PROCEEDINGS OF SCIENCE

Measurements of π^0 and direct photon spectra in ALICE

Dmitri Peressounko[1]
RRC „Kurchatov Institute“
Kurchatov sq.1, Moscow, 123182, Russia
E-mail: `Dmitri.Peressounko@cern.ch`

for the ALICE collaboration

Simultaneous measurement of the direct photon spectrum and the spectrum of neutral pions in AA collisions provide an excellent tool for studying effects related to the energy loss of hard partons: direct photons control the initial state of the collision and a modification of the neutral pion spectrum gives a calibrated estimate of final-state effects.

The ALICE experiment involves a powerful tracking system and a fine electromagnetic calorimeter. It provides several approaches to measure the neutral pion spectrum via two-photon decay: using photon detection in the calorimeter or using photon conversion and e^+e^- pair detection in the tracking system. Both approaches are discussed and compared and a transverse momentum region accessible in the first year of LHC running is estimated. Finally we present methods of direct photon extraction in ALICE.

4th international workshop High-pT physics at LHC 09
Prague, Czech Republic
February 4 – 7, 200

[1] Speaker

1. Introduction

Measuring the π^0 spectrum at high transverse momentum is one of the most straightforward ways to explore energy loss of hard partons in A+A collisions. Relative simplicity of this measurement was the reason why the jet quenching was first observed at RHIC as a suppression of the π^0 spectrum in Au+Au collisions at 130 GeV [1]. Later the hadron spectra and two-hadron correlations were measured in d+Au and Au+Au collisions by 4 RHIC experiments [2] proving that the observed suppression is a final state effect.

A detailed study of the suppression of hard π^0s was performed mainly by the PHENIX experiment which has a powerful electromagnetic calorimeter. Presently the nuclear modification factors R_{AA} for π^0 and other hadrons were measured for different collision energies and colliding species [3,4]. An energy scan demonstrated similar suppression of the π^0 yield at transverse momentum p_t > 6 GeV/c at $\sqrt{s_{NN}}$=62 and 200 GeV. A scan over different colliding systems, Au+Au and Cu+Cu, at the same colliding energy revealed the scaling of the suppression over the number of participants and not over the system size [4]. Unfortunately, it was shown that one can not distinguish between different parton energy loss schemes using the integrated R_{AA} [5]: all models predict almost identical p_t and centrality dependence of the R_{AA}. Therefore it was suggested to study the suppression of the π^0 spectrum in AA collisions with respect to the reaction plane. The yield of π^0 indeed shows considerable anisotropy up to the highest measured p_t [6]. The anisotropy at p_t>5 GeV/c can hardly be interpreted as collective flow, and probably can be used to disentangle different energy loss mechanisms [5].

Direct photons provide another quite important insight into the energy loss of the hard parton. Using direct photons one can test the initial state of the AA collision and look at the possible modification of the parton distribution functions in nuclei. Analyses performed by the PHENIX experiment demonstrated that the yield of direct photons in AA collisions scales with the number of binary nucleus-nucleus collisions N_{bc} at all energies and all colliding species (Au+Au, Cu+Cu, d+Au) except probably the very high p_t~20 GeV/c region in Au+Au collisions at top RHIC energy [4]. It is not clear yet whether this decrease of direct photon R_{AA} can be attributed to the isospin or EMC effect, a suppression of the contribution of fragmentation photons or to the difficulties in handling overlapping showers from π^0 decays in the calorimeter.

Another large experiment at RHIC – STAR – has also measured π^0 and direct photon spectra using several techniques: photon measurement with the electromagnetic calorimeter and through the photon conversion on the material of the inner detectors and beam pipe, which provide some amount of material (~8% of the radiation length X_0). STAR has measured the spectrum of neutral pions with both these techniques [7]. Both measurements agree with each other and with the PHENIX result. Besides the measurement of the π^0 spectrum itself, this result proves that the conversion technique can be successfully used for a photon measurement in the heavy ion environment.

Below we discuss the ability of the ALICE experiment to perform a similar analysis in a new energy regime – at the LHC. We concenrtate on PHOS and the conversion tracking technique. A full evaluation of the EMCAL capabilities has not yet been performed.

2. ALICE setup

A detailed description of the ALICE setup can be found in [8]. We present a schematic view of the cross section of the ALICE setup at central rapidity in Fig.1. Detectors, which will be installed and participate in the run 2009 are shown as filled boxes, while empty boxes represent parts of detectors which will be installed in the next few years.

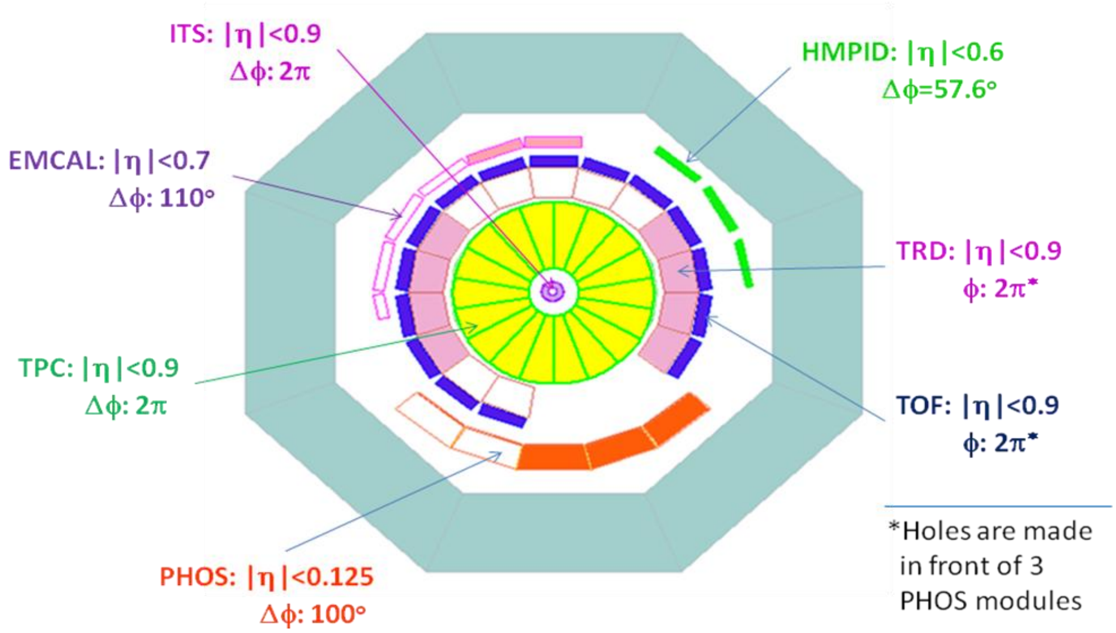

Figure 1: Cross-section of the ALICE setup at η=0.

The tracking system of the ALICE experiment is based on the Inner Tracking System (ITS) and the Time Projection Chamber (TPC), particle identification is improved with a Transition Radiation Detector (TRD) and a Time Of Flight detector (TOF). In addition ALICE has two electromagnetic calorimeters: PHOton Spectrometer (PHOS) and EMCAL. Note that holes are made in the TRD and TOF detectors just in front of 3 PHOS modules to minimize the amount of material before the calorimeter. Main physics goal of the PHOS detector is measuring the neutral meson and direct photon spectrum at low and medium p_t, so it has a fine granularity, excellent energy and position resolution but limited acceptance [9]. EMCAL is designed mainly for studying high p_t physics (photons, mesons and jets) therefore it has limited resolution but larger acceptance [10].

Thanks to the variety of detectors in ALICE one can apply different approaches of photon measurement: photon detection either in PHOS or EMCAL calorimeters, or detection via photon conversion into e^+e^- pair on the material of the inner tracking detectors or beam pipe. Measuring photons in the calorimeters provides high efficiency and good energy resolution but a limited acceptance. Measuring photons through conversion we increase the acceptance but decrease the detection efficiency due to the small amount of material (~5% X_0) before the TPC.

The expected characteristics of the ALICE electromagnetic calorimeters and the conversion approach are summarized in the Table 1. Both energy and position resolutions of

Table 1: Main characteristics of the photon detectors in ALICE.

	PHOS	EMCAL	ITS+TPC ($\gamma\to e^+e^-$ conversion)
σ_E/E, %	$\sqrt{\left(\frac{1.3}{E}\right)^2+\frac{1.3^2}{E}+1.12^2}$	$\sqrt{\left(\frac{11.3}{E}\right)^2+\frac{1.7^2}{E}+4.8^2}$	<2 %
σ_x, mm	$\sqrt{\frac{3.26^2}{E}+0.44^2}$	$1.5+\frac{5.3}{\sqrt{E}}$	~1
R_{IP}, cm	460	428	<160
σ_π, MeV/c^2	5.5 @ $1<p_t<2$ GeV/c	16 @ $1<p_t<2$ GeV/c	3.3 @ $0.8<p_t<2$ GeV/c

PHOS and the conversion technique are comparable and somewhat better than the resolutions of the EMCAL. The best way to compare electromagnetic calorimeters is to compare the widths of the π^0 peak in the two-photon invariant mass distribution measured in p+p or A+A collisions. It is this parameter which defines the signal/background ratio and finally the dominant systematic errors in measuring π^0 and direct photon spectra. We present the comparison of the width of π^0 peak expected in p+p collisions at $\sqrt{s}$=10 TeV at $1<p_t<2$ GeV/c in the bottom of Table 1. Comparing to the width of the π^0 peak measured in the PHENIX experiment in Au+Au collisions [11] – σ_π~10 MeV/c^2, PHOS and conversion technique will provide a twice narrower peak, while in EMCAL we expect a slightly larger width. So in ALICE we will have 3 independent measurements of the photon and neutral meson spectra based on different detection and reconstruction techniques but comparable resolutions which will provide good crosscheck of the results.

2. Extracting the π^0 spectrum

In ALICE we have several possibilities to measure the π^0 spectrum through its $\pi^0\to2\gamma$ decays: either both photons can be detected in PHOS[1], or one photon converts to an e^+e^- pair and the second detected in PHOS, or both photons convert. Each of these methods has their advantages and drawbacks: the low efficiency of the conversion method is almost compensated by a larger acceptance of the tracking detectors in ALICE. We compare the product of the π^0 detection efficiency and acceptance $A\cdot\varepsilon$ for these methods in Fig. 2. The largest value is obtained when two photons are registered in PHOS (Fig. 2a). If one photon is registered in PHOS and the other converted (Fig.2b), $A\cdot\varepsilon$ is ~20 times smaller at high p_t, corresponding to 5% photon conversion probability. Comparing to pure PHOS, $A\cdot\varepsilon$ diminish slower with decrease of p_t, reflecting ability to detect π^0 decayed into photons with large opening angle. Finally, in the pure conversion case (Fig.2c) the $A\cdot\varepsilon$ is as well only ~20 times smaller than PHOS since the lower detection efficiency is compensated to by the larger acceptance.

Having estimated the reconstruction and acceptance factors $A\cdot\varepsilon$ and using NLO predictions on the π^0 yield in p+p collisions at $\sqrt{s}$=10 TeV (program INCNLO [12]), we

[1] In this and next sections we concentrate on PHOS while EMCAL analysis is still to come.

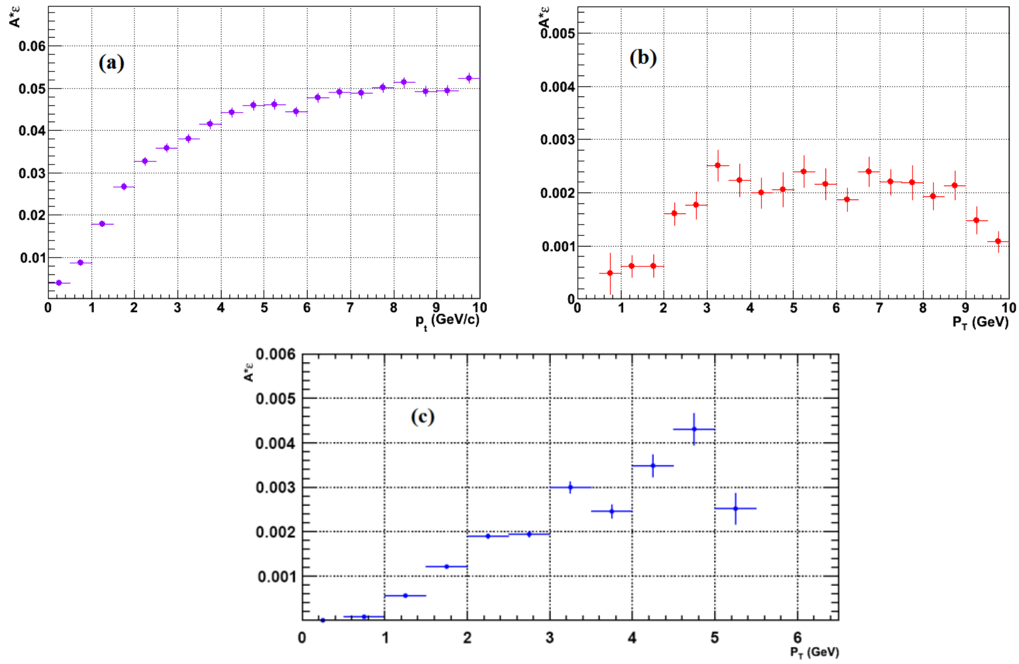

Figure 2: The product acceptance·efficiency A·ε for π^0 detection by 3 methods, (a) both photons in PHOS, (b) one photon in PHOS and second converted, (c) both photons converted.

estimated the number of registered π^0s in different scenarios of LHC running, see Figure 3. To define the accessible p_t range, we estimate the integrated luminosity. The ALICE Minimal Bias trigger includes all detectors, so the event rate is defined by the slowest one – the TPC.

TPC will operate with an initial event rate of 200 Hz, which corresponds approximately to the p+p luminosity of $L=5\cdot10^{27}$, $cm^{-2}s^{-1}$. One month of data taking with this event rate results in $\int L=13\ nb^{-1}$. However, implementation of the PHOS standalone trigger on high-p_t photons will lead to an increase of the effective luminosity up to the one expected at LHC startup $L=5\cdot10^{28}$, $cm^{-2}s^{-1}$ and even up to the nominal LHC luminosity $L=3\cdot10^{30}\ cm^{-2}s^{-1}$, which results in $\int L=130\ nb^{-1}$ and $\int L=7800\ nb^{-1}$, correspondingly. This allows estimate of the accessible range for data taking with the ALICE Minimal Bias trigger and with the PHOS L1 trigger, see Fig.3: In the first case, one can reach p_t~25 GeV/c for both photons detected in PHOS and ~16 GeV/c in the conversion methods. Applying PHOS L1 trigger we extend our range up to p_t~40 GeV/c.

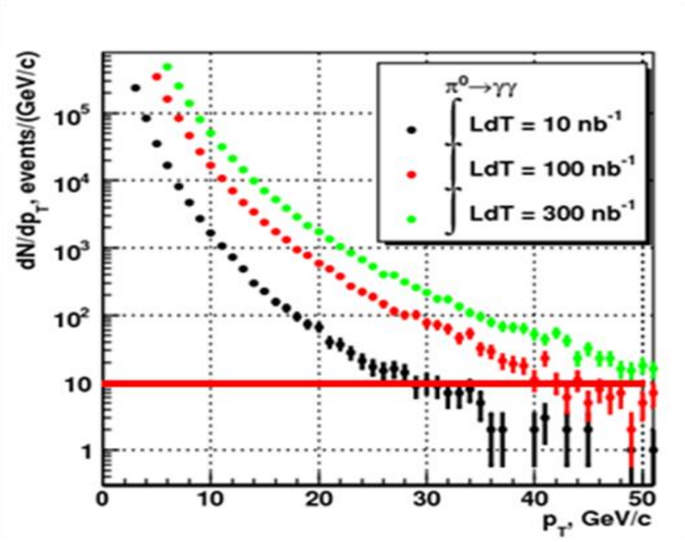

Figure 3: The number of detected π^0 (both photons in PHOS) in p+p collisions at $\sqrt{s}$=10 TeV for several values of the integrated luminosity.

3. Direct photon spectrum

Presently, a set of techniques for the measurement of the direct photon spectrum in p+p and A+A collisions have been developed. The most conventional one is the subtraction method, where one measures the inclusive photon spectrum as well as spectra of π^0, η, ω and other hadrons, and subtracts the contribution of photonic decays of these mesons from the inclusive photon spectrum. To estimate the expected systematic errors of a direct photon spectrum measured with ALICE in Pb+Pb collisions, we use the systematic errors of the direct photon spectrum measured by the PHENIX collaboration in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV [13] and attempt for an extrapolation to LHC energy and the ALICE/PHOS detector. We take into account the difference in multiplicity, energy and position resolutions, the photon identification ability and the material budget in front of the calorimeter. In the Fig. 4 we compare the expected systematic errors (green band), to the theoretical predictions of excess of all photons with respect to the decay photons and estimate the region where direct photons can be measured. Three groups of lines represent different predictions: The blue lines do not account for energy loss effects in prompt photon spectrum and therefore probably overestimate the ratio at high p_t [14]. In the second prediction (black and red curves) parton energy loss is taken into account, but neglected jet-thermal interaction, which should populate the intermediate region $5<p_t<10$ GeV/c [15]. Finally, the magenta line shows a first estimate of the jet-thermal contribution [16]. According to Fig. 4, ALICE will be able to measure the direct photon spectrum down to 3 or even 1 GeV/c, depending on the physical scenario.

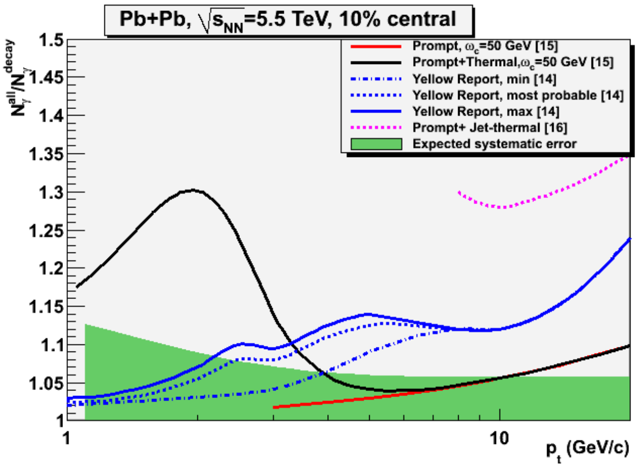

Figure 4: Comparison of the expected systematic error on direct photon extraction with predictions of direct photons excess over the decay photons.

Another technique, which can be applied to the measurement of the direct photon spectrum, is isolation. It is based on the fact that hard hadrons and in particular π^0s are always accompanied by the softer part of the jet while the prompt photons which are emitted by the leading order pQCD processes do not have hard companions. Therefore, to find isolated photons, one defines some cone around the candidate and requires either absence of hard hadrons, or smallness of the total energy in this cone. In ALICE we will use PHOS or EMCAL to detect isolated photons and the central tracking system to find hadrons in the cone. Taking into account the final ALICE acceptance one has to define a rather small cone with opening angle R=0.2, but simulations show that this cone provides a purity of the isolated photon sample better than 7% with reasonable efficiency even in central Pb+Pb collisions [17]. In p+p collisions the result is similar [18]. In the same way as in the π^0 case we estimated the accessible p_t range in the upcoming p+p run: 10 (15) GeV/c with minimal bias (PHOS) trigger.

3. Conclusions

We reviewed the ALICE ability to measure the spectrum of neutral pions and direct photons in p+p and A+A collisions. Photons can be detected both in the calorimeters PHOS and EMCAL and through the conversion to an e^+e^- pair. All methods provide comparable resolutions, but the conversion method has somewhat lower efficiency. We estimate that in the upcoming p+p run at $\sqrt{s}$=10 TeV neutral pions can be measured up to p_t~25 (40) GeV/c with minimal bias (PHOS L1) trigger. We extrapolated the systematic error achieved in Au+Au collisions by the PHENIX experiment to ALICE and found that systematic errors will allow to measure direct photons down to 3 GeV/c in Pb+Pb. The isolation technique can be applied to p+p and Pb+Pb collisions. Direct photon spectra in p+p collisions will be achievable up to 10 (15) GeV/c in the first LHC run with minimal bias (PHOS L1) trigger.

References

[1] K.Adcox et al., Phys. Rev. Lett. **88**, 022301 (2002).

[2] S.S.Adler et al., (PHENIX collaboration) Phys. Rev. Lett. **91**, 072301 (2003),
B.B.Back et al., (PHOBOS collaboration) Phys. Rev. Lett. **91**, 072302 (2003),
J,Adams et al., (STAR collaboration) Phys. Rev. Lett. **91**, 072304 (2003),
I.Arsene et al., (BRAHMS collaboration) Phys. Rev. Lett. **91**, 072305 (2003).

[3] A.Adare et al., (PHENIX collaboration), Phys. Rev. Lett.**101**, 162301 (2008)

[4] K. Reygers for the PHENIX collaboration J.Phys.**G35**:104045, 2008**.**

[5] S.Bass et al., arXiv:0808.0908.

[6] A.Adare et al., (PHENIX collaboration), arXiv:0903.4886.

[7] G. Lin for the STAR collaboration J.Phys.**G35**:104046,2008.

[8] ALICE PPR, Vol. I, CERN/LHCC 2003-049, 7 November 2003.

[9] V.Manko et al., PHOS TDR, CERN/LHCC 99-4, 1999.

[10] P.Cortese et al., EMCAL TDR, CERN/LHCC-2008-014, 2008.

[11] L. Aphecetche et al., NIM **A499** 521-536 (2003).

[12] wwwlapp.in2p3.fr/lapth/PHOX_FAMILY/readme_inc.html, P. Aurenche et a., hep-ph/9910252.

[13] S.S.Adler et a., Phys. Rev. Lett. **94**, 232301 (2005).

[14] F.Arleo et al., CERN-2004-009-D, hep-ph/0311131.

[15] N. Armesto, (ed.) et al. F.Arleo et al, J.Phys.**G35**:054001, 2008.

[16] S.Tubide et al., Phys.Rev.**C72**:014906,2005.

[17] G.Conesa et al., JINST 0803:S08002, 2008.

[18] Y. Mao et al., Eur.Phys.J.**C57**:613-619, 2008.