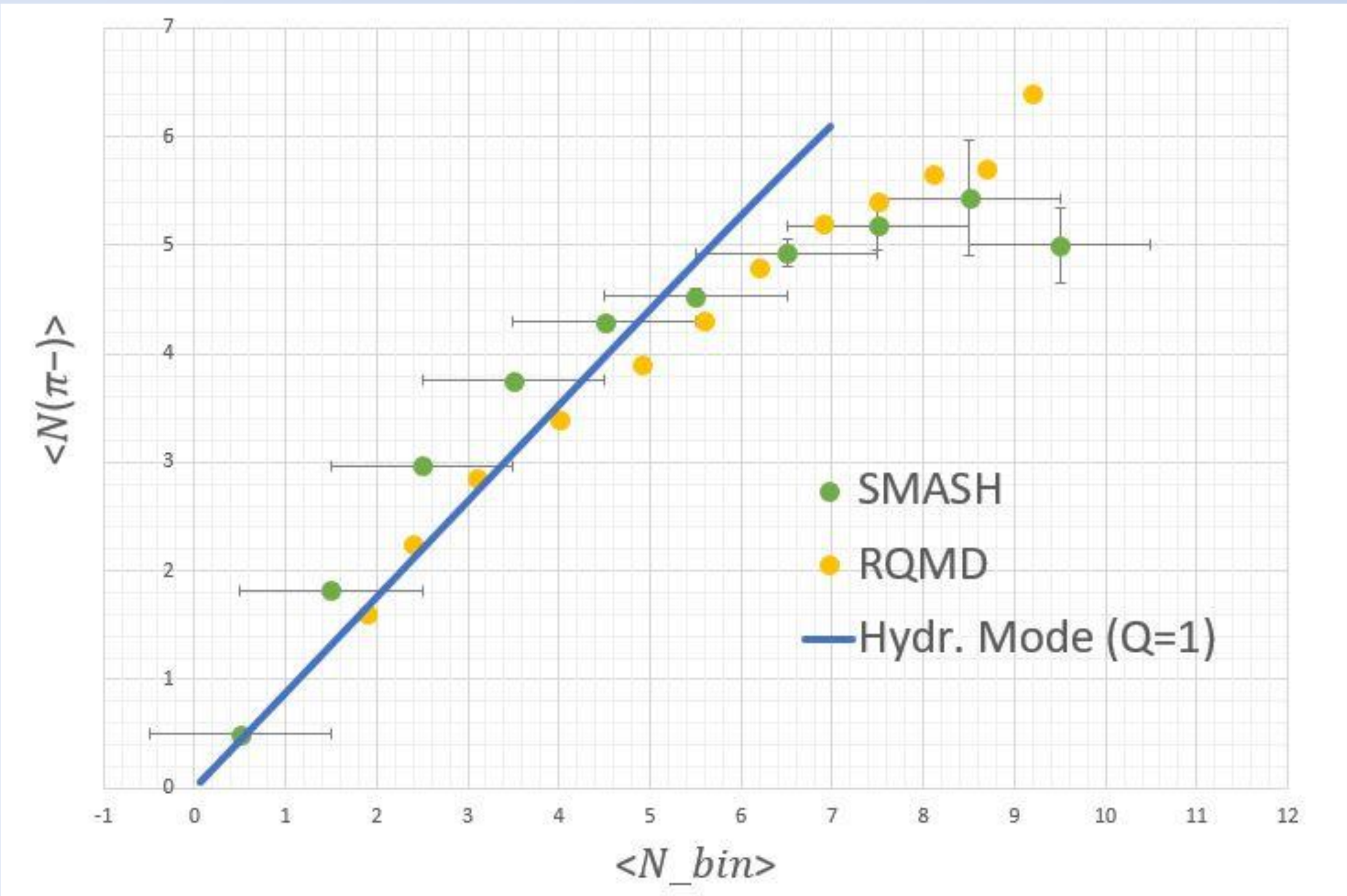

Fig.4 Results of Effective Hydrodynamics Model calculations for the full acceptance of pion multiplicity vs. number of binary collisions obtained for p-Au collisions at 18 GeV/c in comparison to our SMASH [5] MC data and to the RQMD results taken from [1]. Each point on our model graph corresponds to some impact parameter.

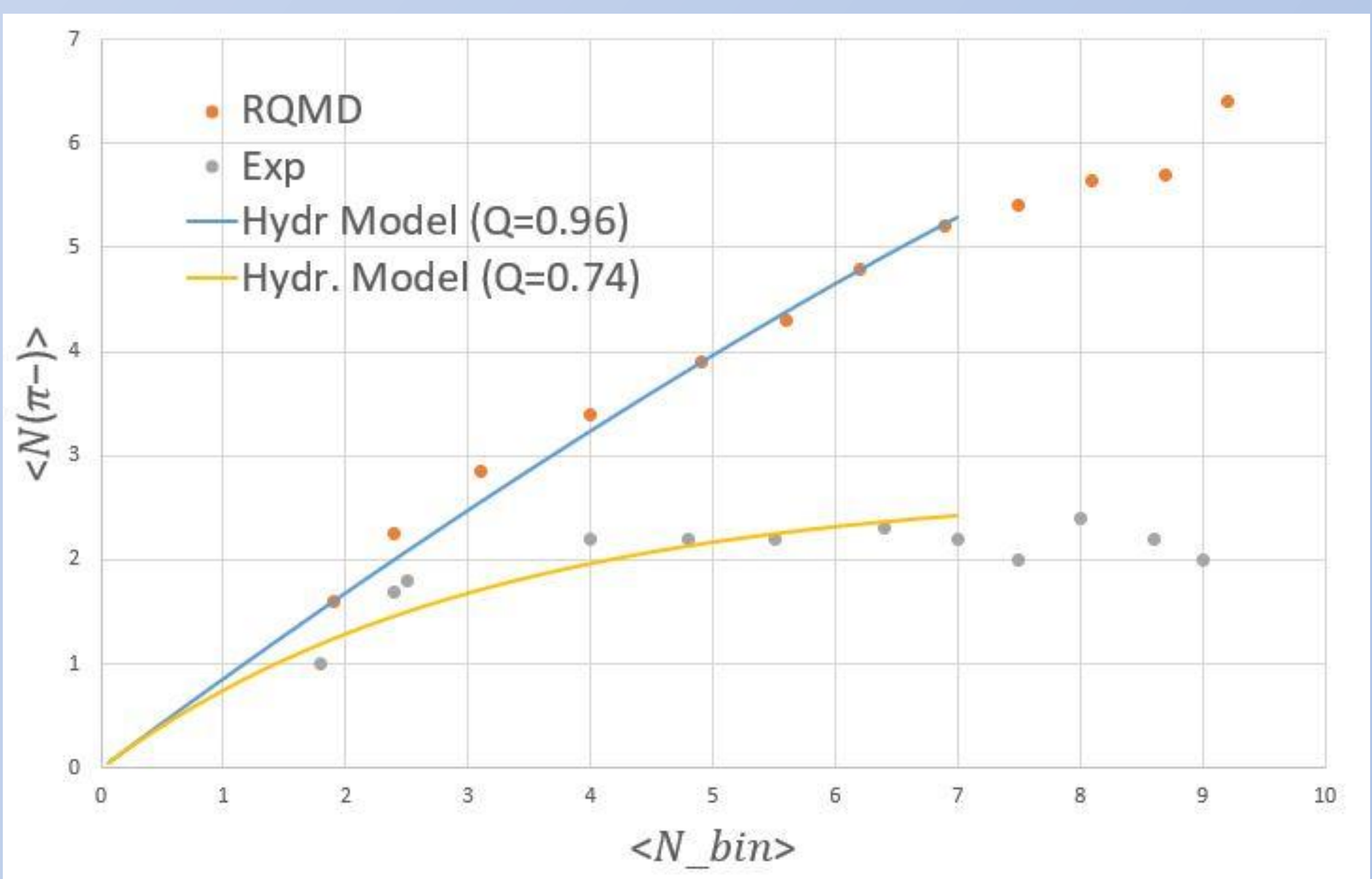

Fig.5 The same calculations but for the case for the limited acceptance. The effect of the last one is taken into account by a factor Q. Gray point represent experimental data and red points represent RQMD results [1].

Conclusion

- A new hydrodynamic model of nucleon stopping that describes the deceleration of a proton in a nucleus and based on hydrodynamics is proposed. No fitting coefficients are required.
- The linear dependences for the p-A collisions were obtained. This is in line with experiment on p-Au collisions at p_lab = 18 GeV/c in the first approximation. Similar dependence is demonstrated by the MC models RQMD an d SMASH.
- The non-linear behavior of multiplicity vs. number of binary collisions - description is found to be a result of limited acceptance of the experimental data.
- Results of these studies of nucleon stopping are important for the future analysis of centrality selection in p-A and A-A collisions at NICA experiments.

Bibliography

[1] I. Chemakin et al., arXiv:nucl-ex/9902009

[2] L. D. Landau, E. M. Lifshitz (1986) / Fluid Mechanics // Theoretical Phisics: V.6 3rd Ed. Moscow: "Nauka"

[3] Cheuk-Yin Wong (1994) / Glauber Model of Nucleus-Nucleus Collision // Intoduction to High-Energy Heavy-Ion Collisions. Singapore: World Scientific Publishing Cu. Pte. Ltd.

[4] Charged particle multiplicity distributions in pp collisions at ISR energies (1997) / W.Thomé, K.Eggert, K.Gibini [etc.] // Nuclear Physics B129. P. 365-389. doi:10.1016/0550-3213(77)90122-5

[5] Particle production and equilibrium properties within a new hadron transport approach for heavy-ion collisions (2017) / J. Weil, V. Steinberg, J. Staudenmaier [etc] // Phys. Rev. C 94, 054906. doi:10.1103/PhysRevC.94.054905