The pomeron conjecture and two gluon glueballs

Pedro Bicudo
Dep. Física and CFIF, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

ABSTRACT

In this talk the pomeron conjecture is reviewed and constituent gluon models are derived. In a simple two-gluon glueball spectrum the pomeron trajectory and the daughter trajectories are computed. The open problems of two-gluon glueballs are discussed, including transversality and Yang’s theorem, the spin tensor interactions, the structure of the string and decays. The related systems of charmed hybrids and of the gluelump are also addressed. To conclude, different aspects of glueballs that could be measured at PANDA are highlighted.

1 Introduction

The pomeron trajectory produces a precise prediction for the location of several glueball masses, see Table 1. The equation for the pomeron trajectory in the
Table 1: Spectrum of glueballs extracted from the Pomeron trajectory in a Regge plot.

| J P C  | 2++ | 4++ | 6++ | 8++ | 10++ | 12++ |
|--------|-----|-----|-----|-----|------|------|
| M[GeV] | 1.92| 3.41| 4.53| 5.26| 5.97 | 6.61 |

\( J, t = M^2 \) space is \( \mathbb{C}^2 \),

\[
J = \alpha_p(t),
\]

\[
\alpha_p(t) = 1.08 + 0.25t.
\]

The intercept \( \alpha_p(t) \) is of the order of 1, and this explains the high energy hadronic cross sections. The pomeron is also expected to correspond to a series of glueball masses. The slope of 0.25 is compatible with the Casimir scaling, where the string tension is proportional to the Casimir invariant \( \lambda_i \cdot \lambda_j \).

For instance the \( \bar{p} - p \) total cross sections increase monotonously at high energies. The cross sections are fitted by,

\[
\sigma = 21.70 s^{0.0808} + 98.39 s^{-9.4525}
\]

The lattice results \(^3\) and model results \(^5\) can also be included in a Regge Plot, see fig.\(^\text{II}1\). They are not inconsistent with the Pomeron \(^6\), and with a daughter trajectory.

In what concerns model calculations, they depend on the gluon mass and on the gluon-gluon interaction. Although one would expect colour gauge invariance to force the gluon to be massless, the generation of a finite mass for the gluon is nevertheless possible. For instance in superconductors the Meissner effect generates a mass for the photon \(^7\). In the QCD case, we have indications from the lattice \(^8\) and from the solution of the truncated Schwinger Dyson equation \(^9\) that the gluon has a constituent mass of 0.7 to 0.8 GeV.

A flux tube picture is also possible, where the string ends in a pair of spin 1, colour octet massive gluons. There are indications, both from lattice simulations \(^10\) and from truncated Coulomb Gauge QCD \(^11\) that the string tension is proportional to the Casimir invariant \( \lambda_1 \cdot \lambda_2 \). Then \( \sigma_{\text{glueball}} = \frac{2}{3} \sigma_{\text{meson}} \).

It is therefore plausible to construct constituent gluon models, similar to the constituent quark model, where the lightest glueballs have just two gluons. In the self-consistent models the gluon mass is generated in the models, and in
other models the mass is just assumed. This results in bound-states similar to mesons, where the quarks are replaced by heavier gluons and where the string tension is also larger.

Essentially I will focus on two approximations of QCD,
- the ITEP approach, of a quantum mechanical glueball string model by Kaidalov, Kalashnikova, Nefediev, Shevchenko, Simonov [11]
- the approach started in the NCSU, of a self-consistent glueball in Coulomb Gauge by Cotanch, Llanes-Estrada, Swanson, Szczepaniak [5, 12, 13]

2 A simple 2-gluon glueball spectrum

From the pomeron a quite simple and precise picture emerges, see fig.2. I think that any glueball study, experimental, theoretical or on the lattice should compare with the pomeron.

Let us assume, in the constituent gluon model perspective, that we have
at least 2 gluons with the highest possible J,

\[ S = 1 + 1 = 2 , \]
\[ J = L + 2 , \] (4)

and with \( L \) even for \( P=+ \). Then these states should be aligned in the pomeron trajectory. The corresponding spectrum is detailed in Table I. This constitutes the simplest and less speculative prediction for glueballs.

To verify experimentally that we have a straight line, at least 3 points should be measured. The first 3 points are expected to be observed if \( M = 5 \) GeV is reached. However, we also know the example of the meson Regge trajectory, where the first point is below the line, and then we need more points to see the line. If an experiment is able to observe glueballs with \( M = 5.3 \pm 0.3 \) GeV, it may be possible to see 4 points. The error appears because the slope of the pomeron trajectory is not precise. For instance, Szczepaniak and Swanson finds a smaller slope than the one first estimated for the pomeron.

Moreover, in the constituent 2-gluon picture the pomeron trajectory

\[ S = 2 , J = L + 2 , \] (5)

is accompanied by 5 daughter trajectories,

\[ S = 2 , J = L + 2 , \]
\[ S = 2 , J = L + 1 , \]
\[ S = 2 , J = L , \]
\[ S = 2 , J = L - 1 , \]
\[ S = 2 , J = L - 2 , \]
\[ S = 0 , J = L . \] (6)

The pomeron and daughters are depicted in fig.2 in the case where the spin-dependent interactions are neglected.

3 Open Problem in two-gluon glueballs

3.1 Transversality

The transversality of the gluon propagator implies that \( JLS^{PC} = 101 + + \) is forbidden, according to Yang’s theorem [5]. In the lattice, and in the Coulomb
Gauge model, a light $J=1$ glueball is not present. In quantum mechanical studies, this state is not avoided. The discovery of a $J=1^{++}$ glueball would rule out the transversality of constituent gluons.

3.2 Spin-Tensor Interactions

The spin-tensor interactions also depend on the model. The exact position of the daughters will measure the spin-dependent interactions.

The $\vec{S}_1 \cdot \vec{S}_2$ interaction splits the $S=2$ daughter ($\langle \vec{S}_1 \cdot \vec{S}_2 \rangle = 1$) from the $S=0$ daughter ($\langle \vec{S}_1 \cdot \vec{S}_2 \rangle = -2$). In particular it produces a $0^{++}$ glueball lighter than the $2^{++}$.

The $\vec{S} \cdot \vec{L}$ interaction increases with $L$ and thus changes the slope of the interaction. It also acts differently on the different daughters,

$$j = l + 2 \quad : \quad \langle \vec{S} \cdot \vec{L} \rangle = 2l ,$$

Figure 2: *Pomeron trajectory and daughters in a Regge plot.*
Figure 3: Leading Regge plot trajectories for the glueballs (in black circles), the gluelumps (in dark gray circles), and the charmonia (in light gray circles).

\begin{align*}
  j = l + 1 & : \langle \vec{S} \cdot \vec{L} \rangle = 2l - 4, \\
  j = l & : \langle \vec{S} \cdot \vec{L} \rangle = -6 \text{ or } \langle \vec{S} \cdot \vec{L} \rangle = 0, \\
  \cdots
\end{align*}

In particular the $\vec{S} \cdot \vec{L}$ interaction produces non-linear trajectories.

The tensor interaction also produces a non-linear pomeron trajectory, moreover it couples $l$ with $l + 2$ and $l - 2$.

In the meson spectrum, the $\vec{S}_1 \cdot \vec{S}_2$ interaction seems to be the most relevant spin-dependent interaction. In the lattice simulations and in the quantum mechanical studies of glueballs, the $\vec{S}_1 \cdot \vec{S}_2$ also seems to be the relevant one. In the truncated Coulomb gauge approach this is not the case. The detection of the glueballs on the daughter trajectories would clarify the nature of the gluon-gluon interaction.
3.3 The string

Are the gluons connected by 1 octet string or by 2 triplet ones? In type II superconductors the double string is favoured, and this results in the doubling of the string constant. In the lattice, there is evidence for a single octet-octet string with a strength proportional to $\lambda_i \cdot \lambda_j$. Although these two approaches only differ by 12.5 $\%$, a precise determination of the slope of the gluonic Regge trajectories would also clarify the nature of the gluon-gluon interaction.

3.4 Decays

The decays of Glueballs decay are not fully understood yet. In the literature, the scalar glueball is essentially the only one with predicted decays. Nevertheless one can estimate that the glueballs will have a larger width than conventional hadrons, because they follow more decay mechanisms. In the double-string model, from string breaking an enhancement of the width by a factor of $2 \times 2$ is expected. Any of the two constituent gluons (attached at the end of the string) may also decay in a quark-antiquark pair. Because the decays of glueballs remain an open problem, measuring the decay widths and the decay processes of glueballs would be extremely interesting.

4 Charmed hybrids and gluelumps

The lowest hybrid states are difficult to separate from the standard chamonium spectrum. However the excited states where the gluon is far from the diquark show different properties. The gluelump is the heavy quark limit of the charmed or bottomed hybrid. This subject has been receiving an increased interest in the literature. In this case the heavy quark-antiquark pair forms a nearly point-like and massive colour octet, equivalent to a very massive gluon. The reduced mass of the real gluon is close to the $c$ quark mass in charmonium. However the string tension is larger than the charmonium one. In a simple constituent gluon picture this results in different trajectories from the glueball trajectories and from the charmonium trajectories. Neglecting the spin-tensor interactions, one gets the $pc=++$ states depicted in fig.
5 Conclusion

Identifying the glueballs with the largest possible angular momentum, up to $5.5 \pm 0.3$ GeV will test the Pomeron conjecture.

The decay widths are expected to be large, and the decays should produce a large number of pions. Nevertheless the states are well separated. The decays of excited glueballs remain a very interesting open problem. The light quark hybrids constitute intermediate decay channels.

The study of glueballs with lower angular momentum (daughter trajectories) will test many aspects of QCD, and will fix the spin dependence of the gluon-gluon interaction.

Moreover there are odd parity trajectories, and more massive trajectories with 3 gluons (contributing to the odderon).

In the charmed hybrid sector, and in the limit of the Gluelump, the study of larger angular momentum may also exhibit a linear Regge behavior.

The decays of the excited glueballs may result in the production of several pions, with a large total $J$.

Question: Is it possible to identify the initial $J$ of the glueball?
Question: Is it possible to reconstruct the initial shape of the string, say with Bose-Einstein correlation?

6 Acknowledgements

I thank Paola Gianotti and the PANDA collaboration for motivating this talk. I also thank discussions on constituent gluon masses and on constituent gluon models with Alexei Nefediev, Pedro Sacramento, Steve Cotanch and Felipe Llanes-Estrada.

References

1. A. Donnachie and P. V. Landshoff, Phys. Lett. B 437, 408 (1998) [arXiv:hep-ph/9806344].
2. J. R. Pelaez and F. J. Yndurain, arXiv:hep-ph/0312187.
3. C. J. Morningstar and M. J. Peardon, Phys. Rev. D 60, 034509 (1999) [arXiv:hep-lat/9901004].
4. D. Q. Liu and J. M. Wu, Mod. Phys. Lett. A 17, 1419 (2002) [arXiv:hep-lat/0105019].

5. F. J. Llanes-Estrada, S. R. Cotanch, P. J. de A. Bicudo, J. E. F. Ribeiro and A. P. Szczepaniak, Nucl. Phys. A 710, 45 (2002) [arXiv:hep-ph/0008212].

6. M. M. Brisudova, L. Burakovsky, T. Goldman and A. Szczepaniak, Phys. Rev. D 67, 094016 (2003) [arXiv:nucl-th/0303012].

7. Pierre-Gilles de Gennes, *Superconductivity of metals and alloys* Published by W.A. Benjamin, New York(1966).

8. C. W. Bernard, Phys. Lett. B 108, 431 (1982).

9. R. Alkofer and L. von Smekal, Phys. Rept. 353, 281 (2001) [arXiv:hep-ph/0007355].

10. L. Del Debbio, M. Faber, J. Greensite and S. Olejnik, Phys. Rev. D 53, 5891 (1996) [arXiv:hep-lat/9510028].

11. Y. S. Kalashnikova, Phys. Atom. Nucl. 59, 1303 (1996) [Yad. Fiz. 59N8, 1363 (1996)] [arXiv:hep-ph/9510371]; A. B. Kaidalov and Y. A. Simonov, Phys. Lett. B 477, 163 (2000) [arXiv:hep-ph/9912434]; Y. A. Simonov, Phys. Atom. Nucl. 64, 1876 (2001) [Yad. Fiz. 64, 1959 (2001)] [arXiv:hep-ph/0110033].

12. A. Szczepaniak, E. S. Swanson, C. R. Ji and S. R. Cotanch, Phys. Rev. Lett. 76, 2011 (1996) [arXiv:hep-ph/9511422]; D. G. Robertson, E. S. Swanson, A. P. Szczepaniak, C. R. Ji and S. R. Cotanch, Phys. Rev. D 59, 074019 (1999) [arXiv:hep-ph/9811224].

13. A. P. Szczepaniak and E. S. Swanson, Phys. Lett. B 577, 61 (2003) [arXiv:hep-ph/0308268].

14. H. y. Jin and X. m. Zhang, Phys. Rev. D 66, 057505 (2002) [arXiv:hep-ph/0208120].

15. C. Michael, Nucl. Phys. B 259, 58 (1985); G. I. Poulis and H. D. Trotter, Phys. Lett. B 400, 358 (1997) [arXiv:hep-lat/9504015]; G. Karl and J. Paton, Phys. Rev. D 60, 034015 (1999) [arXiv:hep-ph/9904407]; Y. A. Simonov, Nucl. Phys. B 592, 350 (2001) [arXiv:hep-ph/0003114].