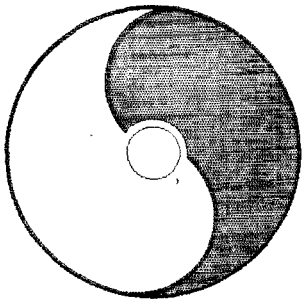
BNL-75092-2005
FORMAL REPORT

Proceedings of RIKEN BNL Research Center Workshop Volume 76

Odderon Searches at RHIC

September 27-29, 2005



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Preface to the Series

The RIKEN BNL Research Center (RBRC) was established in April 1997 at Brookhaven National Laboratory. It is funded by the "Rikagaku Kenkyusho" (RIKEN, The Institute of Physical and Chemical Research) of Japan. The Center is dedicated to the study of strong interactions, including spin physics, lattice QCD, and RHIC physics through the nurturing of a new generation of young physicists.

The RBRC has both a theory and experimental component. The RBRC Theory Group currently consists of about twenty researchers, and the RBRC Experimental Group, of about fifteen researchers. Positions include the following: full time RBRC Fellow, half-time RHIC Physics Fellow, and full-time, post-doctoral Research Associate. The RHIC Physics Fellows hold joint appointments with RBRC and other institutions and have tenure track positions at their respective universities or BNL. To date, RBRC has ~40 graduates of which 14 theorists and 6 experimenters have attained tenure positions at major institutions worldwide.

Beginning in 2001 a new RIKEN Spin Program (RSP) category was implemented at RBRC. These appointments are joint positions of RBRC and RIKEN and include the following positions in theory and experiment: RSP Researchers, RSP Research Associates, and Young Researchers, who are mentored by senior RBRC Scientists. A number of RIKEN Jr. Research Associates and Visiting Scientists also contribute to the physics program at the Center.

RBRC has an active workshop program on strong interaction physics with each workshop focused on a specific physics problem. Each workshop speaker is encouraged to select a few of the most important transparencies from his or her presentation, accompanied by a page of explanation. This material is collected at the end of the workshop by the organizer to form proceedings, which can therefore be available within a short time. To date there are seventy-three proceeding volumes available.

A 10 teraflops RBRC QCDOC computer funded by RIKEN, Japan, was unveiled at a dedication ceremony at BNL on May 26, 2005. This supercomputer was designed and built by individuals from Columbia University, IBM, BNL, RBRC, and the University of Edinburgh, with the U.S. D.O.E. Office of Science providing infrastructure support at BNL. Physics results were reported at the RBRC QCDOC Symposium following the dedication. A 0.6 teraflops parallel processor, dedicated to lattice QCD, begun at the Center on February 19, 1998, was completed on August 28, 1998 and is still operational.

N. P. Samios, Director
May 2005

*Work performed under the auspices of U.S.D.O.E. Contract No. DE-AC02-98CH10886.

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Odderon Searches at RHIC Workshop

September 27-29, 2005

Wlodek Guryn, Yuri Kovchegov, Larry Trueman and Werner Vogelsang

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}	$0.003<-t<0.04$ $A_{NN} \sim 0.01$-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.

WORKSHOP CONCLUSION

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".

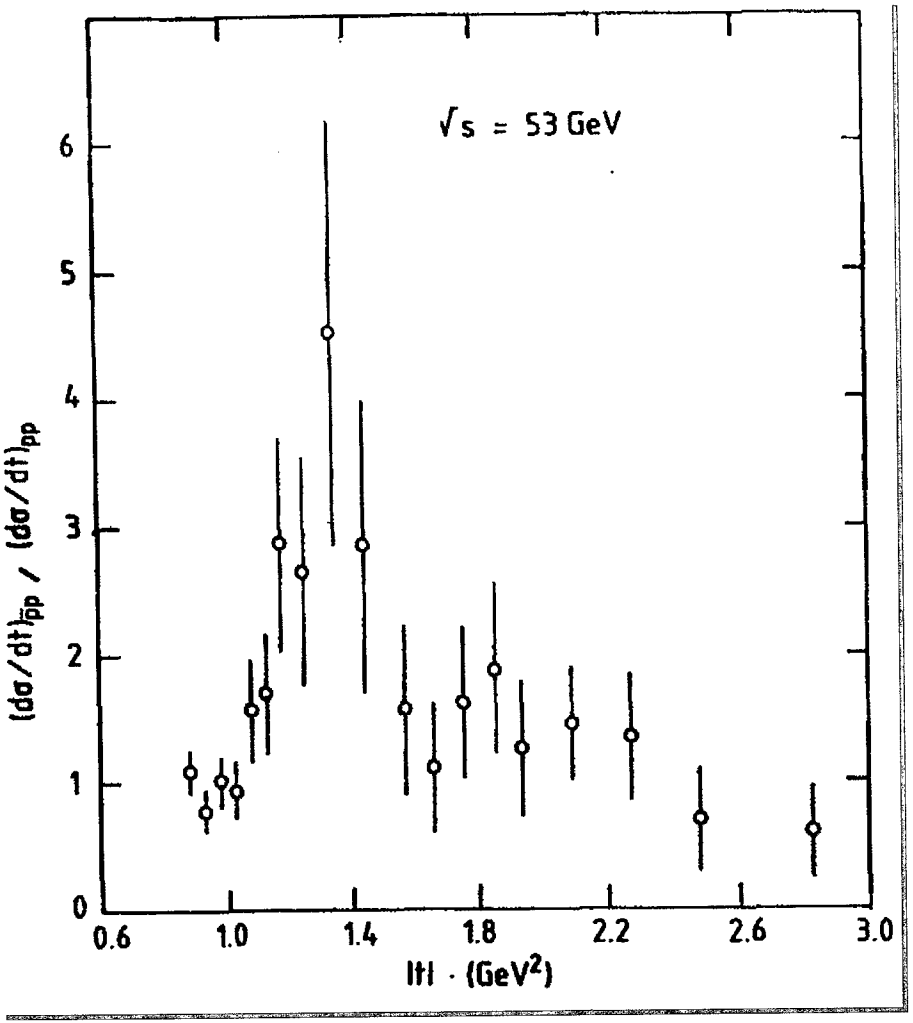
The Present Situation of the Odderon Intercept - Experiment, Theory and Phenomenology

Basarab Nicolescu

LPNHE, CNRS and University of Paris 6, France

EXPERIMENTAL EVIDENCE FOR THE ODDERON

a. Strong evidence for the non-perturbative Odderon with $\alpha_{Odd}(0)=1$



$$R = \frac{(d\sigma/dt)_{\bar{p}p}}{(d\sigma/dt)_{pp}}$$

$|t| = 1.3\ \mathrm{GeV}^2,\ \sqrt{s} = 52.8\ \mathrm{GeV}$

99.9 % confidence level

for this Odderon effect

A. Breakstone et al., *Phys. Rev. Lett.* **54** (1985) 2180.
S. Erhan et al., *Phys. Lett.* **B152** (1985) 131.

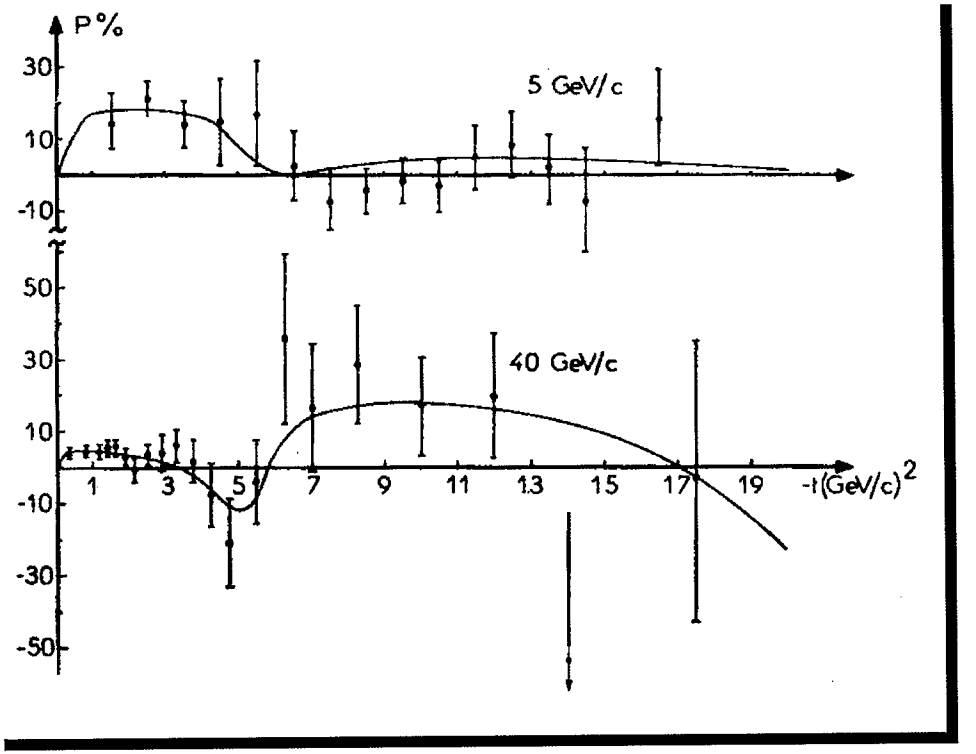
P. Gauron, E. Leader and B. Nicolescu, *Phys. Lett.* **B238** (1990) 406 ; *Nucl. Phys.* **B299** (1988) 640

$\beta_+ = 2 \pm 0.005,\ \beta_- = 2 \pm 0.05$

b. Moderate evidence for the non-perturbative Odderon with $\alpha_{Odd}(0) = 1$

Experimentally, one sees a dramatic change of shape in the polarization in $\pi^- p \to \pi^0 n$, in going from p_L = 5 GeV/c to p_L = 40 GeV/c

D. Hill et al., Phys. *Rev. Lett.* **30** (1973) 239
P. Bonamy et al., *Nucl. Phys.* **52B** (1973) 392
D. Apokin et al., *Z. Phys.* **C15** (1982) 293



D. Joynson, E. Leader, C. Lopez and B. Nicolescu, *Nuovo Cimento Lett.* **15** (1976) 397
P. Gauron, E. Leader and B. Nicolescu, *Phys. Rev. Lett.* **52** (1984) 1952

c. Weak evidence for the non-perturbative Odderon with $\alpha_{Odd}(0) = 1$

A strange effect is seen in the UA4/2 *dN/dt* data at $\sqrt{s}$= 541 GeV, namely bump at $|t| = 2 \cdot 10^{-3}$ GeV^2.

UA4/2 Coll. C. Augier et al., *Phys. Lett.* **B316** (1993) 448

Theoretical interpretation of the « bump »:

P. Gauron, B. Nicolescu and O. Selyugin, Phys. Lett. **B397** (1997) 305

Oscillations of a very small period due to the Auberson-Kinoshita-Martin (AKM) theorem (for the F_+ amplitude) :
G. Auberson, T. Kinoshita and A. Martin, *Phys. Rev.* **D3** (1971) 3185

Generalization for the F_- amplitude:
P. Gauron, E. Leader and B. Nicolescu, *Nucl. Phys.* **B299** (1988) 640

Conclusions

- **only few experimental evidences for the non-perturbative Odderon: this is not a paradox, because experimentalists looked till now only in channels where the Odderon is hidden by the huge Pomeron contribution**
- **no (yet) experimental evidence for the perturbative Odderon, which nevertheless has a much firmer - perturbative QCD - status ! This situation is quite paradoxical, but it will certainly change in the future**
- **many proposals already made for looking for both non-perturbative and perturbative Odderon in the appropriate channels. In this context, the RHIC polarization will certainly bring major (good) surprises.**

THEORY

Odderon - major object of QCD.

It was (theoretically) rediscovered both in QCD and in CGC (Color Glass Condensate).

So, it has to be found.

If not, QCD might be wrong:

Odderon is a crucial test of QCD.

The Janik-Wosiek solution (R. A. Janik and J. Wosiek, *Phys. Rev. Lett.* **82** (1999) 1092) corresponds to an intercept smaller than 1. But it is very near 1. Therefore, it has important phenomenological consequences: this intercept is much higger than the intercept of the leading secondary Reggeons with $\alpha_R(0) = 0.5$:

$$\alpha_{\mathrm{Odd}}(0) = 0.94 - 0.96$$

J. Bartels, L. N. Lipatov and G. P. Vacca, *Phys. Lett.* **B477** (2000) 178.

Solution corresponding to an intercept exactly equal to 1

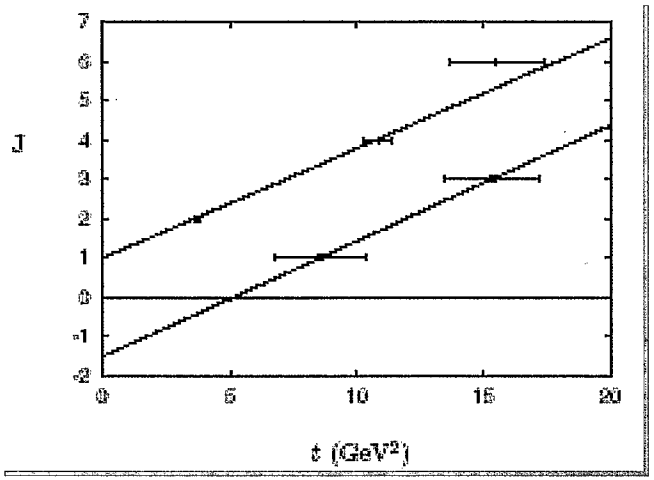
$$\alpha_{\mathrm{Odd}}(0) = 1$$

THE ODDERON INTERCEPT FROM SPECTROSCOPY

There are several calculations, all indicating a low intercept.

However, the way in which this intercept is identified in lattice calculations is questionable.

H. B. Meyer and M. J. Teper, *Phys. Lett.* **B605** (2005) 344
H. B. Meyer, PhD thesis at Oxford, hep-lat/0508002



The authors get a 1^{--} state with mass m_1 = 3.24 GeV and a 3^{--} state with mass m_3 = 4.33 GeV

By drawing a straight line $\alpha(t) = \alpha(0) + \alpha' t$ through these states, they get

$$\alpha_{Odd}(0) = -1.54$$

$$\alpha'_{Odd}(0) = -0.24\ (\mathrm{GeV})^{-2}$$

However, if $\alpha_{Odd} = 1$, then obviously the state 1^{--} can not belong to the leading trajectory - the first state is 3^{--}

In this case $\alpha_{Odd} = 1$ $\alpha' = 0.11$

and therefore, the 1^{--} state belongs to a trajectory with intercept -0.12 → i.e. it is on the first daughter trajectory.

Check of all this: calculation of the mass of 5^{--} (not yet done)

THE ODDERON: PAST AND PRESENT.

Elliot Leader
Imperial College London

We discuss why physicists resisted the idea of an odderon and how the advent of QCD changed this.

We briefly comment on possibilities to detect the odderon experimentally.

RHIC has the unique capability to discover the odderon!

① THE PRE ODDERON ERA

AND

WHY THE BIRTH OF THE ODDERON WAS SO PAINFUL.

REIGNING PARADIGM:

ALL $\sigma_{TOT} \to$ CONST AS $s \to \infty$

REASONS:

i) EXPERIMENT (F1)

ii) INTUITION — black disc of fixed radius or

Pomeron: expanding radius but decreasing opacity.

CONSEQUENCE: **POMERANCHUK THEOREM**

If a) $\sigma_{pp} \to$ CONST AND $\sigma_{\bar{p}p} \to$ CONST

and

If b) Diffractive picture holds: $\frac{\text{Real}}{\text{Imag}} \to 0$

then

$$\sigma_{pp} - \sigma_{\bar{p}p} \longrightarrow 0 \quad \text{as} \quad s \longrightarrow \infty$$

<u>THE ODDERON CONTRADICTS THIS.</u>

$\mathbb{O}$ = odderon is NEGATIVE SIGNATURE

NEGATIVE CHARGE CONJUGATION

SISTER OF THE $\mathbb{P}$OMERON

$$F_{pp} = F_{\mathbb{P}} + F_{\mathbb{O}}$$

$$F_{\bar{p}p} = F_{\mathbb{P}} - F_{\mathbb{O}}$$

$\therefore$ IF $|F_{\mathbb{O}}| \approx |F_{\mathbb{P}}|$ asymptotically

$$\Longrightarrow \quad \sigma_{\bar{p}p} - \sigma_{pp} \not\Longrightarrow 0$$

CONTRADICTING POMERANCHUK

BUT - - - - .

in 1973 the ISR discovered that the pp cross-section GROWS with energy! like $\ln^2 s$.

ALMOST EVERYBODY HAD FORGOTTEN THAT POMERANCHUK "THEOREM" ASSUMED $\sigma_T \to$ CONST

$\therefore$ CONTINUED TO BELIEVE

$$\Delta\sigma \equiv \sigma_{\bar{p}p} - \sigma_{pp} \to 0$$

THIS IS NOT CORRECT !

If $\sigma_{\bar{p}p}$ and σ_{pp} grow, can show

$$\frac{\sigma_{\bar{p}p}}{\sigma_{pp}} \to 1 \quad \text{asymptotically.}$$

DOES NOT imply $\sigma_{\bar{p}p} - \sigma_{pp} \to 0$

<u>COUNTEREXAMPLE</u>

$$\sigma_{pp} = A \ln^2 s + B_1 \ln s + C_1$$

$$\sigma_{\bar{p}p} = A \ln^2 s + B_2 \ln s + C_2$$

$B_1 \neq B_2 \qquad C_1 \neq C_2$

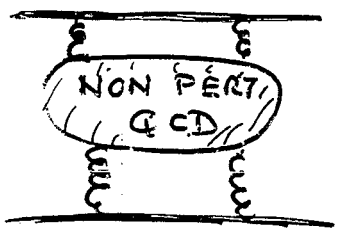
Ratio $\to 1$ <u>but</u> $\Delta\sigma = (B_2 - B_1)\ln s + (C_2 - C_1)$

EVEN increases !

<u>1973</u> : Lukaszuk + Nicolescu propose MAXIMAL ODDERON — largely ignored. But ----

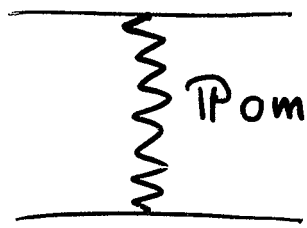
CONNECTION WITH QCD - the new PARADIGM

Non perturbative QCD $\xrightarrow{\text{ALMOST PROVED}}$ Effective field theory : exchange complex objects variable spin $J = \alpha(t)$: "Reggeons"

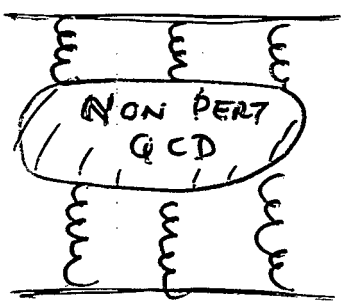


C=+1

$\xrightarrow{?}$

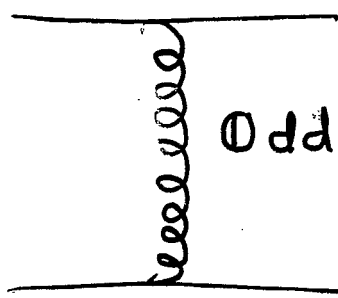


Pomeron



C=+1 and C=−1

$\xrightarrow{?}$



Odderon

Challenges: To calculate $\alpha_{\mathbb{P}}(t)$, $\alpha_{\mathbb{O}}(t)$

To detect odderon experimentally

At RHIC:

1) Expect $\sigma_{pp} - \sigma_{\bar{p}p} \simeq 3$ mb

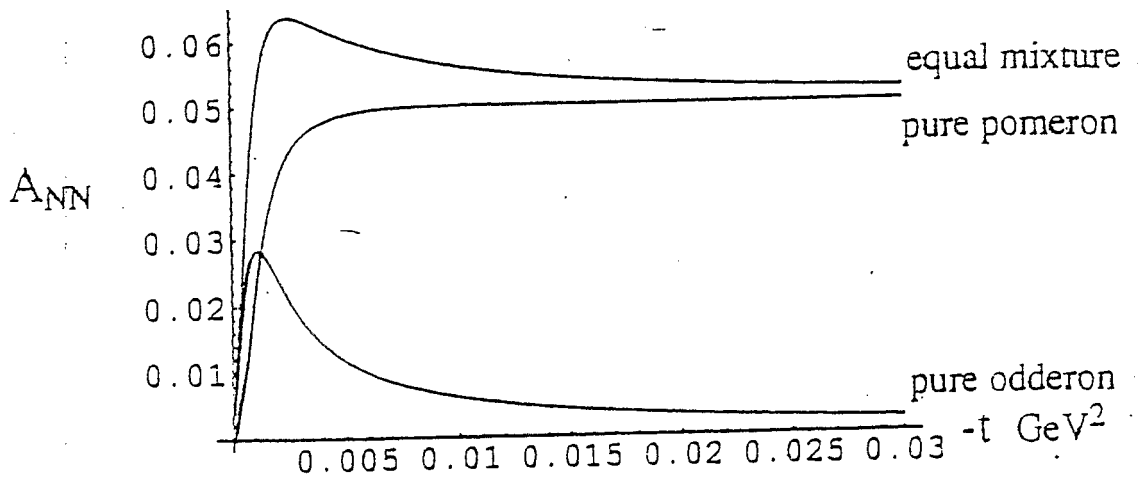
2) Interesting effects in A_{NN}:

(E.L + Trueman: 2000)

Pure Odderon: $\phi_2 = 0.05\, i\, \phi_+$

Pure Pomeron: $\phi_2 = 0.05\, \phi_+$

Mixture: $\phi_2 = 0.05\,(1+i)\,\phi_+$



This workshop proves: The ODDERON has come of age.

RHIC is the unique machine capable of finding it!

Experimental Possibilities at RHIC

Włodek Guryn
Brookhaven National Laboratory, Upton, NY, USA

We describe proposal to extend the physics reach of the STAR detector at RHIC to include the measurement of very forward protons. Tagging on very forward protons, detected by the pp2pp Roman Pots, which could be installed on each outgoing beam around STAR, selects processes, in which the proton stays intact and the exchange has the quantum numbers of the vacuum, thus enhancing the probability of measuring reactions where colorless gluonic matter dominates the exchange, including both Pomeron and Odderon exchanges in elastic and inelastic diffraction.

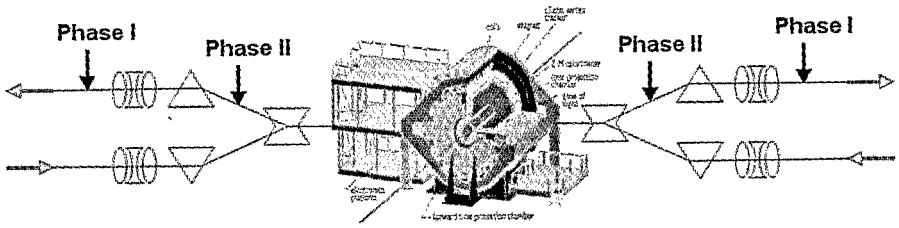
In order to characterize the diffractive processes well, the measurement of the momentum of the forward proton is crucial. Because of the layout of STAR and its solenoidal magnetic field, RHIC accelerator magnets must be used for momentum analysis resulting in forward proton taggers installed either between the DX-D0 magnets or in the warm straight section between Q3 and Q4 magnets, see Fig. 1. Also, to extend the t and ξ ranges to the lowest values, a moveable detector system, approaching the beam as closely as possible, is needed. Hence the use of pp2pp Roman Pots (RPs) is advantageous not only because it is a working system but because it will also allow maximizing the t and ξ ranges.

We propose a scenario of executing the physics program in two phases, which optimizes the use of available resources and maximizes physics output. Phase I can be realized in a short time frame and requires only minimal resources because of the use of the existing and already debugged equipment of pp2pp experiment. To maximize the physics reach one must tag forward protons between the DX-D0 magnets. This would be achieved in Phase II, for which design work is needed.

Processes sensitive to Odderon exchanges are discussed in both elastic and inelastic diffarction are discussed.

Implementation at RHIC

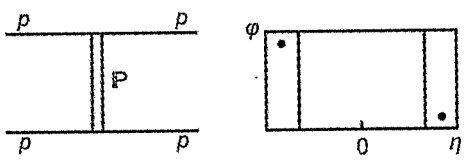
Detectors to tag forward protons (Roman Pots of pp2pp)
and detector with good acceptance and
particle ID to measure central system (STAR)



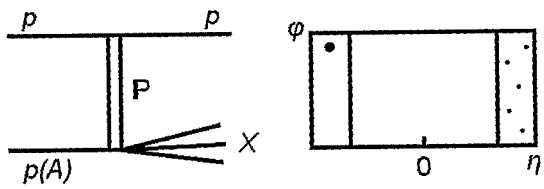
Roman Pots of pp2pp and STAR

Elastic and Inelastic Processes

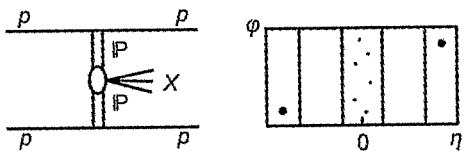
Elastic Scattering



Single Diffraction



Central Production

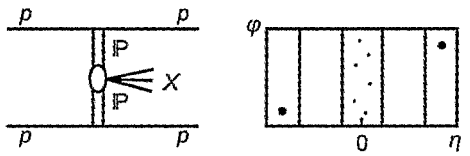


For each proton vertex one has
t four-momentum transfer
$\xi = \Delta p/p$
M_X invariant mass

In terms of QCD, Pomeron exchange consists of the exchange of a color singlet combination of gluons. Hence, triggering on forward protons at high (RHIC) energies predominantly selects exchanges mediated by gluonic matter.

Central Production in DPE

Central Production



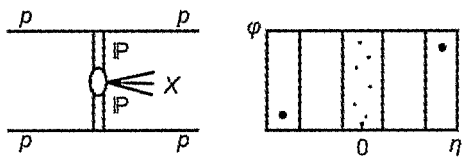
In the double Pomeron exchange process each proton "emits" a Pomeron and the two Pomerons interact producing a massive system MX.

The massive system could form resonances or consist of jet pairs. Because of the constraints provided by the double Pomeron interaction, glueballs, and other states coupling preferentially to gluons, will be produced with much reduced backgrounds compared to standard hadronic production processes.

Applies to processes with Odderon exchange: PO or OO

Glueball Central Production in DPE

Central Production



The idea that the production of glueballs is enhanced in the central region in the process $pp \rightarrow pM_Xp$ was first proposed by F.Close and was demonstrated by WA102.

The pattern of resonances produced in central region depends on:

$$dP_T = |\bar{k}_{T1} - \bar{k}_{T2}|$$

When $dP_T \propto$ LQCD $\bar{q}q$ states are prominent and when dP_T is small the surviving resonances include glueball candidates.

Summary

The physics program of tagged forward protons with STAR at RHIC includes:

- Study of standard hadron diffraction both elastic and inelastic and its spin dependence in unexplored t and √s range;
- Study of the structure of color singlet exchange in the non-perturbative regime of QCD.
- Study of processes with leading particle(s).

- Search for central production of light and massive systems in double Pomeron exchange process - glueballs (final states with charged particles).
- Search for an Odderon - a firm prediction of QCD and an eigenstate of CGC is possible.

The expectation of this workshop is to formulate the plan for Odderon search at RHIC and possibly other exciting topics.

There is a great potential for important discoveries at RHIC in the field of elastic and inelastic diffraction.

Summary continued: best places to look for an Odderon at RHIC

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	10^4/0.05 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/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 $A_{NN} \sim 0.01$-0.02?	ΔA_{NN}=0.005	If peak ⇒ then O, is unique, energy dep. is important $\sqrt{s}$=200 Phase I	**

Also discussed central production with tagged forward protons $pp \rightarrow pM_xp$, where M_X is not by DP process, need to know σ for M_X= J/Ψ, constraint $-1 < \eta(M_X \text{ decay}) < 1$

RHIC Spin Note

September 27, 2005

The odderon and the spin dependence of proton-proton elastic scattering

T.L. Trueman [1]

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Abstract

Results from an earlier determination of the spin-flip coupling of the leading Regge poles are used to estimate the magnitude of the double-spin asymmetry A_{NN} in polarized proton elastic scattering. The required Regge cuts are estimated using the absorptive Regge model. This is then used to determine the sensitivity of experiments at RHIC to the presence of the odderon.

[1]This manuscript has been authored under contract number DE-AC02-76CH00016 with the U.S. Department of Energy. Accordingly, the U.S. Government retains a non-exclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

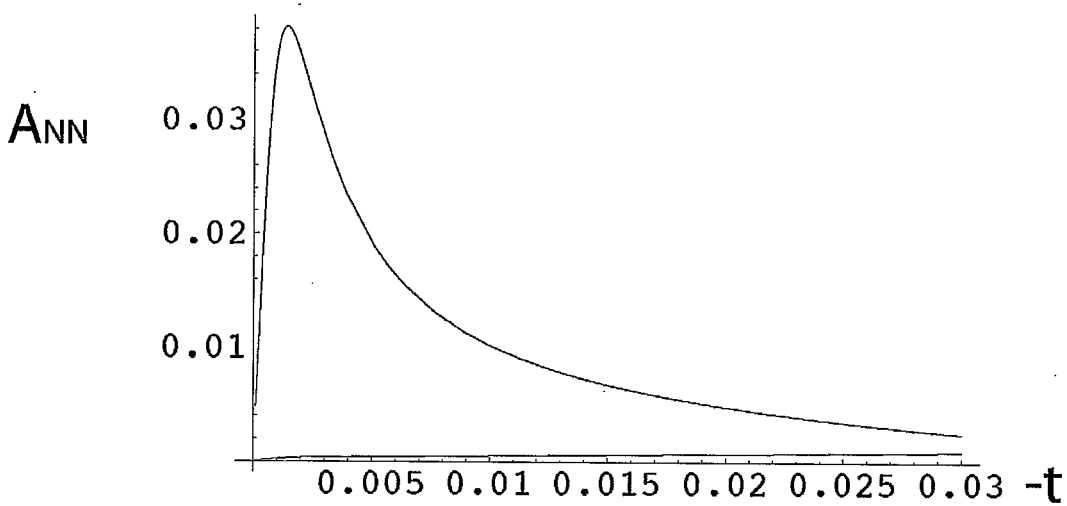
Regge residues in *1/GeV*

non-flip from Cudell et al PR D61:034019

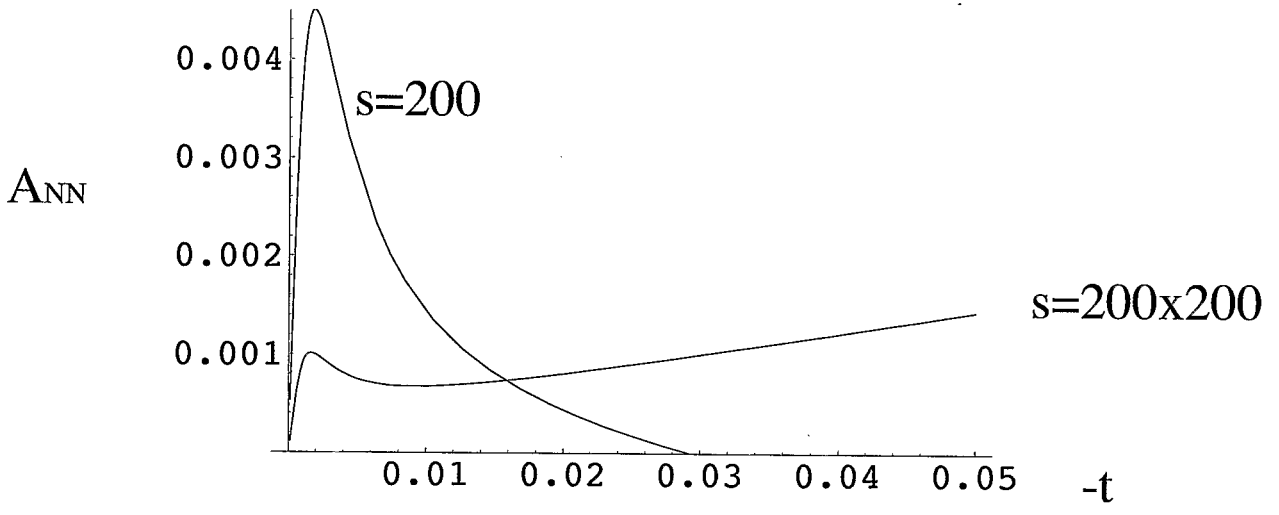
flip from Trueman, Spin2004

	non-flip	*flip*
pomeron	6.95± 0.10	0.626±0.10
C=+	12.73±0.23	-4.12±0.25
C=-	9.65±0.43	10.22±0.77

A_{NN} at 200x200 for odderon flip = rho flip (upper) and for odderon flip = pomeron flip (lower)



A_{NN} from ρ absorptive cut, no odderon at all



Ann(Odderon flip)-Ann(0)/Ann(0)

s GeV^2	Pomeron flip	Rho flip
200	0.0256	6.849
200x200	0.148	39.70
500x500	0.251	67.08

Conclusions

1. If the odderon exists and has a "reasonable" spin-flip coupling there is a good chance of observing it in ANN.

2. The odderon-pomeron cut is essential to producing an observable signal in the small-t region.

3. There is a significant background mainly arising from the ρ -pomeron cut. If the odderon spin-flip is small, but larger than the pomeron spin-flip, measurements of ANN over a wide energy range will be needed to separate out the signal

How to measure
Pomeron phase
and discover odderon
at HERA and RHIC

I.F. Ginzburg
Sobolev Inst. of Mathematics, Novosibirsk, Russia

We suggest to study charge asymmetry of pions with small $k_\perp = (p_+ + p_-)_\perp$ of dipion having effective mass $M = 1.1 \div 1.4$ GeV in the processes with two rapidity gaps

$ep \to e\pi^+\pi^- p$ at HERA ($\mathbb{P}$ and $\mathbb{O}$),

$eA \to e\pi^+\pi^- A$ at e-RHIC ($\mathbb{P}$ and $\mathbb{O}$),

$AA \to A\pi^+\pi^- A$ at RHIC (only $\mathbb{P}$)

$pp \to p\pi^+\pi^- p$ at p-RHIC (??)

Small values of $k_\perp$ are obtained at reasonable values of measurable pion transverse momenta $p_{\pm\perp} \sim 400 \div 500$ MeV.

I.F.G, I.P.Ivanov, N.N. Nikolaev, *Eur. Phys. J. direct* **C5**, 02 (2003); *hep-ph/0110181*, I.F.G, I.P.Ivanov, *Phys. Elem. part. Atomic Nucl.* **35** (2004) 29-45, I.F.G, I.P.Ivanov, hep-ph/0401180 + new results

○ The phase δ_F of the forward high energy hadronic elastic scattering amplitude (Pomeron phase): $\mathcal{A} = |\mathcal{A}|e^{i\delta_F} \equiv |\mathcal{A}| \exp\,[i\pi(1+\Delta_F)/2]$. Measurements in different processes will give either coincident Δ_F (e.g. naive Regge-pole, dipole Pomeron) or different Δ_F (pole+cuts). A phase of such type was measured till now (via the study of Coulomb interference near forward direction) at very high energy only for pp, $\bar{p}p$ elastic scattering – at transverse momenta of recorded particles $p_\perp \approx \sqrt{|t|} \lesssim$ 50 MeV (extremely small scattering angles).

○ The odderon — an elusive but necessary element of the QCD motivated hadron physics. New analysis of HERA data on $\gamma p \to f_2 p'$, etc. is necessary taking into account inaccuracies of previous theoretical estimates.

We only assume existence of odderon obliged amplitude like $\gamma p \to f_2 P$ with cross section $\gtrsim$ 0.01 from that estimated by Heidelberg group ($\gtrsim$ 0.03 from experimental limitation).

Dipion momentum $k = p_- + p_+$, $M \equiv \sqrt{k^2}$.
$z_\pm = (\epsilon_\pm + p_{\pm z})/(2E_\gamma) = (p_\pm P)/(qP)$;
J and $\lambda_{\pi\pi}$ – spin and helicity of dipion,
$\beta = \sqrt{1 - 4m_\pi^2/M^2}$. In the dipion c.m.s:
$(p_- - p_+) = \beta M(0, \sin\theta\cos\phi, \sin\theta\cos\phi, cos\theta)$,
λ_γ – photon helicity.

Forward–backward (FB) and transverse (T) asymmetries variables:

$$FB: \qquad \xi = \frac{z_+ - z_-}{\beta(z_+ + z_-)} = \cos\theta\,,$$

$$T: \qquad v = \frac{p_{+\perp}^2 - p_{-\perp}^2 - \xi k_\perp^2}{\beta M|k_\perp|} = \sin\theta\cos\phi\,.$$

We describe

$$\Delta\sigma_T = \int d\sigma(v > 0) - \int d\sigma(v < 0)\,,$$

$$\Delta\sigma_{FB} = \int d\sigma(\xi > 0) - \int d\sigma(\xi < 0)\,,$$

$$\sigma_{bkgd} = \int d\sigma\,,$$

with integration over (identical) suitable region of final phase space. For the integrated luminosity $\mathcal{L}$, the statistical significance of the result is

$$SS_{T,FB} = \frac{\mathcal{L}\Delta\sigma_{T,FB}}{\sqrt{\mathcal{L}\,\sigma_{bkgd}}}.$$

Important: Charge asymmetry can be seen even if processes with production of C–even dipion (f_2) are below observation limit.

Let A_- and A_+ are amplitudes of production of C–odd and C–even dipions with helicities $\lambda^-_{\pi\pi}$, $\lambda^+_{\pi\pi}$. $\boxed{d\sigma \propto |A_-|^2 + |A_+|^2 + 2Re(A^*_- A_+)}$
The interference term $2Re(A^*_- A_+)$ describes charge asymmetric contribution.

Odd $\lambda^+_{\pi\pi} - \lambda^-_{\pi\pi} \Rightarrow$ **T** asymmetry.

Even $\lambda^+_{\pi\pi} - \lambda^-_{\pi\pi} \Rightarrow$ **FB** asymmetry.

Amplitude $A_- \equiv A_-^{\mathbb{P}}$ – Pomeron exchange;

Amplitude $A_+ = A_+^{\gamma} + A_+^{\mathbb{O}} + A_+^{\rho,\omega}$,

A_+^{γ} – photon exchange , $A_+^{\mathbb{O}}$ – odderon,

$A_+^{\rho,\omega}$ – ρ/ω Regge exchange ($< 0.1nb$ for γp).

Pomeron and odderon amplitudes:

$$\mathcal{A}_\pm = \sum_{Jn} A_{\pm Jn}(s,t,M^2) D_J(M^2) \mathcal{E}_J^{\lambda_\gamma,\lambda_{\pi\pi}} .$$

A_{-Jn} and A_{+Jn} are proper Pomeron and odderon amplitudes for dipion production.

$D_J(M)$ describes the decay of dipion state to pions (e.g. normalized resonance propagator). For Pomeron we use fit from D. Bisello *et al.* [DM2 Collaboration], *Phys. Lett.* **B220**, 321 (1989) (includes ρ running width and ρ'/ρ'' states.) For odderon – $f_2(1280)$ propagator. $\mathcal{E}_J^{\lambda_\gamma,\lambda_{\pi\pi}}$ describes the angular distribution of pions, in their c.m.s. frame

$$\mathcal{E}_J^{\lambda_\gamma,\lambda_{\pi\pi}} = Y^{J,\lambda_{\pi\pi}}(\theta,\phi) e^{-i\lambda_\gamma \psi}.$$

The amplitude A_+^{γ} is the same as that in the $e^+e^- \to e^+e^-\pi^+\pi^-$ (well known).

HERA and e-RHIC

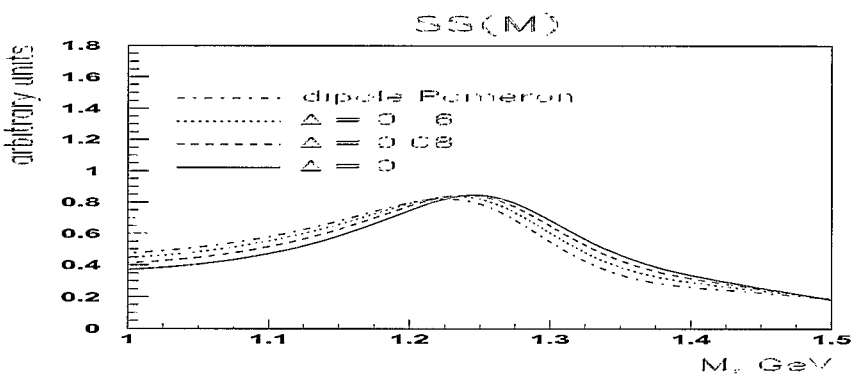
For the ep collisions at HERA, we take $\mathcal{L}_{ep} = 100$ pb^{-1}.

The same values of SS_T are obtained at e–RHIC with $\mathcal{L}_{eA} = 40$ pb^{-1}.

$20 < k_\perp < 100$ MeV, Pomeron phase

Here C–even dipion is produced mainly via photon exchange ($A_+^{\mathbb{O}}$, $A_+^{\rho,\omega}$ negligible). Only transverse asymmetry appears since s–channel helicity conservation (SCHC) for Pomeron. Here $\Delta\sigma_T \propto (k_{\perp max} - k_{\perp min})$,

$$\sigma_{bckg} = A_1(k_{\perp max}^2 - k_{\perp min}^2) + A_2 \ln \frac{k_{\perp max}^2}{k_{\perp min}^2 + Q_m^2}.$$



The local statistical significance of the charge asymmetry (arbitrary units).

Integration over intervals $0.2 < y < 0.8$, $1.1 < M < 1.4$ GeV $\Rightarrow$ $\boxed{SS_T \approx 34}$ with

$$\sigma_{bkgd}^{ep} \approx 1.5 \text{ nb}, \quad \Delta\sigma_T \approx 0.13 \text{ nb}.$$

Discovery of odderon, $k_\perp \gtrsim 200$ MeV

At these $k_\perp$ C–even dipion can be produced only via odderon exchange (photon contribution disappear at these $k_\perp$, ρ, ω Regge exchange contributions are negligibly small at HERA, e-RHIC energy).

Denote: $\sigma_{\mathbb{O}}$ –total cross section of $\gamma p \to f_2 p$.

The shape of local statistical significance is roughly similar to that for Pomeron–photon interference.

• If SCHC takes place also for odderon amplitude, the main charge asymmetry is the forward–backward one. The integration over $k_\perp$ and over $y = 0.2 - 0.8$ results in

$$\sigma^{ep}_{bkgd} = 22\,\text{nb}, \quad \Delta\sigma_{\mathbb{P}-\mathbb{O},FB} = 0.83\text{nb}\sqrt{\frac{\sigma_{\mathbb{O}}}{\text{nb}}}$$

$$\Rightarrow \; SS_{FB} = 56\sqrt{\frac{\sigma_{\mathbb{O}}}{\text{nb}}} = 56 \div 560\,.$$

• If SCHC is violated strongly for odderon, the main charge asymmetry is the transverse one,

$$\sigma^{ep}_{bkgd,T} \approx 9\,\text{nb}\,; \qquad \Delta\sigma_{\mathbb{P}-\mathbb{O},T} \approx 0.34\sqrt{\frac{\sigma_{\mathbb{O}}}{\text{nb}}}\,\text{nb}$$

$$\Rightarrow SS_T = 35\sqrt{\frac{\sigma_{\mathbb{O}}}{\text{nb}}} = 35 \div 350\,.$$

$$A_1 A_2 \to \pi^+\pi^- A_1 A_2$$

at $k_\perp^{\pi\pi} < 60$ MeV, $|k_z^{\pi\pi}| < 3$ GeV,

Here two-photon production of C–even f_2 with cross section $\propto Z^4$ dominates. C–odd dipion is produced in the collision of almost mass shell photon, radiated e.g. by A_1 with nuclei A_2 and *vice versa*. The interference of these amplitudes results in charge asymmetry which changes sign at transition from $k_z^{\pi\pi} > 0$ to $k_z^{\pi\pi} < 0$.

Statistical significance $SS_T \approx 30$ can be obtained at luminosity integral about 10 nb^{-1}

Measurement of Pomeron phase is possible.

$k_\perp^{\pi\pi} > 200$ **MeV**

Here C–odd dipion is produced mainly as written above, in $\gamma^* A$ collision (Pomeron) – see STAR, ALICE.

Mechanisms of production of C–even dipion: odderon, Regge ρ/ω exchange (it is not very small), $\mathbb{P}\mathbb{P}$ central collision. Leading mechanism can not be established now.

– no definite information on odderon.

The same is valid for $p - RHIC$. In the latter case the study of energy dependence can help to eliminate contribution of Regge ρ/ω exchanges.

New studies are necessary here.

Speaker: Jochen Bartels

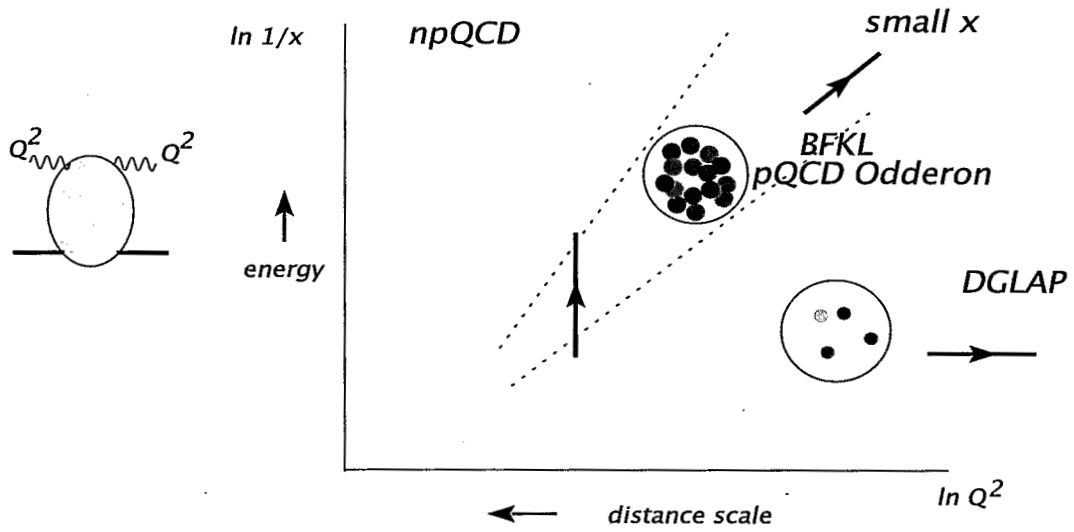
Affiliation: Hamburg University, Hamburg, Germany

Title of the talk: The Odderon - a fundamental object in QCD?

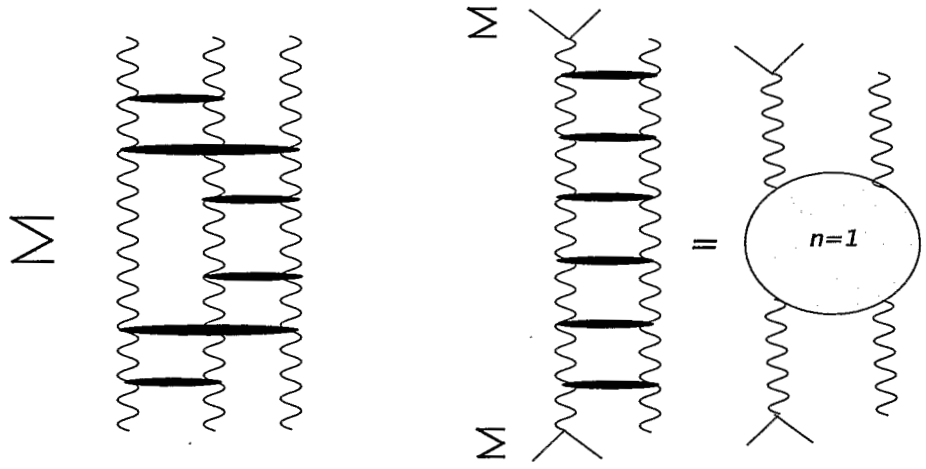
Summary:
The BLV Odderon solution in pQCD is reviewed, and a few possible experimental measurements are discussed. The Odderon is also viewed in the broader context of high energy QCD: here the BFKL Pomeron and the Odderon represent the two fundamental gluonic excitations. In hadron-hadron reactions, both of them are unitarized; in the theoretical analysis of this unitarization saturation may play an important role. At very high energies the BFKL Pomeron and the Odderon become part of a reggeon field theory which exhibits string-like features.

High Energy Behavior: is it fundamental in QCD?

Compared to $\sim$ 30 years ago, there is a change in our perception of the high energy limit.
Quantities such as σ_{tot}, $\frac{d\sigma}{dt}$ in hadron hadron collisions are nonperturbative.
With our present knowledge of QCD: need to start from short distances.
Combination of high energy and small-distance limit: two scales.
Example: small-x limit at HERA energy, $s \longrightarrow W^2 = Q^2/x$, Q^2.



Lowest energy solution:



Remarkable:

1) d-reggeon: degenerate even - signature partner of the gluon
Boostrap inside a three gluon color singlet state.

2) antisymmetric bound state of the d-reggeon and the gluon

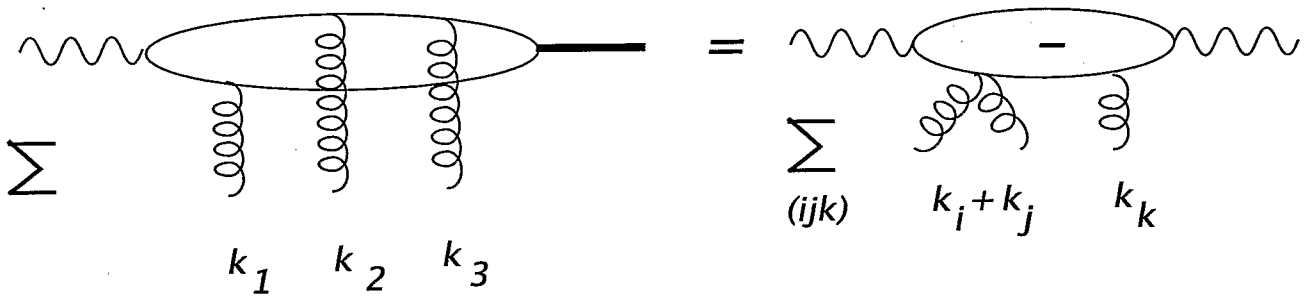
3) In leading order: $\alpha_{odderon-BLV}(0) = 1$

4) More subtle: space of functions ($\longrightarrow$ Vacca's talk)

New features of BFKL dynamics!

The perturbative environment of the Odderon

Coupling to external projectile: the photon impact factor $\gamma^* \longrightarrow \eta_c$
(J.Czyzewski, J.Kwiecinski, L.Motyka, M.Sadzikowski)

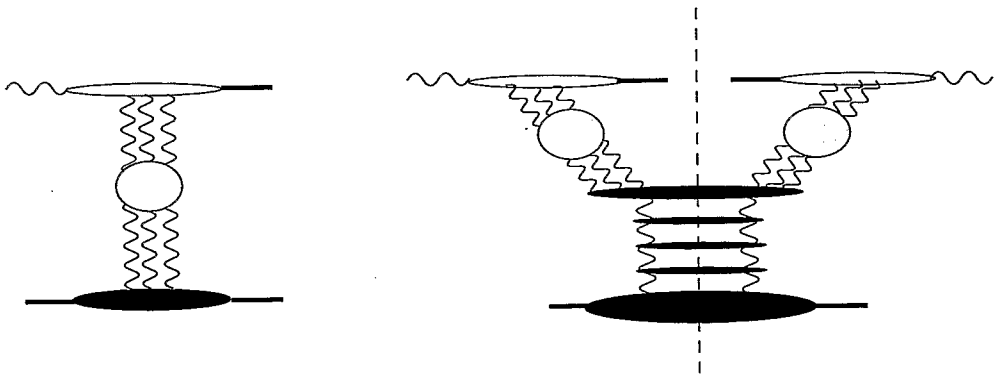


$$\phi(k_1, k_2, k_3) = \sum_{(ijk)} \varphi(k_i + k_j, k_k) - \varphi(k_i + k_j + k_k, 0)$$

Coupling to the external particle 'prepares' the Odderon state!
The symmetric JW solution decouples from this vertex.
Important: Odderon seen in dipole model ($\longrightarrow$ Kovchegov)
and color glass condensate ($\longrightarrow$ Venogopolan, Hatta).

Where and how to look for the pQCD Odderon

1) The Processes $\gamma^* p \to \eta_c p$, $\gamma^* p \to \eta_c X$
(Czyzewski, Kwiecinski, Motyka, Sadzikowski; JB, Colferai, Braun, Vacca)



Dip structure in $\frac{d\sigma}{dt}$; Enhancement of three gluon exchange by factor 5.
Estimated cross section: 1.5 pb for photoproduction, 40 fb for $Q^2 = 25$ GeV^2.
$\gamma^* p \to \eta_c X$ (new vertex!): 60 pb for photoproduction, 1.5 pb for $Q^2 = 25$ GeV^2.

Not studied at HERA.

Summary

- pQCD predicts an Odderon (in the world of short distances):
  it is a bound state of three reggeized gluons, has novel features beyond BFKL
- From here two directions:
  - Connection with soft physics (pp scattering): 'unitarization', theoretical progress, but no solution yet (confinement issue)
  - The pQCD Odderon is part of the general QCD reggeon field theory (merges into a string theory?)
- Several places to look for the pQCD ('hard') Odderon.
  Further studies needed.
- Search for the 'real Odderon': dip structure in $\frac{d\sigma_{pp,p\bar{p}}}{dt}$:
  Polarization?

Is the Odderon a fundamental object in QCD?

Reggeized gluon states in multi-colour QCD: Pomeron vs odderon

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September 21, 2005

Abstract

Considering the high energy Regge limit one can rewrite the scattering amplitude of hadrons in terms of the reggeized gluon states, i.e. Reggeons. These states have either positive or negative $C-$parity, Pomeron and odderon, respectively. The high energy asymptotic of the scattering amplitude corresponding to the N-Reggeon states is set by intercept which is related the Reggeon energy E_N. In order to calculate it and find the Reggeon wave-functions one has to solve the Schrödinger-like (BKP) equation. During this talk I will show the way one can construct the three-Reggeon wave-functions, which are either the leading parts of the odderon wave-functions or the subleading parts of the Pomeron wave functions. The reggeized gluon states for higher number of Reggeons may be related to the subleading odderon as well as Pomeron contribution to the scattering amplitude. Therefore, in the next part of the speech I will describe methods which allows to find the spectrum of the Reggeon energy E_N for the multi-Reggeon states and the spectrum of the conformal charges, which in the considering system play a role of the integrals of motion. This talk is based on the work performed with G. Korchemsky, A. Manashov and S. Derkachov as well as my doctoral dissertation.

Multi-Reggeon Equation (BKP)

The scattering amplitude in the Regge limit: $s \to \infty, \quad t = const$

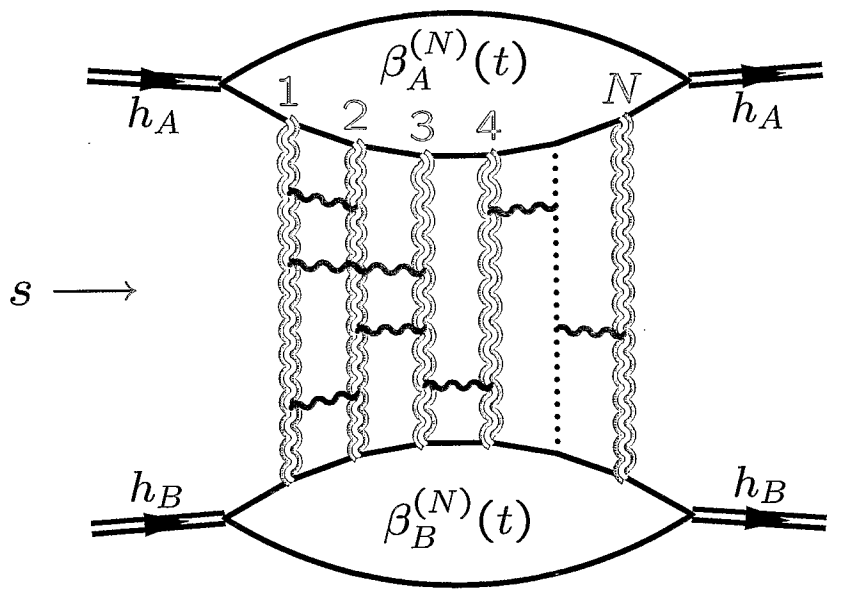
$$A(s,t) \sim -i \sum_{N=2}^{\infty} (i\bar{\alpha}_s)^N \frac{s^{1-\bar{\alpha}_s E_N}}{\sqrt{\bar{\alpha}_s \ln s}} \beta_A^{(N)}(t) \beta_B^{(N)}(t)$$

$\bar{\alpha}_s = \alpha_s N_c / \pi$

The compound N-Reggeon states satisfy the Schrödinger equation:

$$\mathcal{H}_N \Psi(\{\vec{z}_k\}) = E_N \Psi(\{\vec{z}_k\})$$

E_N - the "energy" of the ground states



Pomeron vs Odderon

Pure gluon: $\boxed{A_\mu(x) \xrightarrow{C} -A_\mu^T(x)}$ where $A_\mu(x) = A_\mu^a(x)t^a$

$N = 2$:

$$\mathbb{P}_{\mu\nu}(x,y) = \mathrm{tr}(A_\mu(x)A_\nu(y)) = \tfrac{1}{2}\delta_{ab}A_\mu^a(x)A_\nu^b(y) \qquad \boxed{C = +1}$$

$N = 3$:

$$\mathbb{P}_{\mu\nu\rho}(x,y,z) = -i\,\mathrm{tr}([A_\mu(x), A_\nu(y)]A_\rho(z)) = \tfrac{1}{2}f_{abc}A_\mu^a(x)A_\nu^b(y)A_\rho^c(z) \qquad \boxed{C = +1}$$

$$\mathbb{O}_{\mu\nu\rho}(x,y,z) = \mathrm{tr}(\{A_\mu(x), A_\nu(y)\}A_\rho(z)) = \tfrac{1}{2}d_{abc}A_\mu^a(x)A_\nu^b(y)A_\rho^c(z) \qquad \boxed{C = -1}$$

Reggeons:

$$\begin{cases} \mathbb{P}: & f_{abc} \Leftrightarrow \Psi^{(-)}(\vec{z}_1, \vec{z}_2, \vec{z}_3) \\ \mathbb{O}: & d_{abc} \Leftrightarrow \Psi^{(+)}(\vec{z}_1, \vec{z}_2, \vec{z}_3) \end{cases}$$ where under mirror permutation

$$\mathbb{M}\Psi(\vec{z}_1, \vec{z}_2, \ldots, \vec{z}_N) = \Psi(\vec{z}_N, \ldots, \vec{z}_2, \vec{z}_1)$$

$$\mathbb{M}\Psi^{(\pm)}(\vec{z}_1, \vec{z}_2, \ldots, \vec{z}_N) = \pm\Psi^{(\pm)}(\vec{z}_1, \vec{z}_2, \ldots, \vec{z}_N)$$

$$\Psi^{(\pm)}(\vec{z}_1, \vec{z}_2, \ldots, \vec{z}_N) = \tfrac{1}{2}\left[\Psi_{\{q,\bar{q}\}}(\vec{z}_1, \vec{z}_2, \ldots, \vec{z}_N) \pm \Psi_{\{-q,-\bar{q}\}}(\vec{z}_1, \vec{z}_2, \ldots, \vec{z}_N)\right]$$

where $q = \{q_k\}, -q = (-1)^k q_k$

Wave-Functions for Three Reggeons
$\Psi \equiv \Psi_{\{q_3,\bar{q}_3\}}(\vec{z}_1, \vec{z}_2, \vec{z}_3; \vec{z}_0)$

Lipatov's ansatz:

$$\boxed{\hat{q}_2\Psi = -(h-1)h\Psi \quad \& \quad (\textit{a-h. sec.})} \quad \Longrightarrow \quad \boxed{\Psi = w^h \bar{w}^{\bar{h}} F(x, \bar{x})}$$

where $w = \frac{(z_3-z_2)}{(z_3-z_0)(z_2-z_0)}$ and $x = \frac{(z_1-z_2)(z_3-z_0)}{(z_1-z_0)(z_3-z_2)}$

Janik-Wosiek solution:

$$\boxed{\hat{q}_3\Psi = q_3\Psi \quad \& \quad (\textit{a-h. sec.})} \quad \Longrightarrow \begin{cases} \text{spectrum of } \hat{q}_3 \\ \Psi_{\{q_3,\bar{q}_3\}}(\vec{z}_1, \vec{z}_2, \vec{z}_3; \vec{z}_0) \end{cases}$$

where $\bar{q}_3 = q_3^*$ and $\bar{h} = 1 - h^*$ with $h = \frac{1+n_h}{2} + i\nu_h$ and $n_h \in \mathbb{Z}$, $\nu_h \in \mathbb{R}$

Usually, the wave-functions $\Psi_{\{q_3,\bar{q}_3\}}(\vec{z}_1, \vec{z}_2, \vec{z}_3; \vec{z}_0)$ have mixed $C-$parity, so they contain Pomeron as well as odderon contribution.

Our Method

QCD $\mathcal{H}_N$

$N_c \to \infty$

$\mathcal{H}_N = \sum_i H(\vec{z}_k, \vec{z}_{k+1})$

the integrals of motion $\hat{\vec{q}}_k$

$\mathcal{H}_N(\hat{\vec{q}})$

the Baxter $\mathbb{Q}$-operator

$\mathcal{H}_N\left[\hat{\mathbb{Q}}_{\vec{q}}(u, \overline{u})\right]$

Baxter equations

the integral ansatz for

$\mathbb{Q}(u, \overline{u}) = \int \mathbb{Q}_{\vec{q}}(z, \overline{z}) K(u, \overline{u}, z, \overline{z}) d^2 z$

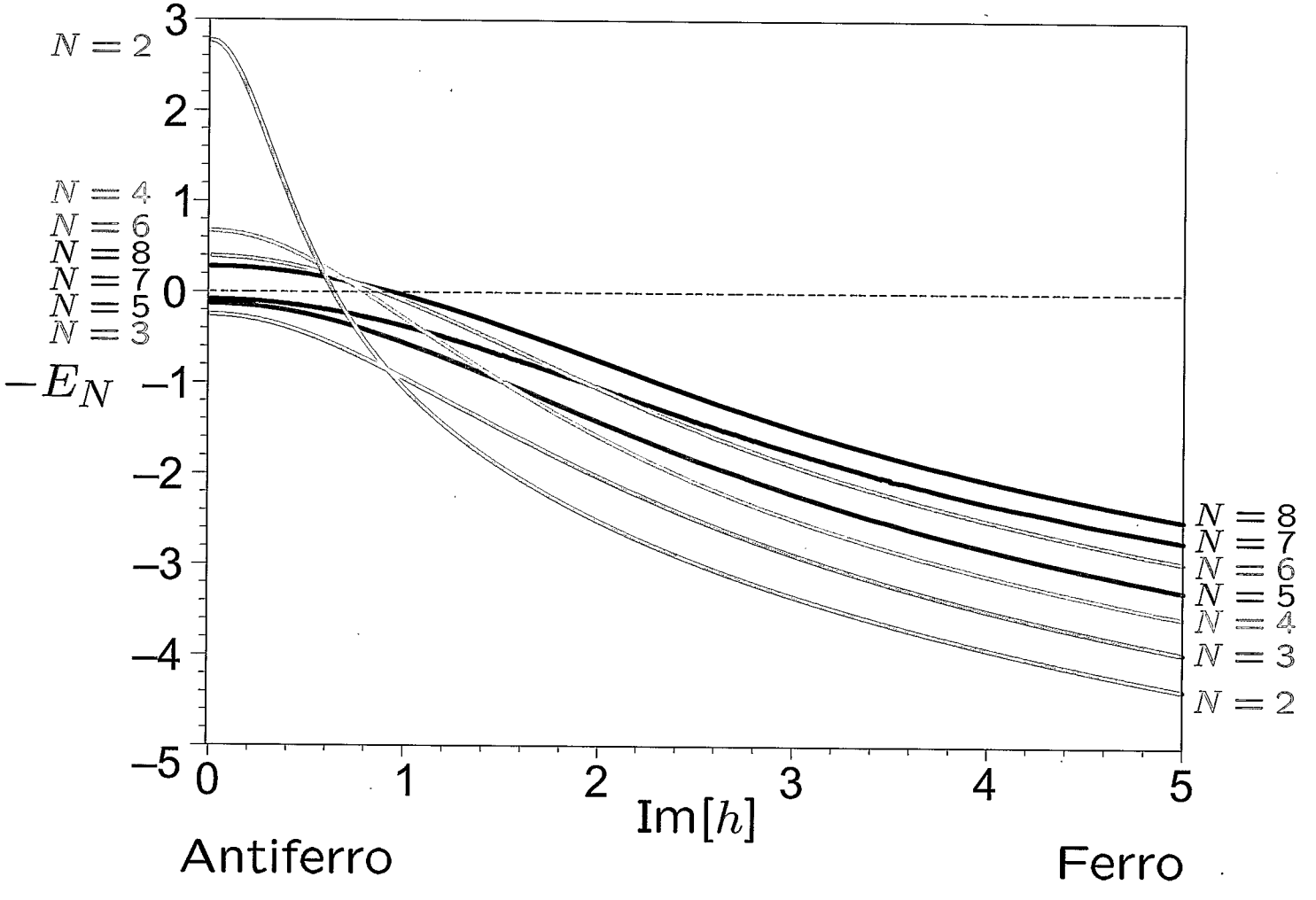
Differential equations for $\mathbb{Q}_{\vec{q}}(z, \overline{z})$

singlevaluedness of $\mathbb{Q}_{\vec{q}}(z, \overline{z})$ in the complex z-plain

Quantum conditions for the eigenvalues of $\hat{\vec{q}}_k$

Spectrum of the energy

The Ground Branches $E_N(\mathrm{Im}(h))$ for $h = \frac{1}{2} + i\nu_h$



Some aspect of the perturbative QCD Odderon

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Abstract

I will place at the heart of this discussion the property of the gluon reggeization. The BFKL approach is based on this property, which is encoded in the self consistent boostrap condition. Concentrating on the LL case, it is shown that to describe the bootstrap mechanism the so called AF space of functions is needed. The reggeization mechanism was crucial to find the BLV Odderon states with maximal intercept and a family of generalized descendent states for n interacting gluons in the large N_c limit. Going beyond the evolution with fixed number of gluons in the t-channel, the effective verteces determining the non linear evolution of Pomeron and Odderon states are also dynamically affected by the gluon reggeization.

Boostrap strongly influences the dynamics

LL case much more investigated (LLA, GLLA, EGLLA)

- At LL octet 8_A and 8_S states have similar behavior: bootstrap works for both in the same way.

- Impact factor side: depending on the constituents of the external particles, n gluon t-channel states may be reduced. Fewer impact factors are fundamental.

- Green's function dynamics may be reduced, look at kernel eigenstates. First case seen is the Odderon channel which starts from 3 interacting gluons. Large N_c multigluon states are also affected. There is a chain of descendent states: physical reason is reggeization.

- Coupling of onium ($q\bar{q}$) to $2, 3, 4, 5, 6$ gluon t-channel states has been analyzed. It is reduced by bootstrap.
  Verteces do appear: $V_{2\to 4} \to$ 3P and $V_{2\to 6} \to$ POO.

- There is reggeization also at NLL. There are some results but more investigation is needed. Difference between 8_A and 8_S states. Does 8_S reggeize? What about Odderon and multigluon states?

- Real hadrons are more complicated. No more pertubative tools available!
  Anyway bootstrap is expected to survive at non-perturbative level at high energies.
  Will it give dynamical insights?

BFKL kernel: Möbius vs AF representation

In the Möbius (M) space the color singlet BFKL kernel and its eigenstates can be redefined according to Möbius invariance (h are the conformal weights):

$$\tilde{H}_{12} = h_{12} + \bar{h}_{12} = \sum_h \int d^2\rho_0 \, \frac{N_h}{|\rho_{12}|^2} \langle \rho | h \rangle \, \chi_h \, \langle h | \rho' \rangle$$

$$\langle \rho | h \rangle = E_h(\rho_{10}, \rho_{20}) = \left(\frac{\rho_{12}}{\rho_{10}\rho_{20}} \right)^h \left(\frac{\rho^*_{12}}{\rho^*_{10}\rho^*_{20}} \right)^{\bar{h}}$$

- But $\tilde{H}_{12} \otimes \psi_g = 0$! It comes from: $\langle h | \psi_g \rangle = 0$.
  The reason is the presence of the term added thanks to gauge freedom.

$$\langle \rho | h \rangle = \langle \rho | h^A \rangle + \langle \rho | h^\delta \rangle$$

- Let's go back (removing the δ's) and define (on the Analytic Feynman (AF) space)

$$H_{12} = \sum_h \tilde{N}_h | h^A \rangle \, \chi_h \, \langle h^A |$$

which is meromorphic. Well behavied on both colorless and colored impact factors.
Compatible with the bootstrap relation.

Bartels, Lipatov, Salvadore, G.P.V. (2005)

M space - AF space

- The space of function considered is associated to the scalar product

$$\langle f|g\rangle = \int d\mu f^* g\,, \quad d\mu = \boldsymbol{k}_1^2 \boldsymbol{k}_2^2 \delta^{(2)}(\boldsymbol{q} - \boldsymbol{k}_1 - \boldsymbol{k}_2) d^2\boldsymbol{k}_1 d^2\boldsymbol{k}_2$$

This is the AF space, associated to functions with propagators (non amputated).
All the objects are meromorphic in the momenta.

- We define the mapping between AF and M spaces spanned by the $|\rho^A\rangle$ basis.

$$\Phi : AF \to M, \quad \Phi = 1 + \frac{F}{1-F} P\,,$$

$$\Phi^{-1} : M \to AF, \quad \Phi^{-1} = 1 - FP\,,$$

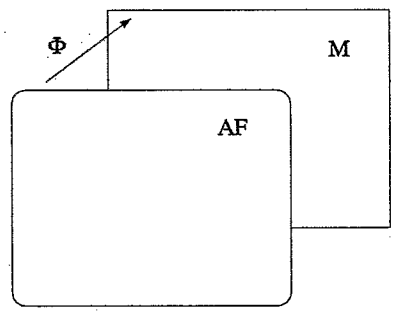
$$F = 2^{1-h-\bar{h}}\,, \quad P = P^2$$

$$Pf(x_1, x_2) = \frac{1}{2}\left[f(x_1, -x_1) + f(-x_2, x_2)\right]$$

such that $\Phi\Phi^{-1} = I_M$ and $\Phi^{-1}\Phi = I_{AF}$
One can extend the action of any operator

In particular $\boxed{\vec{M}_r^{AF} = \Phi^{-1}\vec{M}_r\Phi}$

one can construct a deformed realization of the sl(2,C) algebra.



- There might be a general message: A transformation due to gauge freedom does not spoil the integrability or a symmetry, but may link more or less evident realizations of them, associated to different space of functions.

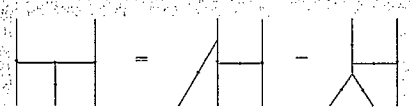
Chain of linked solutions: descendent states

The quantities conserved under the n gluon evolution (kernel H_n) are associated to the operators

$$q_r = \sum_{1\le i_1\le i_2\cdots\le i_r\le n} \rho_{i_1 i_2}\rho_{i_2 i_3}\cdots\rho_{i_r i_1}\; p_{i_1}p_{i_2}\cdots p_{i_r}\;,\;\; [q_r, q_s]=0\,,\;\; [q_r, h]=0$$

with $q_2 = M^2$ (Casimir of Möbius algebra) and $q_n = \rho_{12}\cdots\rho_{n1}P_1\cdots P_n$
Let us concentrate on the non trivial eigenstates of H_3 with $q_3 = 0$ for the Odderon (BLV states) or in general of H_n with $q_n = 0$.

- Require: $\boxed{|q_n|^2 E_n = 0} \Rightarrow |\rho_{12}\cdots\rho_{n1}|^2|\partial_1|^2\cdots|\partial_n|^2 E_n = 0 \Rightarrow$
  $\phi_n = |\partial_1|^2\cdots|\partial_n|^2 E_n = \sum_i \delta^{(2)}(\rho_{i,i+1})g_i$ Classify w.r.t. cyclic permutations:
  ansatz in momentum space (R_n is the cyclic rotation operator)
  $$\boxed{\phi_n(\boldsymbol{k}_1,\cdots,\boldsymbol{k}_n) = \sum_i (R_n)^i c_i \phi_{n-1}(\boldsymbol{k}_1+\boldsymbol{k}_2,\boldsymbol{k}_3,\cdots,\boldsymbol{k}_n)}$$
- Rewrite the kernel as:
  $$\boxed{H_n = \frac{1}{2}\Big(H^{(1)}_{23}+\cdots+H^{(1)}_{n2}\Big)+\frac{1}{2}\Big(H^{(1)}_{12}+H^{(1)}_{n1}-H^{(1)}_{n2}\Big)}$$
- Using the properties: bootstrap and the symmetry for exchange of lines $1\leftrightarrow 3$ of the *commutator* of the real kernel defined as
  $$W(\boldsymbol{k}_1,\boldsymbol{k}_2,\boldsymbol{k}_3|\boldsymbol{k}'_1,\boldsymbol{k}'_3) = V(\boldsymbol{k}_2,\boldsymbol{k}_3|\boldsymbol{k}'_1-\boldsymbol{k}_1,\boldsymbol{k}'_3) - V(\boldsymbol{k}_1+\boldsymbol{k}_2,\boldsymbol{k}_3|\boldsymbol{k}'_1,\boldsymbol{k}'_3)$$



Generalization of BLV Odderon states to n gluons.

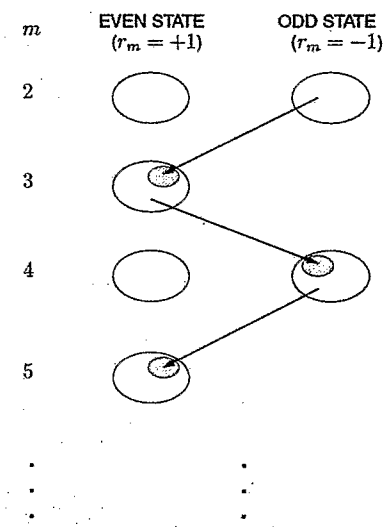
we can obtain states corresponding to n gluons from a construction starting from eigenstates with $n-1$ gluons in the large N_c limit.
If $H_{n-1}\phi_{n-1} = \chi\phi_{n-1}$ and $R_{n-1}\phi_{n-1} = r_{n-1}\phi_{n-1}$ then

$$H_n\phi_n = \chi\phi_n + \Big[\sum_i (R_n)^i \Big(1 + r_{n-1}(R_n)^{-1}\Big) c_i\Big] \int W(1,2,3)\phi_{n-1}(1,3,\ldots n)$$

Last term zero $\Rightarrow$ secular equation with eigenvalue $r_{n-1} = (-1)^n$ and eigenvector $c_i = (-1)^{(n-1)i}$

- n even: $c_i = (-1)^i$. Not physical states because not Bose symmetric (color traces even!)
- n odd: $c_i = +1$. Physical solutions ($n = 3$ corresponds to the BLV Odderon solution)

$$\boxed{E_h^{(m)}(k_1, k_2, \cdots, k_m) = \sum_{i=0}^{m-1} (R_m)^i c_i \frac{(k_1+k_2)^2}{k_1^2 k_2^2} E_h^{(m-1)}(k_1+k_2, k_3, \cdots, k_m)}$$



Note also that the constructing procedure is nilpotent and cannot be iterated.
G.P.V. (2000)

Single Spin Asymmetry of Very Forward Neutron at PHENIX

Sep. 28, 2005

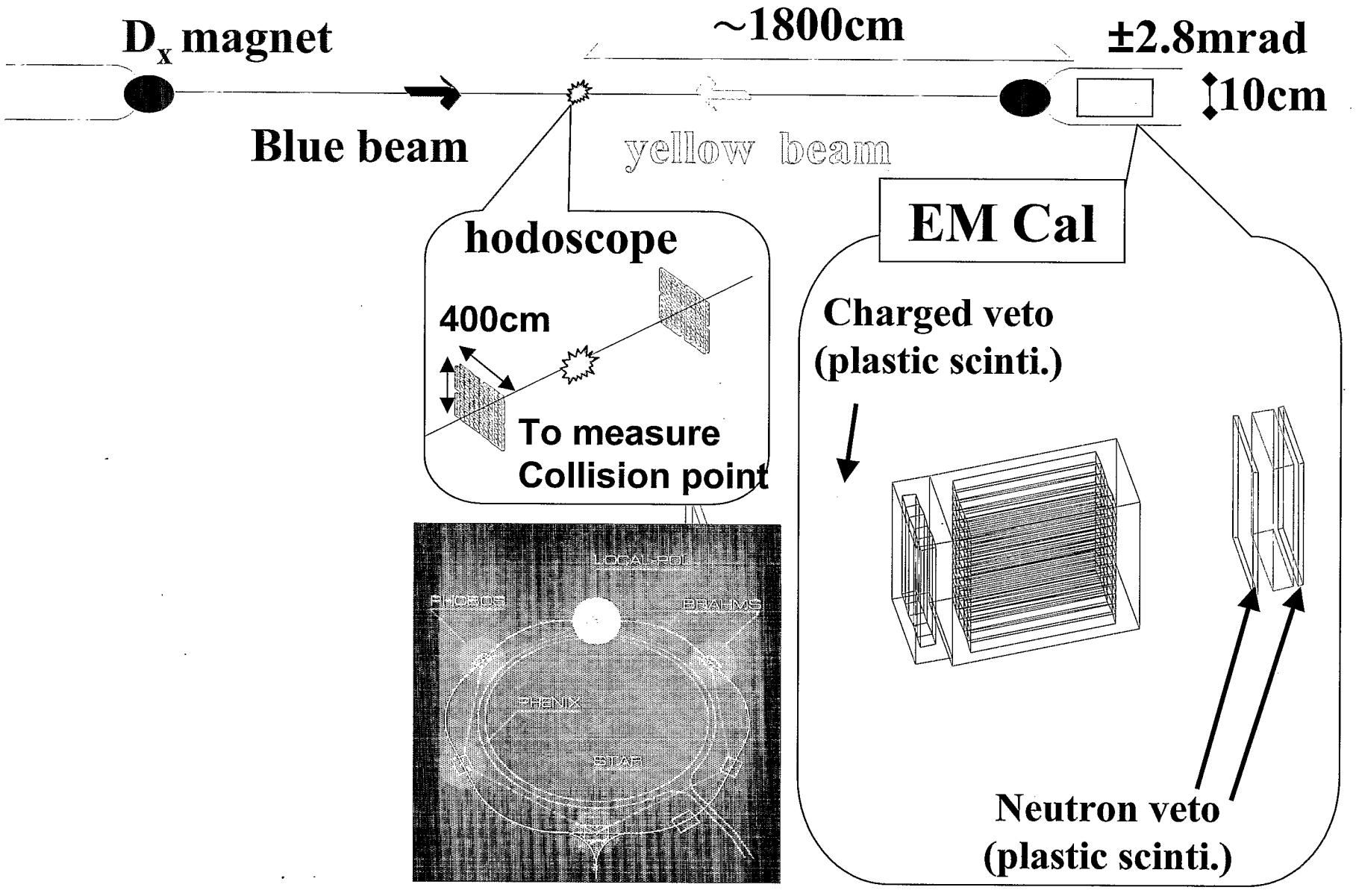
Workshop: “Odderon Searches at RHIC”

Kiyoshi Tanida (RIKEN)

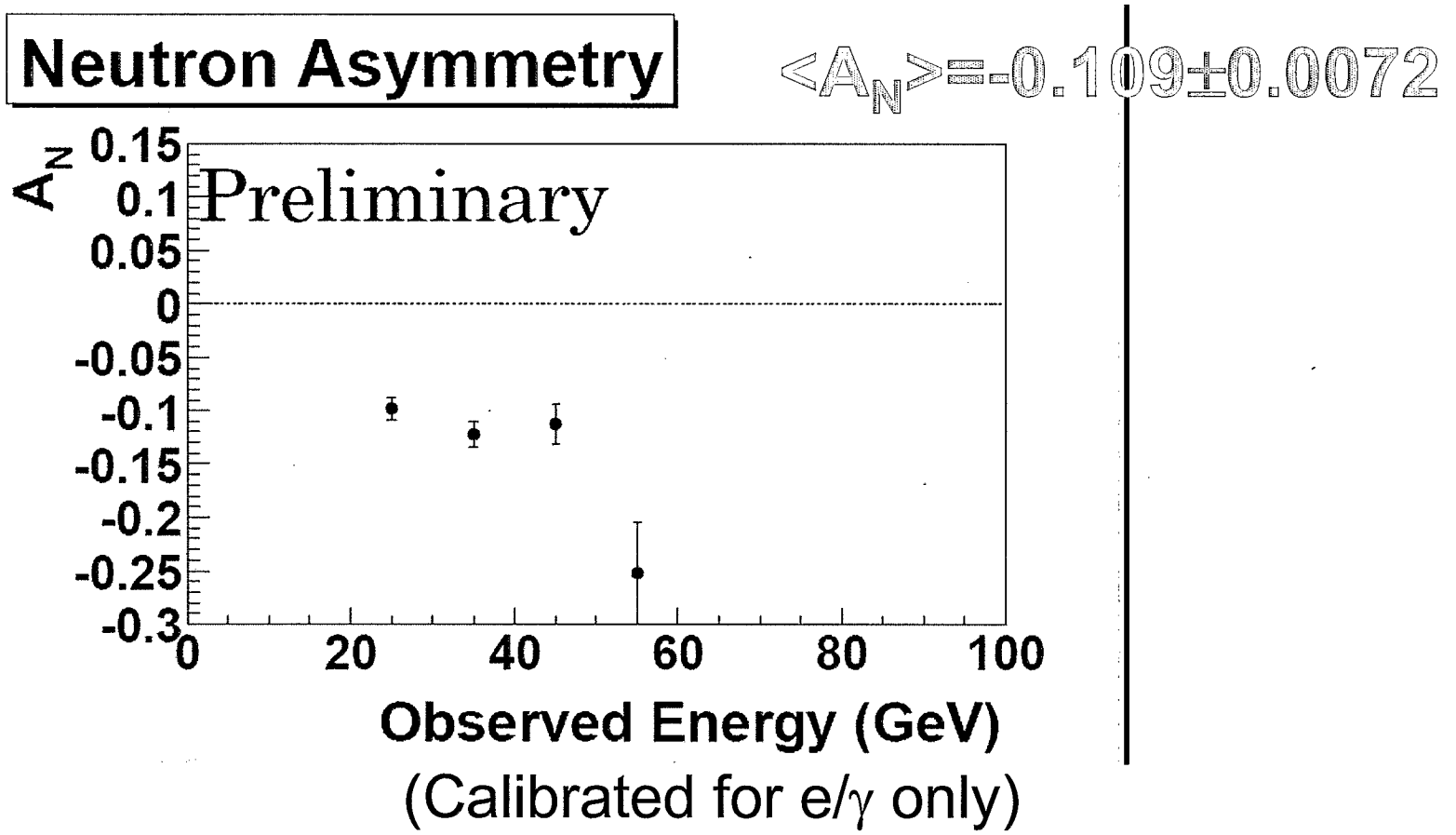
for the PHENIX Experiment

IP12 experiment

sqrt(s)=200 GeV

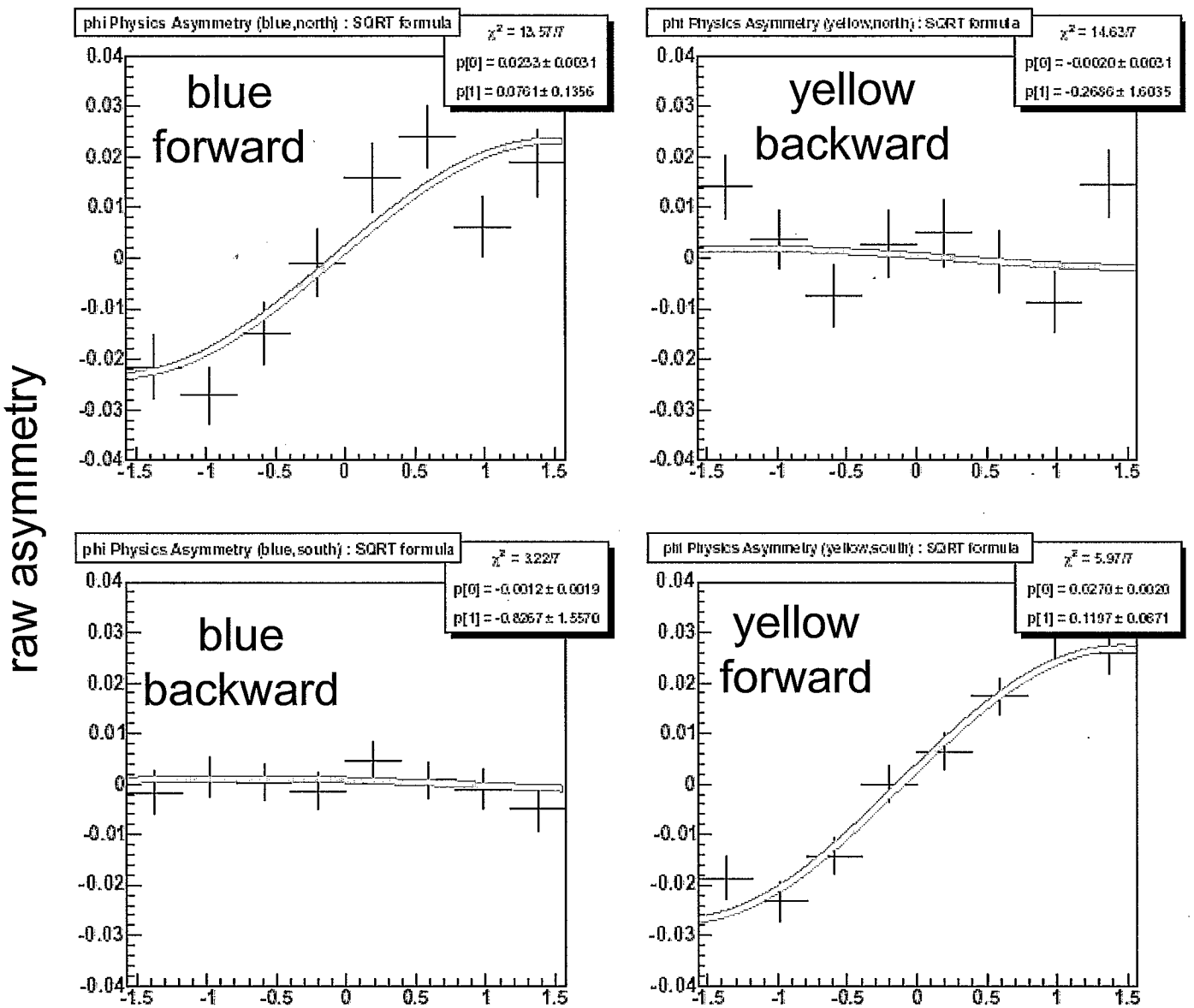


EMCal based results



Average beam pol. ~ 11%

A_N persists at sqrt(s) = 410 GeV



Coincidence of ZDC-BBC

- Tag neutron (or gamma) at ZDC
- Measure A_N of coincident particle at BBC
- Forward neutron, forward BBC, left-right

  $$(-4.50 \pm 0.50 \pm 0.22) \times 10^{-2}$$

- Forward neutron, backward BBC, left-right

  $$(2.28 \pm 0.55 \pm 0.10) \times 10^{-2}$$

  – No significant asymmetry for backward ZDC tagged data or in top-bottom asymmetry.

  – Systematic error doesn't include A_N^{CNI} error.

Summary

- We found a large A_N (-10%) in forward production of neutron in pp collision at sqrt(s) = 200 GeV.
  - Mechanism is unknown ← Place for Odderon??
- Measurement at PHENIX confirmed this.
  - comparable A_N at 200 GeV and 410 GeV.
- Coincident particles at BBC (forward and backward) also have large A_N
  - diffractive-like picture favored.
- Further experiments?

Your input is very appreciated!!

Leszek Łukaszuk

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"Search for Odderon in the Parity Violating Amplitudes' Asymptotics"

Summary

Model dependent arguments are given for the existence of Odderon-type asymptotics in the case of Parity Violating Compton amplitude. Estimated contributions come from the semi-hard region and are not related to the QCD Odderon. Similar behaviour might be observed in p.c. photon-hadron and hadron-hadron spin dependent collisions.

Odderon: crossing-odd $\sigma_{Tot}^{(-)} \xrightarrow[s\to\infty]{} \infty$

QCD Odderon: 7 channel exchange of $C=-1$ object.

Can the behaviour $\sigma^{(-)} \to \infty$ be observed without contribution of QCD Odderon?

- spin averaged cross sections. Here under crossing gluon and sea distributions don't change. To avoid cancellation (up to unimportant valence quarks) one needs $C=-1$ exchange, QCD Odderon.
- spin dependent cases.
  Here under crossing the spin components change, too.
  The difference of polarized distributions, Δg, Δq_{sea} can enter

I shall discuss spin-dependent case.

I assume that Δg, Δq_{sea} are $\sim g, q_{sea}$ large for $x \to 0$ and that – by analogy with unpolarized case – the saturation appears.

B F K L $\quad q_{sea}, g \sim x^{-\lambda} \quad \lambda > 1$

Bartels, Ermolaev, Ryskin Zeit. Phys. C70(96) 273

$$\Delta q_{sea}, \Delta g \sim x^{-\lambda}, \quad \lambda \geq 1$$

$\Downarrow$ saturation mechanism

(Gribov, Levin, Ryskin Phys. Rep. 100 (1983))

+ scaling region

(Staśto, Golec-Biernat, Kwieciński PRL 86 (2001) 596

running c.c. $\to$ Albacete et al. PRD 71, 014003 (2005)

$\Uparrow$

Bakitsky – Kovchegov NPB 463, 99 (1996) PRD 60, 034008 (1999)

Warning: Ermolaev, Greco, Troyan PLB 579 (2004) 321

r.c.: $\Delta q_{sea}, \Delta g \sim x^{-.86}$ Hermes: $-.33 \pm .2$

$$\sigma^{(-)} = \int d\hat{t}\, \frac{d\sigma}{d\hat{t}} =$$

$$= \int f_\gamma^{(-)}(Q^2, x_1)\, f_N^{(+)}(Q^2, x_2)\, dx_1\, dx_2 \int \frac{d\hat{\sigma}}{d\hat{t}}\, d\hat{t}$$

real photon (~~comp~~) ; definite flavor "q^γ" conts

$$f_\uparrow^\gamma = n_+^\gamma (q_\uparrow^\gamma + \bar{q}_\uparrow^\gamma) + n_-^\gamma (q_\downarrow^\gamma + \bar{q}_\downarrow^\gamma) + \text{gluons}$$

do not enter in our case

$$f_\downarrow^\gamma = (+ \leftrightarrow -)$$

$$\delta n^\gamma = n_+^\gamma - n_-^\gamma \quad \text{"sea polariz."}$$

we omitted "hadronic part"

NLO (Glück, Reya, Schuler in PRD 60 054019 (1999)
" " Sieg Eur. Phys. J C 20, 271 (2001)

Nucl. definite flavour "q" conts

$$N_\uparrow = n_+ q_\uparrow + n_- q_\downarrow + \bar{n}_+ \bar{q}_\uparrow + \bar{n}_- q_\downarrow + \text{gluons}$$

$$N_\downarrow = (n_+ \leftrightarrow n_-)$$

$$n = n_+ + n_-$$

$$\bar{n} = \bar{n}_+ + \bar{n}_-$$

$n - \bar{n}$; valence unpolarized

$$f_\gamma^{(-)} = f_\uparrow^\gamma - f_\downarrow^\gamma$$

$$f_N^{(+)} = \cancel{f_{+N\uparrow}}\, N_\uparrow + N_\downarrow$$

For flavours "q^γ" and "q"

$$f^\gamma_{(-)} \cdot f^N_{(+)} \cdot \hat{\sigma} =$$

$$= \delta n^\gamma (n - \bar{n}) \left[\hat{\sigma}(q^\gamma_\uparrow, q_\uparrow) - \hat{\sigma}(q^\gamma_\downarrow, q_\downarrow) + \hat{\sigma}(\bar{q}^\gamma_\uparrow, q_\downarrow) - \hat{\sigma}(\bar{q}^\gamma_\downarrow, q_\uparrow) \right]$$

sea pol. for "q^γ" flavour

valence unpolar. for "q"

The simplification came from observation, that

$$CP \Longrightarrow \hat{\sigma}(a, \bar{b}) = \hat{\sigma}(\bar{a}, b)$$
$$\hat{\sigma}(a, b) = \hat{\sigma}(\bar{a}, \bar{b})$$

where a, b denote "R", "L"

and $q_\uparrow = R$, $q_\downarrow = L$, $\bar{q}_\uparrow \underset{\text{def}}{=} \bar{L}$, $\bar{q}_\downarrow \underset{\text{def}}{=} \bar{R}$

$\hat{\sigma}$ come from interference terms, combination in [ ] cancels if P-violation were neglected

$$f^\gamma_{(-)} = f^\gamma_\uparrow - f^\gamma_\downarrow$$

$$f^N_+ = N_\uparrow + N_\downarrow$$

If, as we assumed, δn^γ is as singular as n^γ for $x \to 0$, then the contribution of jets with

$p_T >$ arbitrary fixed value

to the difference of cross sections

$$\sigma(\gamma_\uparrow + N) - \sigma(\gamma_\downarrow + N) \sim$$

(N unpolarized) is $\sim \ln s$ for $s \to \infty$

Such behaviour should lead to similar behaviour for "GDH" type crossing-odd amplitude in p.c. case:

$$\frac{1}{s}\left[A(\gamma_\uparrow + N_\uparrow) - A(\gamma_\downarrow + N_\uparrow)\right] \sim \ln s$$

~~Perhaps~~ Crossing-odd spin dependent $NN - \bar{N}N$ cross sections should exhibit similar behaviour

Oddball Regge Trajectory and a Low Odderon Intercept

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Using standard many-body techniques, we report [1] a large scale numerical diagonalization of an effective QCD Coulomb gauge Hamiltonian for the gluon sector (corresponds to the lattice quenched approximation). This is an extension of our previous two constituent gluon study [2], which reproduced both the $C = P = +1$ lattice glueball masses and the pomeron, to three gluon states. From our predicted odd signature J^{PC} ($P = C =$ -1) glueball spectra (oddballs) an odderon Regge trajectory clearly emerges having a slope similar to the pomeron and begins with $J^{PC} = 3^{--}$ (the 1^{--} state is on a daughter trajectory). The odderon intercept is lower, however, even smaller than the ω trajectory's intercept which is consistent with the nonobservation of the odderon in high energy total cross section data (i. e. $\sigma_{Total} \propto s^{\alpha(0)-1}$). Our results are supported by calculations [1] with an alternative model based upon an exact Hamiltonian diagonalization for three constituent gluons and also limited lattice data (a 5^{--} prediction is still needed for full confirmation). If the odderon does have an intercept value below the pomeron it may still be possible to observe it by measuring $\frac{d\sigma}{dt}$, which varies as $s^{-2\alpha(t)-2}$, for non-pomeron processes at t well below zero (large $|t|$) where it should dominate all C =-1 meson trajectory contributions that will be suppressed by larger slopes.

[1] F. Lanes-Estrada, P. Bicudo and S. Cotanch, hep-ph/0507205.
[2]) F. Lanes-Estrada, S. Cotanch, P. Bicudo, J. Ribeiro and A. Szczepaniak, Nucl. Phys. A 710, 45 (2002).

Acknowledge: Felipe Llanes-Estrada and Pedro Bicudo
Supported by DOE

- **Effective QCD gluon Hamiltonian**

$$H^g_{eff} = Tr \int d\mathbf{x}\, [\mathbf{\Pi}^a(\mathbf{x}) \cdot \mathbf{\Pi}^a(\mathbf{x}) + \mathbf{B}^a_A(\mathbf{x}) \cdot \mathbf{B}^a_A(\mathbf{x})]$$
$$- \frac{1}{2} \int d\mathbf{x} d\mathbf{y}\, \rho^a_g(\mathbf{x}) V(\mathbf{x}, \mathbf{y}) \rho^a_g(\mathbf{y})$$

- **color charge density** $a, b, c = 1, 2, ...8$

$$\rho^a_g(\mathbf{x}) = f^{abc} \mathbf{A}^b(\mathbf{x}) \cdot \mathbf{\Pi}^c(\mathbf{x})$$

- **Abelian magnetic fields**

$$\mathbf{B}^a_A = \mathbf{\nabla} \times \mathbf{A}^a$$

- **gauge fields** $\mathbf{A}^a$**, conjugate momenta** $\mathbf{\Pi}^a = -\mathbf{E}^a$

$$\mathbf{A}^a(\mathbf{x}) = \int \frac{d\mathbf{q}}{(2\pi)^3} \frac{1}{\sqrt{2\omega_k}} [\mathbf{a}^a(\mathbf{q}) + \mathbf{a}^{a\dagger}(-\mathbf{q})] e^{i\mathbf{q}\cdot\mathbf{x}}$$
$$\mathbf{\Pi}^a(\mathbf{x}) = -i \int \frac{d\mathbf{q}}{(2\pi)^3} \sqrt{\frac{\omega_k}{2}} [\mathbf{a}^a(\mathbf{q}) - \mathbf{a}^{a\dagger}(-\mathbf{q})] e^{i\mathbf{q}\cdot\mathbf{x}}$$

- **bare gluon Fock operators**

$$a^a_\mu(\mathbf{q}) \ \ \textit{momentum} \ \ \mathbf{q} \ , \ \ \textit{spin} \ \mu = 0, \pm 1$$

- **Coulomb gauge transverse condition**

$$\mathbf{\nabla} \cdot \mathbf{A}^a = 0 \Longrightarrow \mathbf{q} \cdot \mathbf{a}^a(\mathbf{q}) = (-1)^\mu q_\mu a^a_{-\mu}(\mathbf{q}) = 0$$

- **Bogoliubov-Valatin canonical transformation (BCS rotation) to dressed gluon operators**

$$\alpha^a_\mu(\mathbf{q}) = \cosh\Theta(q)\, a^a_\mu(\mathbf{q}) + \sinh\Theta(q)\, a^{a\dagger}_\mu(-\mathbf{q})$$

- **satisfy the transverse commutation relations**

$$[\alpha^a_\mu(\mathbf{q}), \alpha^{b\dagger}_\nu(\mathbf{q}')] = \delta_{ab}(2\pi)^3\delta^3(\mathbf{q}-\mathbf{q}')D_{\mu\nu}(\mathbf{q})$$
$$D_{\mu\nu}(\mathbf{q}) = \left(\delta_{\mu\nu} - (-1)^\mu \frac{q_\mu q_{-\nu}}{q^2}\right)$$

- **PQCD vacuum** $|0> \Longrightarrow$ **BCS vacuum** $|\Omega>_{\rm BCS}$
- **minimize ground state energy**

$$\frac{\delta}{\delta\Theta}\left(\frac{\langle\Omega|H_{eff} - E|\Omega\rangle}{\langle\Omega|\Omega\rangle}\right) = 0$$

- **generates a gap equation**

$$\omega(q)^2 = q^2 - \frac{3}{4}\int \frac{d\mathbf{k}}{(2\pi)^3}\hat{V}(|\mathbf{q}-\mathbf{k}|)(1+(\hat{\mathbf{q}}\hat{\mathbf{k}})^2)\left(\frac{w(k)^2 - w(q)^2}{w(k)}\right)$$

- **gluon self-energy**

$$\omega(q) = q e^{-2\Theta(q)}$$

- **confinement via Cornell type potential**

$$V(|\mathbf{x}-\mathbf{y}|) = \sigma|\mathbf{x}-\mathbf{y}| - \frac{\alpha_s}{|\mathbf{x}-\mathbf{y}|}$$
$$\sigma = 0.18(\boldsymbol{from\ lattice})\ \ \alpha_s = 0.42$$

- **solve gap eq. for gluon constituent mass**

$$m_g \equiv \omega(0) \cong 0.8GeV$$

- **predicted gluon condensate (cooper pairs)**

$$\langle \alpha G^a_{\mu\nu} G^{\mu\nu}_a \rangle = (433\ MeV)^4$$
$$[\boldsymbol{agrees\ with\ lattice}\ (441\ MeV)^4]$$

- **TDA two gluon glueball wavefunction**

$$|\Psi^{JPC}_{LS}\rangle = \sum_{am_1m_2} \int \frac{d\mathbf{k}}{(2\pi)^3} \Phi^{JPC}_{LSm_1m_2}(\mathbf{k}) \alpha^{a\dagger}_{m_1}(\mathbf{k}) \alpha^{a\dagger}_{m_2}(-\mathbf{k}) |\Omega\rangle$$

- **solve for glueball mass M_{JPC}**

$$H|\Psi^{JPC}_{LS}\rangle = M_{JPC}|\Psi^{JPC}_{LS}\rangle\ \ [\boldsymbol{agree\ with\ lattice}]$$

- **predict a Regge trajectory close to the pomeron**

$$\alpha_P \approx .25t + 1$$

- **variational three gluon glueball wavefunction**

$$|\Psi^{JPC}\rangle = \int d\mathbf{q}_1 d\mathbf{q}_2 d\mathbf{q}_3 \delta(\mathbf{q}_1 + \mathbf{q}_2 + \mathbf{q}_3)$$
$$F^{JPC}_{\mu_1\mu_2\mu_3}(\mathbf{q}_1, \mathbf{q}_2, \mathbf{q}_3) C^{abc} \alpha^{a\dagger}_{\mu_1}(\mathbf{q}_1) \alpha^{b\dagger}_{\mu_2}(\mathbf{q}_2) \alpha^{c\dagger}_{\mu_3}(\mathbf{q}_3) |\Omega\rangle_{\rm BCS}$$

- **Bose statistics** $C^{abc} = f^{abc}$ $(C = 1)$ **or** d^{abc} $(C = -1)$

- **variational equation for the** J^{PC} **glueball**

$$\frac{\langle \Psi^{JPC} | H^g_{eff} | \Psi^{JPC} \rangle}{\langle \Psi^{JPC} | \Psi^{JPC} \rangle} = M_{JPC} \quad [\textit{agree with lattice}]$$

- **predict leading Regge trajectory (odderon)**

$$\alpha_O^{eff} = .23t - 0.88 \; [\textbf{note low intercept}]$$

- **compare to nonrelativistic constituent model**

$$H_M = \sum_i \frac{\mathbf{q}_i^2}{2m_g} + V_0 + \sum_{i<j} [\sigma r_{ij} - \frac{\alpha}{r_{ij}} + V_{ss} \mathbf{S}_i \cdot \mathbf{S}_j]$$

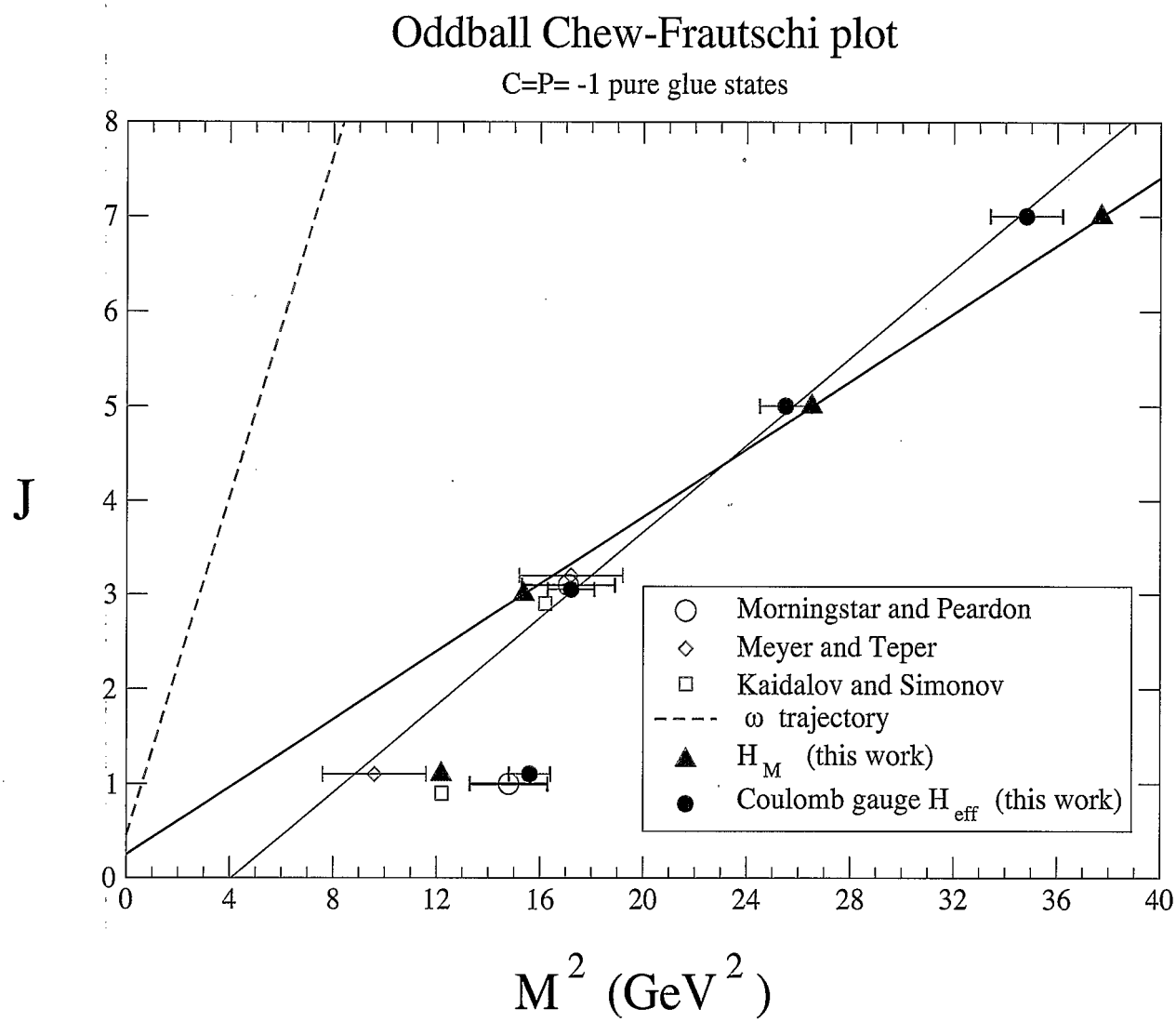
- **use** $q\bar{q}$ **funnel potential**

$V_0 =$ **-.9 GeV,** $\alpha =$ **.27,** $\sigma =$ **.25 GeV**^{2} $m_g =$ **.8 GeV and adjust** $V_{ss} \to 0.085$ **GeV to fit pomeron**

- **predict leading Regge trajectory (odderon)**

$$\alpha_O^M = .18t + 0.25 \; [\textbf{note low intercept}]$$

lattice, H^g_{eff} and H_M odderons vs. ω trajectory



SUMMARY

- lattice, H^g_{eff} and H_M models predict an odderon
- starts with 3^{--} (not 1^{--}, need lattice 5^{--})
- odderon slope is similar to pomeron
- odderon intercept is low, below 0.5
- search for odderon where ω trajectory is not dominant (examine $\frac{d\sigma}{dt}$, not $\sigma_{total} \propto s^{\alpha_\omega(0)-1}$)

A CLASSICAL ODDERON IN HIGH ENEGY QCD

RAJU VENUGOPALAN
BNL

RBRC Workshop, Sept. 27th-29th, 2005

Work in collaboration with Sangyong Jeon (McGill/RBRC)

- **A CLASSICAL ODDERON IN QCD AT HIGH ENERGIES.**
  Sangyong Jeon, Raju Venugopalan **Phys.Rev.D71:125003,2005**

- **RANDOM WALKS OF PARTONS IN SU(N(C)) AND CLASSICAL REPRESENTATIONS OF COLOR CHARGES IN QCD AT SMALL X.**
  Sangyong Jeon, Raju Venugopalan **Phys.Rev.D70:105012,2004**

Odderon paper inspired by

- **ODDERON IN THE COLOR GLASS CONDENSATE.**
  Y. Hatta, E. Iancu, K. Itakura, L. McLerran
  Nucl.Phys.A760:172-207,2005

PATH INTEGRALS:

Generates Odderon excitations!

As in SU(2), with $l^a \longrightarrow Q^a$

MV Path integral measure for SU(3):

$$1 \approx \int [d\rho] \exp\left(- \int d^2 x_\perp \left[\frac{\rho^a \rho^a}{2\mu_A^2} - \frac{d_{abc}\rho^a \rho^b \rho^c}{\kappa_A} \right] \right)$$

$$\kappa_A = \frac{g^3 A^2 N_c}{\pi^2 R^4}$$

Path integral approach reproduces diagrammatic computations of dipole and baryon C= -1 operators

Can compute < O > with "SU(3) measure"

To lowest order,

$$\langle \mathcal{O}(\mathbf{x},\mathbf{y})\rangle = \alpha_S^3 \frac{(N_c^2-4)(N_c^2-1)}{4\pi r_0^2 N_c^3} A^{1/3} \int d^2\mathbf{u} \ln^3 \frac{|\mathbf{x}-\mathbf{u}|}{|\mathbf{y}-\mathbf{u}|}$$

To all orders (in the parton density)

$$\langle \mathcal{O}\rangle = \langle \mathcal{O}\rangle_{\text{l.o.}} \times \mathrm{Tr}\exp\left(-\frac{g^2\mu_A^2(N_c^2-1)}{16\pi^2 N_c}\int d^2\mathbf{z}\ln^2\left(\frac{(\mathbf{y}-\mathbf{z})^2}{(\mathbf{x}-\mathbf{z})^2}\right)\right).$$

$$\boxed{\propto \alpha_S^3 A^{1/3} e^{-C\alpha_S^2 A^{1/3}}}$$

Kovchegov, Szymanowski, Wallon

3-quark Baryon state scattering off CGC

$$\mathcal{B}(\mathrm{x},\mathrm{y},\mathrm{z}) = \frac{1}{3!\,2i}\left(\epsilon^{ijk}\,\epsilon^{lmn}\,V^\dagger_{il}(\mathrm{x})\,V^\dagger_{jm}(\mathrm{y})\,V^\dagger_{kn}(\mathrm{z}) - h.c.\right)$$

To lowest order,

$$\approx \frac{g^3}{144}\,d^{abc}\left\{\left(\alpha^a_x+\alpha^a_y-2\alpha^a_z\right)\left(\alpha^b_y+\alpha^b_z-2\alpha^b_x\right)\left(\alpha^c_z+\alpha^c_x-2\alpha^c_y\right)\right\}$$

$$\langle\mathcal{B}\rangle = \frac{\alpha_S^3}{24\,\pi\,r_0^2}\,\frac{(N_c^2-4)(N_c^2-1)}{N_c^2}\,A^{1/3}\;\times\,\mathrm{logs}.$$

All order result feasible, but tedious…

CONCLUSIONS

- The ground state of a large nucleus contains configurations that generate Odderon excitations - these can be traced to the random walk of valence partons in color space.

- These results represent a "rigorous" proof in the large A asymptotics of QCD at high energies

- Dipole Odderon and Baryon Odderon operators are computed

- Phenomenological consequences - to be investigated further

Perturbative Odderon in the Color Glass Condensate

We derive small-x evolution equation in the Color Glass Condensate formalism. We consider the dipole-color glass scattering and the three-quark-color glass scattering with particular emphasis on the gauge invariant coupling to the external probes.

Yoshitaka Hatta
(RIKEN BNL)

in collaboration with
E. Iancu, K. Itakura L. McLerran

Nucl. Phys. A760, 172 (2005)

Theoretical status of LLA pQCD odderon

- Bartels-Kwiecinski-Praszalowicz (BKP) equation (1980)

- Mapping onto exactly solvable 1D Heisenberg spin

  Lipatov (1993), Faddeev & Korchemsky (1994)

- Exact solutions Janik & Wosiek (1999) $\alpha_{odd} < 1$

  Bartels, Lipatov & Vacca (2000) $\alpha_{odd} = 1$

- Formulation in the dipole model

  Kovchegov, Szymanowski & Wallon (2004)

  in the EGLLA Braunewell & Ewerz (2005)

- Formulation in the CGC

Color Glass Condensate formalism

McLerran & Venugopalan (1994)

An effective theory for the gluon saturation at high energy

A high energy hadron (nucleus) is replaced with strong classical color fields $\alpha \equiv A^{+} \propto 1/g$ distributed according to a weight function $W_{\tau}[\alpha]$.

Hadron-CGC scattering amplitudes T are first calculated with the fixed background field α, then averaged over α.

$$< T >_{\tau} = \int [D\alpha] T(\alpha) W_{\tau}[\alpha]$$

$W_{\tau}[\alpha]$ satisfies the JIMWLK☆ equation

$\longrightarrow$ small-x evolution equation for $< T >_{\tau}$

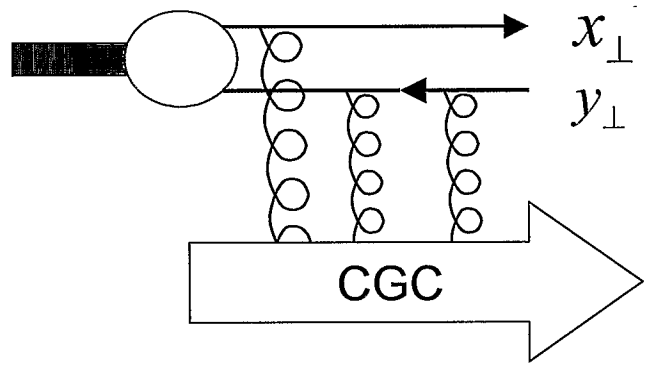
☆ Jalilian-Marian, Iancu, McLerran, Weigert, Leonidov, Kovner

Construction of the odderon exchange amplitude in CGC

Dipole-CGC scattering

$$S^{\rm odd}(x_\perp, y_\perp) = \langle \text{out, odd} \,|\, \text{in, even} \rangle$$

$$= \frac{1}{2N_c} \left\langle \mathrm{tr}(V_x^\dagger V_y) - \mathrm{tr}(V_y^\dagger V_x) \right\rangle_\tau$$



$$S_{xy}[\alpha] = 1 - N_{xy}[\alpha] + \underline{iO_{xy}[\alpha]}$$

Odderon amplitude

Weak field approximation

$$O(x_\perp, y_\perp) \simeq \frac{-g^3}{24N_c} d^{abc} \left\{ 3(\alpha_x^a \alpha_y^b \alpha_y^c - \alpha_x^a \alpha_x^b \alpha_y^c) + (\alpha_x^a \alpha_x^b \alpha_x^c - \alpha_y^a \alpha_y^b \alpha_y^c) \right\}$$

JIMWLK

"CGC Green's function"

$$\frac{\partial}{\partial \tau} \langle O(x_\perp, y_\perp) \rangle_\tau = \frac{\bar{\alpha}_s}{2\pi} \int d^2 z \frac{(x_\perp - y_\perp)^2}{(x_\perp - z_\perp)^2 (y_\perp - z_\perp)^2} \Big(\langle O(x_\perp, z_\perp) \rangle_\tau + \langle O(y_\perp, z_\perp) \rangle_\tau - \langle O(x_\perp, y_\perp) \rangle_\tau \Big),$$

$$\alpha_{odd} = 1$$

Non-linear evolution equation for the dipole-odderon amplitude

Imaginary part of the Balitsky equation

$$\frac{\partial}{\partial\tau}\langle O(x_\perp,y_\perp)\rangle_\tau = \frac{\bar{\alpha}_s}{2\pi}\int d^2z_\perp \frac{(x_\perp-y_\perp)^2}{(x_\perp-z_\perp)^2(z_\perp-y_\perp)^2}$$
$$\Big\langle O(x_\perp,z_\perp)+O(z_\perp,y_\perp)-O(x_\perp,y_\perp)$$
$$\underline{-O(x_\perp,z_\perp)N(z_\perp,y_\perp)}-\underline{N(x_\perp,z_\perp)O(z_\perp,y_\perp)}\Big\rangle_\tau$$

c.f. Kovchegov, Szymanowski, Wallon

$$\tau\to\infty \qquad <O>_\tau \propto \exp\{-c\bar{\alpha}_s^2\tau^2\}$$

Levin-Tuchin law

Saturation effect suppresses the odderon amplitude

Evolution equation for the 3-quark odderon amplitude in the linear regime

$$\frac{\partial}{\partial\tau}\langle B_{xyz}\rangle_\tau = \frac{3\alpha_s}{4\pi^2}\int d^2w_\perp \frac{(x_\perp - y_\perp)^2}{(x_\perp - w_\perp)^2(y_\perp - w_\perp)^2}$$
$$\times\Big(\langle B_{xwz}\rangle_\tau + \langle B_{wyz}\rangle_\tau - \langle B_{xyz}\rangle_\tau$$
$$-\langle B_{wwz}\rangle_\tau - \langle B_{xxw}\rangle_\tau - \langle B_{yyw}\rangle_\tau - \langle B_{xyw}\rangle_\tau\Big)$$
$$+\,(2\ \text{cyclic permutations}).$$

Closed equation for the gauge invariant amplitude $< B(x_\perp, y_\perp, z_\perp) >_\tau$
IR and UV safe
Relation to the BKP equation ?

Perturbative Odderon in the Dipole Model

Yuri V. Kovchegov

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This talk is based on the work done in collaboration with L. Szymanowski and S. Wallon [1].

We show that, in the framework of Mueller's dipole model, the perturbative QCD odderon is described by the dipole model equivalent of the BFKL equation with a C-odd initial condition. The eigenfunctions and eigenvalues of the odderon solution are the same as for the dipole BFKL equation and are given by the functions $E^{n,\nu}$ and $\chi(n,\nu)$ correspondingly, where the C-odd initial condition allows only for odd values of n. The leading high-energy odderon intercept is given by $\alpha_{odd} - 1 = \frac{2\,\alpha_s\,N_c}{\pi}\,\chi(n=1,\nu=0) = 0$ in agreement with the solution found by Bartels, Lipatov and Vacca. We also write down an evolution equation for the odderon at very high energy, where parton saturation/Color Glass Condensate sets in. We argue that saturation makes the odderon solution a decreasing function of energy.

The high energy asymptotics of the perturbative odderon has been unclear over the years: while several solutions exist with negative and zero intercepts, no one has been able to prove that there is no other solution of the three-reggeon BJKP equation with higher intercept. This has become known as the odderon problem.

Here we will present the solution of the odderon problem in the dipole model of high energy scattering. We start by considering DIS in the rest frame of the target proton, where the incoming virtual photon splits into a quark-antiquark pair, which then interacts with the target. The process where the odderon should contribute is diffractive production of a C-even meson, like a pion or η_C. In DIS this corresponds to $q\bar{q}$ pair diffractively interacting with the target via odderon exchange and then forming a meson. The odderon exchange amplitude, which we will denote by $\mathcal{O}(\underline{x}_0, \underline{x}_1; z, 1-z)$ for a dipole with transverse coordinates of the quark and antiquark $\underline{x}_0$ and $\underline{x}_1$ and longitudinal momentum fractions z and $1-z$ correspondingly, should indeed be C-odd. It should change sign under the charge conjugation, which interchanges the quark with the antiquark: $\mathcal{O}(\underline{x}_0, \underline{x}_1; z, 1-z) = -\mathcal{O}(\underline{x}_1, \underline{x}_0; 1-z, z)$.

In Slide 1 we show that the lowest order odderon exchange amplitude, which is mediated by a three-gluon exchange, is indeed odd under $\underline{x}_0 \leftrightarrow \underline{x}_1$ exchange, i.e., it is C-odd. (The leading high energy amplitudes are symmetric under $z \leftrightarrow 1-z$ interchange.)

In Slide 2 we demonstrate that the dipole amplitude with the three-gluon exchange initial conditions remains C-odd after one rung of evolution in Mueller's large-N_c dipole model. This allows us to write down an evolution equation for the odderon exchange, shown in Slide 3. This equation is identical to the Mueller's dipole model analogy of the BFKL equation: the only difference is that the initial conditions for the odderon evolution are different. To pick out the BFKL pomeron contribution one has to use C-even initial conditions for dipole evolution, while to obtain the odderon contribution C-odd initial conditions from Slide 1 have to be employed.

In Slide 4 we show that the leading high energy intercept of the new odderon equation is 0, in agreement with the solution found previously by Bartels, Lipatov and Vacca.

In Slide 5 we generalize the dipole evolution equation to the high parton density regime of Color Glass Condensate. We argue that the effect of parton saturation on the odderon exchange amplitude is to decrease the odderon intercept making it less than 0, i.e., making the amplitude decrease with energy.

The work of Y.K. is supported in part by the U.S. Department of Energy under Grant No. DE-FG02-05ER41377.

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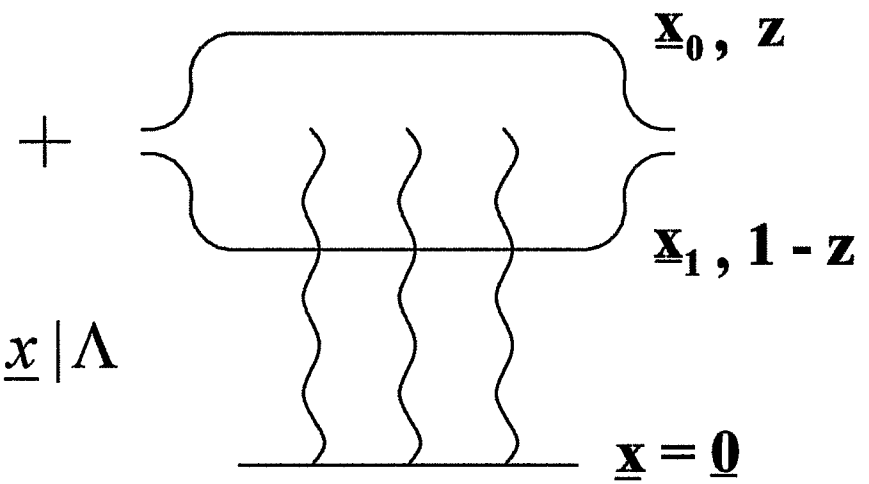
[1] Y. V. Kovchegov, L. Szymanowski and S. Wallon, Phys. Lett. B **586**, 267 (2004) [arXiv:hep-ph/0309281].

Lowest Order

At the lowest order the C-odd odderon amplitude is given by the three-gluon exchange in the color-singlet state:

$$\int \frac{d^2k}{k^2} e^{i\underline{k}\cdot\underline{x}} \sim \ln|\underline{x}|\Lambda$$



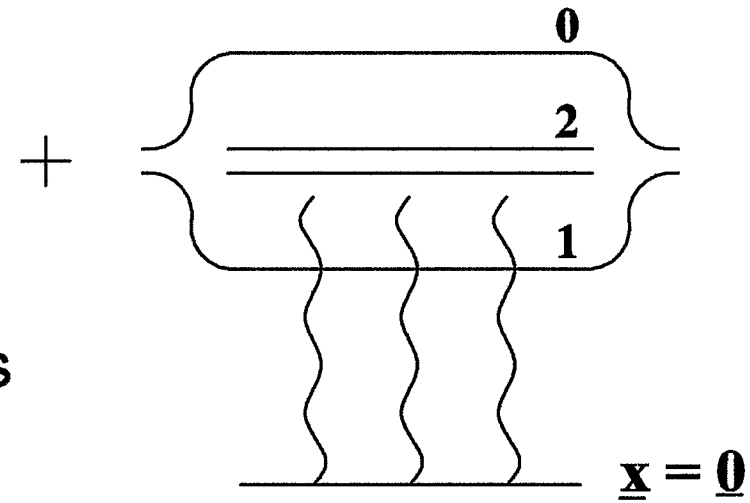
$$O_0(\underline{x}_0, \underline{x}_1) = c_0\, \alpha_S^3 \ln^3 \frac{x_0}{x_1}$$

with c_0 the color factor. The target is located at $\underline{0}$ transverse coordinate.

The above amplitude obviously changes sign under $x_0 \leftrightarrow x_1$!
(All eikonal amplitudes are even under $z \leftrightarrow 1\text{-}z$ interchange.)

One Rung of Odderon Evolution

Let us include one rung of the small-x evolution in the framework of A. H. Mueller's dipole model. We are working in the large N_C limit, so the graphs are planar and the gluon is given by double line:



One rung of evolution gives

$$\frac{\alpha_S N_C}{2\pi^2} \int_{z_{init}}^{\min\{z,1-z\}} \frac{dz_2}{z_2} \int d^2x_2 \frac{x_{01}^2}{x_{02}^2 x_{12}^2} [O_0(\underline{x}_0, \underline{x}_2) + O_0(\underline{x}_2, \underline{x}_1) - O_0(\underline{x}_0, \underline{x}_1)]$$

Substituting the amplitude O_0 from the previous slide we get

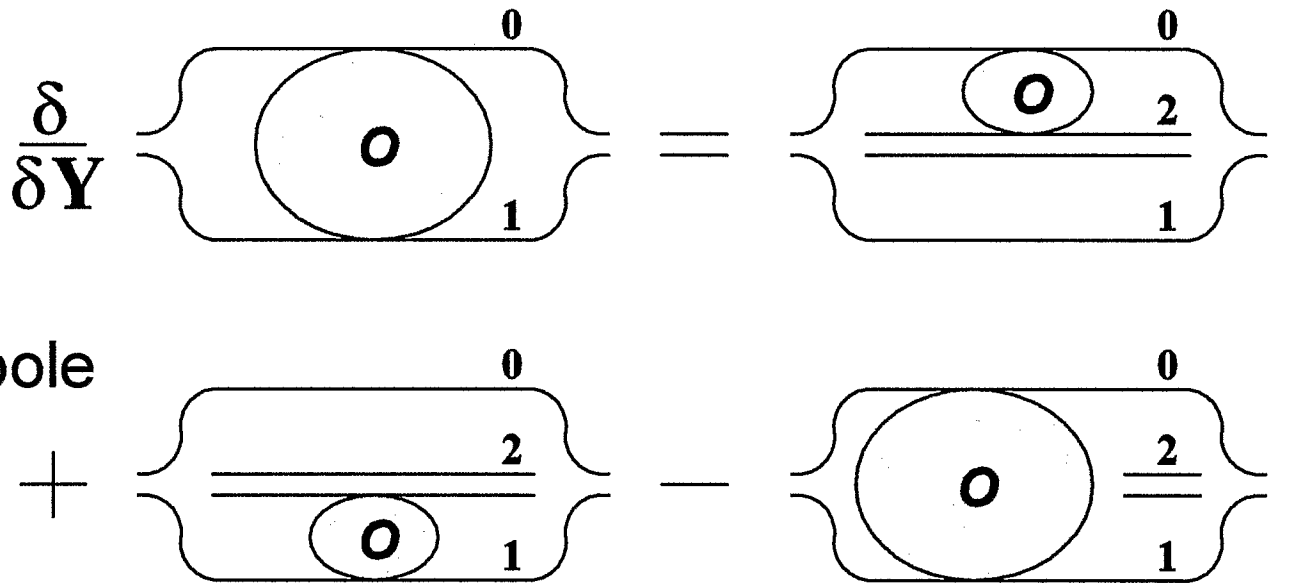
$$3 \frac{\alpha_S N_C}{2\pi^2} c_0 \alpha_S^3 \ln \frac{x_0}{x_1} \ln \frac{\min\{z,1-z\}}{z_{init}} \int d^2x_2 \frac{x_{01}^2}{x_{02}^2 x_{12}^2} \ln \frac{x_0}{x_2} \ln \frac{x_1}{x_2}$$

which is non-zero and C-odd (changes sign under $x_0 \leftrightarrow x_1$).

⇨ "C-oddness" survives dipole evolution!

Odderon Evolution Equation

Now we can easily write down an evolution equation for the odderon amplitude in the dipole model.



$$\frac{\partial O(\underline{x}_0,\underline{x}_1,Y)}{\partial Y}=\frac{\alpha_S N_C}{2\pi^2}\int d^2x_2\,\frac{x_{01}^2}{x_{02}^2\,x_{12}^2}\left[O(\underline{x}_0,\underline{x}_2,Y)+O(\underline{x}_2,\underline{x}_1,Y)-O(\underline{x}_0,\underline{x}_1,Y)\right]$$

This is the same evolution equation as for the BFKL Pomeron in the dipole model! How is the Odderon equation different from the Pomeron equation?

Solution of the Odderon Equation

To find the leading high energy term in

$$\int_{-\infty}^{\infty} d\nu \sum_{odd\, n} \exp\left[\frac{2\alpha_S N_C}{\pi}\chi(n,\nu)Y\right] E^{n,\nu}(\rho_0,\rho_1)$$

one notes that the saddle point of ν-integrals is given by ν=0 for any n. Analyzing the saddle point values χ(n,0) for odd n one can see that n=1 term is the largest.

The leading high energy odderon intercept would then be given by

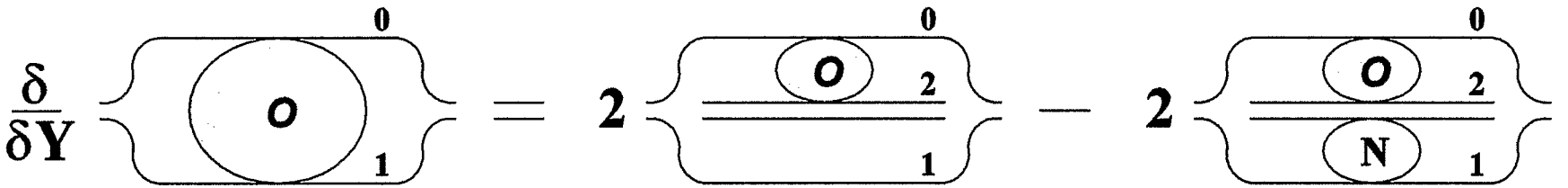
$$\alpha_{odd} - 1 = 2\,\chi(n=1,\nu=0)\frac{\alpha_S\, N_C}{\pi} = 0$$

in agreement with Bartels, Lipatov and Vacca (BLV).

Odderon amplitude is at most constant with energy!

Odderon Evolution in Color Glass

Now one can write down a nonlinear evolution equation for the odderon amplitude, including the effects of multiple pomeron exchanges in the color glass condensate:



$$\frac{\partial O(\underline{x}_0,\underline{x}_1,Y)}{\partial Y} = \frac{\alpha_S N_C}{2\pi^2}\int d^2x_2\,\frac{x_{01}^2}{x_{02}^2\,x_{12}^2}\left[O(\underline{x}_0,\underline{x}_2,Y)+O(\underline{x}_2,\underline{x}_1,Y)-O(\underline{x}_0,\underline{x}_1,Y)\right]$$
$$-\frac{\alpha_S N_C}{2\pi^2}\int d^2x_2\,\frac{x_{01}^2}{x_{02}^2\,x_{12}^2}\left[O(\underline{x}_0,\underline{x}_2,Y)\,N(\underline{x}_2,\underline{x}_1,Y)+N(\underline{x}_0,\underline{x}_2,Y)\,O(\underline{x}_2,\underline{x}_1,Y)\right]$$

(cf. evolution equation for reggeon by K. Itakura, Yu. K., L. McLerran, D. Teaney, '03 and generalization of this equation by Hatta, Iancu, Itakura, McLerran, '05)

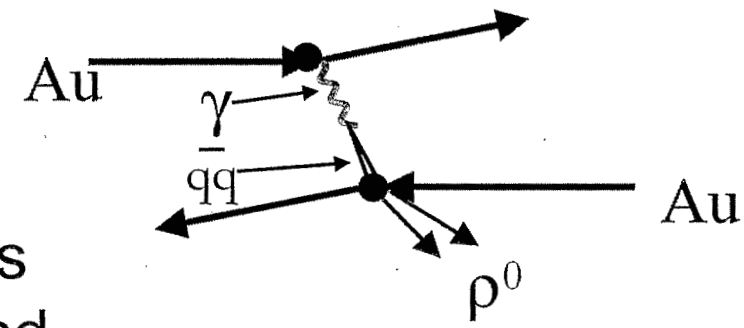
Here N is the C-even (forward) dipole amplitude on the target. N varies from ~0 at low energies to 1 at high energies.

⇨ Saturation effects only <u>decrease</u> the Odderon intercept!

Ultra-peripheral Au-Au physics at STAR

R. S. Longacre
Brookhaven Nat. Lab.

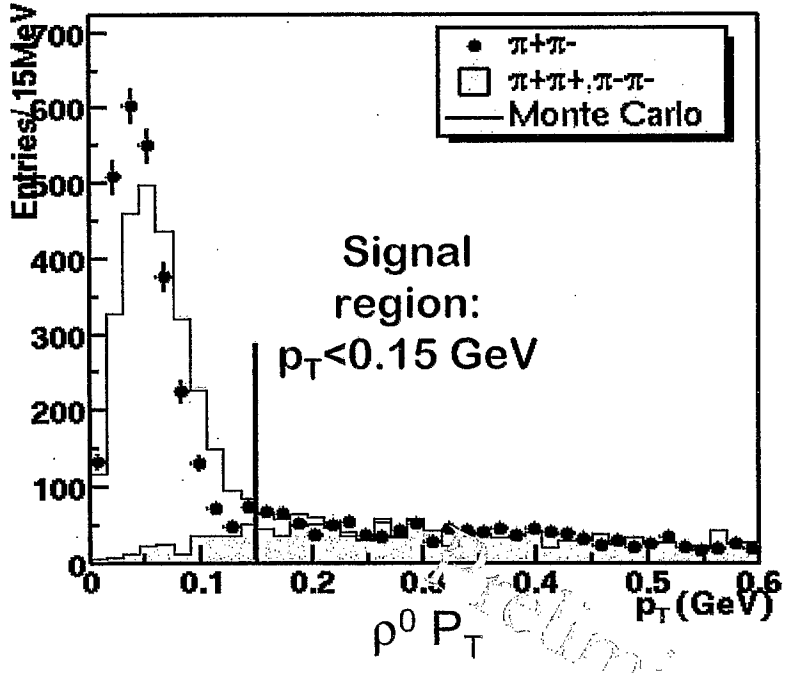
Exclusive ρ^0 Production

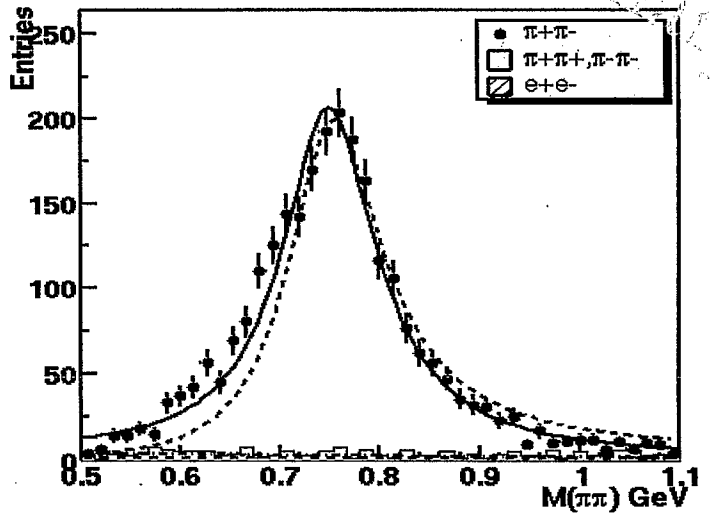


- A virtual photon from one nucleus fluctuates to a $q\bar{q}$ pair which scatters elastically from the other nucleus and emerges as a vector meson
  - Photon emission follows the Weizsacker-Williams method
  - For heavy mesons (J/ψ), the scattering is sensitive to nuclear shadowing
- Coherence photon emission and scattering
  - Rates are high
  - $\sigma(\rho) \sim 8$ % of σ(had.) for gold at 200 GeV/nucleon
    - 120 /sec at design luminosity
  - Other vector mesons are copiously produced
  - Incoherent scattering can also be studied

200 GeV Exclusive ρ^0

- **Enhancement at $\Sigma p_T < 2h/R_A$ ~100 MeV/c**
- 1.5 Million topology triggers
- 2 track vertex
  - non-coplanar; $\theta < 3$ rad to reject cosmic rays
- $\pi^+\pi^+$ and $\pi^-\pi^-$ model background shape
  - $\pi^+\pi^-$ pairs from higher multiplicity events have similar shape
  - scaled up by ~2
  - Incoherent ρ^0 (w/ p_T>150 MeV/c) are defined as background in this analysis
- asymmetric $M_{\pi\pi}$ peak





Cross Section Comparison

	STAR PRL 89, 027302 (2002)	Theory PRL 89, 012301 (2002)
ρ^0 with XnXn	36.6 ±2.4 ±8.9 mb	27 mb
ρ^0 with 1n1n	2.5±0.4±0.6 mb	3.25 mb
Exclusive ρ^0	410±190±100 mb	350 mb

- 130 GeV data
- Normalized to 7.2 b hadronic cross section
- Systematic uncertainties: luminosity, overlapping events, vertex & tracking simulations, 1n selection, etc.
- Exclusive ρ^0 bootstrapped from XnXn
  - limited by statistics for XnXn in topology trigger
- Good agreement
  - factorization works

Conclusions

☆Star has observed photonuclear ρ^0production in Au Au

☆ρ^0 cross section agree with theoretical prediction.

☆Coherent 4-prong events, likely the ρ^{*0} is observed.

☆Future look for exotic mesons in the 4-prong data.

Present Status of the Odderon

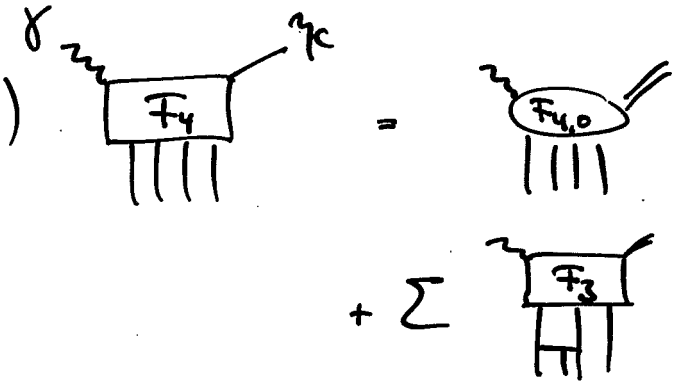
Carlo Ewerz
Università di Milano & INFN

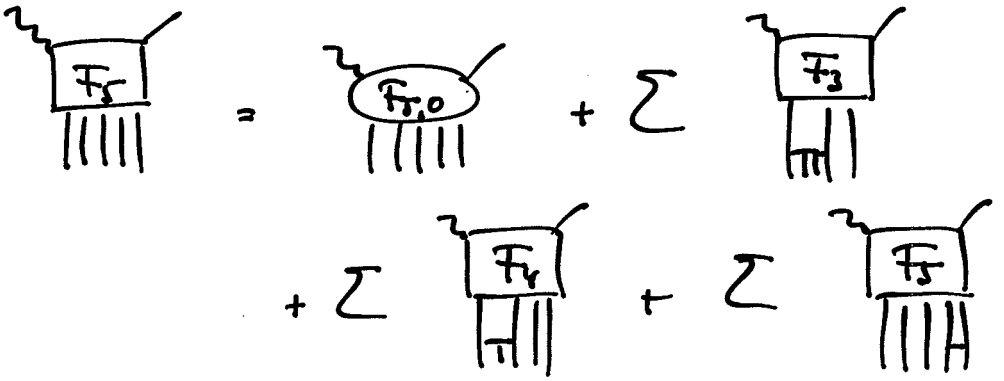
Abstract:
I review the present status of the Odderon both from the theoretical and from the phenomenological point of view. Some emphasis is given to aspects that I consider most promising for future research, and for experimentally finding the Odderon. I add comments on some interesting issues that were discussed during the workshop.

Odderon in EGLLA

Braunewell, CE

* Take into account fluctuations in gluon number in t-channel.

* $(\omega - \sum_i \beta_i)$ 

$(\omega - \sum_i \beta_i)$ 

* → infinite tower of coupled evolution equations

* Analytic solution for 4-gluon Odderon

$$F_4^{a_1 a_2 a_3 a_4}(k_1, k_2, k_3, k_4) =$$

$$= i f_{a_1 a_2 c} F_3^{c a_3 a_4}(k_1+k_2, k_3, k_4)$$

+ other pairs

valid both for

BLV - $\mathbb{O}$ ($\gamma \to \eta_c$ impact factor)

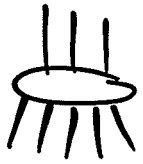
JW - $\mathbb{O}$ ($p \to p$ / $\bar{p} \to \bar{p}$ impact factor)

$\longrightarrow$ Reggeization!

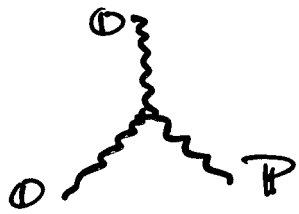
* Next steps:

* 5-gluon Odderon amplitude in EGLLA

$\longrightarrow$ 3-to-5 gluon vertex (?)



$\longrightarrow$ $\mathbb{O} \to \mathbb{O}\mathbb{P}$ vertex



$\longrightarrow$ crossing and conformal properties

+ phenomenology

($\to$ antishadowing ?)

Brodsky, Schmidt, Y.

* Byproduct: impact factors

$\left.\begin{array}{l}\gamma^* \to \gamma^* \\ \gamma^* \to \eta_c\end{array}\right\}$ with arbitrarily many gluons

$p \to p$ with four gluons

$\to$ Reggeization!

n reggeized gluons at the same point in transverse space behave like one reggeized gluon

Hence: coupling to

dipole: only BLV – ①

baryon: BLV + JW – ①

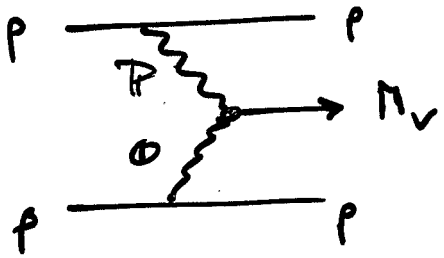
In general:

A general n-gluon state in t-channel requires n constituents in external particles! ($\to$ higher orders)

For less constituents only reggeizing solutions possible.

Alternatively: transition vertices of EGLLA

Double-diffractive vector meson production



$$pp \to p + \underset{\phi}{J/\psi} + p$$

* For unflavoured mesons ϕ, J/ψ reggeon exchange small
* γ exchange under control
* Reggeon and γ exchange important if $p\mathbb{O}$-coupling is small
* In pp destructive interference in (unlikely) case $\alpha_{\mathbb{P}} = \alpha_{\mathbb{O}}$ $\to$ $p\bar{p}$ better than
* Estimate in Regge theory: for J/ψ at $\sqrt{s} = 2$ TeV — Schäfer, Mankiewicz, Nachtmann

$$\sigma = 3\,\text{mb} \cdot c_0^2 \cdot N$$

$c_0 \leq 0.05$ (from ρ)

$N \simeq 0.01$ (all uncertainties)

Summary

* Odderon should exist if our understanding of high energy scattering is correct.

* Odderon under good control in pQCD, mathematically interesting.

* Important aspect: reggeization due to coupling to external particles

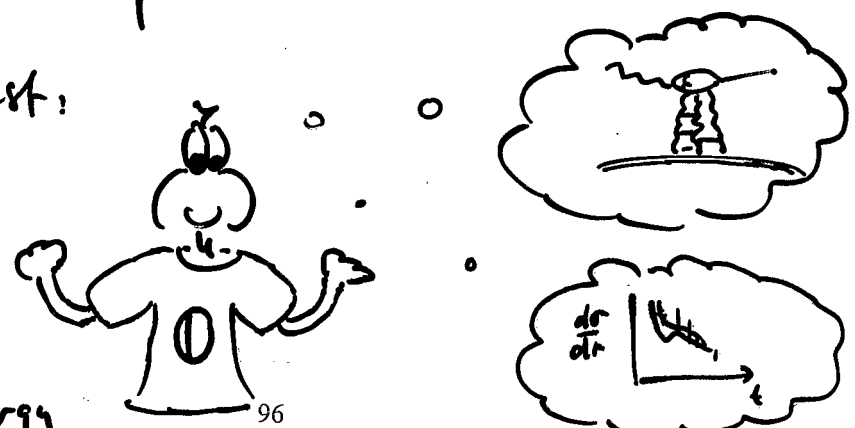
* Nonperturbative Odderon: little known. pO-coupling might tell us about proton structure.

* Experimental evidence for Odderon is weak. Promising are especially exclusive processes.

* Good test:

$$\frac{d\sigma}{dt}$$

for $pp, p\bar{p}$ at same energy



Odderon Searches at RHIC

Participants List
September 27-29, 2005

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Odderon Searches at RHIC

September 27-29, 2005
Physics Department - Small Seminar Room

(Organizers: Wlodek Guryn, Yuri Kovchegov, Larry Trueman and Werner Vogelsang)

Tuesday Morning, September 27, 2005 (Chairman: Larry Trueman)

08:30 – 09:00	***REGISTRATION AND COFFEE***	
09:00 – 09:10	Welcome	*Wlodek Guryn*
09:10 – 09:50	The Present Situation of the Odderon Intercept - Experiment, Theory and Phenomenology	*Basarab Nicolescu*
09:50 – 10:30	The Odderon, Past and Present	*Elliot Leader*
10:30 – 10:50	***COFFEE BREAK***	
10:50 – 11:30	Experimental Possibilities at RHIC	*Wlodek Guryn*
11:30 – 02:00	***LUNCH*** (only served at the Berkner Hall Cafeteria until 1 pm)	

Tuesday Afternoon, September 27, 2005 (Chairman: Elliot Leader)

02:00 – 03:00	The Odderon and the Spin-Dependence of Proton-Proton Scattering	*Larry Trueman*
03:00 – 04:00	Measuring of Pomeron Phase and Possible Discovery of Odderon at RHIC via Charge Asymmetry in Dipion Production with Two Rapidity Gaps	*Ilya Ginzburg*

Wednesday Morning, September 28, 2005 (Chairman: Dmitri Kharzeev)

09:00 – 09:40	The Odderon - a Fundamental Object in QCD	*Jochen Bartels*
09:40– 10:20	Reggeized Gluon States in QCD	*Jan Kotanski*
10:20 – 10:40	***COFFEE BREAK***	
10:40 – 11:20	Some Aspects of the Perturbative QCD Odderon	*Gian Paolo Vacca*
11:20 – 12:00	Single Spin Asymmetry of Very Forward Neutron at PHENIX	*Kiyoshi Tanida*
12:00 – 02:00	***LUNCH*** (only served at the Berkner Hall Cafeteria until 1 pm)	

Wednesday Afternoon, September 28, 2005 (Chairman: Yuri Kovchegov)

02:00 – 02:40	Search for Odderon in the Parity Violating Amplitudes' Asymptotics.....	*Leszek Lukaszuk*
02:40 – 03:20	Oddball Regge Trajectory and a Low Odderon Intercept	*Stephen Cotanch*
03:30 – 04:30	Discussion Session	*Wlodek Guryn*
06:00 – 08:00	***WORKSHOP DINNER***	

Thursday Morning, September 29, 2005 (Chairman: Larry McLerran)

09:00 – 09:40	A Classical Odderon in High Energy QCD	*Raju Venugopalan*
09:40 – 10:20	Perturbative Odderon in the Color Glass Condensate	*Yoshitaka Hatta*
10:20 – 10:40	***COFFEE BREAK***	
10:40 – 11:20	Odderon Evolution and Saturation	*Yuri Kovchegov*
11:20 – 11:40	UPC Program at STAR	*Ron Longacre*
11:40 – 02:00	***LUNCH*** (only served at the Berkner Hall Cafeteria until 1 pm)	

Thursday Afternoon, September 29, 2005 (Chairman: Wlodek Guryn)

02:00 – 03:00	Present Status of the Odderon	*Carlo Ewerz*

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Volume 76 – Odderon Searches at RHIC, September 27-29, 2005 – BNL-

Volume 75 – Single Spin Asymmetries, June 1-3, 2005 – BNL-74717-2005

Volume 74 – RBRC QCDOC Computer Dedication and Symposium on RBRC QCDOC, May 26, 2005 – BNL-74813-2005

Volume 73 – Jet Correlations at RHIC, March 10-11, 2005 – BNL-73910-2005

Volume 72 – RHIC Spin Collaboration Meetings XXXI(January 14, 2005), XXXII (February 10, 2005), XXXIII (March 11, 2005) – BNL-73866-2005

Volume 71 – Classical and Quantum Aspects of the Color Glass Condensate – BNL-73793-2005

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Volume 64 – Theory Summer Program on RHIC Physics – BNL-73263-2004

Volume 63 – RHIC Spin Collaboration Meetings XXIV (May 21, 2004), XXV (May 27, 2004), XXVI (June 1, 2004) – BNL-72397-2004

Volume 62 – New Discoveries at RHIC, May 14-15, 2004 – BNL- 72391-2004

Volume 61 – RIKEN-TODAI Mini Workshop on "Topics in Hadron Physics at RHIC", March 23-24, 2004 – BNL-72336-2004

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Volume 48 – RHIC Spin Collaboration Meeting XIV – BNL-71300-2003

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Volume 39 – RHIC Spin Collaboration Meeting VII – BNL-52659
Volume 38 – RBRC Scientific Review Committee Meeting – BNL-52649
Volume 37 – RHIC Spin Collaboration Meeting VI (Part 2) – BNL-52660
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Volume 29 – Future Transversity Measurements – BNL-52612
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Volume 26 – Circum-Pan-Pacific RIKEN Symposium on High Energy Spin Physics – BNL-52588
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Volume 4 – Inauguration Ceremony, September 22 and Non -Equilibrium Many Body Dynamics –BNL-64912

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Volume 1 – Open Standards for Cascade Models for RHIC – BNL-64722

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RIKEN BNL RESEARCH CENTER

Odderon Searches at RHIC

September 27-29, 2005

Li Keran

Nuclei as heavy as bulls
Through collision
Generate new states of matter.
T.D. Lee

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Speakers:

Joachim Bartels	Stephen Cotanch	Carlo Ewerz	Ilya Ginzburg
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Kiyoshi Tanida	Larry Trueman	Gian Paolo Vacca	Raju Venugopalan

Organizers: Wlodek Guryn, Yuri Kovchegov, Werner Vogelsang, and Larry Trueman