Estimation of γ, π^0 and η ratios in the photonic background in proton-proton collisions at $\sqrt{s} = 7$ TeV with ALICE

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The heavy-flavour production in pp collisions is an important testing ground for perturbative QCD, the field theory for the strong interaction. One way of measuring heavy-flavour hadrons is via the leptons originating from their decays. There are other sources of leptons which represent the background for their measurement. In this report the main sources of the background for the semileptonic decays are evaluated, for pp collisions at $\sqrt{s} = 7$ TeV. For this purpose the photonic method is used; it consists in calculating the invariant mass of an "inclusive" $e^{\pm}$, for which stringent cuts are required to be sure that its track belongs to an $e^{\pm}$, combined with an "associated" one, for which only relaxed cuts are required to maximise the efficiency. Then the background is obtained subtracting the like-sign ($e^{\pm}e^{\pm}$) distribution from the unlike-sign ($e^{\pm}e^{\mp}$) distribution; finally the quantitative contributions of the main sources are derived from a fit.

1 Introduction

1.1 Quark-gluon plasma

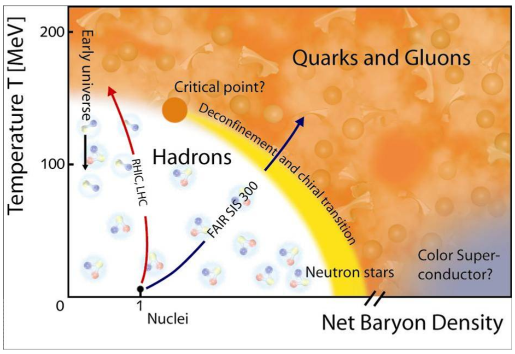

Fig. 1: *Phase diagram of hadronic matter and the hadron gas - quark-gluon plasma phase transition*

Quantum chromodynamics (QCD) predicts that under extreme conditions of very high temperature or baryo-chemical potential μ_B hadronic matter transits to a deconfined phase of matter called *"quark-gluon plasma"* (QGP), in which quarks and gluons are not bound in hadrons.

The QGP is thought to have permeated the universe for few μs after the Big Bang. Experimentally, it can be created in ultra-relativistic heavy-ion collisions.
These collisions create a so called *fireball* of interacting quarks and gluons above the critical temperature, which first reaches the thermal equilibrium, and then quickly expands and cools down. During the cooling starts the *hadronization*, or rather quarks and gluons become again confined and form hadrons.
The last phases are the *chemical freeze-out* and the *kinetic freeze-out*, where, respectively, inelastic and elastic processes cease.

1.2 Heavy-flavour production

The production of hadrons which contain heavy quark (charm or beauty) is an important probe for the QGP. It happens exclusively through initial hard partonic scattering processes when the medium is more dense, because of their higher mass. Heavy quarks lose energy differently than the light quarks in the QGP. They are therefore a signature of the deconfinement, and their behaviour in the medium is useful to characterise the medium itself.

Hadrons carrying heavy flavour can decay by weak interaction, through a *"semileptonic decay"*, in which one lepton (and the corresponding neutrino) is produced in addition to one or more hadrons.
It is important to estimate the background for these decays to quantify the heavy-flavour production.

The main sources for the photonic background are the photon conversions ($\gamma \to e^+e^-$) and the π^0 and η Dalitz decays ($\pi^0 \to e^+e^-\gamma$ and $\eta \to e^+e^-\gamma$), which are the major contribution for the low p_T region (80%÷ 95%).
The aim of this study is to quantify the relative amount of those three sources, especially the ratio between photons and π_0 and η mesons.

2 Data analysis

2.1 Tracks selection

For this analysis MC data for pp collisions at $\sqrt{s}$ = 7 TeV (LHC10f6a) have been used: they are generated with PYTHIA 6 and their behaviour in the detectors (ITS, TPC and TOF) has been simulated with GEANT 3[1].

The idea of this analysis method is to combine an "inclusive" $e^\pm$, whose track is surely related to an electron, with an "associated" $e^\pm$, for which less stringent cuts are required to maximise the efficiency.
The cuts applied to the reconstructed tracks, for "inclusive" and "associated" $e^\pm$, are shown in Table 1.
Finally, using the MC truth information, only the tracks that really belong to $e^\pm$ are selected for both "inclusive" and "associated" $e^\pm$.

2.2 Invariant mass analysis

It is possible to reconstruct the mass of a particle from its decay products
(in our case they will be $e^\pm e^\mp$, or equivalently $e^\pm e^\pm$), using the following relation:

$$m_{ee} = \sqrt{(p_1 + p_2)^2} = \sqrt{(E_1 + E_2)^2 - (\vec{p_1} + \vec{p_2})^2}. \qquad (1)$$

[1] **GE**ometry **AN**d **T**racking package

Tab. 1: *Cuts applied for "inclusive" and "associated"* $e^\pm$

	inc $e^\pm$	**ass** $e^\pm$
χ^2/cluster in the TPC track fit	< 4	< 4
ITS/TPC refit	yes	yes
number of TPC clusters	$\geqslant 120$	$\geqslant 100$
number of ITS clusters	$\geqslant 4$	$\geqslant 2$
number of TPC cluster for PID	$\geqslant 80$	$\geqslant 80$
TPC Ratio found/findable clusters	> 0.6	-
Transverse momentum	$0.1 < p_T < 20$	-
Pseudorapidity	$\mid\eta\mid< 0.8$	$\mid\eta\mid< 0.8$
Reject Kink daughter	yes	yes
DCA in $\mid\vec{r}\mid$-direction [cm]	< 1	< 1
DCA in z-direction [cm]	< 2	< 2
ITS SPD layer hit	First	-

The indices 1 and 2 stand for the two candidates and the energy is calculated from the mass of the daughter particles (in this case m_e = 0.511 MeV), because E_i is not directly measured.

3 Photonic background with MC truth information

Using the MC truth it is possible to select every e^+e^- pair which comes from one of the sources listed before, and then to obtain their invariant mass distributions.

The numbers of γ conversions, π^0 and η Dalitz decays, known from MC truth, are shown in the following table:

Tab. 2: *Amount of* e^+e^- *pairs from the three sources, obtained from the MC truth distributions*

number of γ	418300 ± 600
number of π^0	362000 ± 600
number of η	42100 ± 200
n_γ/n_{π^0}	1.156 ± 0.003
n_γ/n_η	9.94 ± 0.05
$n_\gamma/(n_{\pi^0} + n_\eta)$	1.035 ± 0.002

3.1 Invariant mass distributions

Every measured particle is described by several parameters which determine its kinematic and track.

The initial observables, which describe the particle how it was originally created, are known from the MC truth. From ESD[2] it is possible to obtain the parameters after the interaction of the particle with the material of the detectors, and its track has been reconstructed from the measured information. The invariant mass distributions have been generated first with MC truth, then with ESD observables.
Thus we can notice how the distributions obtained with the reconstructed tracks of the particles are wider than the others, due to the finite resolution of the detectors.
It is finally possible to put together the three contributions, that should represent the majority of the background (at least for $m_{ee} < m_\eta$), and fit the result with a parametric distribution, which summarises the three contributions.

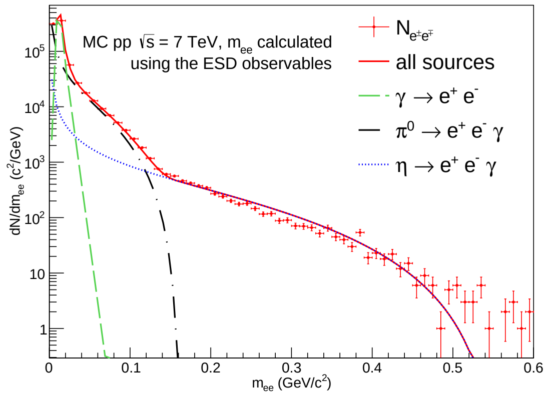

Fig. 2: *Invariant mass distribution for γ conversion, π^0 and η Dalitz decays from MC truth with observables from ESD reconstructed tracks.*

3.2 Fit functions

The parameterization is different for photon conversions and Dalitz decays.
For the first source an exponentially modified Gaussian distribution has been chosen,

$$\frac{dN}{dm_{ee}} = N_\gamma \cdot e^{-\frac{(m_{ee}-M_\gamma)^2}{2\sigma^2}} + \Theta(m_{ee}-M_\gamma)e^{\frac{m_{ee}-M_\gamma}{\tau}} \tag{2}$$

where Θ is the Heaviside function, which is defined equal to zero for $m_{ee} < M_\gamma$ and equal to 1 for $m_{ee} > M_\gamma$.

This function fits reasonably well because the invariant mass of a photon is not exactly zero, in fact the conversion can only happen near to a nucleus, which transfers a fraction of his momentum. In addition for the reconstructed tracks it is necessary to take into consideration the finite resolution of the detectors.

For the Dalitz decays, instead, the Kroll-Wada distribution has been used

$$\frac{dN}{dm_{ee}} = N_X \cdot \frac{2}{m_{ee}} B^{3/2} \sqrt{1 - \frac{4(m_e/M_X)^2}{(m_{ee}/M_X)^2}} \times \\ \times \left\{ 1 + \frac{2(m_e/M_X)^2}{(m_{ee}/M_X)^2} \right\} \cdot F_X(m_{ee}^2) \tag{3}$$

where N_X is a normalisation factor, m_e is the mass of an electron or a positron, M_X the mass of the mother particle and

$$B = (1 + (m_{ee}/M_X)^2)^2 - 4(m_{ee}/M_X)^2. \tag{4}$$

The Form Factor F_X is different for every Dalitz decay. For the π^0 and the η the expressions are

$$\begin{cases} F_{\pi^0}(m_{ee}^2) = \frac{1}{(1-5.5 \cdot m_{ee}^2)^2} \\ F_\eta(m_{ee}^2) = \frac{1}{(1-1.9 \cdot m_{ee}^2)^2} \end{cases} \tag{5}$$

In this analysis the parameters which should represent the mass of the mothers are not the real ones, but they have been fixed from the fit performed to the distribution with all the three sources (selected with MC truth), with the observables calculated from the reconstructed tracks (Fig.2).
In fact the distributions of the Dalitz decays cannot be properly described by the Kroll-Wada, due to the fact that some counts for low transverse momentum and low invariant mass are lost, because particles with low p_T and m_{ee} cannot reach the detectors.
This problem affects more the π^0 distribution than the η one, because the π^0 meson has a lower mass (the real values are $m_{\pi^0} = 139.57$ MeV and $m_\eta = 547.85$ MeV).

The values of the parameters from the fit and the integrals of the single contributions are summarised in Tab.3.

[2] **E**vent **S**ummary **D**ata

Tab. 3: *Amount of e^+e^- pairs from the three sources, obtained from the fit of the MC distribution*

M_γ	0.01107 ± 0.00018 GeV/c^2
M_{π^0}	0.1611 ± 0.0003 GeV/c^2
M_η	0.558 ± 0.004 GeV/c^2
Integral of γ	418300 ± 1100
Integral of π^0	355000 ± 2000
Integral of η	49200 ± 600
I_γ/I_{π^0}	1.179 ± 0.007
I_γ/I_η	8.50 ± 0.11
$I_\gamma/(I_{\pi^0}+I_\eta)$	1.035 ± 0.006

4 Photonic background without MC truth information

In order to approach a realistic analysis strategy to be performed with real data, the MC truth information is ignored in this section.
Therefore every "inclusive" $e^\pm$ is combined to an "associated" $e^\mp$ and for each pair the invariant mass m_{ee} is calculated to create the unlike-sign distribution, that contains both the photonic signal, and the combinatorial background. Then every "inclusive" $e^\pm$ is paired to an "associated" $e^\pm$ for the like-sign invariant mass distribution. This one represents only the combinatorial background, that will be then subtracted from the unlike-sign distribution to obtain only the signal which we are interested in.
In Fig. 3 the two distributions are shown: the red points belong to the unlike-sign distribution, the black ones to the like-sign.
For the like-sign distribution a normalisation was necessary, in fact not all the combinatorial background was subtracted.

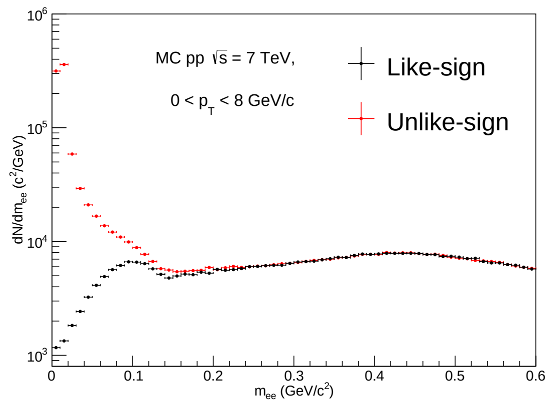

Fig. 3: *The invariant mass distribution of like-sign ($e^\pm e^\pm$) and unlike-sign ($e^\pm e^\mp$) combination.*

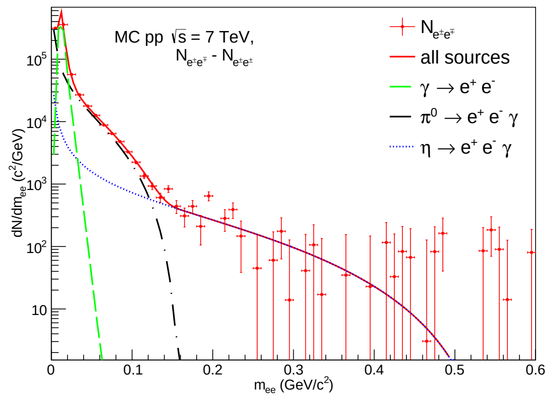

Fig. 4: *The photonic background fitted with the template obtained from the MC truth.*

For every bin the ratio between the unlike-sign and the like-sign distribution has been calculated, and then linearly fitted starting from $m_{ee} > 0.3$ GeV/c^2. Every bin of the like-sign distribution has been then multiplied for the value of the line in the centre of the bin, to obtain the normalised distribution.

Once subtracted the like-sign distribution from the unlike-sign, the resulting photonic background has been fitted with the templates extrapolated from the MC truth in section 3.2, as represented in Fig. 4. The values of the parameters that should represent the masses have been fixed from the ones obtained from the previous fit (Table 3).
The purpose of this method is therefore to obtain the same amount of γ, π^0 and η, as known from the MC truth. The integral of the three contributions and the relative ratios are shown in the following table:

Tab. 4: *Amount of e^+e^- pairs from the three sources, obtained from the fit of the photonic background*

Integral of γ	423000 ± 6000
Integral of π^0	354000 ± 4000
Integral of η	42000 ± 3000
I_γ/I_{π^0}	1.19 ± 0.02
I_γ/I_η	10.0 ± 0.8
$I_\gamma/(I_{\pi^0}+I_\eta)$	1.07 ± 0.02

As we can see the values obtained from the fit are comparable to the real ones known from the MC truth, within the statistical error.

5 Conclusions and Outlook

The goal was to determine the ratio between the contribution from photon conversions and from π^0 and η Dalitz decays to the photonic background to the electrons from heavy-flavor hadron decays.
It has been reached, although more precise results could be obtained fixing some details (for example the problem of higher masses). The ratio between γ and η seems to be the best one to be considered, but it is only due to the large statistical error. In fact the relative error for the number of η is of 7.1%, while for π^0 is 1.1% and for γ 1.4%.
Therefore the ratio between photon conversions and all the contributes from Dalitz decays should be used. Moreover we can notice that some counts from π^0 could be misidentified and contribute to the η integral, as it is possible to observe from the fit performed to the MC truth distribution (Table 3). The total number of Dalitz decays has not changed anyway.

The next step would be look into real proton-proton data, to see if the same ratio is found. Finally, the same study can be applied to Pb-Pb data, to verify that there is an excess of γ, which are supposed to be thermal photons originated by the fireball, which is only created in heavy ions ultra-relativistic collision. More information about this phenomenon can be found in the article [6].

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