At the borderline between exclusive and inclusive physics: Study of Drell-Yan fragments in the PANDA experiment (a preliminary simulation)

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Abstract. Here a preliminary study is presented concerning the detection of the normally unseen Drell-Yan fragments, possible in the PANDA experiment. To work as a multi-purpose apparatus, this experiment will record all the particles produced in the collisions between the antiproton beam and the target, with a rather wide acceptance. So detecting Drell-Yan dileptons with or without analyzing the other fragments is just a matter of applying cutoffs in the data analysis stage. The distribution of the products of 50000 typical Drell-Yan events is here simulated using a well-known generator code (Pythia-8). The resulting distributions are inserted within the PANDA acceptance region to analyze the chances of missing some searched fragment combinations, or of confusing different sets of particles. The most interesting result is that, due to the reduced phase space, the produced states are much simpler than one could imagine: i) almost 50% of the events just consist of a dilepton plus a nucleon-antinucleon pair; ii) practically all events present a nucleon-antinucleon pair; iii) the number of light particles (photons over an infrared cutoff and pions) is pretty small. The presented simulations show that it is possible to study experimentally some, or some aspects, of the most relevant final states, with good statistics and precision.

1 Introduction

The PANDA experiment [1] has a rather wide program, that includes electromagnetic and strong hard processes in collisions between antiproton beams and unpolarized nuclear targets (see ref. [2], or more synthetically ref. [3]). The center-of-mass energy will range from small values up to about $\sqrt{s} \approx 30$ GeV. Among the planned ones, measurements of Drell-Yan processes [4,5] will be performed in the highest part of the beam energy spectrum, with attention to both di-muon and di-electron production.

Drell-Yan is a very well-studied class of inclusive processes, but up to date very little information is available on the (normally undetected) fragments produced in association with the Drell-Yan lepton pair. What is available (essentially: charge multiplicity) was measured in collider experiments at very large center-of-mass energy (e.g. $\sqrt{s} \approx 50–100$ GeV).

No information on the non-leptonic fragments is available from fixed-target experiments. The point is that the really appealing aspect of a Drell-Yan measurement is that one needs not to care these particles, since one may build a relatively simple apparatus where a thick screen absorbs everything but muons, and muons are analyzed downstream with respect to the screens. So, only multi-purpose apparata may be suitable to analyze hadronic or electromagnetic fragments that accompany the dilepton production.

PANDA is a multi-purpose apparatus, with a very peculiar feature: its filters will be reduced to a minimum, so that at each collision all the following fragments will be detected (within the large experiment acceptance). The idea is to record everything, to later select different processes in the data analysis phase.

To understand what kind of phenomenology one could meet, I have performed some simulations, using the popular high-energy Montecarlo generator Pythia-8 [8]. Although this is not the energy regime for which this code has been optimized, some features determining the fragments are so universal (in particular in the PANDA case: the size of the available phase space) that the gross features of the predicted distributions should be reliable. And these features leave room for interesting perspectives.

1 The author of this work is the author of a Drell-Yan phenomenological generator code [9] that has been extensively used for preliminary studies of PANDA dilepton distributions [10–12]. Although this code is optimized on the conditions...
Here I have studied the class of Drell-Yan events where the dilepton mass and transverse momentum are $> 2 \text{GeV}/c^2$ and $> 0.8 \text{GeV}/c$, respectively. Below the mass $1.8 \text{GeV}/c^2$, the effect of the tails of the vector resonances is strong, and it may be ambiguous to associate dileptons to Drell-Yan events. We must remark that at increasing masses the event rates become increasingly suppressed, roughly as $1/M^2$. So, most of the Drell-Yan events considered here have a dilepton mass near $2 \text{GeV}/c^2$, and this will be the situation in PANDA (see refs. [10–12] for systematic studies of the expected dilepton distributions in PANDA).

The choice of the kinematics is dictated by the main goals of the Drell-Yan measurements in PANDA [2]. In present-day unpolarized Drell-Yan, the most interesting observables are those associated with azimuthal asymmetries ([13–15], see also [16] for a very general and systematic treatment of the cross-section structure). These become visible at transverse momenta of magnitude $1–2 \text{GeV}/c$, according with the previous measurements by refs. [17–21]. Taking into account that the Drell-Yan event rates will be peaked at transverse momenta $\approx 0.5–1 \text{GeV}/c$, an event with $q_T = 1 \text{GeV}/c$ will be the most common among the interesting ones [10].

Pythia does not include detailed features like azimuthal asymmetries. So what is simulated here is not exactly what we will see in the experiment, where it will be interesting, and new, to be able to study joint azimuthal distributions of the dilepton and of the fragments. But the Pythia-based analysis presented here may tell us which kind of fragment combinations it will make sense to analyze.

The most appealing result of the following simulations is that Drell-Yan is, in PANDA conditions, the inclusive production, including the lepton pair (so, by definition $N > 2$ here). The cutoffs on the dilepton mass and transverse momentum are $M > 2 \text{GeV}/c^2$, $q_T > 0.8 \text{GeV}/c$.

Table 1. Composition of the final state for the simulated set of 50000 events presented here. All these events are taken with cutoffs $M > 2 \text{GeV}/c^2$, $q_T > 0.8 \text{GeV}/c$, on the dilepton kinematics. From the 4th line (events with $p\bar{p}$ pair) “events with a . . .” means “events with a . . . at least”.

| Total number of events | 50000 |
|------------------------|-------|
| Events with no (anti)baryons | 179 |
| Events with 1NN pair | 49805 |
| Events with 2NN pairs | 16 |
| Events with a $p\bar{p}$ pair | 21765 |
| Events with an $n\bar{n}$ pair | 20078 |
| Events with a $p\bar{n}$ or $n\bar{p}$ pair | 7993 |
| Events with a $p$ | 25761 |
| Events with a $\bar{p}$ | 25754 |
| Events with an $n$ | 24068 |
| Events with a $\bar{n}$ | 24074 |

2 Drell-Yan fragments in PANDA: simulations

2.1 General features of the simulation

50000 Drell-Yan events have been here sorted using Pythia, according to what has been imagined as a reasonable kinematical setup for PANDA: antiproton beam energy $15 \text{GeV}$, at-rest target protons, dilepton minimum mass $2 \text{GeV}/c^2$ and dilepton minimum transverse momentum $0.8 \text{GeV}/c$.

For real photons in the final state, I have included a lower cutoff on the detection: $E_\gamma > 0.2 \text{GeV}$. The number of radiated photons with arbitrarily low energy is in principle infinite. So the particle multiplicities in the following must be understood as excluding “soft” photons.

Neutral pions do not appear directly in the final state. They are present via their offspring photons. So, in the following “pions” means “charged pions”.

of the PANDA case, it does not produce fragments, apart from the lepton-antilepton pair.

Fig. 1. Multiplicity of final particles in Drell-Yan dilepton production, including the lepton pair (so, by definition $N > 2$ here). The cutoffs on the dilepton mass and transverse momentum are $M > 2 \text{GeV}/c^2$, $q_T > 0.8 \text{GeV}/c$.

2.2 Fragment multiplicities

Figure 1 and tables 1, 2 and 3 are devoted to event multiplicities. They include the lepton-antilepton pair into the total event multiplicity. So, the lowest recorded event multiplicity is 4 (normally: lepton, antilepton, nucleon, antinucleon).

The most interesting found features are:

1) 99.7% of the events contain a nucleon-antinucleon pair.
2) Among these, the relative numbers of $p\bar{p}$, $n\bar{n}$ and mixed ($p\bar{n}$ or $n\bar{p}$) pairs are roughly $11 : 10 : 4$.
3) 43% of the events contain four particles only: a dilepton pair and an $NN$ pair (same flavor of course). The mixed $NN'$ pairs are normally accompanied by one charged pion.
4) Special interest have the $p\bar{p}$-only events, i.e. events where the dilepton is only accompanied by a $p\bar{p}$ pair. These are 10747, i.e. 49% of the total number 21765.