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Screening PHOS or not: Impact on the Photon and Electron Physics

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Abstract

We discuss the incidence on the performances of PHOS when material covers its acceptance region. In particular, we evaluate the degrading of the accuracy with which PHOS will be able to measure neutral-meson spectra and hence the deterioration of its sensitivity to direct photon detection. The performance loss being highly prejudicial, a hole in TRD and TOF detectors is required. Furthermore, we demonstrate that by combining information collected by PHOS and by the tracking system, even with a hole in the TRD, ALICE will preserve its performances with respect to electron physics.

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I. INTRODUCTION

To search in the real-photon spectrum for signatures of the formation of a thermalized quark-gluon plasma (QGP), created in ultra-relativistic heavy-ion collisions, constitutes the most direct approach to assess the existence of this new state of matter and to reveal its thermodynamical properties. Indeed the photon spectrum witnesses the history of the collision and therefore carries relevant information on the transition between the partonic and hadronic phases, like the duration of the two phases, the initial temperature of the system, and the critical temperature at which the phase transition occurs. Theoretical calculations [1] indicate that the transverse momentum domain, the most favorable for the detection of the thermal photons, ranges between 1 and 5 GeV/c.

In ALICE the Photon Spectrometer PHOS is the only detector dedicated to measure photons. The photon yield, measured at LHC energies, will be dominated by the electromagnetic decay of neutral mesons: mainly π° and η mesons. Accurate measurement of the neutral meson p_T distributions is thus an indispensable prerequisite to extract the direct photon signal of interest for QGP studies. In the PHOS TDR [2] we have discussed the accuracy with which the π° and η meson yield must be determined to guarantee that the direct photon signal is measured over the entire photon-p_T domain with a sensitivity (defined as the ratio of direct photon yield to the total photon yield) better than 5%. We concluded that the meson yield must be determined, over the whole meson-p_T range, with a statistical accuracy better than 1% for π°, and better than 10% for the η meson. Such values are difficult to reach in the lower p_T region, below ~ 1 GeV/c, due to the limited acceptance of PHOS and in the upper p_T region, beyond 5 GeV/c, because of the limited production rate of high-p_T hadrons. As shown in the PHOS TDR ([2], page 150), these values can however be reached over a broad p_T-range, from about 500 MeV/c up to at least 5 GeV/c for π° and η mesons, with the expected central event statistics collected by ALICE during one year at the nominal luminosity of LHC[1]. It turns out that a highly accurate measurement of the η-meson in PHOS is vital in order to study a possible U$_A$(1) restoration [2,4,5] through an enhancement of the η/π° ratio. To disentangle the different scenarios put forward [5], an accuracy better than 20% in the η measurement is necessary.

In this note we first discuss how material in front of PHOS deteriorates the statistical accuracy with which neutral meson distributions can be measured. The deduced deterioration of PHOS intrinsic characteristics justifies the presence of a hole in the Transition Radiation Detector (TRD) and the Time Of Flight (TOF) detector to preserve the photon physics in ALICE. We then show that, even with the presence of a hole in the TRD within the limited acceptance of PHOS, electron physics remains anyhow feasible by exploiting PHOS ability to properly identify electrons.

II. STATISTICAL ACCURACY OF THE MESON MEASUREMENT

In the p_T range below 50 GeV/c, neutral mesons are identified through invariant-mass analysis of all identified photon pairs:

$$M_{inv} = \sqrt{2E_1E_2(1-\cos\theta_{12})} \tag{1}$$

In central Pb+Pb collisions at LHC energies, due to the expected large decay-photon multiplicity, M_γ, the invariant-mass analysis generates, by combining photon pairs from the decay of two different particles, a large combinatorial background, N_B, proportional to the squared photon multiplicity, $N_B \propto M_\gamma^2$. As estimated and reported in the PHOS TDR, within this environment and in the low p_T range ($p_T \leq 1$ GeV/c), the meson resonance signal, N_S, only amounts to less than a few per cent of the combinatorial background. The situation obviously improves by selecting pairs with increasing p_T values.

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[1]The extension of this analysis is presently under way showing that much higher p_T-values are in principle within reach, $\sim$ 80 GeV/c for π° and at least 100 GeV/c for η-mesons. This result will be published in a forthcoming ALICE Note.

Such a low signal-to-background ratio imposes the collection of a very large statistical sample to achieve the high statistical accuracy required for the measurement of the meson distribution. For π^0 adequate accuracies will be easily reached within the running conditions provided by LHC. However the measurement of low p_T η-mesons (between a few hundreds of MeV/c and about 1 GeV/c) will require at least 10^9 events to achieve the necessary statistical accuracy of 10% per bin of 200 MeV/c ([2], page 150). This kind of statistics can barely be reached in one running year, during which only 8×10^8 central events (10% of the σ_R and assuming the availability of a fast PHOS trigger[2]), can be accumulated. Thus any, even slight, deterioration of PHOS performances will prevent to collect enough statistics for the measurement of η-mesons, and hence noticeably decrease its sensitivity to direct photons. This requires to minimize the amount of material in front of PHOS because the neutral meson efficiency will be decreased due to photon conversion, the occupancy will increase due to interaction in the material, and the effective PHOS energy-resolution will be noticably worse than its intrinsic resolution. The latter consequence will come in addition to the unavoidable resolution degradation due to the high particle-multiplicity environment expected at LHC energies. However since this high multiplicity environment is dominated by low p_T particles, the multiplicity induced degradation affects only the measurement of low p_T particles whereas the material induced degradation affects the measurement of particles of any p_T. We shall next quantify the performance deterioration as a function of the amount of material screening PHOS. The accuracy, a_C, with which the neutral pion production cross-section can be measured is defined as:

$$a_C = \frac{\epsilon_{N_S}}{N_S} \sim \frac{\sqrt{2N_B}}{N_S} \tag{2}$$

where ϵ_{N_S} is the error on the N_S measured meson-events and N_B the combinatorial-background events under the meson signal. By adding material in front of PHOS (we shall consider next the impact of the TRD only), this accuracy will be modified as follows:

[2] 800 Hz central reaction rate in Pb+Pb collisions at 5.5A TeV, PHOS trigger during 10^6 seconds.

- *The conversion of photons.*

  Considering a distance of about 1 meter between the TRD and PHOS and the intensity of the nominal magnetic field (0.2 T), any photon that interacts in the TRD, will not be detected by PHOS, decreasing the PHOS photon efficiency. Since the detection of a neutral meson requires the detection of two photons, the number of detected mesons will be reduced according to

$$N_S^{TRD} = (1 - P_I)^2 \times N_S, \tag{3}$$

  where P_I is the probability that a photon crossing the TRD detector undergoes an interaction.

- *The increased particle multiplicity.*

  Due to secondary interactions in the TRD, the particle multiplicity will increase, decreasing the ratio N_S/N_B. The additional combinatorial background due to this first effect can be simply estimated as:

$$N_{1,B}^{TRD} = (1 + P_I)^2 \times N_B \tag{4}$$

- *The deterioration of the energy resolution.*

  Finally the TRD will deteriorate the energy resolution, smearing the meson resonance signal and consequently increase the underlying background to take into account. Assuming that the combinatorial background is constant around the meson signal, it will be proportional to the invariant mass resolution. We define the parameter, d, to quantify this deterioration:

$$\sigma_E^{TDR} = (1 + d) \times \sigma_E \tag{5}$$

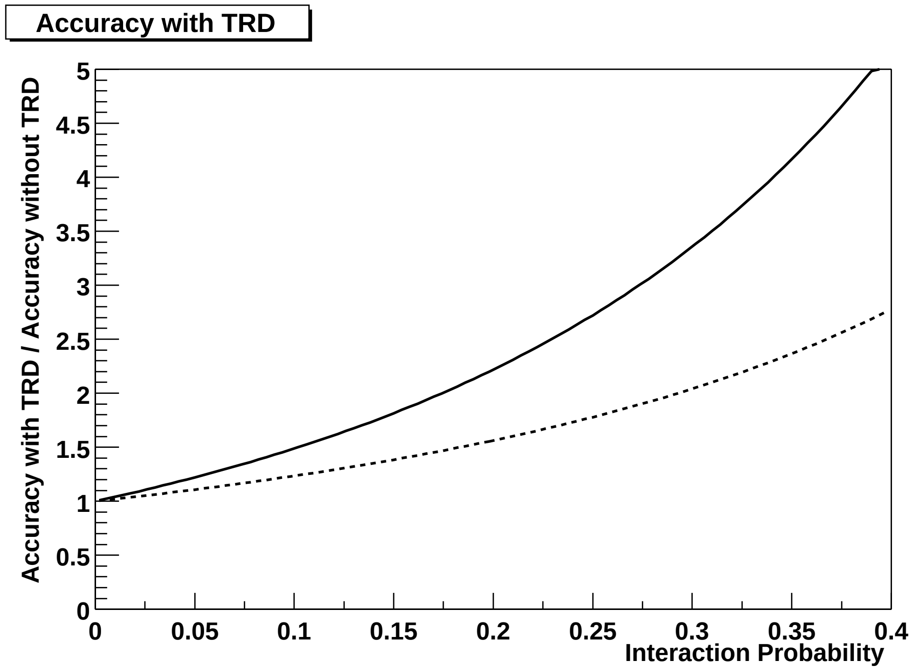

FIG. 1. *Accuracy change of the neutral meson measurement in PHOS as a function the interaction probability in the PHOS geometrical acceptance. We have assumed that the invariant mass resolution deteriorates as a function of P_I following the expression $d = 2P_I$ [3]. THe dashed-line represents the deterioration of the neutral meson accuracy if only the photon conversion effect is considered (see Eq.3).*

The combinatorial background will be further modified as:

$$N_{2,B}^{TRD} = (1 + d) \times N_{1,B} \tag{6}$$

The exact value of d depends on the interaction probability P_I and the particle multiplicity. From preliminary simulations [3] we found that d equals about 0.7 for a material thickness corresponding to 1 X_0 and from a systematic study we deduce that d scales with the interaction probability as $d = 2 \times P_I$.

Finally, combining (2)-(6), the change in accuracy can be expressed as a function of the interaction probability as :

$$\frac{a_C^{TRD}}{a_C} \sim \frac{\sqrt{2N_{2,B}^{TRD}}}{N_S^{TRD}} \sim \frac{1 + P_I}{(1 - P_I)^2} \times \sqrt{1 + 2P_I} \tag{7}$$

We observe (Fig.1) that the deterioration of the neutral meson accuracy amounts to a factor 2 for interaction probabilities of 17%. This deterioration translates, in particular, in a change of the η-meson accuracy from 10% to 20%. As a direct consequence, the direct photon sensitivity is reduced from 5% to 6%. For interaction probabilities around 35%, the deterioration of the neutral meson accuracy amounts to a factor 4. This situation seriously handicaps an accurate measurement of the η-meson (below 20%) needed for the study of a possible $U_A(1)$ restoration.

We conclude that an amount of material corresponding to or more than 17% photon interaction probability, as it would be the case if the TRD screens PHOS, will considerably deteriorate the PHOS sensitivity, preventing the observation of a weak direct-photon excess and of an expected small change in the η-meson production.

III. STATUS OF ALICE DESCRIPTION IN ALIROOT

The amount of material in front of PHOS in the present ALICE design[3] has been extracted from version v3.04 of AliRoot (Table I). We observe that the main contribution is due to the TRD[4], i.e., 9.6% of X_0. The second most important contribution is due to the ITS, 5.7% of X_0. This contribution is not uniform and reaches values up to 8% of X_0. We also observe that the central electrode of the TPC introduces an amount of material of 15% of X_0, however only in a limited acceptance region and is for the present study ignored. Finally the total amount of material in front of PHOS adds to a value close to 25% of X_0. The situation is catastrophic (see Table I), if TOF detector is also added to the material budget in front of PHOS.

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[3] We have considered a hole in the TOF detector. Indeed the TOF material budget amounts to 18.44% of X_0, on average, with 50% variation in the overlap of the strip chambers [6].

[4] After completion of this work, the amount of material of the TRD detector as been revised. The new value is now 60% larger: 15.3% of X_0 [10].

From our analysis we conclude that the presently existing amount of material in front of PHOS will deteriorate the neutral-meson accuracy by more than a factor 2 (Fig. 1) as compared to the requirements of the PHOS technical design report [2].

System	Material(X_0)	Uniformity
HALL	1.4%	Good
ITS	5.7%	35% variation
TPC	2.2%	Good
TPC Central Electrode	15%	-
TRD	9.6% (15.3% [10])	Good
PIPE	0.3%	Good
FULL without TOF	19.1% (24.8%)	10% variation
FULL with TOF [6]	37.5% (43.2%)	30% variation

TABLE I. *Amount of material in radiation-length units introduced by each ALICE subsystems in front of the bottom block of PHOS. These values are taken from the output of an AliRoot v3.05* Lego Plot.

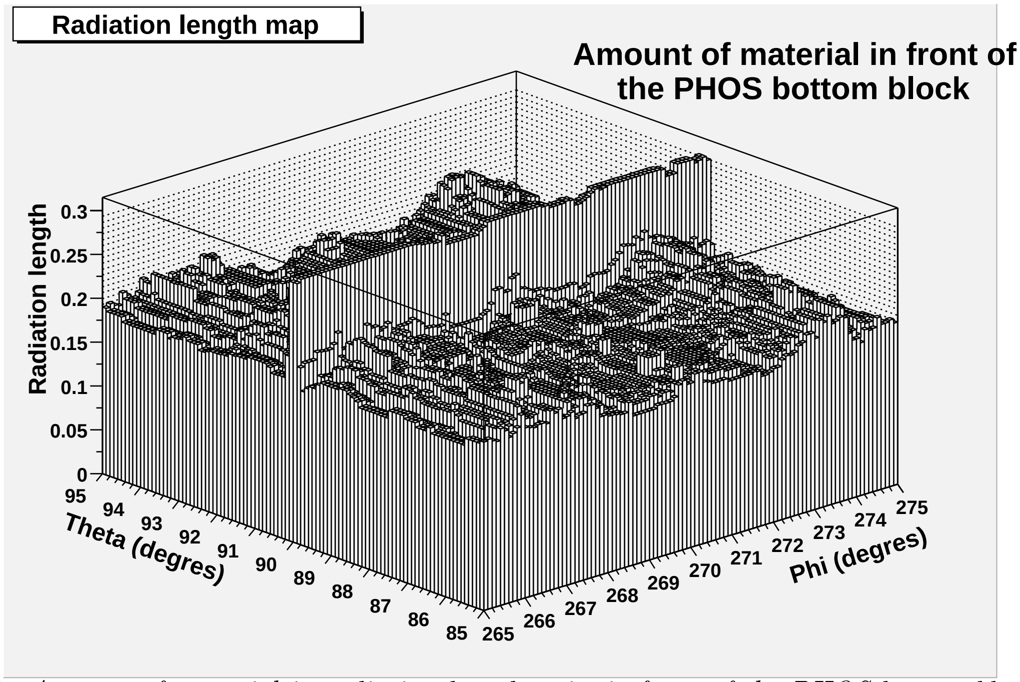

FIG. 2. *Amount of material in radiation length units in front of the PHOS bottom block with a hole in the TOF detector, from the vertex to PHOS. A value close to 20%X_0 is obtained, and we clearly see the effect of the central electrode of the TPC at θ=90°, which increases the amount of material to more than 30%X_0 . Aliroot v3.05.*

IV. PHOS AS AN ELECTRON IDENTIFIER

Obviously, the presence of a hole in the TRD region in front of PHOS, while allowing for an accurate measurement of neutral meson and direct photons in PHOS, will reduce the acceptance of the TDR. In this last section we describe the possibility of using PHOS as an efficient electron identifier, thus compensating for this reduction of the TRD acceptance. Electrons impinging on PHOS will, like photons, develop an electromagnetic shower. Thus, PHOS can also play the role of a very efficient electron-spectrometer. Indeed, noting that:

- the full energy of the electron will be deposited within the 20 radiation-lengths of the calorimeter, and will be measured with a resolution better than 2% for electron with p_T larger than 3 GeV/c [2],
- electron showers present the same characteristics as photon showers, in particular the

lateral development of the shower, R^{width}, will be narrower than the one of hadron induced showers [3], providing a discrimination criterion,

- the ratio between the electron momentum, measured by the ALICE tracking system, and the energy deposited in the calorimeter will be distributed around 1,

we conclude that electrons can be efficiently detected and identified, with an excellent charged-pion rejection, by combining information from PHOS and the ALICE tracking system.

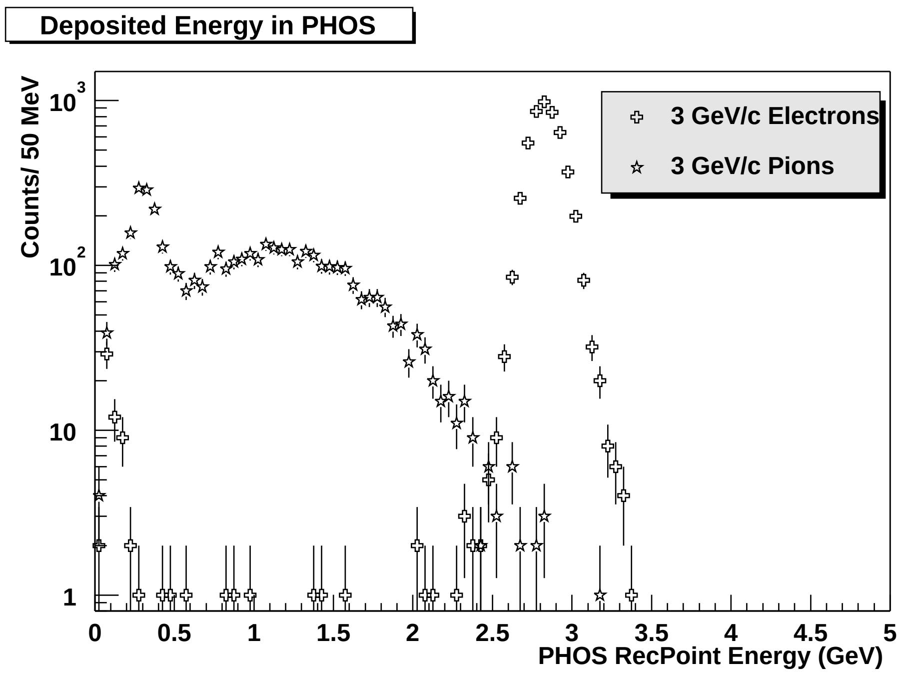

FIG. 3. *Deposited energy in PHOS by electrons and charged pions with $p_T = 3$ GeV/c momentum.*

We have simulated the deposited energy in PHOS by mono-energetic electrons and charged pions with $p_T = 3$ GeV/c momentum. As expected, electrons deposit most of their energy in the calorimeter (Fig.3), leading to a ratio of the energy and the track momentum $E_{PHOS}/P_{track} = (0.947 \pm 0.002)$. More than 99% of the electrons are distributed within a window 3σ wide around the central value of this ratio. In the same window we find only 0.34% of the 3 GeV/c charged pions. Indeed the mean deposited energy is 0.93 GeV, and the ratio E_{PHOS}/P_{track} is only 0.31. In addition, taking into account that the lateral development of the shower is narrower for electromagnetic particles than for charged hadrons, (Fig.4), only 0.16% of the charged pions would pass an appropriate shower-profile selection [3], whereas more than 97% of the electron tracks fulfill these selection criteria.

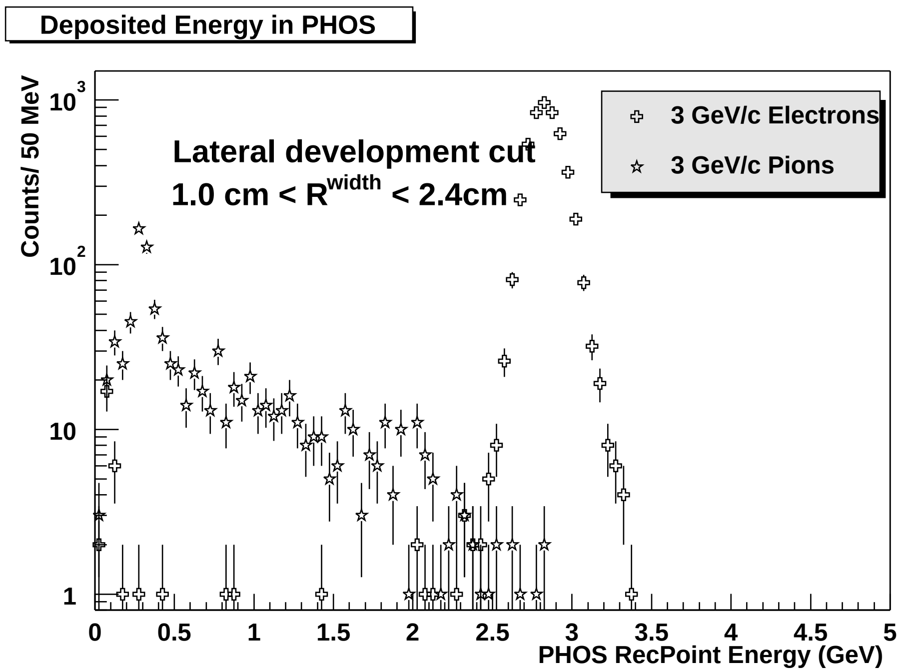

FIG. 4. *Deposited energy in PHOS for electrons and charged pions with a momentum of 3 GeV/c. Only narrow showers are accepted*

Within these conditions, we have calculated the electron efficiency and charged-pion rejection of PHOS as a function of the particle momentum (Fig.5). We find that, beyond 2 GeV/c, the electron efficiency is larger than 95% and the charged pion contamination less than 0.3%. These numbers fulfill the requirements stated for the ALICE electron-identifier [7]. In addition, PHOS measures electrons with an energy resolution lower than 2% for electron momenta larger than 3 GeV/c. This resolution is better than the momentum resolution of the ALICE tracking system (ITS+TPC) in the nominal magnetic field [8]. If the selection on the lateral profile of the shower is not applied for $p_T \sim 1$ GeV/c, then the electron efficiency increases back to 95%, at the cost of a larger pion contamination, reaching then 1.2%.

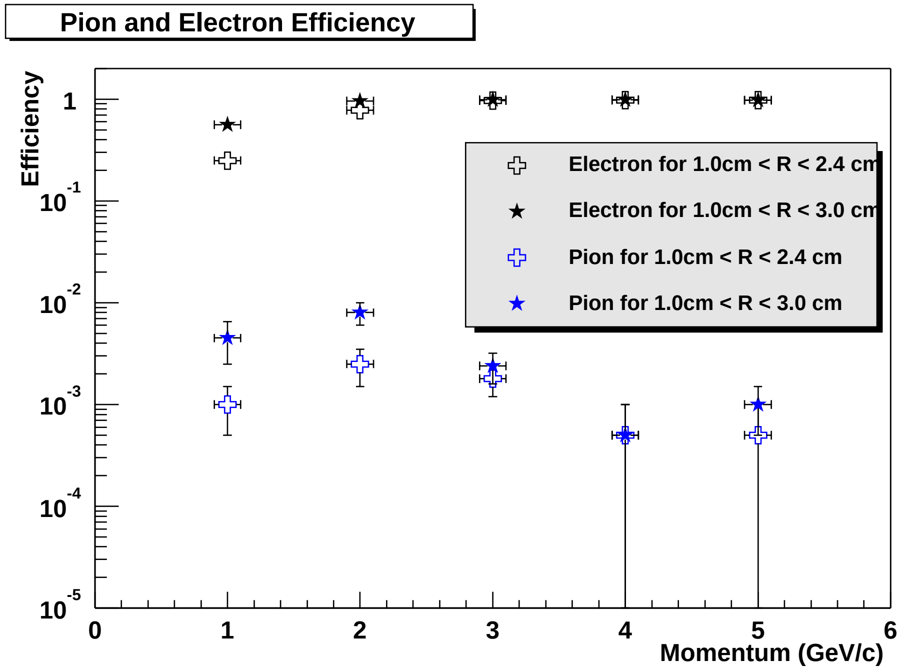

FIG. 5. *Electron efficiency and charged pion rejection as a function of the particle momenta using a combined analysis of PHOS and the ALICE tracking system.*

We conclude that the combination of the analysis of PHOS and of the ALICE tracking system will fulfill the requirements of an electron identifier for ALICE in the PHOS fiducial acceptance region. In this analysis we have assumed that the track matching between the TPC and PHOS is perfect which will not be too far from reality for high p_T tracks [9].

V. CONCLUSIONS

A good accuracy in the measurement of the neutral meson production in Pb+Pb collisions at LHC energies is crucial to keep the sensitivity of ALICE to detect direct photons at the level of 5% [2]. We have studied the evolution of the neutral meson accuracy in the presence of material in front of the PHOS geometrical acceptance region. We conclud that only the addition of the TRD in front of PHOS would worsen by a factor 2 the accuracy with which PHOS will be able to measure the π° and η-meson spectra and consequently reduce the sensitivity of PHOS to direct-photon identification by 20%. Adding TOF would worsen even more dramatically the accuracy by a factor 4!

In Addition, we have shown that the combined analysis of PHOS and the ALICE tracking system (TPC+ITS) allows for an efficient electron-identification, with a charged pion contamination remaining below 0.3%. In summary, with a hole in the TRD in front of PHOS, the intrinsic properties of ALICE with respect to photon and neutral-meson physics will be preserved and, at the same time, the electron physics programme will be unaffected by exploiting the combined information from PHOS and the ALICE tracking system.

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