HADRON–NUCLEUS INTERACTIONS FROM AGS TO SPS*

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Experimental data on hadron–nucleus interactions in the energy range from AGS to SPS are reviewed. Emphasis is put on a comparison with both hadron–hadron and nucleus–nucleus collisions data. Arguments for an extension of hadron–nucleus collision programme into the RHIC domain are given.

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1. Introduction

Nowadays a study of high energy nuclear collisions concentrates mainly on colliding heavy nuclei, preferably symmetric. For a reference, most often also a symmetric case of proton–proton collisions is analysed. One may ask — why study hadron–nucleus collisions, where many intrinsic difficulties result from the inherent asymmetry of the system. A justification may be twofold. First, a question 'how does a multi-collision process look like' might be answered via a study of the target part of the hadron–nucleus collision. Secondly, and I think this is the most important subject, a question 'what is the fate of an incident hadron struck many times' can be answered from the analysis of the projectile part.

In the following I will deal with the following subjects: First, a shortened history of most important findings from the analysis of hadron–nucleus experiments will be given. Then the data from high statistics and good particle identification experiments, at AGS and SPS, will be presented. I will concentrate on the strangeness production, and baryon/antibaryon production.

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2. History

It is a general knowledge, gained from emulsion experiments [1], that the average multiplicity of fast ($\beta > 0.7$) charged particles (mostly pions, so called 'shower tracks', $n_{\rm s}$) produced in the collision of high energy hadron in nuclear emulsion, grows proportionally to the number of so called 'grey' protons. 'Grey' protons (named after medium ionising tracks they leave in emulsion) are mostly the 'knock-out' protons, resulting from the interactions of projectile inside a nuclear target. The number of grey protons can be used to evaluate the number of projectile collisions inside the target. Fig. 1 shows a schematic drawing of such process [2].

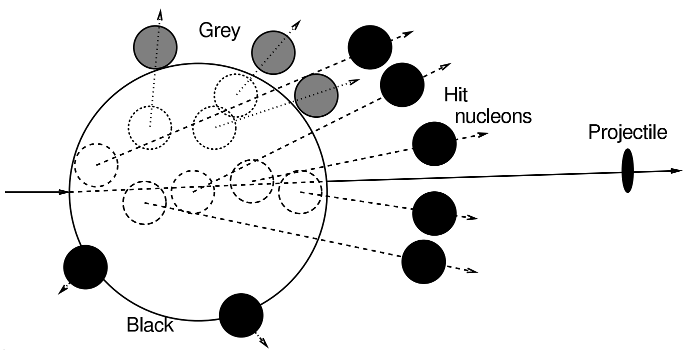


Fig. 1. Sketch of a p–A reaction, with nucleons categorised by momentum (from [2]).

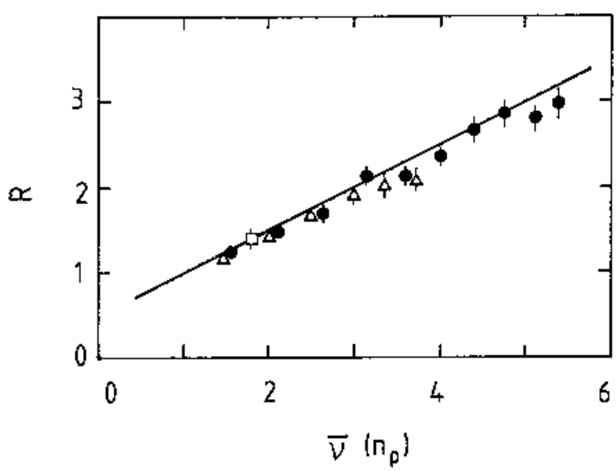


Fig. 2. Ratio R of charged particle multiplicity as a function of the number of collisions in p–Ar and p–Xe collisions at 200 GeV/c.

The translation of the number of grey protons, $n_{\rm g}$, into the number of collisions, ν is usually performed assuming independent collisions inside the target nucleus, and a Glauber model. As an illustration, Fig. 2 shows the (measured in the NA5 experiment, with protons on argon and xenon targets, [3]) proportionality between the ratio R of the average multiplicity of $n_{\rm s}$ tracks to a corresponding multiplicity in proton–proton collisions and ν. It is worth stressing that the value of ν is calculated for a given interval of $n_{\rm g}$, thus enlarging the scope of ν available in 'minimum bias', that is — all inelastic sample for a given target mass number, characterised by an average value of ν.

3. AGS results on strangeness

Nowadays experiments on hadron–nucleus collisions employ such detection techniques as to assure wide phase space coverage, high statistics and good particle identification.

The E910 experiment at the Brookhaven National Laboratory studies particle production in proton–gold collisions at 17.5 GeV/c. Data on neutral strange particles (Λ and K^0), charged kaons and cascade hyperons (Ξ^0) are available ([4] and references quoted therein).

An important factor in the analysis of such data is the possibility of triggering (off line) on the number of slow protons (an analogue of emulsion 'grey' protons). This allows for a selection of interactions in different centrality classes, characterised by different numbers of collisions, ν. Often another quantity, a number of participants, or nucleons participating in the collision is used. For hadron–nucleus interactions $N_{\rm part} = (1+\nu)$. Often a term 'number of wounded nucleons' is also used, $N_{\rm W}$, where a wounded nucleon is a nucleon that has interacted at least once.

At the AGS energy, the rapidity range in the nucleon–nucleon system extends from -1.6 to 1.6. This does not allow for a distinct separation of the target and projectile region, which largely overlap.

Fig. 3 shows the average multiplicity of the Λ hyperons produced in the collisions of 17.5 GeV/c protons with a gold target, [6], as a function of the number of collisions, ν, evaluated from the number of grey protons, $n_{\rm g}$. For comparison, a straight line derived from the Wounded Nucleon Model WNM [5] is shown. In this model, the number of produced particles is given by a simple scaling from the elementary collisions:

$$N_{\rm prod} = \tfrac{1}{2} N_{pp\ {\rm prod}}(1+\nu)\,.$$

An increase of the average Λ multiplicity with the number of participant nucleons is observed, with some excess over the WNM prediction. This increase seems to saturate above ν of about 6.

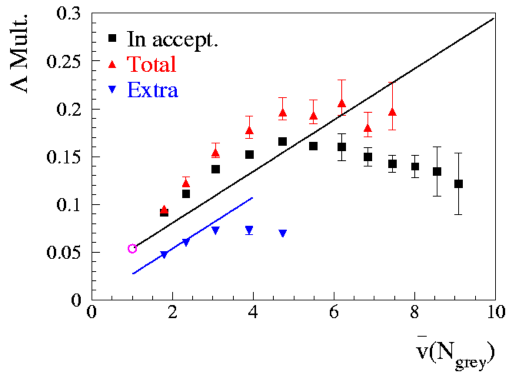


Fig. 3. Average Λ multiplicity from p–Au collisions at 17.5 GeV/c as a function of the number of collisions.

A similar trend is observed in a preliminary data on charged kaons from the same reaction. Fig. 4 displays an increase of the average charged kaon multiplicity with the number of collisions, even stronger than for the Λ, again saturating and dropping down for higher ν.

New data on Ξ production in proton–gold collisions is now available. Fig. 5 shows the rapidity distributions of Ξ for various centrality samples, (upper panel) and the lower panel — the average Ξ multiplicity as a function of the number of collisions. Here for ν values up to 3 an increase is definitely faster than a simple participant scaling. Incidentally, this fast increase allows for a reasonable extrapolation, describing the Ξ production in Au–Au collisions at AGS [4].

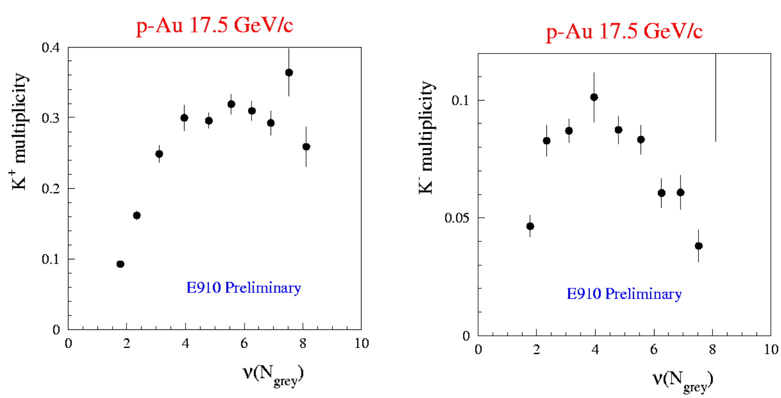
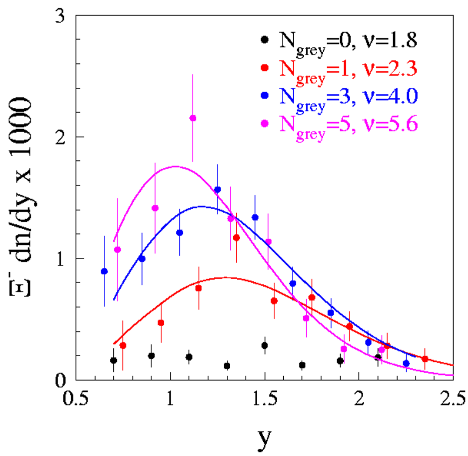


Fig. 4. Average charged kaon multiplicity as a function of the number of collisions from 17.5 GeV/c p–Au .



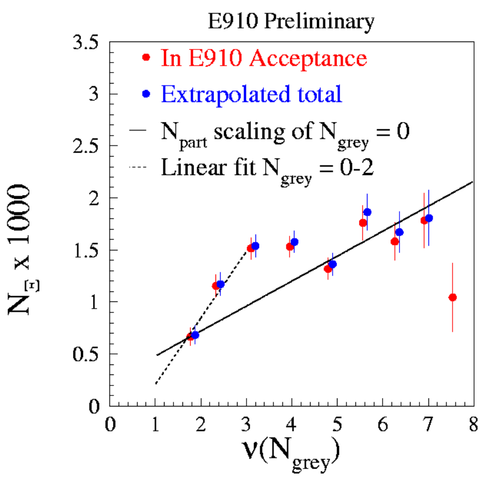


Fig. 5. The rapidity distribution (upper panel) and average multiplicity (lower panel) of Ξ hyperons from 17.5 GeV/v p–Au collisions as a function of the number of collisions.

4. SPS results on strangeness

Data on strangeness production in hadron–nucleus collisions from the SPS accelerator at CERN come mainly from two experiments, NA49 [7] and WA97 [8]. Both study particle production in the collisions of 158 GeV/c protons with lead target. At this energy the rapidity for nucleon–nucleon system extends from -2.9 to 2.9, and the target and projectile domain can be separated.

The WA97 experiment covers approximately one unit of rapidity around the midrapidity. NA49 acceptance extends over most of the forward hemisphere.

4.1. Charged kaon production

Charged kaon production in the forward c.m. hemisphere of a p–Pb collision has been studied in the NA49 experiment. The kaon identification comes from multiple ionisation sampling in time projection chambers, supplemented by the time of flight detectors. A selection of different centrality classes has been performed on-line, triggering on the number of slow ('grey') protons. It is perhaps worth stressing that the distributions of the actual number of collisions, ν, for minimum-bias and centrality selected samples in p–Pb collisions look very different, as illustrated in Fig. 6 from [9].

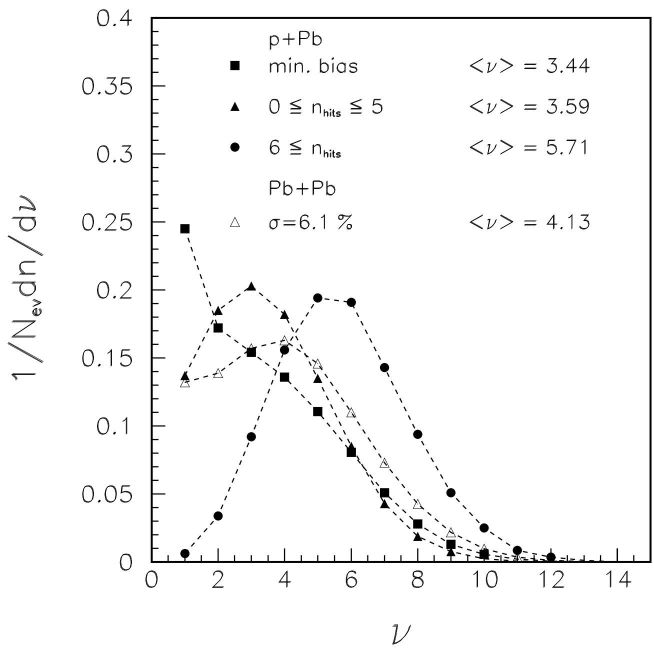


Fig. 6. The distribution of the number of collisions for different centrality selections of p–Pb and Pb–Pb reactions at 158 GeV/c.

Fig. 7 ([7]) compares the average multiplicity of various particle species in nucleus–nucleus and proton–nucleus collisions as a function of the number of participants (for A–A) and the number of collisions (for p–A). Notice that the yields are normalised to the average charged pion yields. A clear increase in the number of kaons per pion in both types of reactions is observed with increasing centrality — albeit in a different scale.

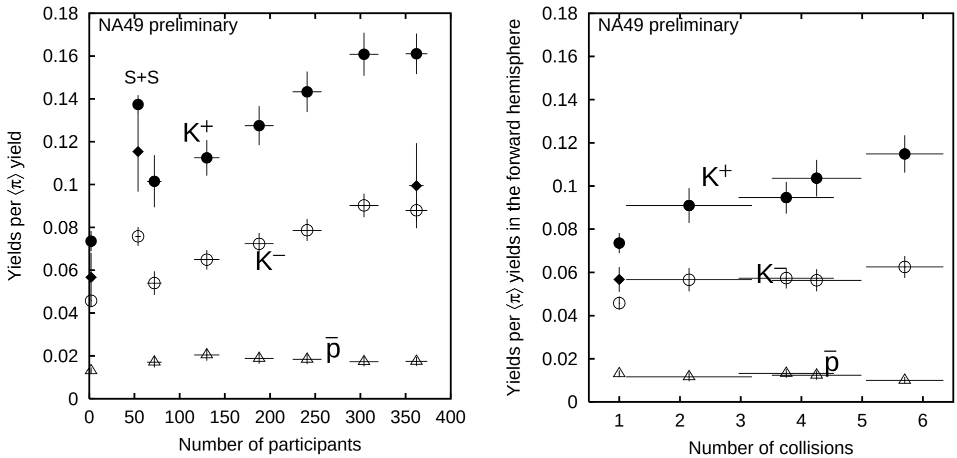


Fig. 7. Average total yields of different particle species (normalised to the average number of charged pions) as a function of the number of participants in Pb–Pb (left panel) and average total yields in the forward c.m. hemisphere, normalised to the average number of charged pions, as a function of the number of collisions for p–Pb.

A more detailed insight is obtained from the study of the longitudinal distribution of this enhancement. Figs. 8 show the K/π ratios in p–Pb collisions, normalized to the same ratio in p–p collisions, for positive and negative kaons. Notice that the longitudinal distribution, in the Feynman x variable, refers to the forward hemisphere only. Both Fritjof and Venus model predictions fail to describe these data.

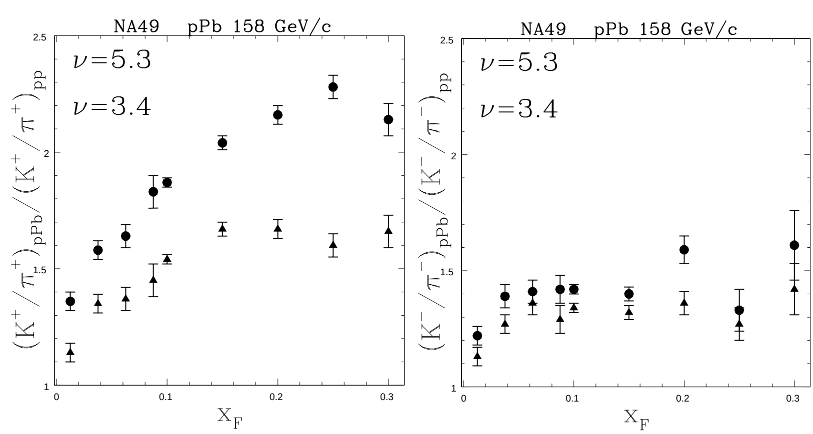


Fig. 8. Preliminary results of NA49 on charged kaon multiplicity as a function of the Feynman x variable for two centrality classes of p–Pb reactions at 158 GeV/c.

These figures illustrate the centrality dependence of the charged kaon enhancement in p–Pb collisions, as a function of the $x_{\rm F}$. The ν values have been evaluated for two samples with different triggers on the number of grey protons.

For the $x_{\rm F}$ values above 0.1, we observe a sizable enhancement (as compared to p–p)for both positive and negative kaons. This enhancement decreases towards $x = 0$, where apparently the target contribution starts to dominate. Comparing charged kaon/pion ratios in p–p, p–A and AA collisions, one should be aware of the isospin effects. The K^+ is paired with K^0, not a K^-. And in p–p collisions the π^+ is 'favoured', π^- 'disfavoured', in n–n collisions — just the opposite. Thus the proton and neutron content in the nucleus does influence the above mentioned ratios. The best approach would be to use $(K^+ + K^-)/(\pi^+ + \pi^-)$.

It is interesting to look at the energy dependence of the K/π ratios in high energy p–A collisions, in comparison to A–A collisions. This is shown in Fig. 9, for midrapidity, where most of the data is available. For the K^+/π^+ ratio the three data points above $\sqrt{s}$ of 5 do not change visibly with energy, similarly to the A–A data points [9].

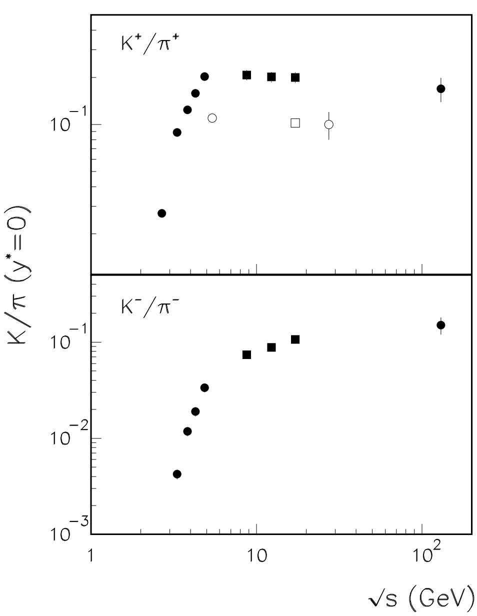


Fig. 9. Energy dependence of midrapidity ratios of charged kaons to pions from nucleus–nucleus collisions, together with three points from hadron–nucleus collisions.

4.2. Hyperon production

Fig. 10 shows the hyperon and antihyperon production rate at midrapidity for p–p, p–Be, p–Pb and Pb–Pb collisions at 158 GeV$/N$, measured for different centralities, from the WA97 and NA49 experiments [10]. The

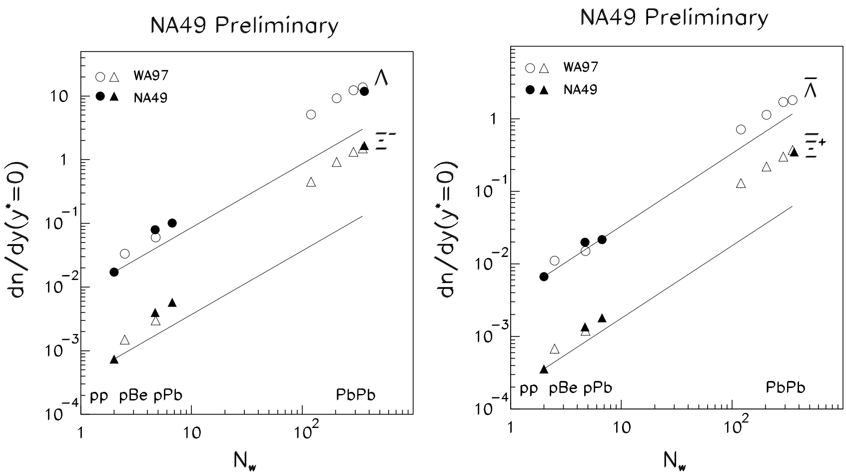


Fig. 10. The average midrapidity yields of hyperons and antihyperons, normalised to the number of participant pairs, from p–p, p–Pb and Pb–Pb collisions of different centralities at 158 GeV$/c$.

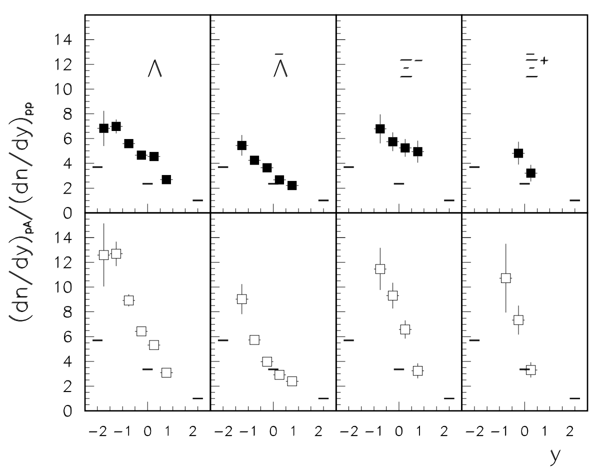


Fig. 11. Ratios of hyperon multiplicities in centrality selected p–Pb and p–p reactions at 158 GeV$/c$. Upper panel — average $\nu = 3.7$, lower panel — average $\nu = 5.7$. Horizontal bars mark Wounded Nucleon Model predictions.

straight lines show the Wounded Nucleon Model prediction, clearly exceeded by the data. Since a p–p reference point (measured in the same experiment) is now available, one can see that the enhancement arises already in proton–nucleus collisions.

It is interesting to study the ratio of rapidity density of the hyperons in p–Pb collisions to the corresponding number in p–p collisions in a wider rapidity range, as illustrated in Fig. 11. In the backward hemisphere there is a strong enhancement with respect to the WNM predictions. At midrapidity the enhancement is still present, stronger for the hyperons than the antihyperons. Once again, an isospin argument should be recalled, which influences Ξ and anti Ξ yields.

5. Antibaryon to baryon ratios

In view of the recent results on net baryon density at RHIC, it is interesting to look at both energy and system size dependence of the antibaryon to baryon ratio (at midrapidity) at the SPS energy, as shown in Fig. 12. Two effects can be seen. First, a systematic lowering of these ratios from

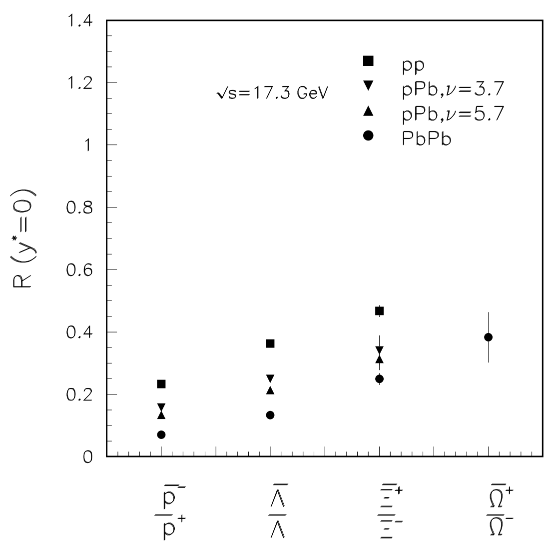


Fig. 12. Midrapidity antibaryon to baryon ratios for different strangeness baryons from p–p, p–Pb and central Pb–Pb interactions at 158 GeV/c.

proton–proton to proton–nucleus to central nucleus–nucleus collisions. Second, an increase of the ratios with the strangeness content of a baryon. In this context, it would be very important to measure the Ω production in proton–proton collisions. One should, however, keep in mind that the antibaryon to baryon ratio should also depend on the isospin composition of the states, and thus in order to compare elementary to nuclear collisions it is again important to measure these ratios also in the neutron channel.

6. Outlook

As is usually the case, the results answer some physics questions, but open up still more new ones. In order to answer, one would like to see new measurements. In particular:

- Measure the K/π and $\bar{B}/B$ ratios at intermediate energy and/or intermediate mass target — in order to look for possible change from 'smooth evolution' to 'rapid onset'.
- Measure the above in a deuteron beam — in order to check the isospin effects.
- Study proton–nucleus collisions at RHIC
  - — for strangeness and (anti)baryons,
  - — for high transverse momentum effects — Cronin *vs* 'jet quenching' (this subject was not covered in the talk, but it certainly calls for more detailed look at proton–nucleus data).

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