CENTRAL PRODUCTION OF EXOTICS

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Abstract
The availability of glueball studies with the COMPASS setup is presented. Central production of X^0 decaying into $\eta\eta$ was used to estimate the registration efficiency. A few scenarios of the possible setup geometry are compared.

1. PHYSICS MOTIVATION

Spectroscopy of light quark systems and glueballs is one of the goals of the COMPASS programme. Since the experiment proposal was published six years ago new experimental data and theoretical descriptions have appeared. But still there are a lot of open questions in this field, high-statistics detailed data are needed to clarify the picture. A detailed review of this subject was made by S. Godfrey at this workshop, so my presentation will be short. QCD predicts the existence of non-$q\bar{q}$ mesons such as glueballs and hybrids. The best glueball mass estimates come from lattice gauge theory calculations. The lightest glueball has $J^{PC} = 0^{++}$ and its mass should be in the range 1.45–1.75 GeV.
Special methods based on production characteristics, decay patterns and relations to other mesons could be applied for a glueball search, namely:

- search for the states with J^{PC} not allowed for normal $q\bar{q}$ states, for example 1^{-+};
- a study of the extra states, that is states that have the quantum numbers of already completed nonets, with low masses (to exclude radially excited nonet members);
- a detailed study and look for the states with unusual branching ratios;
- search for the states preferentially produced in gluon-rich processes (Fig. 1): Pomeron–Pomeron scattering, J/ψ decays, proton–antiproton annihilation, special hadronic reactions.

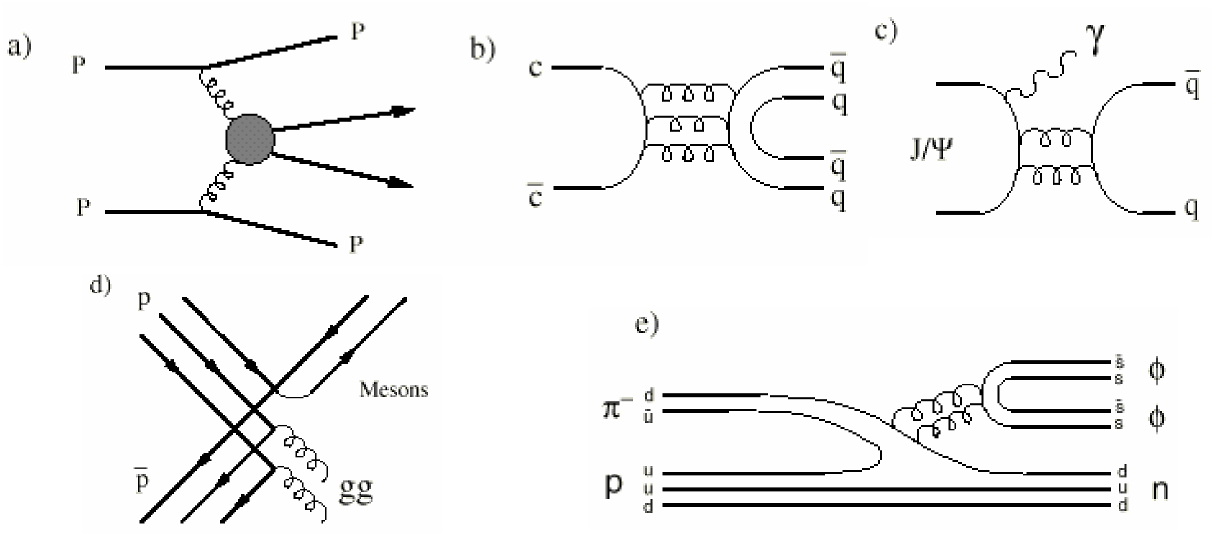

Fig. 1: Gluon-rich processes: a) Pomeron–Pomeron exchange; b) and c) J/ψ decays; d) $p\bar{p}$ annihilation; e) reactions involving disconnected quark lines.

According to lattice inspired models, glueballs will mix strongly with nearby $q\bar{q}$ states with the same J^{PC}. The three states in the glueball mass range are: $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$. The WA102 Collaboration published, for the first time in a single experiment, a complete data set for the decay branching ratios of these mesons to all pseudoscalar meson pairs: $\pi\pi$, $K\bar{K}$, $\eta\eta$, $\eta\eta'$, 4π. Based on this data, an analysis of the scalar glueball-$q\bar{q}$ mixing was done by A. Kirk and F. E. Close [1]. They identify a systematic correlation between glueball mass, mixing, and flavour symmetry breaking and conclude that the glueball may be rather lighter than some quenched lattice QCD computations have suggested.

A result that is more general than any specific mixing scheme is that no pair out of the three $f_0(1370)$, $f_0(1500)$, $f_0(1710)$ can be in the same pure $q\bar{q}$ nonet; other degrees of freedom are required. The WA102 data and world averages lead to the summary for the favoured results

	$f_{i1}^{(G)}$	$f_{i2}^{(S)}$	$f_{i3}^{(N)}$
$f_0(1700)$	0.39 ± 0.03	0.91 ± 0.02	0.15 ± 0.02
$f_0(1500)$	-0.65 ± 0.04	0.33 ± 0.04	0.70 ± 0.07
$f_0(1370)$	-0.69 ± 0.07	0.15 ± 0.01	0.07 ± 0.07

for which m_G = 1443 ± 24 MeV, m_N = 1377 ± 20 MeV and m_S = 1674 ± 10 MeV. The solution is compatible with the relative production strength in pp central production, $p\bar{p}$-annihilations and J/ψ radiative decays.

An interesting empirical observation of a different topology for central production of glueball candidates and $q\bar{q}$ mesons was done [2]. It was observed, that the ratio

$$R = \frac{N(\Delta P_T < 0.2\,\text{GeV})}{N(\Delta P_T > 0.5\,\text{GeV})}$$

for the number of events N with small and large ΔP_T is sensitive to the resonance nature. ΔP_T here is the absolute value of the momentum transfer difference for fast and slow hadrons. For undisputed $q\bar{q}$ mesons produced by Double Pomeron Exchange (DPE) $R < 0.1$, $R \approx 0.25$ for the states which cannot be produced by DPE ($I = 1$ or $G = -$); $R \approx 1$ for the states with a rich gluon component. The results of the WA102 experiment are presented in Fig. 2.

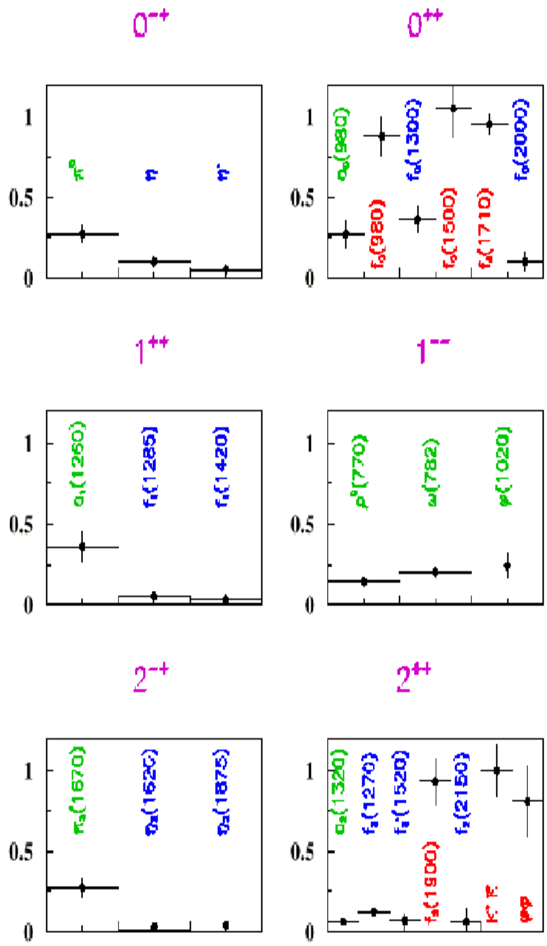

Fig. 2: Gluon filter.

2. EXPERIMENTAL LAYOUT

The COMPASS spectrometer setup for the central production measurements (Fig. 3) is described in the original experiment proposal. I will concern myself with few detectors only which are essential for the hadron part of the programme. The spectrometer consists of a large and a small angle spectrometer stage. The standard COMPASS tracking system is the same as for the muon setup. Two RICH detectors are used for charged particle identification. A 40 cm long liquid hydrogen target is installed in the RPDS [3]. Guard lead scintillator sandwiches were placed after the RPDS. The 30 × 30 cm^2 scintillator counter was installed at the end of the setup to register the fast hadron produced in the central production reaction. This counter has a hole of 5.2 cm in diameter to transport the non-interacting beam. The RPDS will select events consistent with only one particle coming from the target. Measurements of this slow particle velocity will be done. An essential part of the hadron setup is the electromagnetic calorimeters ECAL1 and ECAL2.

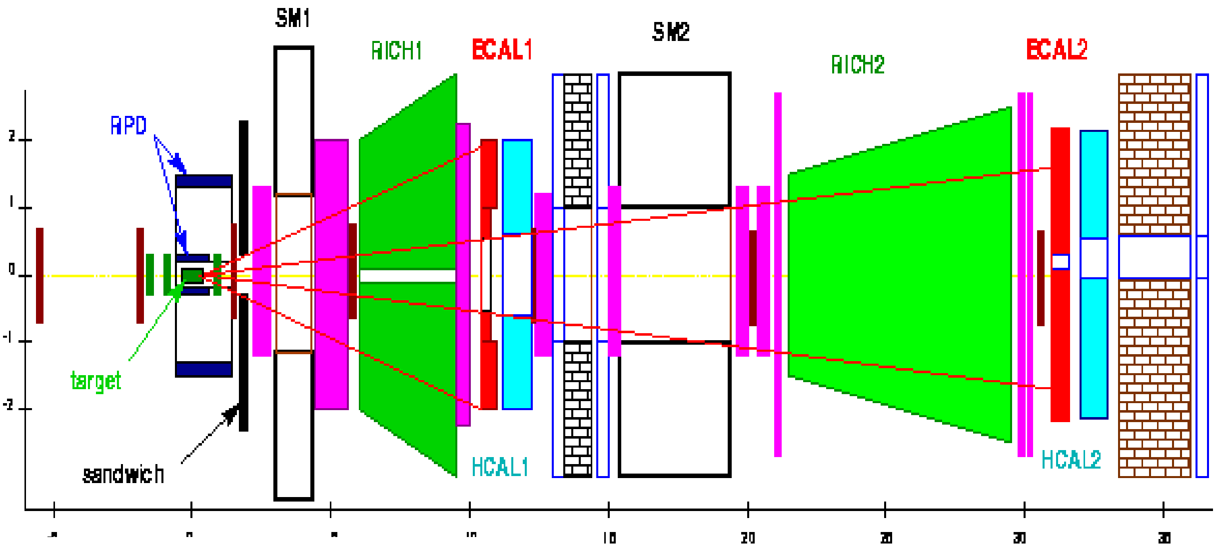

Fig.3: COMPASS Cental Production layout.

The main characteristics of the detectors are:

- ECAL1:
  - Total number of channels: 3216
  - Size: 4 × 2.9 m^2
  - $\sigma(E)/E = 5\text{–}6\%/\sqrt{E} \otimes 2\%$
- ECAL2:
  - Total number of channels: 3436
  - Size: 4.4 × 2 m^2
  - $\sigma(E)/E = 5\text{–}6\%/\sqrt{E} \otimes 2\%$
- Liquid H_2 target:
  - Length: 40 cm, 2.83 g/cm^2, 0.046 X_0
- RPDS
  - Total number of channels: 60
  - Time measurements
    - TOF resolution: 350 ps for MIP
    - Space resolution: A layer: 1.8 cm, B layer: 2.7 cm
  - Amplitude measurements:
    - Space measurements based on light attenuation
    - dE/dx
  - Measurement accuracy (P_{slow},) for time and amplitude are comparable.

3. MONTE CARLO SIMULATION

To understand the COMPASS spectrometer performance for the central production process a Monte Carlo simulation was made for the most pessimistic version of the setup with an ECAL2 size that was half that of the basic setup. Due to this change ECAL1 was placed at 15 m from the target instead of 11 m.

To study the setup operation for registration of the central production event the reaction

$$h\ p \rightarrow h_{fast}\, p_{slow}\, M_{centr}$$

was used, where h is the beam hadron, h_{fast} the fast secondary hadron, p_{slow} the slow recoil proton, M_{centr} the produced central system.

Two decay channels of the central system were studied:

$$M_{centr} \rightarrow \eta\eta,\quad \eta\eta \rightarrow 4\gamma \qquad \text{(the neutral decay channel)}$$

$$M_{centr} \rightarrow \eta\eta,\quad \eta \rightarrow 2\gamma,\quad \eta \rightarrow \pi^0\pi^+\pi^-,\quad \pi^0 \rightarrow 2\gamma \qquad \text{(the mixed decay channel)}$$

The program COMGEANT was used to generate the Monte Carlo events. The generator for the central production events was analogous to that used in the WA102 experiment. The range of the generated events on M_{centr} was 1.2–4 GeV. The beam energy was 180 GeV, the beam size $1.2 \times 1.2\ mm^2$, the beam divergence 0.3 mrad for both coordinates.

At the event generation the following trigger requirements were imposed:

1) a hit of only one counter in both the A and B layers of the RPDS;
2) absence of hits in the guard sandwiches;
3) a hit in the counter for fast hadron detection.

The generated events were reconstructed using the CDRA2 program and the following events were taken for further analysis:

a) neutral mode:
   1) one primary vertex with one secondary track with an energy of more than 140 GeV was reconstructed in the setup target;
   2) four photons found with energy more than 0.4 GeV in ECAL1 or more than 0.8 GeV in ECAL2.

b) mixed mode:
   1) one primary vertex with three secondary tracks, one of which with an energy of more than 140 GeV;
   2) four photons in ECAL1 and ECAL2 with the same energy cuts as above.

Then the events passed through the kinematics fit and the events with the probability of more than 1% for a corresponding hypothesis were selected (C3-fit for the neutral mode and C4-fit for the mixed mode).

The energy distribution for h_{fast} is shown in Fig. 4. As seen in this figure, the energy of h_{fast} is generally higher than 150 GeV and close to the beam energy.

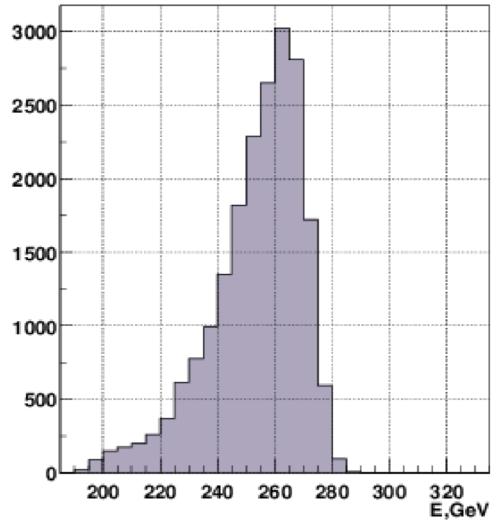

Fig. 4: Fast hadron energy.

In Fig. 5 one can see the momentum distribution of generated p_{slow} as well as that satisfying the trigger requirements. The threshold due to proton absorption in liquid hydrogen and RPDS material is clearly seen. The energy distribution of the M_{centr} versus its mass is shown in Fig. 6. It is seen that the mean energy of M_{centr} is growing with the mass.

Mass resolution of the reconstructed events appeared to be about 12 MeV (Fig. 7), and it is approximately the same for both decay modes.

In Fig. 8 one can see the x_F distribution of reconstructed events.

The setup registration efficiency as a function of M_{centr} is presented in Fig. 9 (the neutral mode) and Fig. 10 (the mixed mode). This efficiency includes the geometrical efficiency, the CORAL reconstruction efficiency and the influence of the selection criteria used.

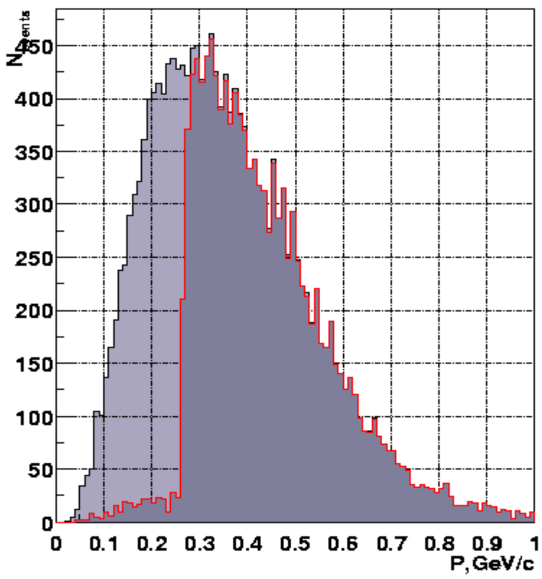

Fig. 5: Slow proton momentum.

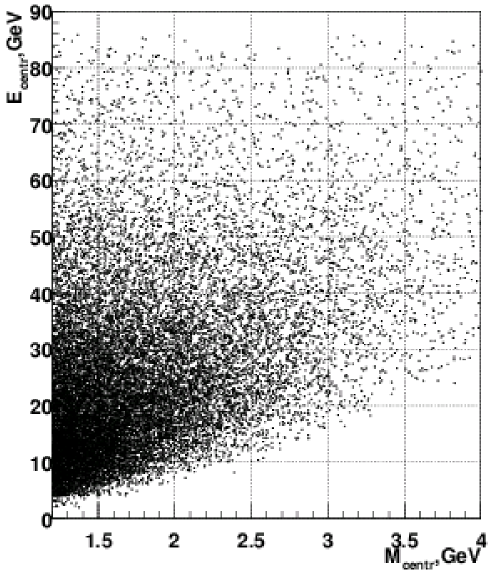

Fig. 6: Central system energy vs mass.

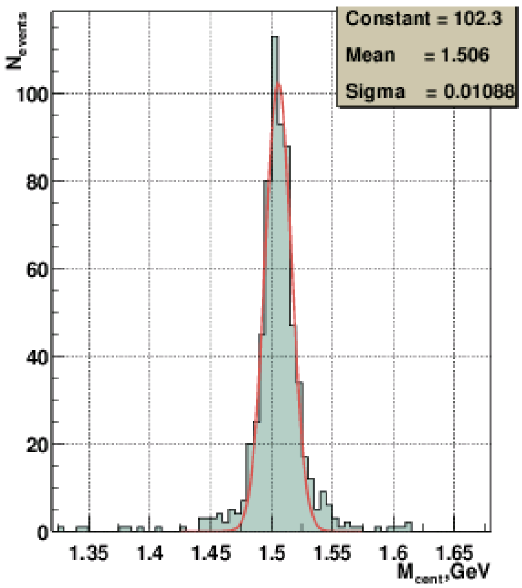

Fig. 7: Mass resolution, $\eta\eta \to 4\gamma\pi^+\pi^-$, C4-fit.

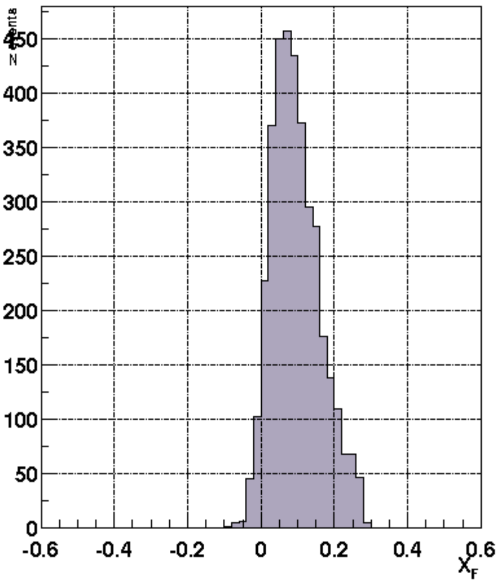

Fig. 8: x_F, $\eta\eta$ (4γ) central system.

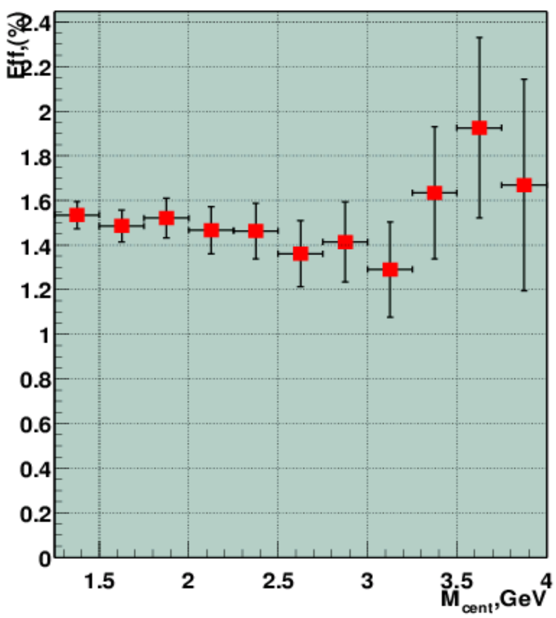

Fig. 9: Efficiency, $\eta\eta \to 4\gamma\pi^+\pi^-$, ECAL2 at 34 m.

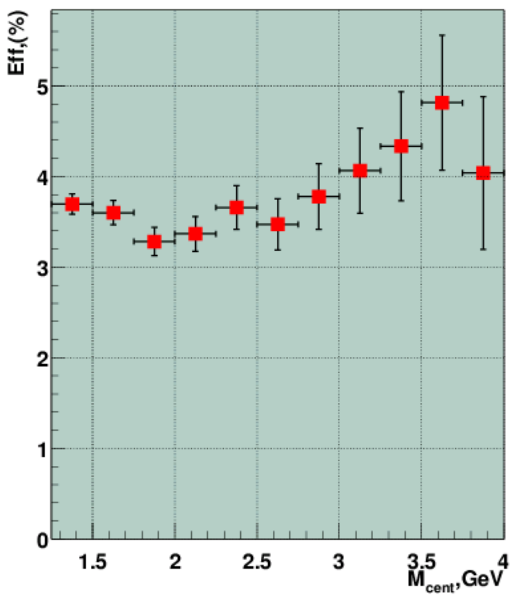

Fig. 10: Efficiency, $\eta\eta \to 4\gamma$, ECAL2 at 34 m.

The WA102 result for the cross section of the $f_0(1500)$ central production in pp interaction at 450 GeV is 2914±301 nb [4]. To estimate the COMPASS counting rate of the centrally produced $f_0(1500)$ in the ηη decay mode a value of 3 μb was used. With beam intensity 2.5×10^7 particles/spill (limited by the radiation hardness of the ECAL2 calorimeter) one can expect 450 events/day. The total statistics of WA102 for $f_0(1500)$ in the ηη decay mode is 3351 events [5].

There are evident recommendations to increase the counting rate. The nominal COMPASS setup with the proposed ECAL2 improves by a factor two in γ acceptance (18% for the simulated pessimistic setup), moreover the use of the sandwich type electromagnetic calorimeter in place of the sandwich counter (Fig. 3) gives the possibility to increase this value up to 95%. The acceptance cuts for different geometries are presented in Fig. 11. Another possibility is to produce a radiation-resistant ECAL2 central part to increase the acceptable beam intensity.

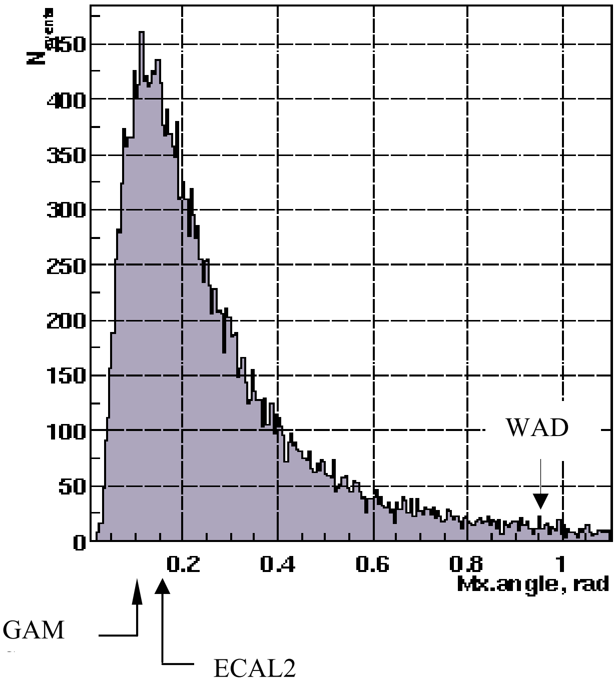

Fig. 11: γ acceptance for centrally produced ηη system decaying into 4γ.

4. CONCLUSION

The features of the COMPASS spectrometer are large geometrical acceptance, high mass, energy and angular resolution for the decay products, good particle identification, powerful data acquisition system, availability to operate in high-intensity beams. The estimated value of the registration efficiency calculated with COMGEANT is one order of magnitude higher then that for the WA102 setup. All this opens the possibility to use COMPASS for precise high statistics measurements of the centrally produced mesons decaying particularly into ηη, ηη′, η′η′, in which one may expect a manifestation of the gluonic component.

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