EUROPEAN LABORATORY FOR PARTICLE PHYSICS

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Addendum 4 to the proposal P330

Proposal for secondary ion beams and update of data taking schedule for 2009-2013

By the NA61 Collaboration
`http://na61.web.cern.ch`

Abstract

This document presents the proposal for secondary ion beams and the updated data taking schedule of the NA61 Collaboration. The modification of the original NA61 plans is necessary in order to reach compatibility between the current I-LHC and NA61 schedules. It assumes delivery of primary proton beam in 2009–2012 and of primary lead beam in 2011–2013. The primary lead beam will be fragmented into a secondary beam of lighter ions. The modified H2 beam line will serve as a fragment separator to produce the light ion species for NA61 data taking. The expected physics performance of the NA61 experiment with secondary ion beams will be sufficient to reach the primary NA61 physics goals.

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1 Introduction

The physics program of the NA61/SHINE (SHINE ≡ SPS Heavy Ion and Neutrino Experiment) experiment at the CERN SPS [1] consists of three main subjects:

- measurements of hadron production in hadron-nucleus interactions needed for neutrino (T2K) and cosmic-ray (Pierre Auger Observatory and KASCADE) experiments,
- measurements of hadron production in proton-proton and proton-nucleus interactions needed as reference data for a better understanding of nucleus-nucleus reactions,
- measurement of the energy dependence of hadron production properties nucleus-nucleus collisions as well as in p+p and p+Pb interactions, with the aim to identify the properties of the onset of deconfinement and find evidence for the critical point of strongly interacting matter.

In order to perform the necessary measurements primary beams of protons and of C, Si, and In ions were requested in the NA61 proposal [1]. Data taking with proton and pion beams as well as the first run with sulphur beam were already recommended by the SPSC in its session of June 27, 2007. Based on the I-LHC schedule at the time of the NA61 proposal submission data taking with ion beams was requested for 2009, 2010 and 2011 [2]. However, compatibility with the present I-LHC schedule now requires a modification of the original NA61 beam request. An adapted data taking schedule for NA61 was discussed and agreed upon with representatives of the CERN AB department in April 2008. This addendum complies with the agreed schedule in which Pb ion beam can be delivered to NA61 starting in 2011. However, as a result of the recent LHC incident, modifications to the present schedule may occur most likely to be known after the scheduled LHC Chamonix meeting in February 2009. NA61 will use the same type of primary ions in the SPS as prepared for I-LHC running. Proton beam can be delivered to NA61 in every year of the period 2009-2013.

The necessity to use the same primary ions in the SPS and the I-LHC implies that NA61 can initially run with low mass ion beams only by fragmenting the primary Pb ions. Therefore NA61 proposes to modify the H2 beam line such that it can be used as a fragment separator. The physics performance expected with the secondary ion beams will be shown to be sufficient to reach the principal NA61 physics goals.

This document is organized as follows. The status of the NA61 experiment is reviewed in Section 2. A summary of discussions with the AB department concerning SPS ion fixed target operation is given in Section 3. Requirements on the ion beams for NA61 are presented in Section 4. The modifications of the H2 beam line needed for the production of secondary ion beams and the performance of the modified beam line and the NA61 facility are described in Section 5. The status of the complementary experimental programs at BNL RHIC, FAIR SIS-300 and JINR NICA is discussed in Section 6. Finally, the updated data taking schedule is presented in Section 7 and Section 8 summarizes the document.

Sections 3 and 5 have been prepared in close collaboration with Ilias Efthymiopoulos and Stephan Maury from CERN.

2 Status of the experiment

This section summarizes the status of the NA61 project.

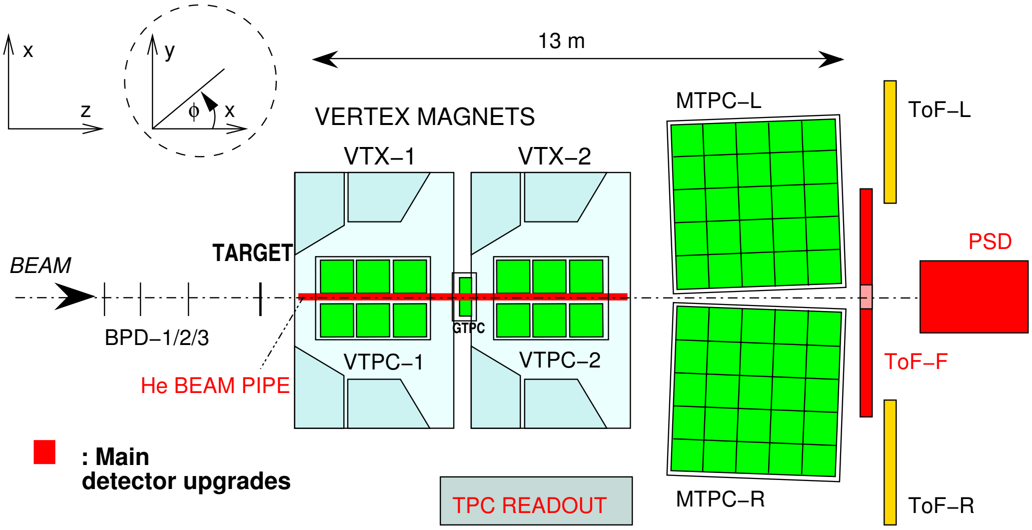

Figure 1: The layout of the NA61/SHINE set-up (top view, not to scale) with the basic upgrades indicated in red.

The NA61/SHINE experiment is a large acceptance hadron spectrometer at the CERN-SPS for the study of the hadronic final states produced in interactions of various beam particles (π, p, C, S and In) with a variety of fixed targets at the SPS energies. The layout of the NA61/SHINE set-up is shown in Fig. 1. The main components of the current detector were constructed and used by the NA49 experiment [3]. The main tracking devices are four large volume Time Projection Chambers (TPCs), see Fig. 1, which are capable of detecting up to 70% of all charged particles created in the reactions studied. Two of them, the vertex TPCs (VTPC-1 and VTPC-2), are located in the magnetic field of two super-conducting dipole magnets (maximum bending power of 9 Tm) and two others (MTPC-L and MTPC-R) are positioned downstream of the magnets symmetrically with respect to the beam line. One additional small TPC, the so-called gap TPC (GTPC), is installed on the beam axis between the vertex TPCs. The setup is supplemented by time of flight detector arrays two of which (ToF-L/R) were inherited from NA49 and can provide a time measurement resolution of $\sigma_{tof} \approx 60$ ps.

For the 2007 run a new forward time of flight detector (ToF-F) was constructed in order to extend the acceptance of the NA61/SHINE set-up for pion and kaon identification as required for the T2K measurements. The ToF-F wall is installed downstream of the MTPC-L and MTPC-R (see Fig. 1), closing the gap between the ToF-R and ToF-L walls.

Furthermore, numerous small modifications and upgrades of the NA61/SHINE facility were performed before the 2007 run. They include:

- speed-up of the ToF-L/R readout,
- modification of the DAQ system to allow writing data on disk,
- refurbishment of the Beam Position Detectors (BPD-1/2/3 in Fig. 1),

- preparation of the targets and target holders and
- preparation and installation of new beam counters for a new trigger logic.

Two carbon (isotropic graphite) targets were used during the 2007 run:

- a 2 cm-long target (about 4% of a nuclear interaction length, λ_{I}) with density $\rho = 1.84$ g/cm^3, the so-called thin target,
- a 90 cm long cylinder of 2.6 cm diameter (about 1.9 λ_{I}), the so-called T2K replica target with density $\rho = 1.83$ g/cm^3.

Proton beam particles are identified and selected by means of CEDAR-West and threshold Cerenkov counters as well as several scintillation counters. The trajectory of beam particles is precisely measured by the BPDs. These detectors consist of pairs of proportional chambers and are positioned along the beam line.

Interactions in the target were selected by an anti-coincidence of the incoming beam particle with a small scintillation counter (S4) placed on the beam axis between the two vertex magnets.

Two detector prototypes were constructed and tested during the 2007 run, namely:

- one super-module of the Projectile Spectator Detector (PSD) [4] and
- the front-end electronics tester needed for the development of the new TPC readout electronics.

As documented in [5] the main goals of the 2007 NA61/SHINE run were reached, namely:

- the NA61/SHINE apparatus, including the new ToF-F system, was run successfully and detector prototypes were installed and tested,
- pilot physics data on interactions of 31 GeV/c protons on the thin and T2K replica carbon targets were registered,
- the NA61 reconstruction and simulation software was set up and used successfully to process the events from the pilot run,
- calibrations of all detector components were performed successfully and preliminary uncorrected identified particle spectra have been obtained,
- high quality of track reconstruction and particle identification similar to NA49 was achieved,
- the data as well as new detailed simulations confirmed that the NA61 detector acceptance and particle identification capabilities cover the phase space required by the T2K experiment; the new ToF-F system significantly extends the NA49 PID acceptance in the domain relevant for the T2K measurements.

A major step forward - the TPC readout and DAQ upgrade - was achieved for the 2008 run. During the run the upgrade was tested. It results in an increase of the data rate by a factor of about 10 compared to the NA49 rate. The 2008 run was cut short due to the LHC incident.

3 SPS ion fixed target operation and I-LHC

A summary of discussions between representatives of the AB department and NA61 concerning a schedule of the NA61 ion runs is presented below. The schedule was prepared in April 2008 before the LHC incident 2008, once the LHC start-up will be known the schedule will be reviewed, and a shift of one year is not excluded. However, the sequence of events for the production of the requested ion beams most likely will remain unchanged.

I-LHC and SPS Ion Fixed Target Operation

Marek Gazdzicki (NA61), Stephan Maury (CERN)
April 2008

After discussions of representatives of the NA61 experiment with CERN AB, it was agreed that:

1. NA61 will use the same type of ion as ALICE and for the choice of the light ion species a discussion between all users is necessary,
2. The first year of NA61 Physics with Pb ions cannot take place before 2011,
3. For heavy ion extraction for NA61, an additional SPS ion cycle and new hardware will be needed. The commissioning could take place in 2010,
4. NA61 should go through the SPSC with a new proposal for lead ions physics or secondary ions resulting from the primary Pb ion beam fragmentation.
5. For preparing the p-Pb collisions in the LHC (2012?) studies should start at least 2 years before. For the light ion species studies one or two years are needed.

Preliminary calendar: As NA61 will use the same ion species as ALICE, this calendar is strongly LHC Physics dependent.

2009: - Complete the SPS commissioning with Pb ions for the LHC,
- Commissioning of the LHC with Pb ions,
- LHC Physics run with Pb ions, early beam,
- Nominal Pb ion beam studies for the LHC.

A total of 29 weeks is necessary. The number of necessary weeks for each process is the same as presented in the ABMB seminar on 1/10/2007 in slides on "Compatibility between NA61 and I-LHC".

2010: - LHC Physics run with Pb ion beam (early/intermediate beam),
- p-Pb studies for the LHC (on paper or in the injectors),
- Hardware commissioning of SPS for NA61.

A total of 18 weeks is necessary.

2011: - Light ion1 studies (source),

- LHC Physics run with Pb ion intermediate/nominal beam,
NA61 Physics run with Pb ion beam or secondary ion beams and
- Commissioning of p-Pb in the injectors.

A total of 29 weeks is necessary.

2012: - Commissioning of light ion1 in the injectors,
- LHC Physics run with p-Pb collisions,
- NA61 Physics run with Pb or secondary ion beam.

A total of 31 weeks is necessary.

2013: - Light ion2 studies (source),
- LHC Physics and NA61 Physics run with light ion1 beam.

A total of 29 weeks is necessary.

2014: - Commissioning of the injectors with light ion2 beam
- LHC Physics and NA61 Physics run with light ion2 beam

A total of 31 weeks is necessary.

Conclusion:

1. The ion injector chain will be very busy in operation from April to December during the coming years,

2. Resources are needed (money, manpower and operations team),

3. Solutions to all the modifications in the SPS (cycle, North Area) should be found for the year 2010.

4 Requirements on a secondary ion beam for NA61

The NA61 physics program requires low and intermediate mass ion beams. However, only Pb beams will be available from the SPS for some years starting in 2011. Thus the use of a secondary ion beam derived from the fragmentation products of primary Pb ions is proposed. The NA61 detector and the physics goals impose several requirements on the secondary ion beam at the NA61 target. These are summarized in this section.

In the following all Pb fragments accepted and transported by the secondary ion beam line to the NA61 detector are denoted as *all-ions*. These consists of fragments with a range of charges and masses. The NA61 trigger selects ions with the desired charge Z (denoted as *t-ions*). These *t-ions* still consist of a fragment mixture with different nuclear mass numbers. In the case of the primary beam *t-ions* are equal to *w-ions*. Operating the beam line with suitable parameters ensures that ions with the wanted mass number A (denoted as *w-ions*) are the dominant component of *t-ions*.

1. **Beam intensity and purity.**
   The maximum read-out rate of the upgraded NA61 detector is 80 Hz. In order to reach a read-out rate of about 40 Hz the trigger rate should be about 80 Hz. Assuming typical values for the target thickness corresponding to 1.5% inelastic interaction probability and an on-line centrality selection of the 20% most central of all inelastic interactions one gets for the recommeded *t-ion* intensity during the spill:

$$I(t\text{-}ions) \geq 3 \cdot 10^4 \text{ ions/sec} .$$

The maximum beam particle flux (*all-ions*) is constrained by the time-resolution and maximum readout rate of the PSD and Z detectors:

$$I(\textit{all-ions}) \leq 2 \cdot 10^5 \text{ ions/sec} .$$

Thus, the fraction of *t-ions* in the *all-ion* beam should be larger than 15%.

2. **Beam size and divergence.**
The active area of the current Beam Position Detectors is 4.8x4.8 cm^2. The Helium beam pipe to be installed in the Vertex TPCs has a radius of 2.3 cm. The secondary ion beam should be well inside the BPDs and the He beam pipe which is satisfied when:

$$\sigma(\textit{all-ions}) \leq 1 \text{ cm} .$$

The upper limits for the secondary ion beam divergence follows from the requirement that the beam is well contained inside the He beam pipe at its downstream end (about 700 cm from the NA61 target) and the BPD-1 counter at its upstream end (about 3100 cm from the NA61 target). The limits are:

$$\text{div}_\text{x}(\textit{all-ions}) \leq 0.3 \text{ mrad}$$

and

$$\text{div}_\text{y}(\textit{all-ions}) \leq 0.3 \text{ mrad} .$$

5 Secondary ion beams in the H2 beam line

After it became clear that no light ions will be accelerated in the SPS and delivered to fixed target experiments before 2013, the NA61 collaboration decided to investigate the possibility to use light ion beams resulting from primary lead ions hitting a suitable target in the primary target area of the H2 beam line. This study was motivated by the successful use of Si- and C-ion beams in the NA49 experiment [3] and by beam tests investigating high energy secondary beams of ion fragments for instrumental tests (e.g. AMS) at CERN [6].

5.1 The fragment separator principle

The principle of heavy beam fragmentation and subsequent separation has been extensively employed in the past to produce exotic Isotope beams for nuclear reaction studies both at low as well as at intermediate energy facilities. The primary ions interact with a relatively thick target of a few interaction lengths. The distribution of fragment multiplicity in charge and mass is to a large extent independent of the incident ion energy. This universality of multi-fragmentation has been well established at BEVALAC/SIS energies [7]. It is also valid at SPS energies as demonstrated in Fig. 2 where Aladin [9] and SPS data [6] are compared. The mean velocity of the fragments which leave the target is close to the velocity of the original ion. However, the momenta of the fragments are smeared in angle and absolute value due to Fermi motion. A high resolution (SPS) beam line will transport all fragments with a chosen rigidity P/Z or $B \cdot \rho$ within a range of about ±1%. The final momentum range transmitted

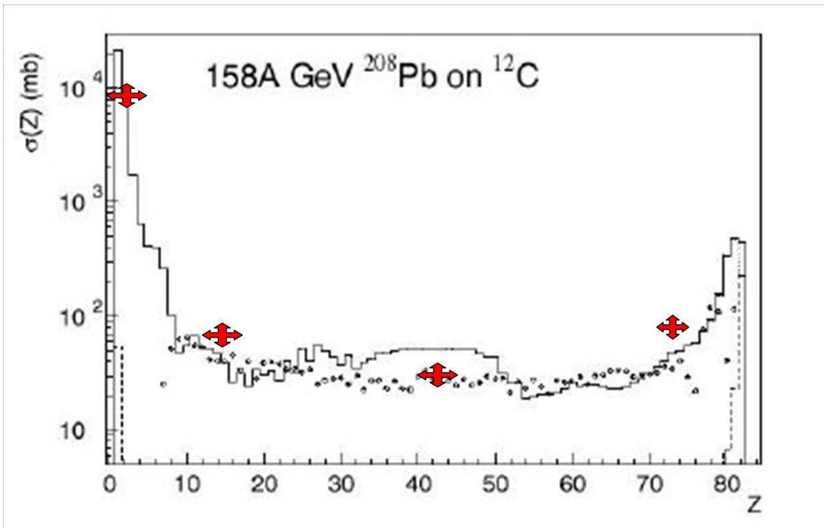

Figure 2: Fragment production cross section as function of charge Z in Pb+C at 0.6A GeV [9] (red symbols), in Pb+C collisions at 158A GeV [6] (small symbols), and the theoretical prediction for the latter results from [10] (histogram).

to the experiment can be significantly narrowed by closing the collimators at the focal points. The resulting beam will consist of a variety of nuclei in addition to the nuclei wanted in the experiment, all having velocities similar to the one of the incoming Pb ions, but various charges Z and total momenta P according to their mass numbers A. The ratio of the wanted to background ions in the ^{32}S region is of the order of 0.05. An additional separation of the fragments with originally equal rigidity can be achieved by passing the beam at an intermediate focus through matter (degrader). The resulting energy loss of the fragments depends on their charge Z. A second rigidity selection after the degrader will separate fragments with different Z. This principle of charge separation is in use at various nuclear reactions facilities, e.g. at the FRagment Separator (FRS) at GSI, Darmstadt. The schematics of the fragment separator is shown in Fig. 3.

5.2 Fragment separation in the H2 beam line

In the following we show the performance of the H2 beam line in selecting ^{32}P (the desired *w-ions*) from the fragmentation products of a Pb-beam impinging on a carbon target. We used the beam transport and interaction code "MOCADI" (thanks to H. Weick and H. Geissel, GSI, Darmstadt) to generate and propagate all fragments produced in Pb interactions in a 8.5 g/cm^2 ^{12}C target. In MOCADI the production cross sections of the fragments are computed according to the EPAX2 parameterizations [8]. The beam line simulation includes all active and passive elements except for some gap sizes of bending magnets. The energy of the incident ^{208}Pb beam was set to 47.6A GeV corresponding to a rigidity P/Z = 120.7 GeV/c. The secondary beam line was tuned to rigidity 101.5 GeV/c assuring that ^{32}P ions (Z=15) with the same velocity as the incident Pb ions are transported. Fig. 4 shows the yields per incident Pb ion after the target of those fragments which are accepted by the beam line. Note that the simulation of

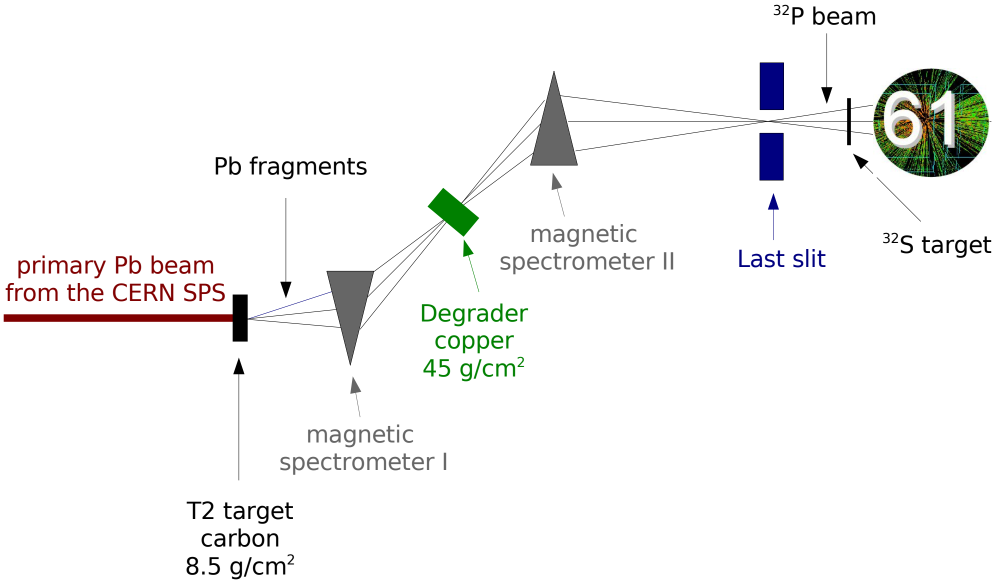

Figure 3: Schematics of the proposed fragment separator in H2 beam line (side view, not to scale). As an example selected trajectories of ^{32}P fragments are indicated by thin solid lines, for further details see text.

fragments was restricted to the ranges Z=12-18 and A=21-40 which are sufficient to populate the phase space transmitted through the last slit. The yields are histogrammed as functions of mass (left) and charge (right). Multiplying the corresponding yields with the total reaction cross section (3.3 barns) yields apparent production cross sections which are approximately a factor of two smaller than those given in Fig. 2. This is due to re-interactions of the produced fragments in the production target.

The main and essential components of the beam line (see Fig. 3) are the first vertical bending (up) section which acts as rigidity (P/Z) filter, the degrader at the first focus, the second bending (down) section which separates different charge states due to the Z-dependent energy loss in the degrader, and the last slit which selects the wanted ions. Fragments with rigidity 101.5 GeV/c ±1.5% pass the first vertical bending section up to the first focus where the degrader, a copper plate of 45 g/cm^2 thickness, is positioned. In it the Z=15 fragments lose approximately 1% more energy than Z=14 fragments. This differentiation occurs at the expense of removing of the order of 80% of all ions from the beam phase space due to nuclear or electromagnetic interactions. Note that the electromagnetic dissociation cross section was not (yet) implemented in the beam simulation. The second vertical bending section will transport a large fraction of the remaining ions. The mass and charge distributions at the next focal plane in front of the last slit are shown in Fig. 4 (bottom panels). The yield suppression by a factor of roughly 100 compared to the yields in Fig. 4 (top panels) is due to the large losses in the degrader. Due to the energy loss in the degrader the position distributions of the Z=14, 15, 16 fragments will be (vertically) displaced resulting in separations roughly equal to the dispersion σ of the position distribution of fragments with a fixed charge Z. This is illustrated

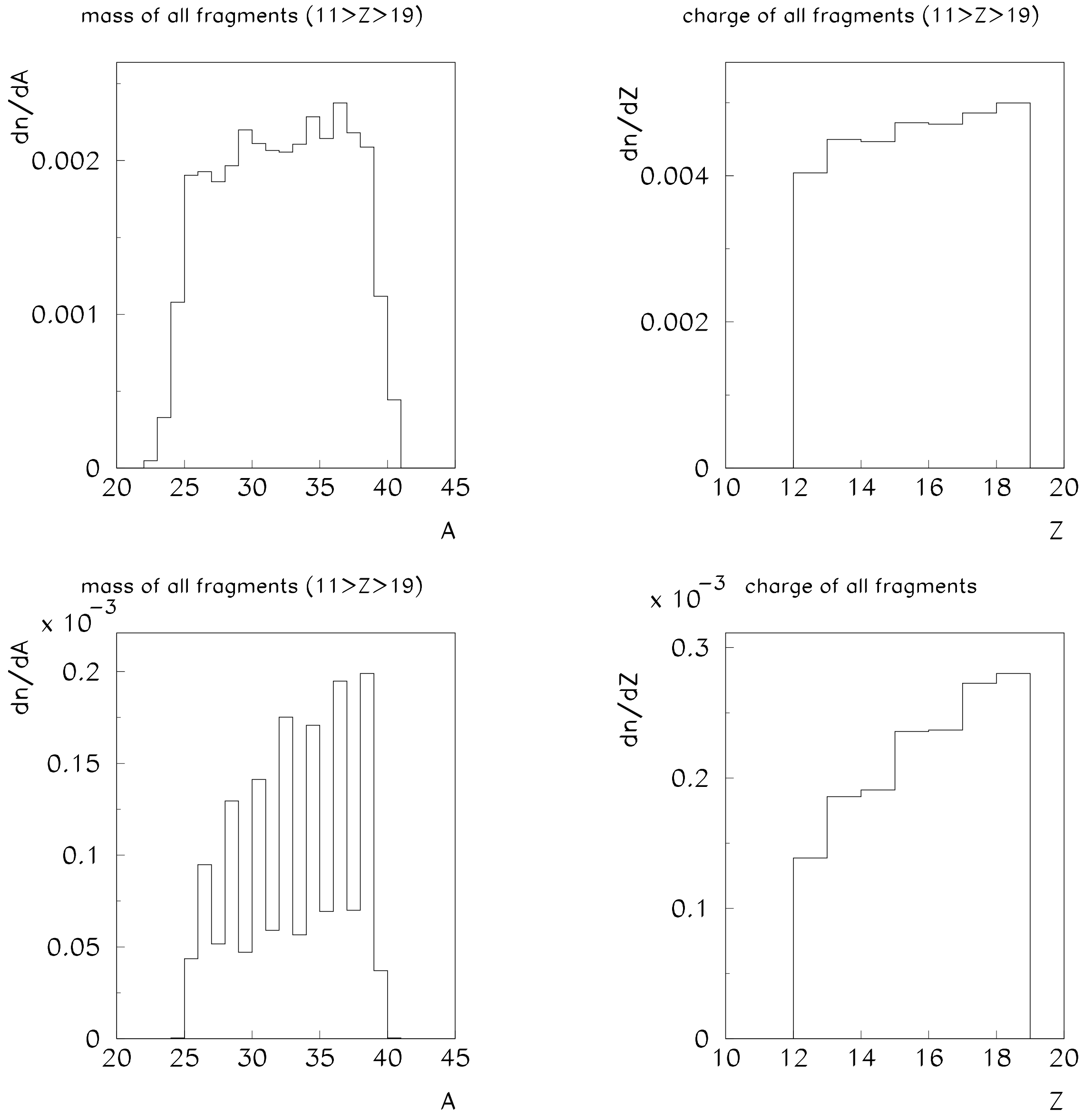

Figure 4: Top panels: Produced fragments in Pb+C collisions at 47.6A GeV as function of fragment mass number A (left) and of fragment charge Z (right). Bottom panels: Transmitted fragments in Pb+C collisions at 47.6A GeV nucleon as function of fragment mass number A (left) and of fragment charge Z (right) before the last collimator.

in Fig. 5 which shows distributions of the positions of the transported beam particles in the focal plane (and bending-direction) for all fragments (panel top left), for Z=15 fragments (panel top right), for Z=16 fragments (panel bottom left), and for Z=14 fragments (panel bottom right). Without degrader the distributions would have the same mean for all charges. With degrader they are displaced by about 2.3 mm per charge unit. The dispersion σ of the distribution for each charge is about 2.5 mm. The opening and vertical position of a horizontal slit in the focal plane can thus be used to optimize the ratio of *w-ions* to *all-ions*. With the slit width set to

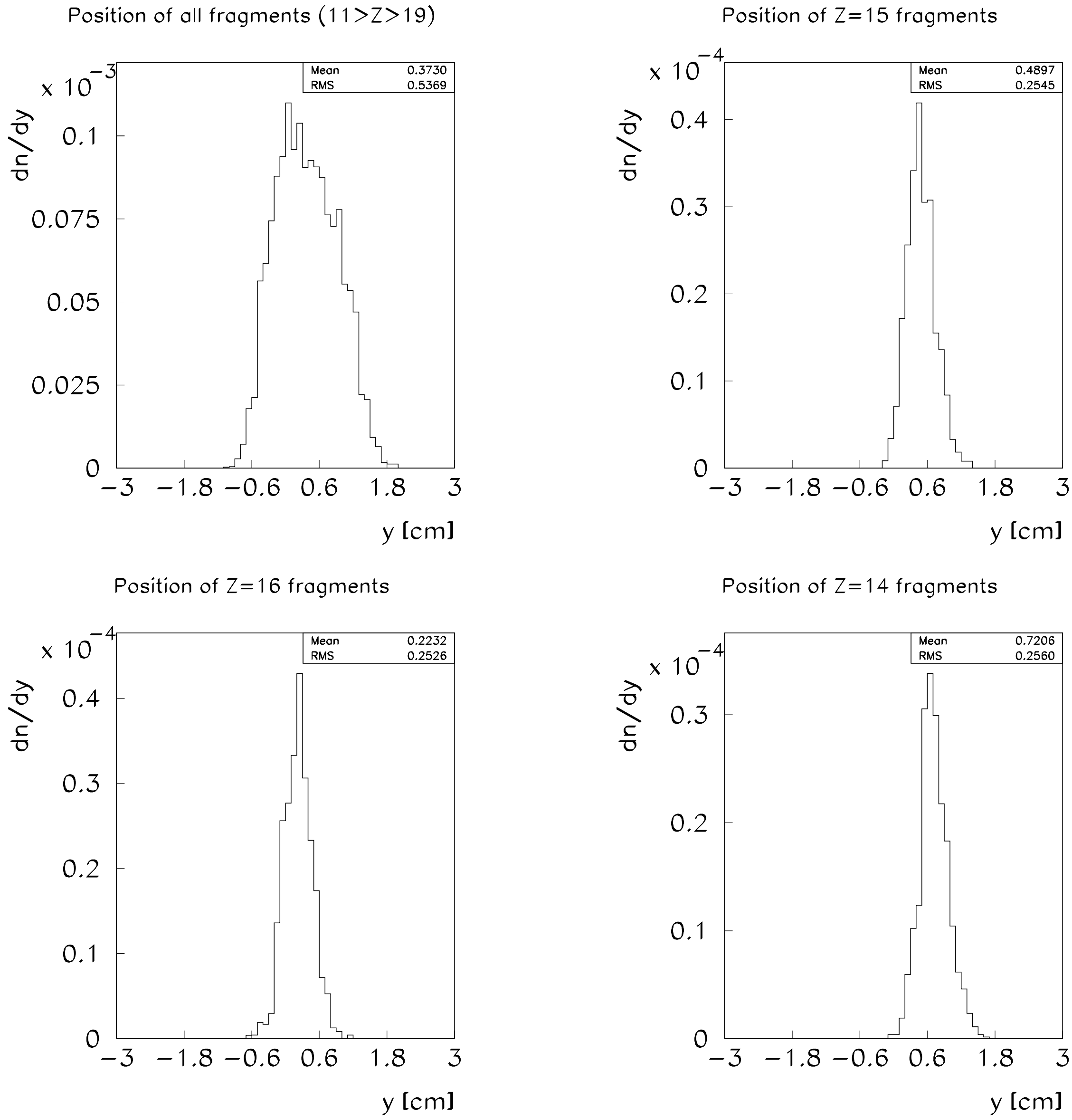

Figure 5: Transmitted fragments in Pb+C collisions at 47.6A GeV as function of vertical position before the last collimator: all fragments (top left), Z=15 fragments (top right, Z=16 fragments (bottom left), and Z=14 fragments (bottom right).

10 mm we obtain (after the slit) the charge distribution shown in Fig. 6 (left). Obviously the distribution peaks for the desired charge Z=15. Nevertheless, roughly 75% of the fragments passing the last slit have $Z \neq 15$, thus the ratio of *t-ions* to *all-ions* is about 0.25. The yield of Z=15 fragments after the last slit (*t-ions*) per incident beam particle (see Fig. 6 (left)) is $\approx 2.2 \cdot 10^{-4}$.

After the last slit ions with charge Z=15 will be selected by the NA61 trigger. The mass composition of these selected Z=15 ions is displayed in Fig. 6 (right). One obtains a sharp maximum at A=32 which contains 75% of all trigger selected ions with Z=15.

The systematic error on the presented results is estimated to be about 20% and is due to neglecting: electro-magnetic dissociation processes (-10%), gap sizes in the bending magnets (-10%), optimization of the *w-ion* species (+20%) and optimization of the production cross-section (± 20%).

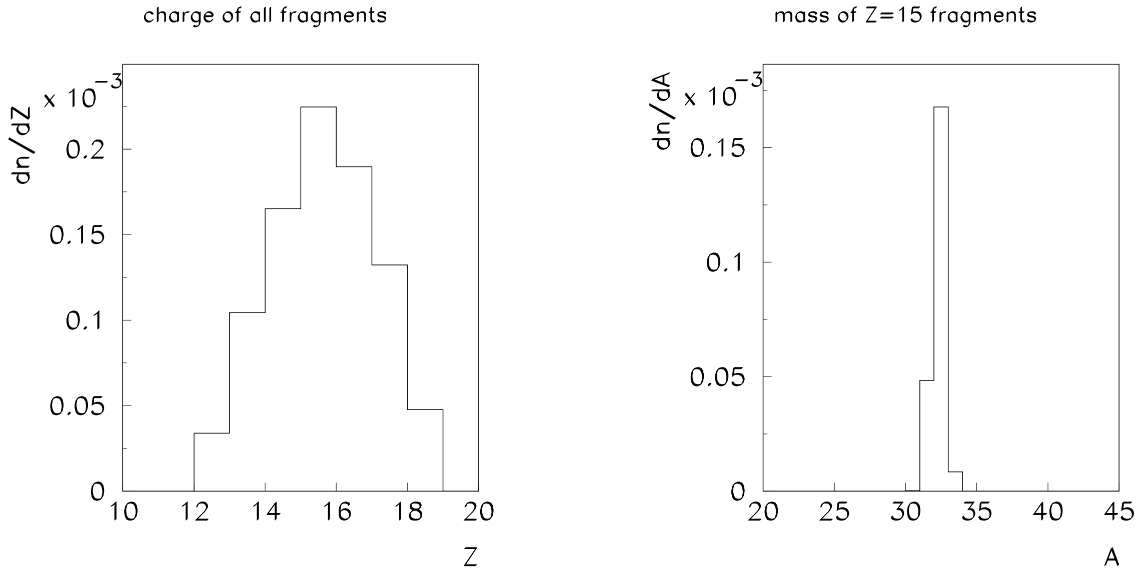

Figure 6: Distribution of all fragment charges Z (left) and distribution of the fragment mass number A of Z=15 fragments (right) after the last collimator in Pb+C collisions at 47.6A GeV.

5.3 Fragment charge measurements

In order to achieve good charge identification of secondary fragments delivered to the experimental area we plan to use a Cherenkov counter.

The construction of the NA61 Z-detector will be based on that developed by the AMS collaboration [14, 15]. The prototype of the AMS Cherenkov imager has been tested with a 20A GeV ion beam coming from the fragmentation of a primary Pb beam. For a 3.1 cm thick silica areogel developed by the Catalysis Institute of Novosibirsk ($n = 1.05$) the measured resolution in charge number Z was about $\sigma(Z) = 0.3$ in the region of Fe ions (see Fig. 7).

The Z resolution obtained from a Gaussian fit to the reconstructed charge spectrum was in agreement with an estimate based on the statistical error of the number of detected photo-electrons and the PMT photo-electron resolution. The photon multiplicity was of the order of 10-15 in a single ring for particles with $\beta = 1$ and Z=1. The efficiency, defined as the ratio of reconstructed and selected ions to all ions passing through the radiator, was about 90% for ^{9}Be ions at energy $\geq 10A$ GeV.

The proposed structure of the Z-detector is shown in Fig. 8. The entrance window of the detector will be made from a mylar/kapton foil. A silica aerogel radiator supported by a honeycomb plate (diameter about 4 to 5 cm) will be placed at a small distance (about 2-3 cm) behind the entrance window. The detector will be about 20 cm long and will be filled with He

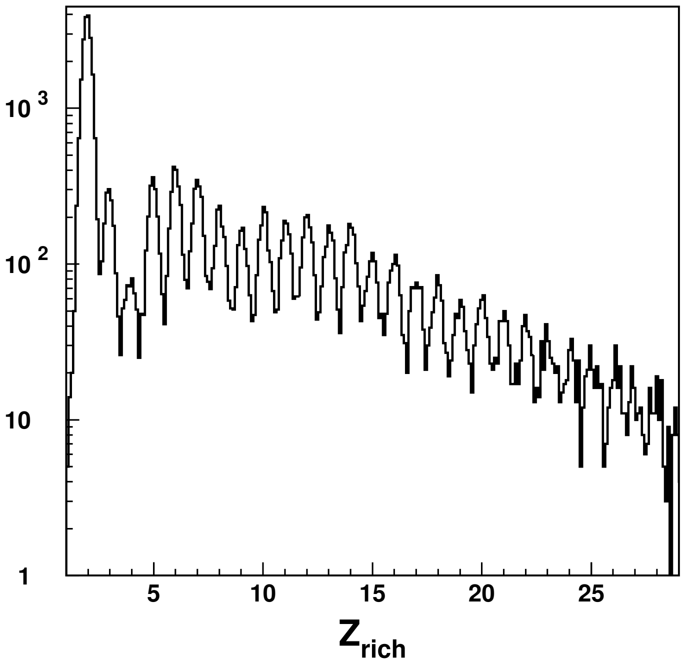

Figure 7: Reconstructed charge spectrum measured with $20A$ GeV Pb ion fragments by the AMS collaboration [14, 15].

at atmospheric pressure. The exit window of the detector will also be made of mylar/kapton foil.

Because we do not need to measure the velocity of the ions (diameter of Cherenkov rings) the light will be focused by a mirror on a set of hybrid photo-diodes (LHCb RICH-1 detector type) located around the entrance window of the detector. The proposed mirror will have cylindrical symmetry and a hole of about 5 cm diameter in the center. The use of photomultiliers is also considered as an alternative.

We expect that the charge resolution of the Z-detector will be similar to that obtained by the AMS collaboration. Using readout front-end electronics for hybrid photo-diodes similar to that used by the LHCb collaboration we will be able to read the data from the detector within 1 μsec.

5.4 Fragment mass measurements

Measurements of the fragment mass distribution could provide additional information on the background contamination in the fragmentation beam. Such a measurement would be especially valuable for estimating the reliability of the models used in the beam line simulation. The only practical method is the determination of the time-of-flight (*tof*) of beam ions. For relativistic ions as used by NA61 and the TOF detector placed at $l = 160$ m upstream from the NA61 target the *tof* is about 0.5 μsec. Despite this large value, the *tof* difference between ions which differ by a single nucleon is small. The *tof* difference Δt between ions of mass numbers A and

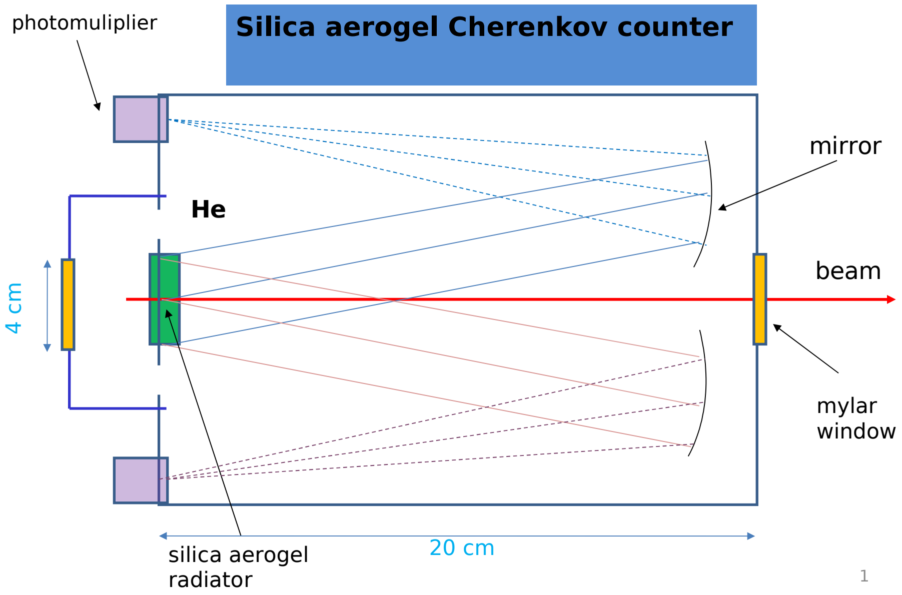

Figure 8: Schematics of the Z-detector.

A+1 can be approximated as:

$$\Delta t \approx \frac{l}{c \cdot (p_N/(1\ \mathrm{GeV/c}))^2 \cdot A}\,, \tag{1}$$

where p_N is the ion momentum per nucleon in GeV/c and $c = 3 \cdot 10^8$ m/sec. The time difference amounts to $\Delta t \approx 160$ $p$sec for the case of $A \approx 32$ ions and $p_N = 10$ GeV/c. A *tof* resolution of about 50 $p$sec is achievable with modern detector technologies. It is thus clear that fragment mass measurements are possible only for sufficiently low energies and and fragment masses.

Cherenkov counters with quartz radiators seem to be the simplest solution for the beam TOF system. The schematics of the A-detectors is shown in Fig. 9.

The first Cherenkov counter must be placed 160 m upstream from the NA61 target, behind the last beam slit. The second one will be located in the NA61 area in front of the NA61 target. The obtained *tof* information will be used for the reconstruction of the mass-spectrum of the beam ions and for the subsequent comparison with the results of the simulation. The accuracy of A-reconstruction will depend on the time resolution of the Cherenkov counters only and might reach σ=0.5 mass units. The contribution to σ resulting from the finite momentum range of the selected *t-ions* (0.1%) is significantly (more than a factor 10) smaller than the one from the tof resolution.

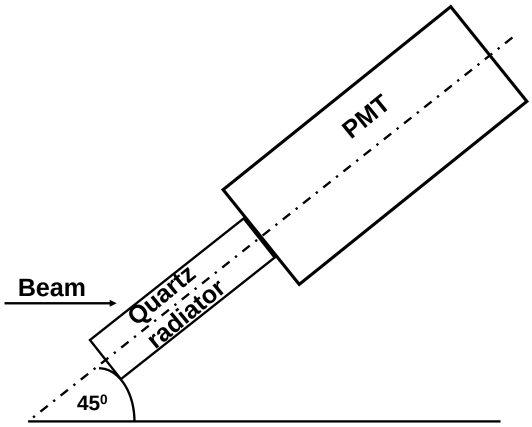

Figure 9: Schematics of the A-detector.

5.5 Intensity requirements and physics performance

This subsection discusses the intensity requirements and physics performance resulting from the feasibility study presented above of using secondary ion beams instead of the originally requested primary light ion beams.

5.5.1 Intensity requirements

The primary Pb beam intensity at the fragmentation target needed to reach the requested event rate of 40 Hz is: $1.5 \cdot 10^8$ ions/sec[1]. This number results from the ratio of the required intensity of the *t-ions* at the NA61 target ($= 3 \cdot 10^4$) to the yield of *t-ions* at the NA61 target per Pb nucleus at the fragmentation target ($= 2.2 \cdot 10^{-4}$). The estimated fraction of *t-ions* in the *all-ion* beam is about 25%, significantly larger than the lower limit of 15% imposed by the read-out time of the beam and trigger detectors.

5.5.2 Physics performance

The minimum duration of data taking required to reach the principal physics goals of NA61 with the secondary ion beams is 7 days for each reaction and energy. The first day will be devoted to beam and trigger set up and the remaining 6 days to data taking. Assuming a primary Pb-beam intensity of $1.5{\cdot}10^8$/sec, a beam duty cycle of 25% and 60% overall data taking efficiency we expect about $3{\cdot}10^6$ events per reaction and energy.

In the proposal [1] NA61 requested to register $2{\cdot}10^6$ central events and $4{\cdot}10^6$ minimum bias events per reaction and energy. The principal physics goals, i.e. the search for the critical point and the study of properties of the onset of deconfinement, require central events. Thus,

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[1] The required intensity is about 50% higher than the one achieved in the past, 4.0^{10} charges/pulse (5 sec flat top in 19.2 sec cycle), but within reach of the accelerators.

the anticipated statistics with the secondary ion beams is sufficient to reach these goals. The possibility to record and study minimum bias interactions is under discussion. To this end, one can consider taking data with two triggers simultaneously, namely with the trigger for central collisions and a scaled trigger for minimum bias interactions.

The trigger will select interactions of *t-ions*, which in addition to the wanted *w-ions* include a contamination ($\approx 25\%$) of ions with A different from the wanted one. A possible bias of the physics results due to this contamination is discussed below.

The r.m.s. of the mass distribution of the *t-ions* (Z=15) at the NA61 target is calculated as $\sigma(A) \approx 0.4$. This gives the scaled variance of the projectile participants in central ^{32}P+^{32}S collisions selected by the PSD as:

$$\omega(N_P^{Proj}) \approx \sigma(A)^2/\langle A\rangle \approx 0.4^2/32 = 0.006.$$

Among properties relevant for the NA61 ion physics, the fluctuations of charged hadron multiplicity are the most sensitive to the fluctuations in the mass number of *t-ions*. As an example, the contribution of the A fluctuations to the scaled variance of the negatively charged hadrons in the NA49 acceptance [16] is estimated to amount to:

$$\Delta\omega(n(h^-)) \approx 0.006 \cdot 0.6 \approx 0.003,$$

where 0.6 stands for the mean multiplicity of negatively charged hadrons per nucleon in the NA49 acceptance [16]. This contribution is 100 times smaller than the expected maximum increase of the scaled variance due to the the critical point (≈ 0.3 [16]).

The model estimate of the mass distribution of *t-ions* will be cross-checked by a direct measurement of the distribution at 10A GeV using the proposed time-of-flight detectors (A-detectors).

With the considered beam intensities of about 10^5 *all-ions* per second a typical distance in time between two ions will be several μsec. Two interactions in the target can be well separated using the TPC information provided the time difference between them is larger than 5 μsec. In this case the tracks from both interactions are separated along the drift direction by more than 5 cm, well above the resolution of the TPC measurements.

In about 3% of registered events there will be a pile-up interaction(s) within the time window of ± 5 μsec around the trigger time. For off-line rejection of the events with pile-up interactions the following procedure will be used.

- For each ion from the *all-ion* beam its charge Z is measured upstream of the NA61 target by the Z-detector. This allows to calculate the total momentum P_{ion} of the ion:

  $$P_{ion} = (P/Z) \cdot Z \ ,$$

  where (P/Z) is the rigidity given by the beam line settings and Z is the charge measured by the Z-detector.

- For each ion from the *all-ion* beam its total energy, E_{PSD}, is measured downstream of the target by the PSD detector.

- The values of Z and E_{PSD} measured for all ions within the time window ± 5 μsec around the trigger time will be stored together with the event data.

- In the off-line analysis the events accompanied by additional ions in the time window ±5 μsec around the trigger with a significant difference between P_{ion} and E_{PSD} will be rejected as candidates with pile-up interactions.

The performance of the Z- and PSD [4] detectors is sufficient for the proposed suppression of pile-up interactions. First, the read-out time of both detectors is ≤ 1 μsec. Second, the expected resolutions are $\sigma(Z) \approx 0.3$ and $\sigma(A) \leq 1$ for Z and PSD detectors, respectively. The PSD resolution in A results from the resolution of the energy measurement [4], $\sigma(E_{PSD})/E_{PSD} \approx 50\%/\sqrt{E_{PSD}}$, where E_{PSD} is given in GeV.

5.6 Hardware, manpower and cost

This subsection summarizes the hardware modifications of the H2 beam line needed for conversion to a secondary ion beam line for NA61 as well as the necessary upgrades of the NA61 facility. Estimates of the requested time and cost are also given.

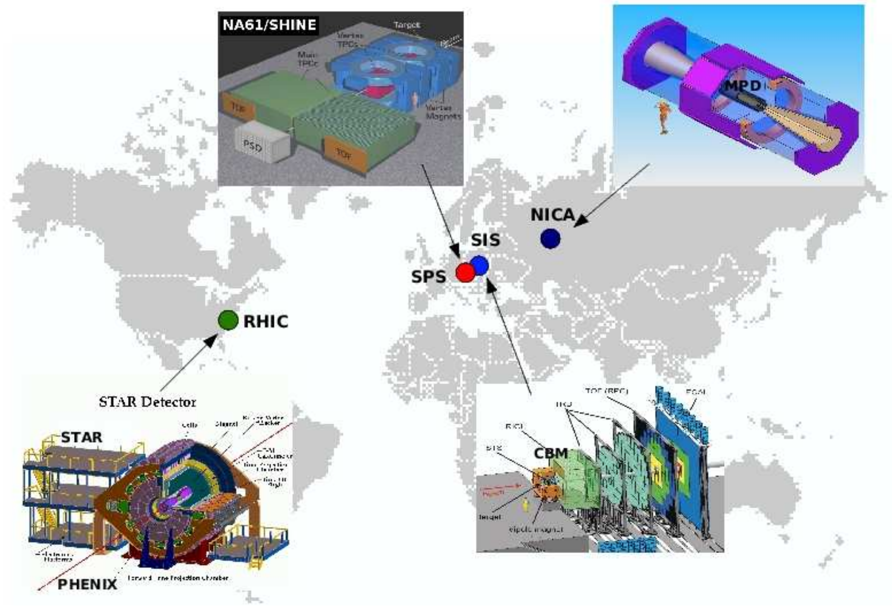


Figure 10: A world map indicating laboratories and experiments which plan to perform measurements of nucleus-nucleus collisions at CERN SPS energies within the next 10 years.

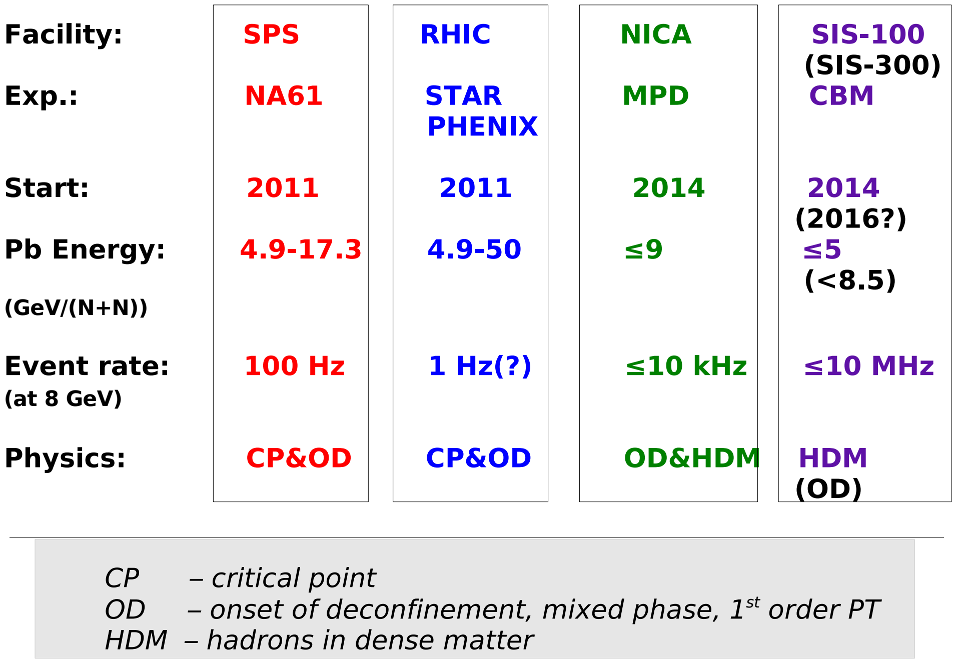
- Fragmentation target: graphite 8.5 g/cm^2. The present T2 target assembly has to be modified or a new assembly has to be prepared. The final solution has to involve Radiation Protection and ALARA arguments. Estimated time: 30 weeks of work including possible delays for material orders. Estimated cost: 55 kCHF.

- Degrader: copper 45 g/cm^2. There are different possible options for the degrader assembly. Estimated time: 4 weeks of work. Estimated cost 10 kCHF.

The cost of the conversion of the H2 beam line to to the secondary ion beam line will be covered by NA61. The manpower will be covered by the CERN EN-MEF team.

The A-detector will be constructed by the NA61 group from the Institute for Nuclear Research, Moscow, Russia. The Z-detector will be constructed by the NA61 group from the Jagiellonian University, Cracow, Poland. The cost of the A-detector is estimated to be about 30 kCHF and the cost of the Z-detector about 60 kCHF. The cost of both detectors will be covered jointly by the NA61 common fund and the grants of the Cracow and Moscow groups.

6 Experimental landscape related to the NA61 ion program



Facility:	**SPS**	**RHIC**	**NICA**	**SIS-100** **(SIS-300)**
Exp.:	**NA61**	**STAR** **PHENIX**	**MPD**	**CBM**
Start:	**2011**	**2011**	**2014**	**2014** **(2016?)**
Pb Energy: **(GeV/(N+N))**	**4.9-17.3**	**4.9-50**	**≤9**	**≤5** **(<8.5)**
Event rate: **(at 8 GeV)**	**100 Hz**	**1 Hz(?)**	**≤10 kHz**	**≤10 MHz**
Physics:	**CP&OD**	**CP&OD**	**OD&HDM**	**HDM** **(OD)**

CP – critical point
OD – onset of deconfinement, mixed phase, 1st order PT
HDM – hadrons in dense matter

Figure 11: The main parameters of the experimental programs studying nucleus-nucleus collisions in the CERN SPS energy range within the next 10 years.

The exciting and rich physics topics which can be studied in nucleus-nucleus collisions at the CERN SPS energies also motivates physicists from BNL, JINR and FAIR to perform experimental studies in this energy range which will complement the CERN SPS program. Figure 10 shows a world map indicating laboratories and experiments which plan to carry out measurements of nucleus-nucleus collisions at CERN SPS energies within the next 10 years. Two fixed target programs (CERN SPS [1] and FAIR SIS-300 [13]) and two programs with ion colliders (BNL RHIC [11] and JINR NICA [12]) are foreseen. The basic parameters of the

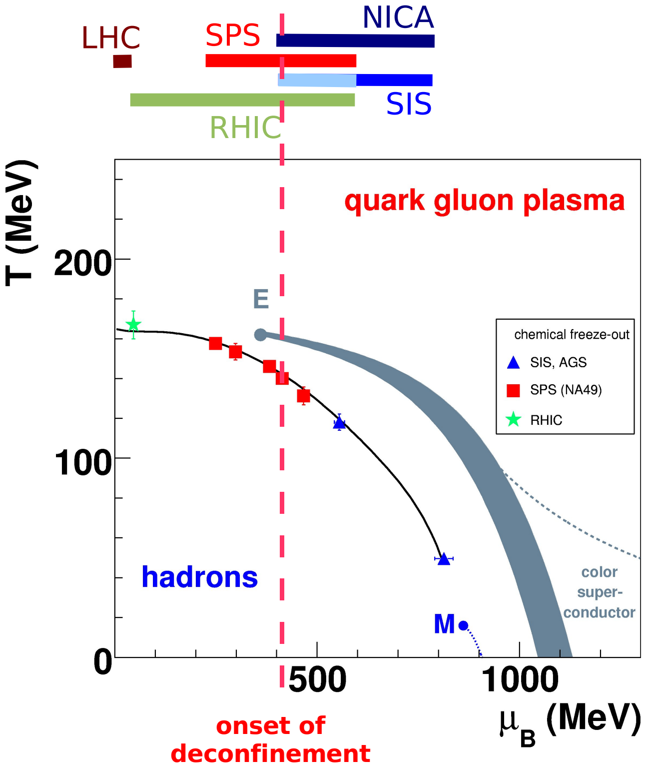


Figure 12: Phase diagram of strongly interacting matter with indicated chemical freeze-out points of central Pb+Pb (Au+Au) collisions at different energies, and baryon-chemical potential ranges covered by the future programs.

future programs are summarized in Fig. 11. The SPS and RHIC energy range covers energies significantly below and significantly above the energy of the onset of deconfinement (≈30*A* GeV in the fixed target mode). Thus these machines are well suited for the study of the properties of the onset of deconfinement and the search for the critical point. The top energies of NICA and SIS-300 are just above the energy of the onset of deconfinement. The physics at these machines thus focuses on the study of properties of dense confined matter close to the transition to the QGP. This is illustrated in Fig. 12 which shows the range of baryon chemical potential in the phase diagram of hadronic matter covered by the new programs together with existing measurements of the freeze-out points and physics benchmarks in collisions of heavy nuclei.

The advantages of the NA61 ion program over the RHIC energy scan program are:

- measurements of identified hadron spectra in a broad rapidity range which allow to obtain the mean hadron multiplicities in full phase-space,
- measurements of the total number of the projectile spectator nucleons comprising free nucleons and nucleons bound in nuclear fragments,

- high and similar event rate over the full SPS energy range including the lowest energies,
- high flexibility in selecting the nuclear mass number (thanks to the secondary ion beam) and energy (thanks to the SPS features) of the projectile ions.

Beam Primary	Beam Secondary	Target	Energy (A GeV)	Year	Days	Physics	Status
p			400				
	p	C(T2K)	31	2009	21	T2K, C-R	*recommended*
p			400				
	π^-	C	158,350	2009	2x7	C-R	*recommended*
p			400				
	p	p	10,20,30,40,80,158	2009	6x7	CP&OD	*recommended*
p			400				
	p	p	158	2010	77	High p_T	*recommended*
Pb			10,20,30,40,80,158				
	$A \approx 30$	$A \approx 30$	10,20,30,40,80,158	2011	6x7	CP&OD	*recommended*
p			400				
	p	Pb	158	2011	6x7	High p_T	*recommended*
Pb			10,20,30,40,80,158				
	$A \approx 10$	$A \approx 10$	10,20,30,40,80,158	2012	6x7	CP&OD	*to be discussed*
p			400				
	p	Pb	10,20,30,40,80,158	2012	6x7	CP&OD	*recommended*
Pb			10,20,30,40,80,158				
	$A \approx 100$	$A \approx 100$	10,20,30,40,80,158	2013	6x7	CP&OD	*to be discussed*

Table 1: The NA61/SHINE data taking plan. The runs with secondary ion beams are planned for 2011, 2012 and 2013. In these runs the nuclear mass number of the selected ions will be $A \approx 30$, $A \approx 10$ and $A \approx 100$, respectively. The following abbreviations are used for the physics goals of the data taking: CP - Critical Point, OD - Onset of Deconfinement, C-R - Cosmic Rays.

7 Updated data taking schedule

The NA61/SHINE data taking plan is presented in Table 1. This plan preserves all runs requested in the NA61 proposal and addenda. It takes into account conclusions from the discussion between NA61 and AB department representatives. Three runs with secondary ion beams are planned with the nuclear mass numbers of $A \approx 10, 30, 100$. These are indicated correspondingly in Table 1.

For each reaction and energy with the secondary ion beams 7 days of beam time are planned. The first day will be devoted to the adjustment of the accelerators as well as the beam and trigger setup. The data will be registered during the remaining 6 days. The ion runs at 10A GeV (the lowest energy, for the first time in the SPS) and 158A GeV (the highest radiation at the T2 target) may require an additional technical effort and the beam intensity may be lower than in the case of the runs at 20A-80A GeV.

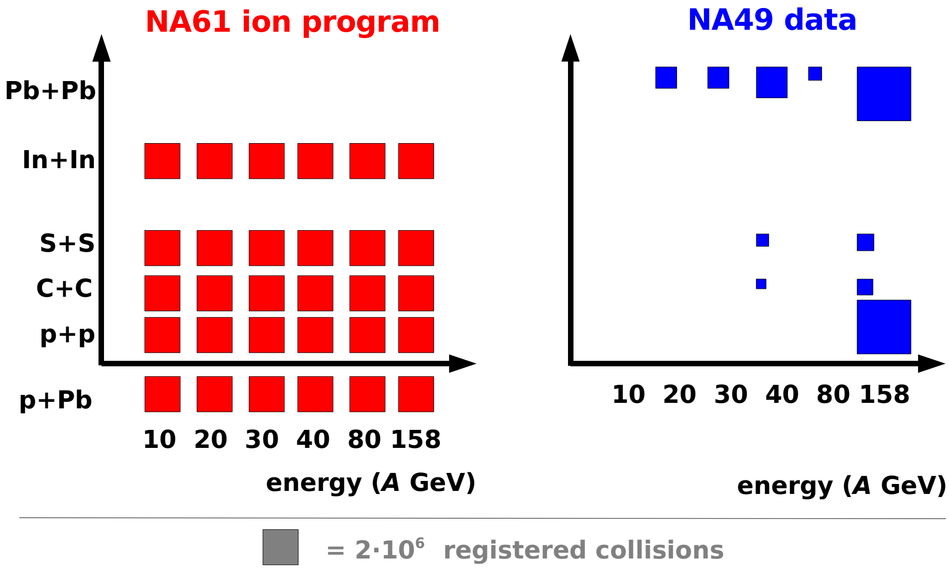


Figure 13: The data sets planned to be recorded by NA61/SHINE (left) with the ion program and those recorded by NA49 (right). The area of the boxes is proportional to the number of registered central collisions, which for NA61/SHINE will be $2 \cdot 10^6$ per reaction and energy.

The feasibility of efficient data taking with a secondary ion beam of ^{32}P ($A \approx 30$) planned for 2011 was demonstrated in Section 5. The properties of the secondary C beam ($A \approx 10$) requested in 2012 are expected to be even better than those of the ^{32}P beam. This is because the production cross-section of the C fragments is about 10 times higher than the corresponding cross-section of P fragments and the relative charge difference between Z=6 and Z=7 ions is larger than the difference between Z=15 and Z=16 ions. This larger difference leads to improved purity of the selected ion species (*w-ions*). In ($A \approx 100$) ions are requested in 2013. The production cross-section of In is similar to the one of P ions, however the relative charge difference for Z=100 and Z=101 ions is smaller than for the P case. Therefore a simulation concerning the feasibility of a secondary $A \approx 100$ beam for NA61 is necessary. On the other hand, in 2013/14 primary light ion beams are considered for I-LHC. Thus, one could try to select an intermediate mass number ion which would satisfy the needs of both I-LHC and NA61 physics. This would allow NA61 to take data with primary intermediate mass ion beam.

The data sets planned to be recorded by NA61/SHINE for the ion program and those recorded by NA49 are compared in Fig. 13.

8 Summary

This document presents the proposal for a secondary light-ion beam and the implied update of the data taking schedule of the NA61 collaboration. These modifications of the plans of NA61 became necessary in order to reach compatibility with the current I-LHC schedule. Delivery of primary proton beam in assumed in the period 2009–2012 and of primary Pb beam in 2011–2013. The primary Pb beam will be fragmented and data taking is planned with the resulting secondary beams of lighter ions. The H2 beam line will be modified to serve as a fragment separator. The physics performance of the NA61 experiment with secondary ion beams is expected to be sufficient to reach the principal NA61 physics goals provided the primary Pb beam intensity will be about $1.5{\cdot}10^8$ ions/sec during the spill.

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