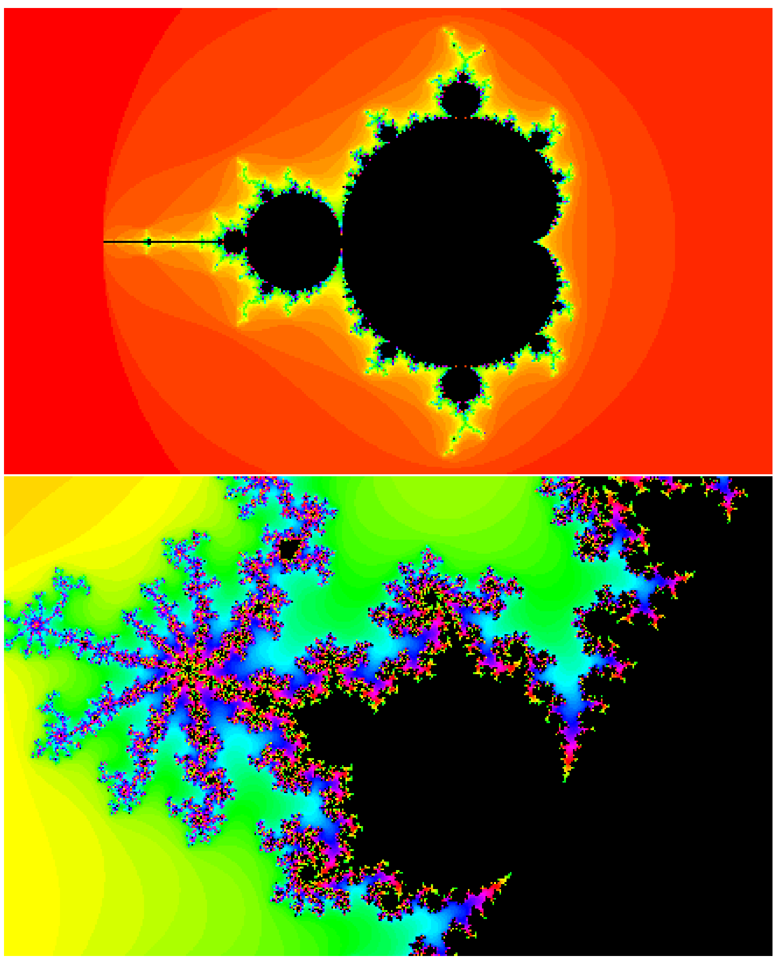
Evidence for Quark-Hadron Duality in the Proton Spin-Structure Function
POPULAR SUMMARY

Since ancient times the discovery of patterns and structures buried inside larger structures which themselves comprise larger structures has sparked fascination and wonder. In modern times, this is seen most widely in the study of fractals. When one examines these beautifully intricate and colorful pictures with finer and finer detail, one finds the same patterns reproduced in miniature. Figure 1 shows an example of this; the lower figure is a tiny portion of the upper figure.

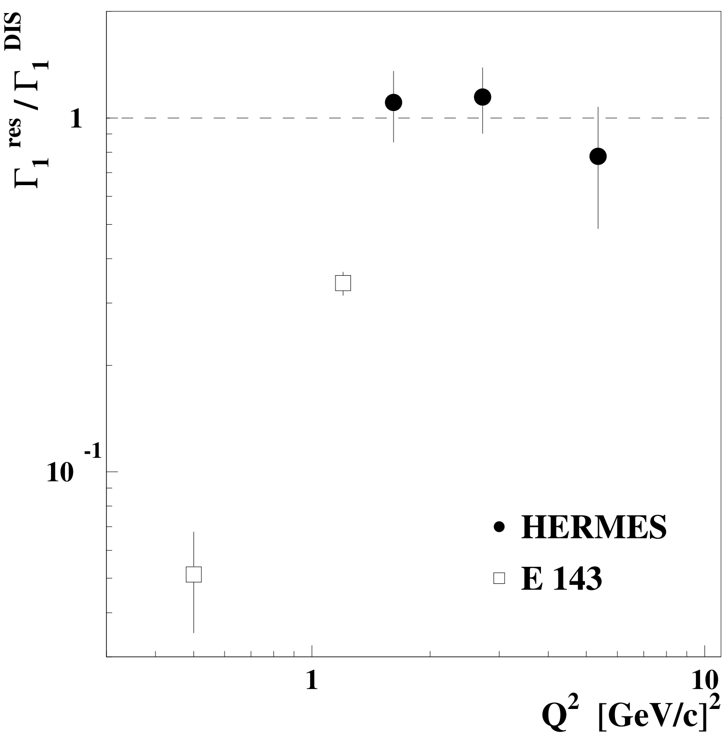


A particular example in the study of the structure of the proton is the observation of quark-hadron duality. Simply stated, this is the observation that when the proton is studied at a small scale (the "quark" view) it looks very similar to the proton at a larger scale (the "hadron" view). Instead of a fractal picture, one is looking at the photon absorption cross section, but otherwise the analogy is almost complete. In fact, you can see that the fractal pictures are not exactly alike; you have to"average" out some of the little extra bumps. The same occurs in the proton case; the hadron cross section has some extra bumps ("resonances") that have to be averaged out. Given that we now understand the proton to be a complex assembly of very strong color fields, valence quarks and a sea of virtual quarks and anti-quarks, this is a striking result. Moreover, it is a result without a full and clear explanation. Thus, like the ancients, we wonder just what Nature is trying to tell us.

This duality was observed in the earliest days of the study of the proton structure at the Stanford Linear Accelerator, even before the quark model was fully developed. Recent studies at Jefferson Lab in the US have shown that duality is not only observered in a large global average of the cross sections but in small ranges of the cross section as well, again similar to what one finds in fractals.

At HERMES, polarized light has been used to look at the proton at the quark and hadron scales, and once again one finds that the results indicate a simple relation. To actually use the polarized light one typically looks at the difference between light absorption in two different polarization states, which for simplicity can be called "+" and "−". The quarks themselves can be polarized and so can the proton. One says that the "spins" of the protons and quarks are polarized, when they all point in the same direction in space (the "spin" is a basic quantum mechanical property of any particle; it is like a little compass arrow which can point in a particular direction). Only quarks with "−" polarization can absorb "+" light while quarks with "+" polarization can only absorb "−" light. By looking at the light absorption and changing the polarization states of both the proton and light, one can determine what fraction of the spins of the quarks inside the proton are pointed in the same direction as the spin of the proton itself. This is known as the spin structure of the proton.

When we look at the proton at the big hadron scale with polarized light, we again see the bumps and wiggles as with unpolarized light. However, when we average over the wiggles, we get back the same difference in polarized light absorption that we saw when looking at the small quark scale. Since the structure of the proton which causes the bumps and wiggles is understood to be quite complicated, this is again quite a surprise to find the simple relation between observations at the quark and hadron scales. In Fig. 2, the actual experimental results are shown; the ratio of the averaged polarized cross section differences (Γ) for the hadron view is divided by that from the quark scale, and indeed seems to be consistent with one, in other words, the averaged picture in the hadron view is equal to the one from the quark scale.



Future studies will try to understand this new duality in detail; in particular can we keep breaking the spectrum into smaller pieces and still finding the same simple relation? Meanwhile, theoretical physicists are working to understand just what in the complex structure of the proton gives us this simplicity and beauty.