Investigation of the Inner Structure of Glueball Candidate Scalar Mesons with the ALICE Detector

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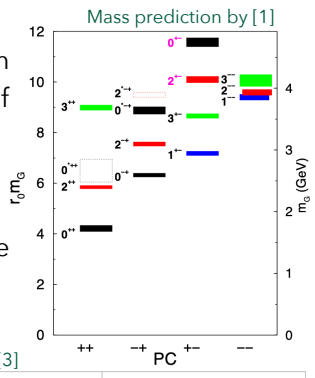
Introduction

Glueball

- A glueball is a particle predicted by Quantum Chromodynamics (QCD). It is composed solely of gluons and exists in a color-neutral (singlet) state.
  - Quantum number (light) [1] : $J^{CP} = 0^{++}, 0^{-+}, 2^{++}$
  - Mass [1] : 1 - 2 GeV/c^2
- Some scalar meson candidates meeting the above criteria have already been found [5]
  - All the candidates decay into ππ, KK, ηη

Mass prediction by [1]



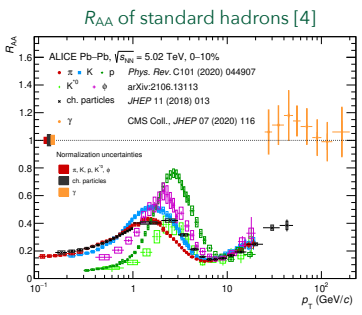
Properties of the candidates listed in PDG [2] and BESIII [3]

	M_{PDG} (GeV/c^2)	M_{BESIII} (GeV/c^2)	Γ_{PDG} (GeV/c^2)	$\Gamma_{BESSIII}$ (GeV/c^2)
○ f_0(1370)	1.2 to 1.5	1.350±0.009	0.2 to 0,3	0.231±0.021
○ f_0(1500)	1.506±0.006	1.505±0.000	0.112±0.009	0.109±0.000
○ f_0(1710)	1.704±0.012	1.765±0.002	0.123±0.018	0.146±0.003

Glueball hunting in heavy ion (HI) collisions

- The wealth of knowledge accumulated over the past two decades has revealed that the nuclear modification factor (R_{AA}) and the v_2 magnitude depend on the internal structure of hadrons
- Comparison between the candidates and the standard hadrons can give insight into the inner structure of the candidates and clarify if they are consistent with the glueball assumption

R_{AA} of standard hadrons [4]



Golden channel in HI collisions

- The combinatorial background in HI collisions due to high multiplicity makes the reconstruction of the candidates difficult
- $K^0_sK^0_s$ pair decay is the promising channel because of the lower combinatorial background with respect to the background of ππ and ηη, and of the higher purity compared to K^+K^- over a wide p_T range

Contents of this analysis

- The comparison between the candidates reconstructed via $K^0_sK^0_s$ and standard hadrons can reveal if one of the candidates is a glueball. First, let's establish the reconstruction method of the candidate in pp and pA at LHC

Analysis

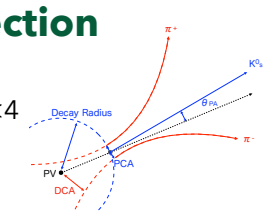
Strategy

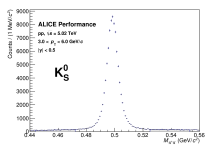
- Many resonances below 2 GeV/c^2 in $K^0_sK^0_s$ pairs
  $J^{CP} = 0^{++}$: f_0(1370), f_0(1500), f_0(1710), (f_0(1790)), etc
  $J^{CP} = 2^{++}$: f_2(1270), f_2(1525), etc
- It is difficult to extract each hadron component because interference between hadrons with the same quantum numbers could exist due to large widths (Γ > 100 MeV/c^2) in such a narrow mass range

The goal is to measure various final results as a function of invariant mass after background subtraction.

K^0_s reconstruction and candidate selection

- V0 reconstruction technique is used ($c\tau$=2.68 cm)
- The daughter pions are identified by TPC and TOF: $|N\sigma_\pi|<4$
- V0 pointing angle cut and decay radius cut are applied to reject secondary K^0_s: $\cos\theta_{PA} > 0.97$ & $R_{decay} < 20$ cm
- The distance between two daughter tracks cut and decay radius cut are applied to reduce combinatorics: $L_{PCA} < 1$cm & $R_{decay} > 0.5$ cm
- 0.47<$M_{\pi\pi}$<0.53 GeV/c^2 is regarded as K^0_s candidate

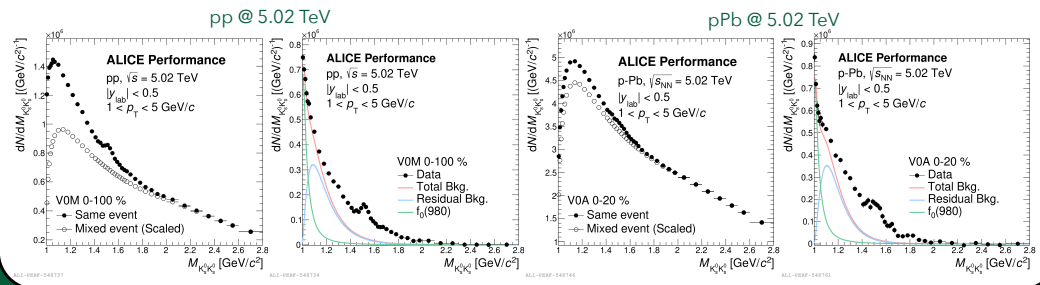




Signal extraction of $K^0_sK^0_s$ pairs

- The combinatorial background is estimated by the event mixing method
- The Maxwell-Boltzmann function is used to describe the residual background
  - $f(x) = (x - 2m_{K^0_S})^b \exp(-a(x - 2m_{K^0_S})^c)$
- Contribution from f_0(980) is estimated by template mass distribution
- The fitting process that includes both residual background and f_0(980) contributions is carried out using data outside the signal region, specifically for mass ranges other than 1.15 < M < 2 GeV/c^2.

pp @ 5.02 TeV　　pPb @ 5.02 TeV



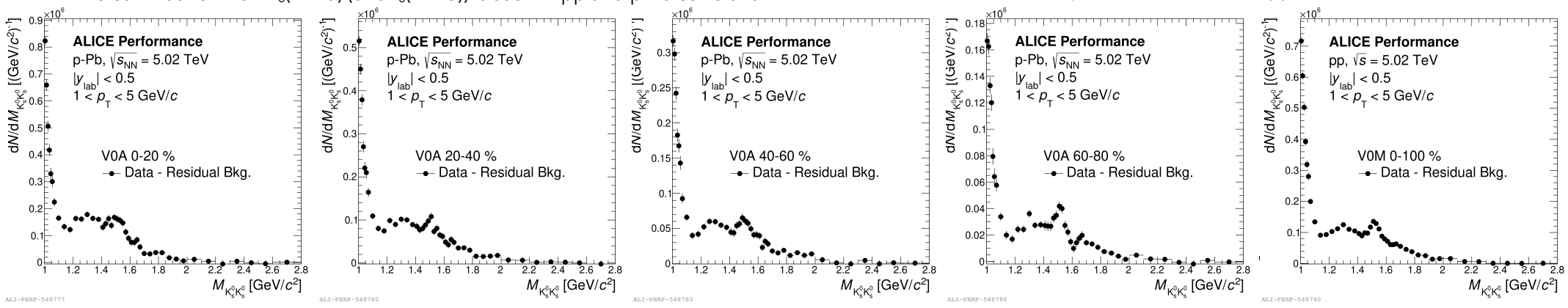
Result

Signal distribution structure

- The signal is extracted by subtracting the residual background
- Clear structures can be seen in pp and all p-Pb centralities
  - The narrow peak at the edge of the lower mass is the contribution from f_0(980)
  - The broad peak at 1.2 to 1.4 GeV/c^2 is the contribution from f_0(1370) and f_2(1270)
  - The clear peak at 1.5 GeV/c^2 is from f_2(1525), and f_0(1500) is possibly behind the contribution
  - The contribution from f_0(1710) (and f_0(1790)) is seen in pp and p-Pb collisions

Discussion

- The basic shape is the same, but the contributions between 1.2 to 1.6 GeV/c^2 have different shapes as a function of centrality
  - The sharp peak at 1.5 GeV/c^2 is observed in pp and p-Pb peripheral collisions, but it is blurred in central collisions in p-Pb
  - The clear valley at 1.45 GeV/c^2 is seen in pp and p-Pb peripheral collisions, but it becomes shallow in central collisions in p-Pb
  - Caveat: The efficiency corrections are not applied



Summary

- Some scalar meson candidates, f_0(1370), f_0(1500), and f_0(1710) meeting the criteria of the expected glueball quantum number have been found [5]
- Comparison between the candidates reconstructed via $K^0_sK^0_s$ pair and the standard hadrons can give insight into the inner structure of the candidates and clarify if one of the candidates is a glueball
- This analysis has demonstrated the ability to reconstruct the candidates in pp and p-Pb collisions at the LHC
- The invariant mass distributions in pp and p-Pb collisions look similar, but a modification may exist in most central p-Pb collisions
- **The reconstruction method has been established and it is ready to measure R_{pPb} and R_{PbPb}!**

References

[1] C. Morningstar and M. Peardon, "Glueball spectrum from an anisotropic lattice study", Phys. Rev. D 60, 034509 (1999).
[2] Particle Data Group, https://pdg.lbl.gov, "Meson Summary Table"
[3] BESIII Collaboration, "Amplitude analysis of the Ks Ks system produced in radiative J/ψ decays", PHYSICAL REVIEW D 98, 072003 (2018)
[4] ALICE Collaboration, "A journey through QCD", arXiv:2211.04384
[5] Particle Data Group, https://pdg.lbl.gov, "Spectroscopy of Light Meson"

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