DEVELOPMENT OF FRAGMENTED LOW-Z ION BEAMS FOR THE NA61 EXPERIMENT AT THE CERN SPS

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Abstract

The NA61 experiment, aims to study the properties of the onset of deconfinement at low SPS energies and to find signatures of the critical point of strongly interacting matter. A broad range in T-μ_B phase diagram will be covered by performing an energy (13A-158A GeV/c) and system size (p+p, Be+Be, Ar+Ca, Xe+La) scan. In a first phase, fragmented ion beams of 7Be or 11C produced as secondaries with the same momentum per nucleon when the incident primary Pb-ion beam hits a thin Be target will be used. The H2 beam line that transports the beam to the experiment acts as a double spectrometer which combined with a new thin target (degrader) where fragments loose energy proportional to the square of their charge allows the separation of the wanted A/Z fragments. Thin scintillators and TOF measurement for the low energy points are used as particle identification devices. In this paper results from the first test of the fragmented ion beam done in 2010 will be presented showing that a pure Be beam can be obtained satisfying the needs of the experiment.

INTRODUCTION

The NA61/SHINE [1] is a new fixed-target experiment at the CERN SPS, based on the upgraded setup of the NA49 apparatus. The major physics goal of NA61 is the systematic measurement of hadron production in proton-proton, proton-nucleus, hadron-nucleus, and nucleus-nucleus collisions. This comprehensive study mainly concerns the following objectives: (1) search for the critical point by an energy - system size scan, (2) study the properties of the onset of deconfinement by the energy - system size scan, (3) establish, together with the RHIC results, the energy dependence of the nuclear modification factor.

In order to perform the necessary measurements primary beams of protons and of C, Si, and In ions were requested in the initial NA61 proposal in 2006 [2]. However due to hardware and manpower limitations, the necessity to use for NA61 the same primary ion in SPS as in the I-LHC program, implied that NA61 can initially run with low mass ion beams only in secondary beam mode by fragmenting the primary Pb ions. Dedicated running with primary low-Z ions (Ar, Xe) is still in the plans but require development of the ion source and hardware (RF) modifications in the accelerators, presently not possible before 2014.

In 2010 a 14-day long test of secondary light-ion beams produced by the fragmentation method was performed. Primary Pb ion beams of 13.9 and 80 GeV/c per nucleon were used to produce ^{7}Be and ^{11}C beams for the experiment. The method of producing these beams in the secondary beam line and the obtained performance results are discussed in the next sessions.

THE H2 BEAM LINE AS FRAGMENT SEPARATOR

Fragmented ion beams have been used in the past for tests in the H8 beam line [3], but the performance requirements for NA61, in particular the selection of a single isotope are much more challenging.

The layout of the H2 secondary beam line is shown in Figure 1. The extracted primary Pb^{82+} beam is focused

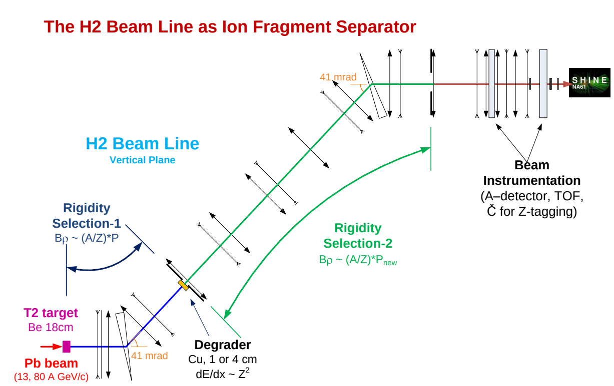

Figure 1: Schematic view of the vertical plany of the H2 beam line, relevant for the ion fragment separation.

onto the primary T2 target made of 180 mm of Be. During its passage through the target the Pb beam loses energy and undergoes inelastic collisions. The resulting fragments have a significant spread in momentum per nucleon mainly due to Fermi motion and to the energy loss in the target (of the primary lead beam and the secondary fragments). The fragments emitted in the solid angle given by the geometrical acceptance of the H2 beam line are transported up to the first vertical spectrometer which does a rigidity

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selection: $B\rho \sim (A/Z)_w \, P_{w-init}$, where A and Z correspond to the atomic number and charge of the wanted ion and P_{w-init} is the mean value of its momentum after traversing the primary Be target. Along with the *w-ions*, the beam line will transport all other ions with $(A/Z) \, P_{init}$ within the $\pm 1.5\%$ rigidity window around the value of $(A/Z)_w \, P_{w-init}$. After passing through a degrader (1 or 4 cm long Cu plate), in which they lose energy in proportion to the square of their electric charge, the fragments enter the second spectrometer. This spectrometer is set to a value of $B\rho \sim (A/Z)_w \, P_{w-new}$ such to bring the *w-ions* on axis taking into account their energy loss at the degrader. Other ions, depending on their charge, will be shifted off-axis. Therefore by choosing the settings of a collimator in the beam line the transmission of the *w-ions* towards the experiment can be optimized.

The ion beam is monitored at different locations using profile monitors and thin scintillator counters that are sensitive to the charge (Z) of the ions - their signal is proportional to Z^2. Special scintillator counters placed 140 m apart in the line could achieve a time resolution of about 100 ps thus provide via for time-of-flight measurement the mass (A) determination of the ions, but only for the low energies (¡20A GeV/c).

BEAM PERFORMANCE

The tests with the secondary light ion beam took place from November 22 to December 6,2010. Due to large schedule conflicts with LHC running ion beams for first time the foreseen test program was drastically reduced. In particular a large part of the foreseen tests of the beam extraction and optimization including the focusing at the primary targets was reduced to minimum to allow time for the tuning of the H2 beam line and the secondary ions.

The primary ion beam

Tests of different injection schemes and debunching were performed. In particular, cycles with nine and one injections into the SPS were used, see Fig. 2. Each injec-

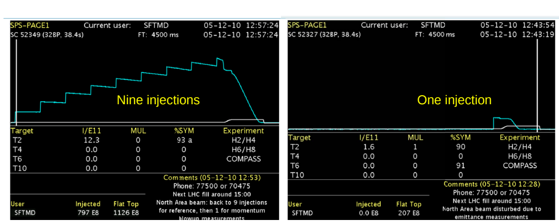

Figure 2: Screen shots of the SPS Page 1 illustrating an SPS cycle with nine ($left$) and one ($right$) injections of Pb ions at 13.9A GeV/c.

tion yields a single batch of about $3{\cdot}10^8$ ions consisting of four bunches spaced by 100 nsec. Injections are separated by 1 μs, thus the nine injections fill 8 $\mu s$of the machine leaving the remaining 14.7 $\mu s$of a single revolution empty. This strongly bunched scheme is rather crucial for the operation of the experiment as it may result in an irreducible double particle background in the detector. For an intensity of $2 \cdot 10^5$ ions/sec at the experiment, about 25% of the interesting triggers have a second off-time particle within ± 1 μswindow that need to be rejected. We hope to reduce this effect in 2011 with optimized filling of SPS and better debunching using the RF system.

The H2 secondary beam

Most of the tests were done with a 13.9A GeV/c primary ion beam, to profit from the additional ioin tagging possibility using the time-of-life detectors. With the two spectrometers of the H2 beam line set to select ^{11}C fragments and using a 4 cm long Cu degrader Fig 3 shows the Z^2 spectra of the beam passing through the spectrometer collimator set to full opening (-10, +10) mm. The peaks cor-

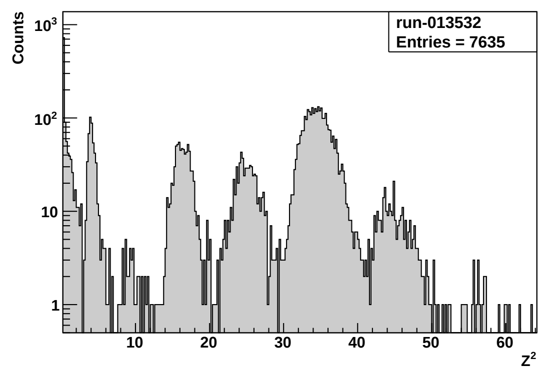

Figure 3: The Z^2 spectra of secondary light ions resulting from fragmentation of the primary Pb beam at 13.9A GeV/c. The results for the slit of the spectrometer collimator opened to (-10, +10) mm.

responding to beryllium ($Z^2 \approx 16$) and carbon ($Z^2 \approx 36$) are clearly visible. Moving the collimator slit off-center to let go through particles with lower(higher) rigidity values we can select different ion fragments as shown in Fig. 4. The obtained purity of the wanted ions (^{11}C in this example is just above 15%. Using a 1 cm thick degrader, thus less ion losses (12% intensity gain) the purity increases to about 20% with beam flux of $0.3 \cdot 10^4$ ions/sec. This result validates the method of fragment separation thanks to the capacity of the H2 beam line with the two very fine spectrometers.

For the 13.9A GeV/c beam, a further study on the isotope composition was possible using the TOF information. The TOF spectra for the C and Be peaks are showin in Fig. 5. The carbon peak is found to consist of ≈70% ^{11}C and ≈30% ^{12}C , whereas only ^{7}Be is seen in the beryllium peak. This is because ^{5}Be and ^{8}Be isotopes are short-lived, $4.2 \cdot 10^{-17}$ sec and $2.5 \cdot 10^{-15}$ sec respectively, thus do not reach the NA61 detector. This important result shows that by carefully selecting the beam rigidity for a A/Z com-

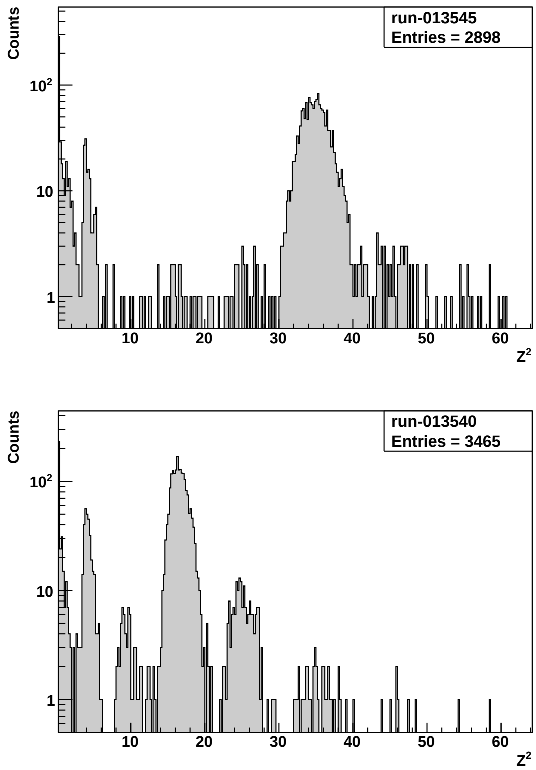

Figure 4: Same Z^2 spectra as in Fig. 3 but with the slit of the spectrometer collimator opened to (-5, -3) mm top and (+8, +12) mm bottom.

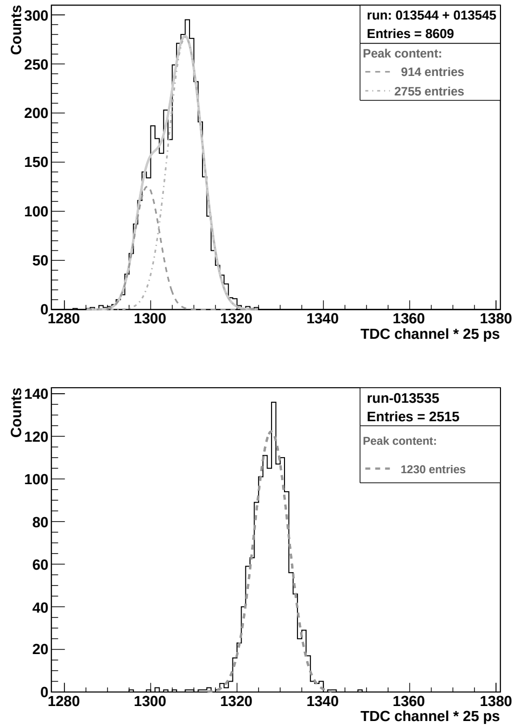

Figure 5: The tof spectra of ions for the carbon (top) and beryllium ($bottom$) peaks resulting from fragmentation of the primary Pb beam at 13.9A GeV/c. The spectrum of carbon is fitted by a sum of two Gauss functions, whereas that of beryllium by a single Gaussian.

bination, single isotope beams can be delivered to experiments. For higher energies where the TOF information won't be available, the tuning of the H2 beam line spectrometers will be based on the Z^2 spectra information as calibrated in the low energies. A full FLUKA simulation of the beam line is available and will be used to find the starting value for spectrometers corresponding taking into accound the energy loss at the primary target and degrader. Further tuning will be required to optimize the ion flux based on the Z^2 spectra. A short test at 80A GeV/c primary was also done with similar performance.

SUMMARY AND OUTLOOK

The results of the 14-day long test of secondary light ion beams performed at the H2 beam line of the CERN SPS in November/December 2010 are presented. The test During the test a fragment separator technique was successfully used to produce secondary light ion beams (highest momentum 80A GeV/c so far), confirming previous results in the H8 beam line and demonsrated the capability of the SPS secondary beams, and H2 in particular, to produce and deliver ion fragments to experiments. Also, for the first time a primary Pb beam of 13.9A GeV/c was accelerated in the SPS. The results indicate that the secondary beam properties are sufficient to reach the basic physics goals of NA61. Further improvements necessary to reach and monitor the required performance for NA61 physics operation were identified and will be implemented for the 2011 run. They include: an optimization of the SPS cycle, the beam extraction and focusing on the T2 target, and improvement on the beam instrumentation for faster feedback during beam tuning. Physics performance with ^{7}Be and ^{11}C beams were found equivalent. Comparing the intensity and purity of both beams we come to the conclusion that the beryllium beam is preferred for the 2011 physics run once be verified at other energies.

ACKNOWLEDGMENTS

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