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# Spectator induced electromagnetic effects on charged meson production in nucleus-nucleus collisions from NA61/SHINE at CERN SPS

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The SPS Heavy Ion and Neutrino Experiment (NA61/SHINE) studies the properties of hadron emission in collisions of beams of hadrons and nuclei with fixed hadronic and nuclear targets. In recent years, the NA61/SHINE physics program has been supplemented with studies of electromagnetic (EM) effects, induced by the spectator charge on spectra and ratios of emitted charged mesons. This paper reports the first results on spectator induced EM effects on charged pion ($\pi^+/\pi^-$) ratios, for $\pi$ mesons emitted in Ar+Sc collisions at 40 A GeV/$c$ beam momentum ($\sqrt{s_{NN}}$ = 8.76 GeV). The presented data include the first ever measurement of these effects in a small peripheral nucleus-nucleus system at the CERN SPS, and the first analysis of the full range of centrality in Ar+Sc collisions in NA61/SHINE.

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## 1. Introduction

In recent years the physics program of the NA61/SHINE experiment at the CERN SPS has been complemented with studies of electromagnetic (EM) effects. These effects are induced by the spectator system which is the nuclear remnant. The spectators do not take direct part in the collision, but the presence of their charge results in a distortion of the trajectories of emitted $\pi^+$ and $\pi^-$ mesons. It has been shown that the shape of that distortion as a function of longitudinal and transverse kinematical variables brings new information on the space-time evolution of the system [1]. In this context, the first preliminary data on Ar+Sc reactions at 150 $A$ GeV/$c$ for central and intermediate collisions has already been released [2]. This paper presents new data on EM effects in Ar+Sc collisions at 40 $A$ GeV/$c$ in the full range of centrality, ranging from central up to fully peripheral collisions. This is the first measurement of EM effects in peripheral small systems at the CERN SPS. This is also the first analysis of the full range of centrality in Ar+Sc collisions in NA61/SHINE. The EM distortion studied in this paper is sensitive to the distance between the pion formation zone and the spectator system ($d_E$). It has been established [3] that there is a decrease of $d_E$ with increasing pion rapidity, which means that faster pions are produced closer to the spectator system. In the paper [1] the first-ever realistic description of spectator induced EM effects appeared to necessitate the inclusion of phenomena like vorticity, pion creation time and flow. This study brought independent information on the time scale for the creation of fast pions, which is significantly shorter than for slow pions produced at mid-rapidity. It is expected that the new data presented in this paper can constitute further experimental input to such phenomenological studies.

## 2. Analysis

Presently, new results have been obtained on the electromagnetic distortion of charged pion spectra for Ar+Sc collisions at beam momentum of 40 $A$ GeV/$c$. In view of the novel character of the analysis, dedicated cuts on collision events and particle tracks were applied. The experimental data have been obtained with a minimum bias trigger (T4). The experiment [4] consists of a set of five Time projection chambers (TPCs). Two TPCs, VTPC1 and VTPC2 are placed in a magnetic field. In the TPC system, both track reconstruction and particle identification are based on specific energy loss. Centrality selection was ensured based on the forward energy deposited in a hadronic calorimeter, the projectile Spectator Detector (PSD). In order to remove background events found in the data, a geometrical cut on the number of tracks versus the PSD energy deposit plane has been applied. Every event has been checked for its main vertex status, and only events with a number of vertex tracks greater than 4 were accepted in the analysis to further reduce the beam-induced background. This introduced a minimal bias on low multiplicity events in the study, with an expected negligible effect on the observed $\pi^+/\pi^-$ ratio. Additional studies show that after these cuts, the remaining beam-induced background remains below 1%. Ionization energy loss in the TPC system has been used to identify the particles via the $dE/dx$ method. Fig. 1 shows the ionization energy loss ("Bethe-Bloch") functions for identified particles such as $\pi^-$, $K^-$, $e^-$ and $p^-$. The pion candidates are isolated by using a $\pm$ 5% cut around the pion Bethe Bloch. Only pions with $x_F > 0.05$ have been considered for analysis in order to avoid contamination induced by Bethe

Bloch crossing, see Fig 1. This simple identification method can be readily used for the $\pi^+/\pi^-$ ratio studies (even if it would induce biases *e.g.* for rapidity distributions). For $\pi^+/\pi^-$ ratios, the biases mostly cancel out; the remaining biases can be estimated by simple methods.

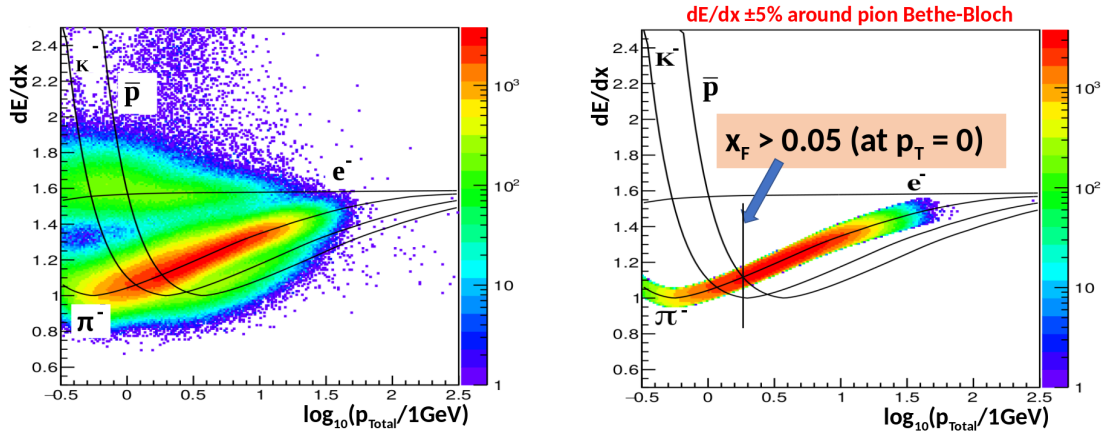


**Figure 1:** The ionization $dE/dx$ as a function of logarithm of total momentum. The plots are made for negative particles in TPC system for Ar+Sc collisions at 40 $A$ GeV/$c$, on the *left* all the particles registered, on the *right* pion candidates identified via the cut of ± 5% around the pion Bethe-Bloch.

## 3. Results and discussion

This paper deals with the electromagnetic effect on charged pion spectra and $\pi^+/\pi^-$ ratios. Earlier measurements of this phenomenon exist for Pb+Pb collisions at 158 $A$ GeV/$c$ beam momentum by the NA49 collaboration [5] and for Ar+Sc collisions at 150 $A$ GeV/$c$ by NA61/SHINE [2]. The information which EM effects bring on the space-time evolution of the system was described in Refs. [1, 6, 7].

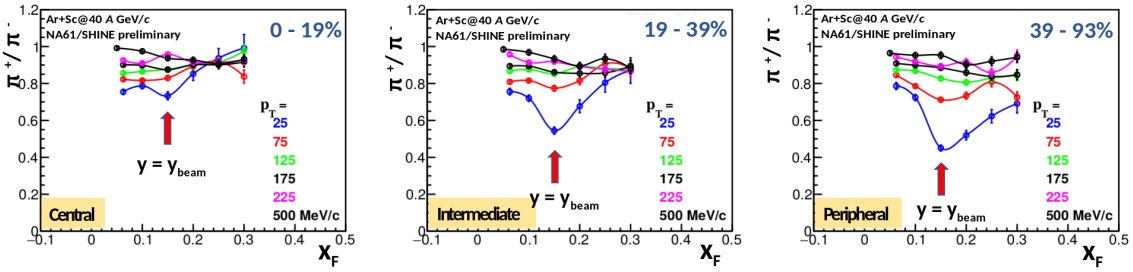


**Figure 2:** The $\pi^+/\pi^-$ ratio in three different centrality selected samples of Ar+Sc collisions at 40 $A$ GeV/$c$. The percentage of total cross-section is indicated in the right upper corner of each panel. As the percentage increases the centrality shifts to peripheral.

Fig. 2 shows the $\pi^+/\pi^-$ ratio plotted as a function of $x_F = \frac{p_L(pion)}{p_L(beam\ nucleon)}$ for three centrality selected samples of Ar+Sc collisions, for six different values of pion transverse momentum $p_T$. Both variables $(x_F, p_T)$ are given in the collision centre-of-mass reference system. A clear suppression of this ratio is visible at low $p_T$ of the pion. This effect slowly increases from central to peripheral

collisions as a consequence of the corresponding increase of spectator charge. The largest effect is observed at $x_F = 0.15 = m_\pi/m_p$, which corresponds to pions moving at same velocity as the spectator system ($y \approx y_{beam}$). The presented result is the first observation of the spectator induced EM effect in Ar+Sc reactions at 40 $A$ GeV/$c$, and the first observation of this effect in peripheral small systems at the CERN SPS. The EM distortion is strong enough to break isospin symmetry, meaning that the final state $\pi^+/\pi^-$ ratio is lower than the proton/neutron ratio in the initial system. This demonstrates, in a model-independent way, that the effect is caused by the EM interaction. As visible in Fig. 2 (left), a trace of EM effects is seen even in the most central 0-19% of the total cross-section. Thus, in a subsequent analysis all the centrality samples have been divided into two as shown in Fig. 3. Needless to say, the statistics is somewhat limiting but the detailed centrality dependence is clearly visible. Here in the most central i.e. 0-10% sample, no EM effect is seen.

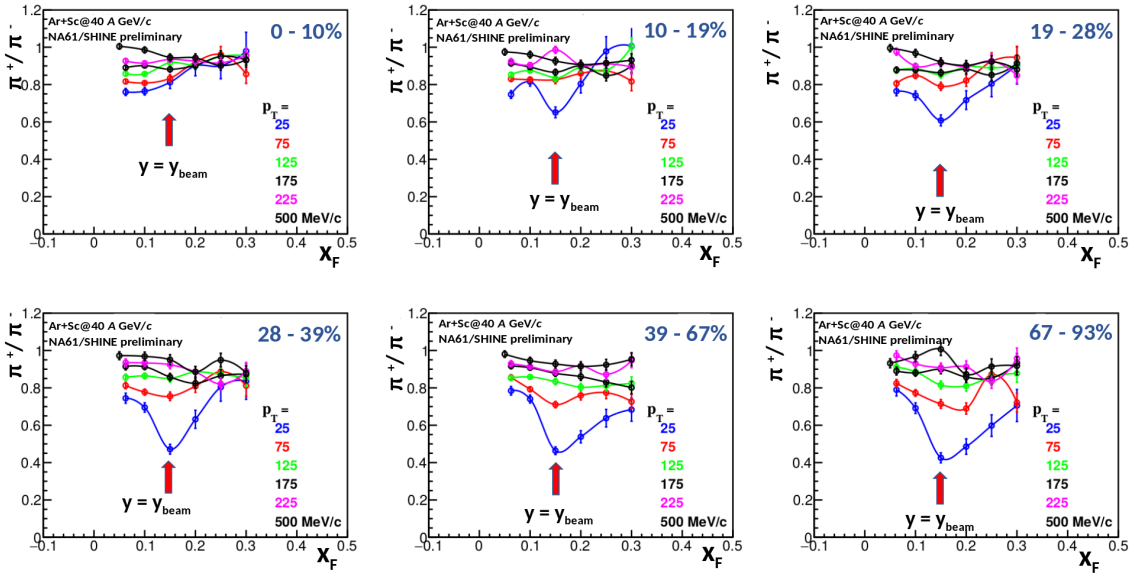


**Figure 3:** The $\pi^+/\pi^-$ ratio in six different centrality selected samples of Ar+Sc collisions at 40 $A$ GeV/$c$. The percentage of total cross-section is indicated in the right upper corner of each panel. As the percentage increases the centrality shifts to peripheral.

## 4. Summary and conclusions

First-ever data on the full centrality dependence of spectator induced electromagnetic effects on charged pion ratios in a small system at the CERN SPS, and a first analysis of a peripheral small system in NA61/SHINE have been presented. The experimental data show that the spectator induced EM effects are present in small systems despite the small spectator charge. A very slow centrality dependence has been discerned (EM effects remain visible for all the studied centrality samples apart from most central collisions). We expect that these new experimental data will boost the future phenomenological studies of the space-time evolution of the system from EM effects.

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## References

[1] Andrzej Rybicki and Antoni Szczurek. "The Spectator Electromagnetic Effect on Charged Pion Spectra in Peripheral Ultrarelativistic Heavy-Ion Collisions". In: *Phys. Rev.* C75 (2007), p. 054903. DOI: 10.1103/PhysRevC.75.054903. arXiv: nucl-th/0610036 [nucl-th].

[2] M Kiełbowicz. "Electromagnetic effect on charged pion spectra at SPS energies". In: *Acta Phys.Polon.Supp.* 12 (2019), p. 353. DOI: 10.5506/APhysPolBSupp.12.353.

[3] Andrzej Rybicki et al. "Electromagnetic effects on meson production: a new tool for studying the space-time evolution of heavy ion collisions". In: *EPJ Web of Conferences* 130 (July 2016). DOI: 10.1051/epjconf/201613005016.

[4] N. Abgrall et al. "NA61/SHINE facility at the CERN SPS: beams and detector system". In: *JINST* 9 (2014), P06005. DOI: 10.1088/1748-0221/9/06/P06005. arXiv: 1401.4699 [physics.ins-det].

[5] Andrzej Rybicki. "Strong and electromagnetic interactions at SPS energies". In: *PoS* EPS-HEP2009 (2009), p. 031. DOI: 10.22323/1.084.0031.

[6] Andrzej Rybicki and Antoni Szczurek. "Spectator induced electromagnetic effect on directed flow in heavy ion collisions". In: *Phys. Rev.* C87.5 (2013), p. 054909. DOI: 10.1103/PhysRevC.87.054909. arXiv: 1303.7354 [nucl-th].

[7] V. Ozvenchuk et al. "Spectator induced electromagnetic effects in heavy-ion collisions and space-time-momentum conditions for pion emission". In: *Phys. Rev. C* 102.1 (2020), p. 014901. DOI: 10.1103/PhysRevC.102.014901. arXiv: 1910.04544 [nucl-th].