Exclusive glueball candidates production in AA collisions at the LHC*

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Outline

- Short motivation
- Exclusive glueball production in AA collisions
- Glueball production in UPC collisions
- Summary and conclusions

Short Motivation

- Glueballs are predicted by several theoretical formalisms and by lattice calculations.
- Scalar sector ($J^{PC} = 0^{++}$) seems promising as good candidates for the lightest glueball.
- Exclusive production presents smaller cross sections but a better balance signal/background.
- In heavy ion collisions, 3 channels of production have similar final state configurations (two large rapidity gaps): the processes $I\!P - I\!P$, $\gamma - \gamma$ and $\gamma - I\!\!O$.
- Here, we will focus on two-pomeron and two-photon processes in PbPb collisions at LHC.

The $I\!P I\!P$ process

- Here, we consider the Bialas-Landshoff model for exclusive production of glueballs (scalar mesons).

  $$\sigma_{I\!P I\!P}(pp \to p + G + p) \propto S^2_{\text{gap}} \int \overline{|M_{fi}|^2} \left[F\left(t_1\right) F\left(t_2\right)\right]^2 dPH$$

  where $F\left(t\right) \approx \exp\left(b\,t\right)$, with $b = 2$ GeV^{-2}, is the nucleon form factor and dPH the phase space factor.
- $S^2_{\text{gap}}(\sqrt{s})$ is the gap survival probability factor.
- The scattering matrix is given by,

  $$\mathcal{M}_{fi} \quad = \quad \mathcal{M}_0 \left(\frac{s}{s_1}\right)^{\alpha(t_2)-1} \left(\frac{s}{s_2}\right)^{\alpha(t_1)-1} \exp\left(\beta\left(t_1 + t_2\right)\right).$$

- $\mathcal{M}_0$ is the amplitude in forward scattering limit ($t_1 = t_2 = 0$).
- The Pomeron trajectory is given by $\alpha\left(t\right) = 1 + \epsilon + \alpha' t$ with $\epsilon \approx 0.08$, $\alpha' = 0.25$ GeV^{-2}.

Glueball production model

- Following BL model, $\mathcal{M}_0$ for colliding hadrons is,

$$\mathcal{M}_0 = 32\,\alpha_0^2\,D_0^3 \int d^2\vec{\kappa}\,p_1^\lambda V_{\lambda\nu}^J p_2^\nu \,\exp(-3\,\vec{\kappa}^2/\tau^2),$$

- $V_{\lambda\nu}^J$ is the $gg \to G^J$ vertex depending on the polarization J of the G^J glueball meson state.
- For the cases considered here, $J = 0$, one obtains:

$$p_1^\lambda V_{\lambda\nu}^0 p_2^\nu = \frac{s\,\vec{\kappa}^2}{2M_{G^0}^2} A,$$

- A is expressed by the mass M_G and the width $\Gamma(gg \to G)$ of the glueball meson through the relation,

$$A^2 = 8\pi M_G\,\Gamma(gg \to G)$$

- For decays widths we use $\Gamma(G \to gg) = \mathrm{Br}(G \to gg)\,\Gamma_{tot}(G)$.

Glueball production model: details

- Two-gluon width can be computed from the resonance branching fraction in J/ψ radiative decay,

$$\mathrm{Br}\,(G(0^{++}) \to gg) = \frac{8\pi(\pi^2-9)\,Br[\psi \to \gamma\,G(0^{++})]}{c_R\,x|H_J(x)|^2\,\Gamma_{tot}}\,\frac{M_\psi^2}{M_G}$$

- F. E. Close, G. R. Farrar, Z. Li, PRD55, 5749 (1997).
- To calculate the AA cross section we consider that,

$$\sigma_{AA}^{\mathrm{CD}} = A^2 \int d^2b\,T_{AA}(b)\,\exp\left[-A^2\,\sigma_{pp}^{in}\,T_{AA}(b)\right]\,\sigma_{pp}^{\mathrm{CD}}$$

- See C. Pajares and V.A. Ramallo, Phys. Lett. B107 (1981).
- The σ_{pp}^{in} and $\sigma_{pp}^{\mathrm{CD}}$ are the inelastic and CD cross sections in proton-proton case, respectively.
- Estimations are done for a few glueball condidates ($f_0(1500)$, $f_0(1710)$ and $X(1835)$).

Results for pp collisions at LHC

Glueball	Γ_{gg} [MeV]	$\sigma_{I\!PI\!P}$ @ LHC [μb]
$f_0(1500)$	69.8	3.0
$f_0(1710)$	70.2	4.6
$X(1835)$	70.27	5.2

- Cross sections for exclusive glueball production in double Pomeron exchange process for LHC energy ($\sqrt{s} = 7$ TeV).
- To be considered only order of magnitude estimate.
- Gap survival factor taken from KKMR model.
- Modelling: pure glueball supposition to compute $\mathrm{Br}(G \to gg)$.

Results for PbPb collisions at LHC

Glueball	Γ_{gg} [MeV]	$\sigma_{I\!PI\!P}$ @ LHC [μb]
$f_0(1500)$	69.8	28.8
$f_0(1710)$	70.2	42.5
$X(1835)$	70.27	48.0

- Cross sections for exclusive glueball production in double Pomeron exchange process for LHC energy ($\sqrt{s} = 5.5$ TeV).
- Cross section is sensitive to the value of Pomeron intercept.
- Interpolation for $\sqrt{s} = 2.76$ TeV is straightforward.

Glueball production in $\gamma\gamma$ process

- We use Equivalent Photon Approximation (EPA).
- Cross section for $PbPb \to PbPb\,G$ process can be factorized into the equivalent photon spectra, $N(\omega, b)$, and $\gamma\gamma \to G$ subprocess cross section:

$$\sigma\left(PbPb \to PbPbG\right) = \int \hat{\sigma}\left(\gamma\gamma \to G; W_{\gamma\gamma}\right)\,\theta\left(|\mathbf{b}_1 - \mathbf{b}_2| - 2R_A\right) \times N\left(\omega_1, \mathbf{b}_1\right) N\left(\omega_2, \mathbf{b}_2\right) \mathrm{d}^2\mathbf{b}_1 \mathrm{d}^2\mathbf{b}_2 \mathrm{d}\omega_1 \mathrm{d}\omega_2$$

- Photon flux can be expressed in terms of the charge form factors $F(Q^2)$:

$$N\left(\omega, b\right) = \frac{Z^2 \alpha_{em}}{\pi^2} \frac{1}{b^2 \omega} \left(\int_0^\infty u^2 J_1\left(u\right) \frac{F\left(Q^2\right)}{Q^2}\, du \right)^2,$$

$$Q^2 = \frac{\left(\frac{b\omega}{\gamma}\right)^2 + u^2}{b^2}$$

Glueball production model

- The glueball production in two-photon fusion can be calculated using the narrow resonance approximation:

$$\sigma\left(\gamma\gamma \to G\right) = (2J+1)\,\frac{8\pi^2}{M_G}\,\Gamma(G \to \gamma\gamma)\,\delta\left(W_{\gamma\gamma}^2 - M_G^2\right)$$

- $\Gamma(G \to \gamma\gamma)$ is the partial two-photon decay width of G, M_G is the glueball mass and J is the spin of the state G.
- For pure gluonic state, width can be computed using a nonrelativistic gluon bound-state model.
- See E.H. Kada, P. Kessler, J. Parisi, PRD39, 2657 (1989).
- Unknown parameters as the digluon wavefunction, are determined by using measured values of $\Gamma(J/\psi \to G\gamma)$.
- More sophisticated modelling is possible.

Results for PbPb collisions at LHC

Glueball Candidate	$\Gamma_{\gamma\gamma}$ [eV]	$\sigma_{\gamma\gamma}$ @ LHC [μb]
$f_0\,(1500)$	0.77	1.3
$f_0\,(1710)$	7.03	8.6
$X\,(1835)$	0.021	0.02

- Cross sections for pure glueball candidates production through photon-photon fusion in electromagnetic nucleus-nucleus collisions at LHC energies.
- Note: for pure $q\bar{q}$ the cross section is strongly higher!

Results for PbPb collisions at LHC

- We get a parameterization of the ultraperipheral AA cross section as a function of the resonance mass at the LHC.
- This makes simple the computation of event rates provided the specific meson state and its two-photon decay width.
- In the interval $400 \leq M_R \leq 4000$ MeV we obtain:

$$\frac{\sigma_{\rm upc}\,(AA \rightarrow R_J + AA)}{(2J+1)\,\Gamma(R_J \rightarrow \gamma\gamma)} = \frac{\sigma_0\, M_R^{\beta}}{1 + (M_R/4)}$$

- Here, $\sigma_0 = 4.9147$ mb/GeV and $\beta = -3.45335$; $\Gamma_{\gamma\gamma}$ and M_R are the decay width and the resonance mass in units of GeV, respectively.

Summary and comments

- Present calculation is an upgrade to previous estimates in AA collisions (new for Pomeron-Pomeron channel).
- To be considered only order of magnitude estimate.
- Experimental separation between the channels photon-photon and Pomeron-Pomeron has to be refined (e.g., p_T cuts for produced particles).
- Several uncertainties: e.g., model dependence in obtaining the two-photon and the two-gluon widths for a pure glueball meson.
- The $\gamma\mathbb{O}$ (photon-Odderon) channel contribution is currently unknown.