EUROPEAN LABORATORY FOR PARTICLE PHYSICS

Memorandum to
SPSC - SPS and PS Experiments Committee

Open Charm Measurements: Pb-beam schedule and detector upgrade

by the NA61/SHINE Collaboration at the CERN SPS

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Abstract

This memorandum presents requirements for successful measurements of open charm production in Pb+Pb collisions at the CERN SPS by NA61/SHINE. First, the required data statistics is summarized, and implications for the Pb beam schedule are discussed. Second, the status of the detector upgrade is presented, and readiness for data taking on the open charm production is discussed. The memorandum is motivated by COVID-19 related delays in data taking on open charm production and the restricted Pb-beam time foreseen in the preliminary beam schedule for 2022.

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1 Introduction

NA61/SHINE proposed to perform unique measurements of open charm production in Pb+Pb collisions at 150A GeV and 40A GeV/c [1,2]. The SPSC recommended the programme [3] and the Research Board approved the first data taking [4]. Results on spectra, centrality dependence and energy dependence will be provided. The measurements require high statistics and large acceptance data on Pb+Pb collisions. They can be recorded providing a sufficient Pb-beam time is allocated, and the NA61/SHINE detector is upgraded. The status of these requirements is summarized in this memorandum.

2 Required data statistics and Pb-beam time

(i) **The requested statistics of Pb+Pb collisions at 150A GeV/c is 500M events** (Ref. [1] page 31). As illustrated by Table 1 (from Ref. [1] page 32) the data should provide for D meson production rapidity and transverse momentum spectra for central collisions (tens of thousands reconstructed decays) and establish centrality dependence of mean D meson yield in the acceptance (thousands of reconstructed decays).
The requested statistics of Pb+Pb collisions at 40A GeV/c is 250M events (Ref. [1] page 31). It should result in thousands of reconstructed decays (Ref. [1] page 31) and allow the first measurement of the collision energy dependence of mean yield. Note that the above estimates are model-dependent and thus have rather large uncertainty.

(ii) The baseline scenario of the data taking presented in Ref. [1] (page 91) assumes that the mean duty cycle (the ratio of spill duration integrated over the data-taking time to the data-taking time) is 0.15. This is the mean duty cycle for the data taking on Xe+La collisions in 2017 and Pb+Pb collisions in 2018. It is also assumed that the data-taking rate after the detector upgrade is 800 Hz. With these assumptions, one estimates ([1] page 91) that **12 weeks are needed to record the data at 150A GeV/c and six weeks the data at 40A GeV/c**.

(iii) Assuming that Pb beam will be available in 2022, 2023, 2024 and 2025 the requested Pb-beam time for the open charm measurements can be scheduled as follows:

(a) 2022 - **two weeks** of data taking for open charm at 150A GeV/c (**four weeks are allocated**, but the first week has to be used for the beam and trigger setup as well as detector commissioning with Pb beam collisions, the last week will be used for data taking for cosmic-ray experiments)

(b) 2023 - **five weeks** of data taking for open charm at 150*A* GeV/*c*

(c) 2024 - **five weeks** of data taking for open charm at 150*A* GeV/*c*

(d) 2025 - **six weeks** of data taking for open charm at 40*A* GeV/*c*

	0–10%	10–20%	20–30%	30–60%	60–90%
$\#(D^0 + \overline{D^0})$	31k	20k	11k	13k	1.3k
$\#(D^+ + D^-)$	19k	12k	7k	8k	0.8k
$\langle W \rangle$	327	226	156	70	11

Figure 1: Expected number of reconstructed charm mesons in centrality selected Pb+Pb collisions at 150*A* GeV/*c* assuming 500M minimum bias events recorded, see Ref. [1] for detail. The mean number of wounded nucleons $\langle W \rangle$ calculated within the Wounded Nucleon Model is also given.

3 Readiness for data taking

Open charm measurements motivated a significant modification of the NA61/SHINE spectrometer, which was conducted in 2019-2021. In particular, the upgrade will lead to a tenfold increase of the data-taking rate to about 1 kHz and double the momentum-space coverage of the Vertex Detector.

Status of the upgrade. The upgrade of most of the detector's subsystems was finished in 2021. The upgrade of the remaining subsystems will be completed by the spring of 2022. The systems which are tested and commissioned are:

(i) The data acquisition system

(ii) The trigger system

(iii) The Main and Forward Projectile Spectator Detectors (MPSD and FPSD)

(iv) The Vertex- GAP- and Forward-TPCs

(v) The Forward Time-of-Flight detector (F-ToF)

Moreover, the hardware and software of the following systems were fully tested, and the hardware installation should be completed in spring 2022:

(i) The Vertex Detector.

(ii) The Beam Position Detectors (BPDs).

(iii) The Left Time-of-Flight detector (L-ToF).

The completion of the MTPC upgrade and production of all boards for the DRS-based readout depends on the delivery of the missing electronic components. These are connectors for the output adapters of MTPC readout and electronic components (amplifiers, voltage regulators, FPGAs) for the DRS-boards:

(i) We are missing connectors to equip ten MTPC sectors out of 50.

(ii) We are missing electronic components to produce 10 DRS-boards out of 115.

Due to COVID-related supply chain disruption, the delivery of the missing hardware was already delayed several times. Thus the current delivery dates are highly unsure.

Given the situation, we have two plans concerning the upgrade completion:

(i) the default plan, which assumes the hardware will be delivered on time.

(ii) the contingency plan, which assumes the hardware will not be delivered on time.

Both plans grant physics data-taking as requested in the NA61/SHINE 2022 beam request.

The default plan. The upgrade hardware installation will be fully completed in March 2022, and it will be commissioned with beam before the first data taking requested for late summer 2022.

The contingency plan. Ten MTPC sectors will not be ready for the data taking. The idle sectors will be located as shown in Fig. 2. In the idle sectors, the relative track number is low, and their momentum acceptance overlaps with the acceptance of VTPC1. Thus having no data from the idle sectors will impact only the dE/dx particle identification for a small fraction of tracks. The simulation shows that less than 1% of D^0 decay products have clusters in the idle sectors. Consequently, open charm physics will be insignificantly affected. There will

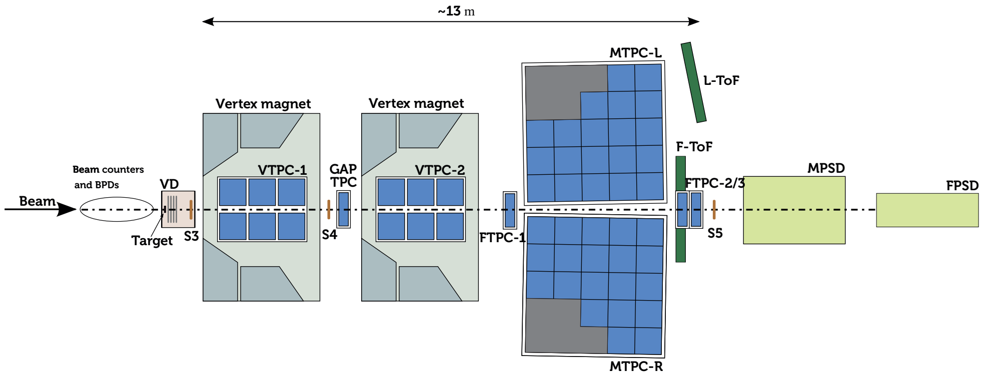

Figure 2: The contingency layout of the NA61/SHINE spectrometer with the idle MTPC sectors marked in grey.

be no effect on the measurements for the nuclear fragmentation program. Concerning measurements for neutrino physics, the simulation shows that the only non-negligible effects will be on measurements of Λ and K^0_S decays when decay products cross the idle sectors. To minimize this effect, an optimization is under study.

The DRS boards are needed to read out:

(i) The BPD detectors and beam counters - 43 boards are required.

(ii) The F-ToF detectors - 4 boards are required.

(iii) The MPSD and FPSD calorimeters - 14 boards are required.

(iv) The L-ToF detector - 54 boards are required.

Different configurations of detectors are used for data taking for open charm, neutrino physics and cosmic-ray physics planned for this year. They require different numbers of DRS boards. The BPD, L-ToF and PSD detectors will be used for the data taking for open charm. To fully read out these detectors, 111 DRS boards are required. The 150A GeV/c Pb beam is narrow, and thus only reduced BPD acceptance is needed. 32 boards can read it out. Then the total number of the required boards is 100, which is less than the available number of boards, 105. There is no need for the reconfiguration of the DRS boards for the data taking for neutrino and cosmic-ray physics, as for the complete readout of the used detectors only 57 and 47 DRS boards are needed, respectively.

In conclusion, even if the missing hardware is not delivered on time, the contingency plan allows for efficient data taking in 2022. Of course, both plans assume that experts and shifters will be able to travel to CERN to complete the upgrade, commission the detector in March-May 2022 and take data in summer and fall 2022. In particular, five weeks of proton beam at 31 GeV/c for data taking for T2K at J-PARC is planned for summer 2022. The replica target and its support are constructed in Japan. The default plan assumes that colleagues from Japan supervise the installation of the target and data taking. In case travel from Japan to CERN is not possible, two options are considered. The target installation and data taking will be supervised remotely, or the data taking for T2K will be swapped with the data taking for the FNAL experiments requested for 2023 (K^+ beam at 60 GeV/c) and 2024 (p beam at 120 GeV/c).

References

[1] A. Aduszkiewicz, [NA61/SHINE Collab.], “Study of Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS: Early Post-LS2 Measurements and Future Plans,” Tech. Rep. CERN-SPSC-2018-008. SPSC-P-330-ADD-10, CERN, Geneva, Mar, 2018. https://cds.cern.ch/record/2309890.

[2] A. Aduszkiewicz, [NA61/SHINE Collaboration Collab.], “Reply to the SPSC questions on Addendum CERN-SPSC-2018-008 entitled Study of Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS: Early Post-LS2 Measurements and Future Plans ,” Tech. Rep. CERN-SPSC-2018-019. SPSC-P-330-ADD-11, CERN, Geneva, Jun, 2018. http://cds.cern.ch/record/2621751.

[3] “Minutes of the 130th Meeting of the SPSC, Thursday and Friday, 7-8 June 2018,” Tech. Rep. CERN-SPSC-2018-020. SPSC-130, CERN, Geneva, Jun, 2018. http://cds.cern.ch/record/2622174.

[4] “Minutes of the 232nd meeting of the Research Board, held on 11 March 2020,” Tech. Rep. CERN-DG-RB-2020-495. M-232, CERN, Geneva, Mar, 2020. http://cds.cern.ch/record/2712812.