EXPERIMENTAL RESULTS FROM LIGHT ION COLLISIONS

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ABSTRACT

Some recent results from experiments with deuterons and α-particles at FNAL, and at the CERN SPS and ISR are reviewed. The experimental evidence for inelastic screening in elastic pd, dd, pα and αα scattering is discussed. The particle density in the pionization region in inelastic proton-nucleus and nucleus-nucleus collisions is compared with predictions. Following a theoretical suggestion on how to look for a phase transition to quark matter, an exercise is performed using pα and αα data from the Split-Field Magnet detector. The inclusive cross section for large p

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1. INTRODUCTION

The size of light ions is a critical issue: they are considered as being too small by those who want to use ion-ion collisions to search for anomalous phenomena [1], and too big by fundamental particle physicists. Should we judge the size of a helium nucleus following Heracleitos, who said: 'O ἴδιον ἔστι τὸ μέγατον ὁ ΄ιος ἔκειται' [2]? Today, we need a more objective scale. Moreover, we are not interested in a scale for the size as such (radius \( R \) or mass number \( A \) do well for this purpose), but for the "nuclear efficacy", which can be derived from the cross sections. If \( A \) and \( B \) are the mass numbers of projectile and target, respectively, then such a measure is provided by:

\[
\sigma_X = AB\sigma_{nn} - \sigma_{ab}
\]

the difference between the cross section sum of \( A \) times \( B \) independently interacting nucleon pairs and the actual cross section. Thus \( \sigma_X \) is the well known cross section defect due to shadowing [3]. Alternatively, we may take the ratio

\[
\langle \nu \rangle = \frac{AB\sigma_{nn}}{\sigma_{ab}}
\]

which is the average number of NN collisions per AB collision. Table 1 [4] gives a few examples for these two scales. On the \( \nu \)-scale, \( \sigma_X \) can almost compete with PbPb. But if one wants to see dramatic effects then these numbers call clearly for PbPb collisions.

However, if one prefers (instead of big steps) the Taylor expansion around the point in AB space, which we know fairly well, although we do not understand it very well -- the pp interactions -- then the case for light ions is given. For instance, if one wants to write the amplitude for a nuclear collision as an explicit series of multiple collision terms, one is limited to light ions. Moreover, if a detailed knowledge of the nuclear wave function is needed for this task, then again we have to stay with light ions; indeed, at present even the \( \alpha \)-particle is somewhat too heavy for this task [5]. There are two other reasons why one may prefer light ions: feasibility and access to the highest energies. Deuterons and \( \alpha \)-particles can be accelerated in the CERN Proton Synchrotron (PS) using the standard source and LINAC [6]. Subsequent storage in the Intersecting Storage Rings (ISR) yields c.m. energies which beat the Super Proton Synchrotron (SPS) by a factor of 2.5 in \( s = E^2 \) or in incoming momentum \( p_{\text{inc}} \) on a fixed target (200 GeV/nucleon at the SPS versus 500 GeV/nucleon at the ISR). The hopes of having heavy ions in the ISR have lately been dashed, but there is still a hope of getting a run with light ions. A factor 2.5 in \( s \) is interesting even if one does 'ln(s) physics', and more so of course for large positron phenomena or processes with high energy thresholds. (The c.m. energy for proton nucleus collisions in the ISR is the same as it will be at the FNAL Tevatron).

<table>
<thead>
<tr>
<th>A B</th>
<th>( \sigma_{ab}[\text{mb}] )</th>
<th>( \sigma_X[\text{mb}] )</th>
<th>( \langle \nu \rangle )</th>
</tr>
</thead>
<tbody>
<tr>
<td>p d</td>
<td>74.8</td>
<td>5.2</td>
<td>1.07</td>
</tr>
<tr>
<td>d d</td>
<td>158.</td>
<td>34.</td>
<td>1.21</td>
</tr>
<tr>
<td>p A</td>
<td>129.</td>
<td>31.</td>
<td>1.24</td>
</tr>
<tr>
<td>A A</td>
<td>408.</td>
<td>360.</td>
<td>1.83</td>
</tr>
<tr>
<td>p Pb</td>
<td>3300.</td>
<td>4733.</td>
<td>2.45</td>
</tr>
<tr>
<td>Pb Pb</td>
<td>13770.</td>
<td>2 040 000.</td>
<td>150.</td>
</tr>
<tr>
<td>(^{16}\text{O}^{16}\text{O} )</td>
<td>2100.</td>
<td>22080.</td>
<td>5.35</td>
</tr>
</tbody>
</table>
In this review some recent results from experiments with light ions at high energies are discussed. It is not a complete survey but rather a selection of a few typical and perhaps important results from experiments with the lightest ions, deuterons, performed at the highest energy accelerators, i.e. at FNAL, and at the CERN SPS and ISR.

2. DIFFRACTION

A number of experiments at intermediate energies, in the few GeV/c range, have shown that elastic scattering of nuclei can be well described by the Glauber model [7] in terms of single and multiple NN encounters. Each NN scattering amounts to a phase shift of the incoming wave and for successive (re)scattering the phase shifts add coherently. The rich structure of the differential cross sections results from the interference between single and multiple scattering terms.

Fig. 1: Space-time evolution in the MPM for pd elastic scattering: a) planar single-, b) planar double-, c) non-planar double scattering diagram, d) Double scattering with intermediate inelastic state (IIS).

In this model the motion of the incoming nucleon is governed by wave mechanics, but its interaction is treated more classically. The nucleons behave somewhat like billiard balls in successive collisions -- they remain billiard balls between and after each scattering. There are, however, reasons to expect that at high energy the intrinsic nature of the rescattering process changes.

Firstly, the interaction time gets Lorentz-dilated with increasing energy. This can be understood, for instance, in a specific realization of soft field theories -- the multiperipheral parton model (MPM) [8]. The incoming nucleon emits a 'ladder' of partons with decreasing rapidity y in order to connect with a target nucleon. The time to emit and reabsorb a ladder proportional to the incoming momentum \( p_{inc} \) (Fig. 1a). At lower energy the incoming nucleon can rescatter by emitting such a ladder a second time (Fig. 1b). But if \( r \gg \lambda \), where \( \lambda \) is the time between two interactions in the nucleus, these planar diagrams get suppressed. Instead, non-planar diagrams are needed (Fig. 1c); they are naturally explained as parallel, simultaneous interactions of constituents [9].

A second, complementary reasoning [10] is as follows. At high energy, rescattering can proceed via inelastic intermediate states (IIS) (Fig. 1d). In order not to destroy the nucleus or the coherence of the outgoing wave, the coherence condition has to be fulfilled:

\[
q \lambda \ll h.
\]

where the momentum transfer \( q \) to excite the intermediate mass \( M \) is

\[
q = \frac{(M^2 - m^2)}{2p_{inc}}.
\]

With increasing \( p_{inc} \) higher masses \( M \) can be reached. Thus an energy dependence
is introduced into the nuclear scattering amplitude in addition to the one due to the energy dependence of the elementary NN amplitude.

\[ \Delta \sigma_{\text{in}} = \sigma_{\text{measured}} - \sigma_{\text{Glauber}} \]

**Fig. 2:** Measured total cross section defect \( \Delta \sigma_{\text{in}} \), \( \Delta \sigma_{\text{in}} = \sigma_{\text{measured}} - \sigma_{\text{Glauber}} \) versus incoming momentum \( p_{\text{lab}} \) for \( p\alpha \) interactions.

So much about speculations. What do the experiments say? The IIS should even throw their shadow on the total cross section. Thus we can look at the deviation \( \Delta \sigma_{\text{in}} \) between the measured total cross section and the one calculated in a Glauber model. For \( p\alpha \) collisions this has been done by two experiments, one at FNAL [11] and one at CERN [12]. Both measured the elastic differential cross section and determined the total cross section by the optical theorem. They call the difference \( \Delta \sigma_{\text{in}} \), suggesting that it is due to IIS. Fig. 2 shows a comparison of the results. The NA3 experiment at CERN finds rather small deviations (2-4 mb), while the internal gas jet experiment at FNAL finds values around 10 mb. The difference is simply due to an 8 mb difference in the extrapolated total cross section. Both experiments agree about the measured slopes so there must be a systematic normalization error in one of the experiments. The curve represents the presumed IIS correction [13].

The situation for \( p\delta \) scattering is not clear either. A CERN ISR experiment [14] claims the need for IIS correction while a FNAL experiment [15] indicates no such need. The data of the two experiments are not inconsistent, but different inputs to the Glauber model calculation lead to the different interpretations.
Fig. 3: Differential elastic pp (a) and αα (b) cross sections. Data from references [16, 17] and calculations from references [5, 18].

Proton-α and αα scattering have been measured in the ISR by two experiments [16, 17]. Their results (fig.3) clearly disagree in the t region where the two experiments overlap, so the measurements should be redone. But the theoretical calculation for αα [18] is encouraging since it shows a very strong effect due to IIS. So it should, in principle, be easy to draw a conclusion on the IIS correction, if this is the cause for 'Dsin'.

One has to conclude that the evidence for IIS in light ion elastic scattering is still questionable at present. More and better data, and also more theoretical studies are needed.

The next subject after elastic scattering and before inelastic interactions should be diffraction dissociation. I will skip this subject by referring to a very interesting and extensive review on the relevant experiments and theoretical efforts which can be found in a recent article by Alberi and Goggi [9]. This subject proves once again that owing to the interference between single and multiple scattering terms new information can be obtained on an amplitude --this time the dissociation amplitude. Light nuclei act in the true sense of the word as an interferometer for the incoming hadronic state. Moreover, since d and α are isoscalar targets, they provide the corresponding quantum number selection rule for the produced state and help in determining the background of isovector exchanges in inclusive measurements of diffraction dissociation.
3. NON-DIFFRACTIVE INELASTIC INTERACTIONS

The region in phase space which is dominated by products of non-diffractive interactions is the central region, i.e., of particles with c.m. rapidities around zero. Various models predict the ratio of the particle density in hadron-nucleus or nucleus-nucleus collisions to the one in NN collisions in the central region:

\[ R_y(pA/pp) = \frac{(dN(pA)/dy)}{(dN(pp)/dy)} \quad \text{at} \; y=0. \]

This ratio is shown in fig. 4 as a function of \( \langle y \rangle \). The first point from the left is for pA from the ISR [19,20], followed by a number of points taken from a compilation by Shabelsky and Schekhter [21] and 4 points from the NA5 experiment at CERN [22]. Note that \( \langle y \rangle \) is defined here using the production cross sections instead of total cross sections as in table 1. The trend of the data is consistent. Even the point for pA would fit in here but perhaps one should not put data for nucleus-nucleus and proton-nucleus collisions on the same graph, because in the latter case multiple interactions are but reinteractions of the incoming proton, whereas for nucleus-nucleus collisions parallel, simultaneous interactions of two or more NN pairs can take place in addition.

![Graph showing ratio of particle densities](image)

**Fig. 4:** Ratio of particle densities (see eq. 5) as a function of the mean number of inelastic collisions \( \langle y \rangle \) compared with theoretical predictions.

Clearly, the data are not compatible with the line \( R = \langle y \rangle \) which one would expect if each pA interaction and reinteraction yields the same number of produced particles. They are also not consistent with the old planar multiperipheral parton model (MPM) [23] or the energy flux cascade model (EFC) [24], which both predict a central ratio equal to one. However, two classes of models, additive quark models (AQM) [25] and two-chain or dual fragmentation models (DFM) [26] are almost indistinguishable up to \( \langle y \rangle = 3 \). If we had much heavier nuclei, we should see, according to the AQM, \( R_y(pA/pp) \) saturating at 3, but the other models would let \( R_y(pA/pp) \) rise further, provided enough energy was available. Likewise, the difference between the predictions of AQM and DFM for nucleus-nucleus collisions is very small, perhaps
too small to allow an experimental decision as to which model is correct.

What is the relevance of the data points from a's in the ISR? At first sight they follow the trend indicated by earlier measurements with heavier nuclei and at lower energy. In addition they are in a region of $(\langle p_{t} \rangle)$ where one can definitely not distinguish between the two models in question. But the measurement was nonetheless useful since the energy is much higher than for previous experiments and with respect to the central rapidity region the energy can almost not be high enough in order to have the central region well developed and free from fragments of the projectile and target.

Apart from the central particle density, many more aspects of $\alpha p$ and $\alpha \alpha$ inelastic interactions have been studied using the recent ISR data, for example multiplicity distributions, rapidity and $p_{t}$ distributions, two-particle correlations [19, 28, 29] and correlations between central multiplicity fluctuations and forward going energy [27, 29]. It seems now that much can be explained on the basis of some relatively simple models for the dynamics of single and multiple NN interactions, like the AQM or DFM, implemented by a geometrical calculation of multiple interaction probabilities. One should not forget, however, that the assumptions of these models are not trivial and we should still look for observables to exclude one or both of them. Of course, the data also bar wild speculations.

![Graph](image)

Fig. 5: Multiplicity dependence of inclusive $p_{t}$ distributions of $\alpha$ particles produced in the central region $|\text{abs}(y)| < 1.5$ (a) for pp and (b) $\alpha \alpha$ interactions. The data points are shifted up by 2 units for each following $Z$ bin. The horizontal lines indicate the value of one for the ratio as defined in eq. 6.

A recent study, which might be of interest at this meeting deals with the multiplicity dependence of the $p_{t}$ distribution of particles in the central region. The idea behind this is perhaps naive. With increasing multiplicity the initial energy density should increase; we can estimate it by extrapolating
particle trajectories backwards in time to their common origin. Thus we can examine whether the temperature at the time of particle emission changes as a function of the multiplicity, i.e. of the initial energy density. Fig. 5 shows the inclusive $p_t$ distribution of particles produced in the central region $|\text{abs}(\eta)|<1.5$ for different bins of the ratio $Z=H^-/(N^-)$, divided by the average inclusive distribution (for which $Z=1$) and scaled down by $Z$ ($N^-$ is the total multiplicity of negative tracks per event)

(6) \[ R_{p_t}(Z) = \frac{\langle dN(2)/dp_t \rangle}{\langle Z dN/dp_t \rangle}. \]

One expects this ratio to be equal 1 independent of $p_t$ if the particle density simply increases linearly with $N^-$ and the temperature does not change as a function of $Z$. It can be seen that the ratio is close to one. There are small deviations which perhaps indicate a temperature increase at high $Z$, however this effect is stronger for pp (fig. 5a) than for $\alpha\alpha$ (fig. 5b) collisions.

The following is an exercise done for this workshop and should be considered only as such. The problem is to find a signature for a phase transition in the $\alpha$ data [30]. Halzen and Liu [31] argue that in central nucleus-nucleus collisions the shear viscosity between interacting nucleons and spectator nucleons is reduced if the interacting nucleons have formed a quark-gluon plasma. As a consequence they predict an increase of the rapidity separation $\Delta y$ or of the relative velocity $\beta$ between spectators and interacting nucleons. There are two reasons why we cannot test their main prediction. Firstly, we measured $\alpha$ interactions in the ISR only at one energy, so we cannot study the effect in passing the energy threshold above which the phase transition should occur. Secondly, one cannot select central collisions in the usual way by requiring high multiplicity or loss of spectator protons, because both requirements would directly and grossly change the rapidity distribution while one wants to see a fairly subtle change due to the phase transition.

Table 2
Momentum separation between spectators and interacting nucleons according to Halzen and Liu [31].

<table>
<thead>
<tr>
<th></th>
<th>$\beta$</th>
<th>$\Delta y$</th>
<th>$p_\pi$</th>
<th>$p_\alpha$</th>
<th>$p_\alpha$</th>
<th>$p_\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>no viscosity</td>
<td>0.87</td>
<td>1.33</td>
<td>5.</td>
<td>15.7</td>
<td>5.</td>
<td>15.7</td>
</tr>
<tr>
<td>normal viscosity; no plasma</td>
<td>0.35</td>
<td>0.36</td>
<td>9.6</td>
<td>13.8</td>
<td>9.3</td>
<td>13.3</td>
</tr>
<tr>
<td>reduced viscosity; plasma</td>
<td>0.61</td>
<td>0.71</td>
<td>7.3</td>
<td>14.7</td>
<td>7.2</td>
<td>14.6</td>
</tr>
</tbody>
</table>

$\beta$ = relative velocity between spectators and interacting nucleons.
$\Delta y$ = rapidity difference
$p_\pi$ = momenta of spectator nucleons in ISR (GeV/c)
$p_\alpha$ = momenta of interacting nucleons in ISR (GeV/c)

However, we may try to study part of the effect by comparing $\alpha\alpha$ with $\alpha\alpha$. For $\alpha\alpha$ a bigger part of each $\alpha$ is heated up on the average than for the $\alpha$ in $\alpha\pi$ collisions. So there should be a higher probability of producing a large plasma volume. The major work of this exercise is transforming the relative velocities between spectators and interacting nucleons into laboratory momenta. (It is
preferable to use momenta instead of rapidities since we measure only momentum and charge while mass and rapidity are not uniquely determined).

\[ f(p_y) = p_y(dN^+/dp_y + dN^-/dp_y) \]

and of the positive excess

\[ \Delta f(p_y) = p_y(dN^+/dp_y - dN^-/dp_y) \]

in pp, pp and αα inelastic collisions as a function of \( p_y \). The positive excess of particles emitted from an α particle has to be attributed to protons. One recognizes in Fig.6c two peaks of spectator protons at around 15 GeV/c with a shoulder on the low momentum side due to interacting protons. Fig.6b shows the positive excess in pp with the one in αα collisions superimposed on the a side and the one in pp collisions superimposed on the p side. A slight shift of the shoulder of interacting protons to lower momenta in αα collisions compared to pp collisions can be recognized as it is predicted for plasma formation. However, there is no corresponding `acceleration' of the spectators at the high momentum side. This is hardly possible since these spectators are apparently real spectators carrying the full momentum of the incoming nucleons; it should be noted that the concept of viscosity acting on the spectators introduces a new sort of interacting nucleons -- those which suffered only final state interactions and were spectators with respect to the initial interaction. The extended shoulder at lower \( p_y \) could probably be explained more trivially by the fact that in αα collisions more nucleons interact on the average and thus the relative weight between interacting and non-interacting nucleons changes.
The conclusion from this exercise is that looking for a phase transition in this way might not be easy (even with heavier nuclei).

4. HARD INTERACTIONS

According to several authors [11], hadrons with transverse momenta between 1 and 4 GeV/c originate from quarks or gluons which were directly emitted from a hot plasma, before expansion and cooling. Such a plasma would already be formed in pp collisions at ISR energies. If the interpretation is right, then the "anomalous nuclear enhancement" of high $p_T$ hadrons produced from nuclear targets, which was first observed by the Chicago-Princeton Collaboration at FNAL [32], could perhaps be explained as being due to the formation of larger or hotter plasmas in proton-nucleus collisions. This interpretation has yet to be confronted with the ISR pp data on the structure of high $p_T$ events which seems to favour the standard explanation that the underlying processes are direct parton-parton interactions.

One of our main reasons for measuring high $p_T$ pp and $\alpha\alpha$ collisions in the ISR was the possibility of studying the structure of the final state, including all charged secondaries and beam fragments, with one of the large solid angle detectors at the ISR, the SSM.

By extrapolation from the Chicago-Princeton data [32] the high $p_T$ hadron yield in $\alpha\alpha$ interactions was estimated to be a factor 4 to 5 higher than in pp interactions, at the same c.m. energy per NN collision and for $p_T > 3$ GeV/c. Thus being convinced that the inclusive production cross sections in $\alpha\alpha$ and pp interactions would be anomalously enhanced we wanted to search for a corresponding anomaly in the event structure by comparing $\alpha\alpha$ and pp with pp events.

Four ISR experiments have obtained results for the inclusive cross section of their high $p_T$ trigger particle. Fig. 7 shows the invariant cross section as a function of $p_T$ for $\alpha\alpha \rightarrow h^-$ [28, 33] and $\alpha\alpha \rightarrow \pi^0$ [34] in comparison with pp collisions [29]. Of course, the first question to ask is whether there is an anomalous nuclear enhancement similar to the one found at FNAL, i.e. whether the cross section at high $p_T$ is larger than 16 times the cross section in pp interactions, corresponding to 4 x 4 independently interacting nucleon-pairs and similarly, for $\alpha\alpha$ interactions, whether the cross section is larger than 4 times the cross section in pp interactions.

Therefore in Fig. 8 the cross section ratios for $\pi^-$ and $\pi^0$ production

\[
R_{pT}(\alpha\alpha/pp) = \frac{\sigma(\alpha\alpha/pp)}{\sigma(pp/pp)}
\]

are shown as a function of $p_T$. Here we have added $\pi^0$ data from the fourth detector [36] which extend up to $p_T = 8$ GeV/c. In the figure for $R_{pT}(\alpha\alpha/pp)$ (fig. 8b) the plotted curve shows the extrapolation from the Chicago-Princeton data: for $R_{pT}(\alpha\alpha/pp)$ (fig. 8a) a theoretical prediction [37] is shown which is based on the assumption that the mechanism causing the anomalous nuclear enhancement is multiple hard parton scattering. The data seem to be consistent with each other, but exhibit a surprising behaviour at large $p_T$. The ratio $R_{pT}(\alpha\alpha/pp)$ rises with $p_T$ to values much higher than predicted. But $R_{pT}(\alpha\alpha/pp)$ is significantly lower than the prediction or rather extrapolation. Therefore it is very difficult to draw any firm conclusions from the data at present. One should presumably wait for a confirmation of the data in the high $p_T$ range above 4 GeV/c.
Fig. 7: Invariant cross section as a function of $p_T$ for production of negative particles (mainly $\pi^-$) and of $\eta^0$ in $\alpha\alpha$ collisions, compared with the cross section in $pp$ interactions at equal c.m. energy $\sqrt{s_{NN}}$ per NN collision.

Fig. 8: Production cross sections in (a) $\alpha\alpha$ and (b) $\alpha p$ interactions divided by the ones in $pp$ interactions (see eq. 9).
Fig. 9: Distribution in azimuthal angle $\Delta \phi = \text{abs}(\phi - \phi_{\text{trig}})$ of associated charged particles ($\text{abs}(y) < 0.8$) in three $p_T$ intervals for $pp$ and $\alpha \alpha$ interactions with a high $p_T$ trigger particle ($p_{T_{\text{trig}}} > 2.5 \text{ GeV/c}$) [33].
The three large solid angle detectors at the ISR, the Solenoid, the Split-Field and the Axial-Field Magnet detectors, have studied various properties of the structure of final states in high $p_T$ $\alpha\alpha$ and $\alpha\beta$ interactions in comparison with pp interactions. So far most of the results have revealed more similarities than striking differences. But the precision is not good enough to conclude that there are no differences at all at the level of 10-30%. The events show a similar kind of planarity; see for instance the azimuthal $\phi$-distribution, fig.9 [33]; for $\alpha\beta$ interactions the enhancements on the trigger side and opposite (away) side, which are attributed to jets, sit on a higher isotropic background of low $p_T$ particles.

![Diagram showing transverse momentum flow versus rapidity for $p_T$ trigger conditions](image)

**Fig.10:** Transverse momentum flow of associated charged particles as a function of the rapidity $y$ for two large $p_T$ trigger conditions (events with $(p_T)_{\text{trig}} > 30$ GeV/c). a) positive trigger particle at $y = 0.8$ and b) at $y = -0.8$. Negative values of the $p_T$ flow correspond to particles on the trigger side ($|\Delta\phi - \phi_{\text{trig}}| < 23^\circ$) and positive values to particles on the away side ($|\Delta\phi| > 157^\circ$). The dashed lines indicate the momentum flow in minimum bias inelastic events, the dotted and dashed-dotted lines represent the particle flow in large $p_T$ events multiplied by the average $p_T$ \langle$p_T$(mibi)\rangle in minimum bias events.

The transverse momentum flow as a function of rapidity $y$

$$F(p_T) = p_T \frac{dN}{dy}$$

near the plane defined by the beams and the high $p_T$ trigger particle, is shown in fig.10 [30] and compared with the $p_T$ flow in minimum bias inelastic events. On the trigger side the (jet) enhancement is narrow, on the recoil side it is broader in $y$. The comparison with the particle flow times average $p_T$ in minimum bias events \langle$p_T$(mibi)\rangle shows that the average $p_T$ of the particles accompanying the high $p_T$ trigger particle is higher than \langle$p_T$(mibi)\rangle in the regions of
enhancements. These are features well known from studies of hard pp interactions at the ISR. Moreover, it was found that the $p_T$ or $x_e$ distributions on the away side (recoil jet or jets) [$x_e = p_T/(p_T)_{\text{trig}}$] are the same for $\alpha\alpha$, $\alpha p$ and $pp$ interactions within statistical errors of 20-30% at high $x_e (x_e > 0.4)$ [29]. Thus there is no evidence yet for rescattering of hard partons which would produce more than one recoil jet and hence tend to steepen the $x_e$ distribution.

Let us continue for the moment, before we have our next run with $\alpha\alpha$'s and deuterons in the ISR, with a gedanken experiment. Assuming we find no difference in event structure for large $p_T$ $\alpha\alpha$, $\alpha p$ and $pp$ events but nevertheless a clear anomalous enhancement of the cross sections, what would we conclude? Probably, that one of the mechanisms evoked [38] to explain the anomalous nuclear enhancement is also strongly at work in pp collisions. So the measurement with nuclear targets would have contributed at least to our understanding of hard pp interactions.

5. CONCLUSIONS

We are left with a lot of questions:

How important is the correction for intermediate inelastic states in light ion elastic scattering? What are the causes for the deviations from the pure Glauber model description?

Are there only three quarks in a nucleon which can be wounded in inelastic interactions or more? Are there any effects not explainable by the present standard models for multiple soft NN interactions (additive quark model and dual fragmentation model)? Can we see a signature for unusual states of matter and how?

Are the ISR results for the inclusive invariant $\alpha\alpha$ and $\alpha p$ cross sections at large $p_T$ compatible with the FNAL anomalous nuclear enhancement? Will we find any sign for the mechanism(s) causing the nuclear enhancement?

There are, however, two firm conclusions:

-- The measurements with light ions have raised a lot of questions.
-- We should continue measuring and analysing.

Acknowledgement

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References and footnotes


[2] Ascribed to the Greek philosopher Heraclitus, about 500 BC. Engl. transl. 'The sun (heaters) is as big as it appears'.

[3] 'Shadowing' is somewhat misleading in this context, since the nucleons in the shadow are nonetheless fully exposed to the beam.


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