Odderon Searches at RHIC Workshop

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The Odderon, a charge-conjugation-odd partner of the Pomeron, has been a puzzle ever since its introduction in 1973. The Pomeron describes a colorless exchange with vacuum quantum numbers in the t-channel of hadronic scattering at high energies. The concept was originally formulated for the non-perturbative regime of Quantum Chromodynamics (QCD). In perturbation theory, the simplest picture of the Pomeron is that of a two-gluon exchange process, whereas an Odderon can be thought of as an exchange of three gluons. Both the Pomeron and the Odderon are expected in QCD. However, while there exists plenty of experimental data that could be successfully described by Pomeron exchanges (for example in electron-proton and hadron-hadron scattering at high energies), no experimental sign of the Odderon has been observed. One of the very few hints so far is the difference in the diffractive minima of elastic proton-proton and proton-antiproton scattering measured at the ISR.

The Odderon has recently received renewed attention by QCD researchers, mainly for the following two reasons. First of all, RHIC has entered the scene, offering exciting unique new opportunities for Odderon searches. RHIC provides collisions of nuclei at center-of-mass energies far exceeding those at all previous experiments. RHIC also provides collisions of protons of the highest center-of-mass energy, and in the interval, which has not been explored previously in $p\bar{p}$ collisions. In addition, it also has the unique feature of polarization for the proton beams, promising to become a crucial tool in Odderon searches. Indeed, theorists have proposed possible signatures of the Odderon in some spin asymmetries measurable at RHIC. Qualitatively unique signals should be seen in these observables if the Odderon coupling is large.

Secondly, the Odderon has recently been shown to naturally emerge from the Color Glass Condensate (CGC), a theory for the high-energy asymptotics of QCD. It has been argued that saturation/CGC effects tend to decrease the Odderon intercept, possibly providing an explanation for the lack of experimental evidence for the Odderon so far. This has added further motivation for pursuing searches for the Odderon.

During the workshop the status of the Odderon in QCD and its phenomenology were reviewed. The participants also agreed on the most promising observables for the Odderon search at RHIC, which we list in the following table:

Observable	Range	Exp. Error	Comments	Rating
$d\sigma/dt$(dip) pp vs $p\bar{p}$	$\sqrt{s}$=500 GeV $0.12<-t<1.3$ GeV^2	10^4 evts./0.05 GeV^2	Limited by $p\bar{p}$ errors, but well determined shape in pp, Phase II	***
σ_{tot}	$50 < \sqrt{s} < 500$ GeV		Can measure shape well Phase I and II	*
$d\sigma/dt$	$0.003<-t<0.04$ GeV^2	$>10^4$ evts./bin	$F_+(\rho)$ and $F_-(\rho)$ to extract F_- by comparing with $p\bar{p}$, limited by $p\bar{p}$ errors. Phase I	**
A_{NN}	$0.003<-t<0.04$ A_{NN} ~ 0.01-0.02?	ΔA_{NN}=0.005	If peak $\Rightarrow$ then O, is unique, energy dep. is important $\sqrt{s}$=200 Phase I	**

Some of the conclusions from various participants follow.

Elliot Leader:

1) For $|t| << \Lambda_{QCD}$, we are in a truly non-perturbative region where we are unable to calculate any scattering amplitudes. However, very detailed and accurate calculations are possible just outside this region, and these unambiguously show that QCD amplitudes have both a pomeronic and odderonic component at high-energies. The Pomeron exchange amplitude is clearly seen at HERA at very small x. Thus there is every reason to expect that the calculation of an Odderon amplitude is believable, and if QCD is correct, we should see it experimentally.

2) However, we do not have unambiguous evidence for the Odderon component, but if, as seems necessary, the difference between p-p and $p\bar{p}$ differential cross-sections at the ISR is due to the Odderon, then we expect the magnitude of the Odderon amplitude to be much smaller than the Pomeron, say of order 5% of it. This would explain why it is not seen at HERA, but why it should be clearly seen at RHIC with its much larger luminosity.

What are the best possibilities for seeing the Odderon?

1) Because the Odderon amplitude is 90 degrees out of phase with the Pomeron one, it might contribute strongly to certain spin-dependent observables, which are highly sensitive to phases. One example is A_{NN} whose shape and energy dependence could show a remarkable an unambiguous signature of the Odderon. RHIC is ideally suited for this kind of experiment.

2) The Odderon is expected to create a difference between the p-p and $p\bar{p}$ total cross sections. This could be investigated by comparing a RHIC p-p measurement with the known $p\bar{p}$ result from the CERN $Sp\bar{p}S$ collider.

3) If the ISR difference between p-p and p $\bar{p}$ differential cross-sections continues to exist at RHIC energies that would be unambiguous proof of an Odderon amplitude.

4) A measurement of the ratio of real to imaginary parts of the forward p-p amplitude at RHIC energies would help, via dispersion relations, in determining the properties of the Odderon amplitude.

5) Because we cannot calculate the ratio of spin-flip to non-flip of the Odderon coupling to nucleons, a wide attack based on all of the above set of experiments is recommended.

Basarab Nicolescu:

I am convinced that the "banner" of the project must be the Color Glass Condensate (CGC) approach. It is fully formulated in the framework of QCD but it is more intuitive than other similar approaches of the Odderon (my own approach, based on asymptotic theorems, included). CGC fully shows that the Pomeron-Odderon phase is an un-escapable feature of the QCD at high energies and this is, of course, really fundamental. In such a formulation, one can assert that the Odderon is a crucial test of QCD.

Yuri Kovchegov:

Why is Odderon a fundamental object of QCD?

It is predicted perturbatively, and is not prohibited non-perturbatively. Along with the Pomeron, it is intimately tied to the properties of high-energy scattering in QCD. We have theoretical control over it in some cases (mostly DIS). It's just as fundamental as any other perturbative or non-perturbative QCD calculation: it's as fundamental as structure functions, parton model, sum rules, the Pomeron, etc.

How does one state what we are doing?

Odderon is probably just as fundamental as (and is possibly related to) various spin flip amplitudes - and we can learn much about it by studying various spin observables. Experimental program to search for the Odderon at RHIC would be complementary to RHIC spin program.

Also, since the Odderon naturally follows from the Color Glass Condensate (CGC) formalism, searching for it would allow us to test CGC, which, in turn, is important for heavy ion collisions, in which CGC may be responsible for providing initial conditions for quark-gluon plasma formation. An intriguing new evidence for CGC has been generated in d+Au collisions at RHIC already. Some of the experimentalists involved in analyzing CGC signals in d+Au collisions at RHIC may also be interested in further testing CGC through the search for the Odderon.

Finally, with RHIC upgrade (RHIC II) being discussed a lot, it appears that most of the

proposed RHIC II measurements are more of precision measurements than "discovery measurements". Odderon search proposal would really have the potential of a discovery measurement, at a relatively low cost.

The conclusion of the workshop is that the best available setup to address experimental questions related to the search for the Odderon at RHIC is the proposed combination of STAR experiment and Roman pots of pp2pp experiment, described in the proposal “Physics with Tagged Forward Protons with the STAR detector at RHIC”.