

## A new SPS programme

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A new experimental program to study hadron production in hadron-nucleus and nucleus-nucleus collisions at the CERN SPS has been recently proposed by the NA49-future collaboration. The physics goals of the program are:

- search for the critical point of strongly interacting matter and a study of the properties of the onset of deconfinement in nucleus-nucleus collisions,
- measurements of correlations, fluctuations and hadron spectra at high  $p_T$  in proton-nucleus collisions needed as for better understanding of nucleus-nucleus results,
- measurements of hadron production in hadron-nucleus interactions needed for neutrino (T2K) and cosmic-ray (Pierre Auger Observatory and KASCADE) experiments. The physics of the nucleus-nucleus program is reviewed in this presentation.

*Critical Point and Onset of Deconfinement*

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## 1. Introduction

Recently The NA49-future Collaboration has proposed [1] to study hadron production in hadron-proton interactions and nucleus-nucleus collisions at the CERN SPS. This proposal follows the Expression of Interest [2] and the Letter of Intent [3] submitted to the CERN SPS committee in November 2003 and January 2006, respectively.

The proposed physics program consists of three subjects:

- measurements of hadron production in nucleus-nucleus collisions, in particular fluctuations and long range correlations, with the aim to identify the properties of the onset of deconfinement and find evidence for the critical point of strongly interacting matter,**
- measurements of hadron production in proton-proton and proton-nucleus interactions needed as reference data for better understanding of nucleus-nucleus reactions; in particular correlations, fluctuations and high transverse momenta will be the focus of this study,**
- measurements of hadron production in hadron-nucleus interactions needed for neutrino (T2K) and cosmic-ray experiments (Pierre Auger Observatory and KASCADE).**

It is foreseen to take data with proton and pion beams starting from 2007, and with the beams of nuclei (C, Si and In) starting from 2009. The data taking period should end in 2011. The envisaged run schedule is based on the assumption that the proposal is approved not later than by the end of May 2007.

The nucleus-nucleus program has the potential for an important discovery – the experimental observation of the critical point of strongly interacting matter. We intend to carry out for the first time in the history of heavy ion collisions a comprehensive scan in two dimensional parameter space: size of colliding nuclei versus interaction energy. Other proposed studies belong to the class of precision measurements.

The collaboration proposes to perform these measurements by use of the upgraded NA49 apparatus [4]. The most essential upgrades are an increase of data taking and event rate by a factor of 24 and the construction of a projectile spectator detector which will improve the accuracy of determination of the number of projectile spectators by a factor of about 20. The cost of all upgrades and detector maintenance is estimated to be 1.5 MSFR. Synergy of different physics programs as well as the use of the existing accelerator chain and detectors offer the unique opportunity to reach the ambitious physics goals in a very efficient and cost effective way.

The NA49 apparatus at the CERN SPS served, during the last 10 years, as a very reliable, large acceptance hadron spectrometer and delivered high precision experimental data over the full range of SPS beams (from proton to lead) [5, 6] and energies (from 20A GeV to 200A GeV) [7, 8]. Among the most important results from this study is the observation [7, 8] of narrow structures in the energy dependence of hadron production in central Pb+Pb collisions. These structures are located at the low CERN SPS energies (30A–80A GeV) and they are consistent with the predictions [9] for the onset of the deconfinement phase transition. The questions raised by this observation

serve as a strong motivation for new measurements with nuclear beams in the SPS energy range at the CERN SPS as proposed by us and also envisaged at BNL RHIC [10]. The proposed SPS and RHIC programs are to a large extent complementary mainly due to different collision kinematics: beams on a fixed target at SPS and colliding beams at RHIC.

A report from the Villars meeting on "Fixed-Target Physics at CERN beyond 2005" [11] recognizes that the ion beams at the CERN SPS remain ideal tools to study the features of the phase transition between confined and deconfined states of strongly interacting matter. It notes that an ion program aimed at the identification of the critical point and the study of its properties is likely to be of substantial significance. The NA49-future goals to measure hadron production in hadron-nucleus interactions needed for neutrino and cosmic-ray experiments as well as a search for the critical point in nucleus-nucleus collisions were summarized in the Briefing Book for European Strategy for Particle Physics [12]. The documents supporting the NA49-future physics program [1] were provided by Frank Wilczek and by the T2K, Pierre Auger Observatory and KASCADE experiments.

For the proposal in preparation the NA49 apparatus and two detector prototypes were tested in a 5-day long test run in August 2006 [13]. The performance of the NA49 TPCs has not shown any sign of degradation since the beginning of their operation (1994). In addition, this test clearly demonstrated the ability of the new collaboration to operate the NA49 facility and the feasibility of the proposed concepts of the new detectors.

This presentation is based on the proposal of the NA49-future Collaboration [1] and is limited to the review of the nucleus-nucleus part of the physics program.

## **2. Physics of Nucleus-Nucleus Collisions in NA49-future**

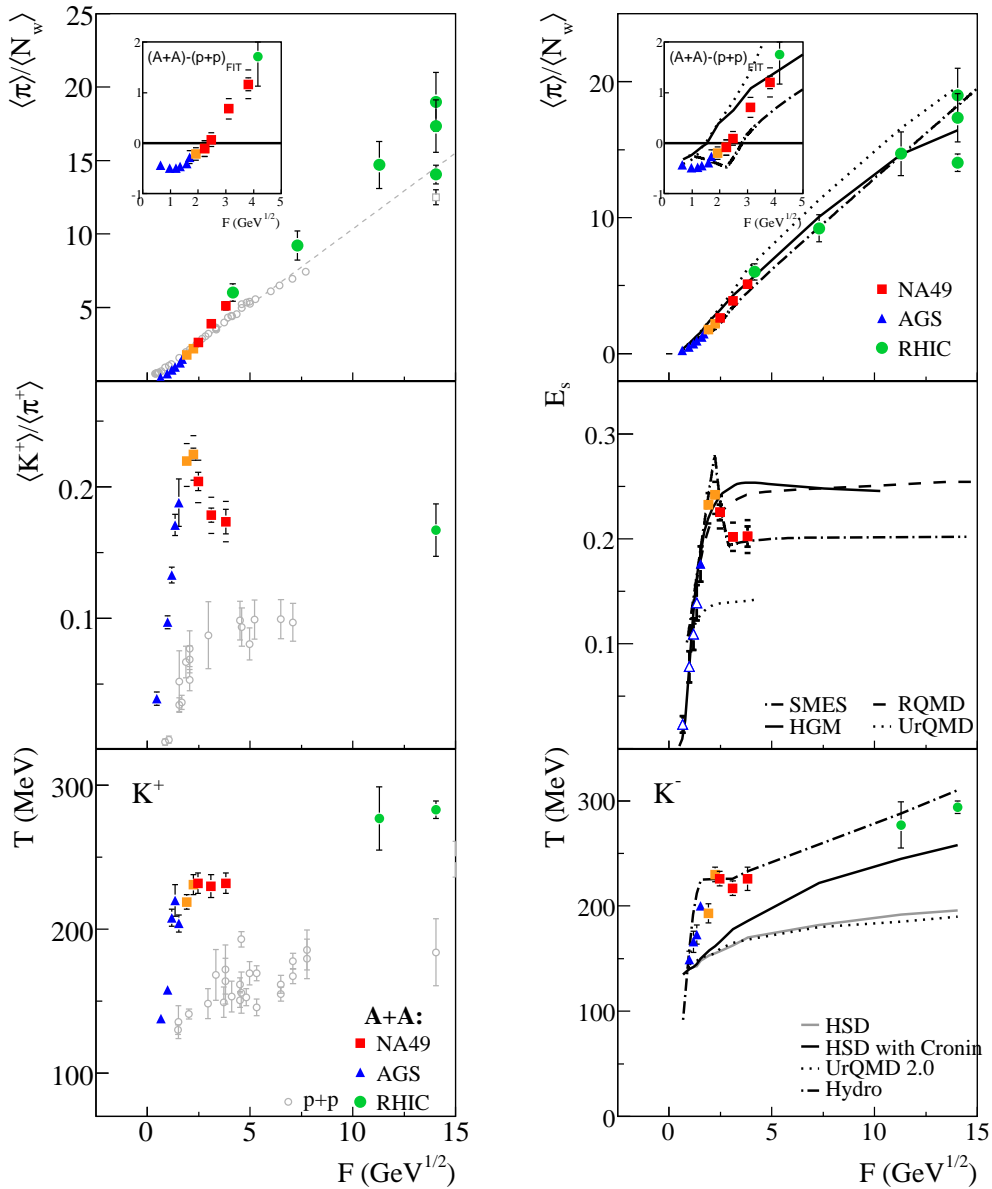
### **2.1 Key questions**

One of the key issues of contemporary physics is the understanding of strong interactions and in particular the study of the properties of strongly interacting matter in equilibrium. What are the phases of this matter and how do the transitions between them look like are questions which motivate a broad experimental and theoretical effort. The study of high energy nucleus-nucleus collisions gives us a unique possibility to address these questions in well-controlled laboratory experiments.

### **2.2 Onset of Deconfinement**

Recent results on the energy dependence of hadron production in central Pb+Pb collisions at 20A, 30A, 40A, 80A and 158A GeV coming from the energy scan program at the CERN SPS serve as evidence for the existence of a transition to a new form of strongly interacting matter, the Quark Gluon Plasma (QGP) in nature. Thus they are in agreement with the indications that at the top SPS [14] and RHIC [15] energies the matter created at the early stage of central Pb+Pb (Au+Au) collisions is in the state of QGP.

The key results and their comparison with models are summarized in Fig. 1. Energy dependence of the mean pion multiplicity per wounded nucleon, of the  $\langle K^+ \rangle / \langle \pi^+ \rangle$  ratio and of the



**Figure 1:** Left: Energy dependence of hadron production properties in central Pb+Pb (Au+Au) collisions (closed symbols) and p+p interactions (open symbols). Right: The results for Pb+Pb (Au+Au) reactions are compared with various models. For details see text.

inverse slope parameter  $T$  of the transverse mass spectra of  $K^+$  mesons measured in central Pb+Pb (Au+Au) collisions compared to results from p+p( $\bar{p}$ ) reactions are shown in Fig. 1 (left). The rapid changes in the SPS energy range (solid squares) suggest the onset of new physics in heavy ion collisions at the low SPS energies. Energy dependence of the mean pion multiplicity per wounded nucleon, the relative strangeness production measured by the  $E_S$  ratio and the inverse slope parameter of  $m_T$ -spectra of  $K^-$  mesons measured in central Pb+Pb (Au+Au) collisions are compared with predictions of various models in Fig. 1 (right). Models which do not assume the deconfine-

ment phase transition (HGM [16], RQMD [17], UrQMD [18] and HSD [19]) fail to describe the data. The introduction of a 1<sup>st</sup> order phase transition at the low SPS energies (SMES [9] and hydro [20, 21]) allows to describe the measured structures in the energy dependence.

The energy dependence of the same observables measured in p+p interactions (open symbols in Fig. 1 (left)) is very different than that measured in central Pb+Pb (Au+Au) collisions and does not show any anomalies.

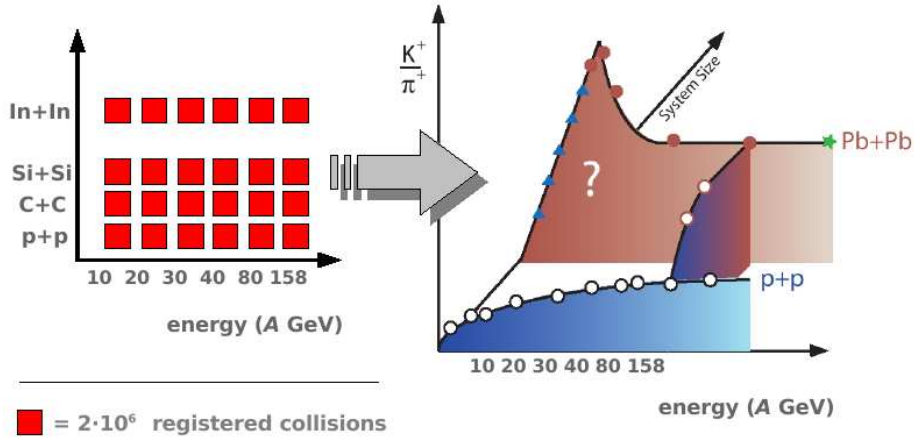
There are attempts to explain the results on nucleus-nucleus collisions by (model dependent) extrapolations of the results from proton-nucleus interactions [22, 23]. As detailed enough p+A data exist only at the top AGS and SPS energies the extrapolations are limited to these two energies and thus there are no predictions concerning energy dependence of the quantities relevant for the onset of deconfinement (see Fig. 1). The underlying models are based on the assumption that particle yield in the projectile hemisphere is due to production from excited projectile nucleon(s). This assumption is, however, in contradiction to the recent results at RHIC [24] and SPS [25] energies which clearly demonstrate a strong mixing of the projectile and target nucleon contributions in the projectile hemisphere. Furthermore, qualitative statements on similarity or differences between p+A and A+A reactions may be strongly misleading because of a trivial kinematic reason. The center of mass system in p+A interactions moves toward the target nucleus A with increasing A, whereas its position is A-independent for A+A collisions. For illustration several typical examples are considered. The baryon longitudinal momentum distribution in A+A collisions gets narrower with increasing A and, of course, it remains symmetric in the collision center of mass system. In p+A collisions it shrinks in the proton hemisphere and broadens in the target hemisphere (for example see slide 5 in [22]). Thus a naive comparison would lead to the conclusion that A+A collisions are qualitatively similar to p+A interactions if the proton hemisphere is considered, or that they are qualitatively different if the target hemisphere is examined. One encounters similar difficulty in a discussion of the A-dependence of particle ratios in a limited acceptance. For instance the kaon/pion ratio is independent of A in p+A interactions if the total yields are considered [26], it is however strongly A-dependent in a limited acceptance (e.g. see slides 10 and 11 in [22]). Recent string-hadronic models ([17, 18, 19]) take all trivial kinematic effects into account and parametrize reasonably well p+p and p+A results. Nevertheless they fail to reproduce the A+A data (see e.g. Fig. 1).

Further progress in understanding effects which are likely related to the onset of deconfinement can be done only by a new comprehensive study of hadron production in proton-nucleus and nucleus-nucleus collisions.

The two most important open questions are:

- **what is the nature of the transition from the anomalous energy dependence measured in central Pb+Pb collisions at SPS energies to the smooth dependence measured in p+p interactions?**
- **is it possible to observe the predicted signals of the onset of deconfinement in fluctuations [29] and anisotropic flow [30]?**

The qualitative progress in the experimental situation which will be achieved by the proposed new measurements is illustrated in Fig. 2 using as an example the  $K^+/\pi^+$  ratio. A detailed discus-



**Figure 2:** An illustration of the impact of the new measurements (of central collisions) on clarifying the system size dependence of the  $K^+/\pi^+$  anomaly observed in central Pb+Pb collisions at the low SPS energies.

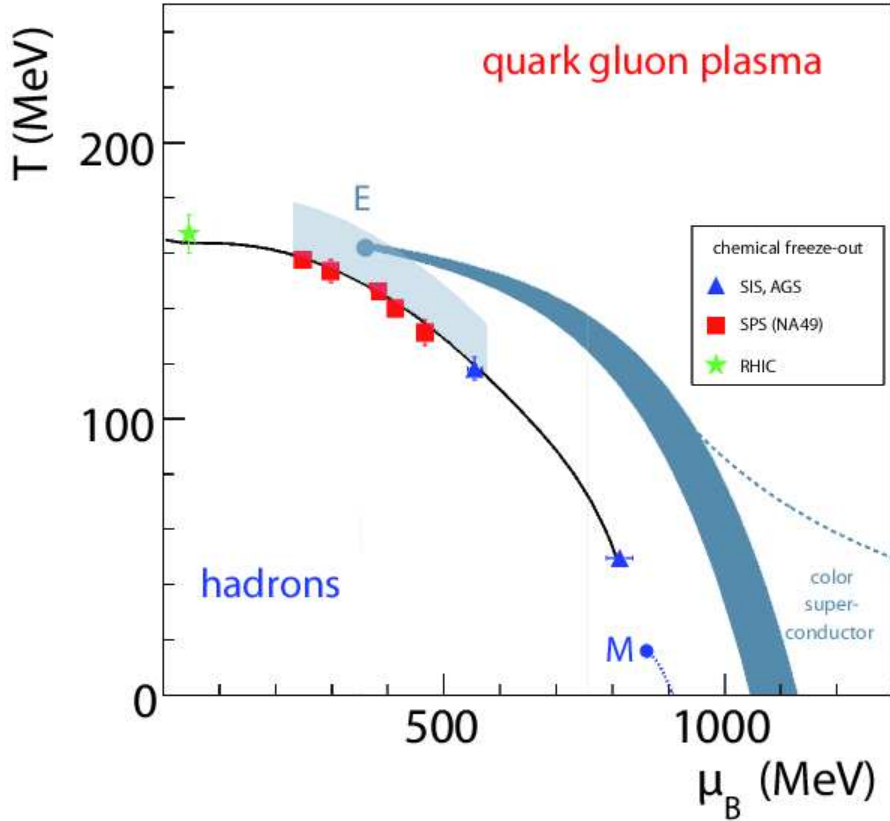
sion of the requested reactions is given below.

### 2.3 Critical Point

In the letter of Rajagopal, Shuryak, Stephanov and Wilczek addressed to the SPS Committee one reads: ... *Recent theoretical developments suggest that a key qualitative feature, namely a critical point (of strongly interacting matter) which in a sense defines the landscape to be mapped, may be within reach of discovery and analysis by the SPS, if data is taken at several different energies. The discovery of the critical point would in a stroke transform the map of the QCD phase diagram which we sketch below from one based only on reasonable inference from universality, lattice gauge theory and models into one with a solid experimental basis.* ... More detailed argumentation is presented below.

Rich systematics of hadron multiplicities produced in nuclear collisions can be described reasonably well by hadron gas models [31, 32, 33]. Among the model parameters fitted to the data are temperature,  $T$ , and baryonic chemical potential,  $\mu_B$ , of the matter at the stage of freeze-out of the hadron composition (the chemical freeze-out). These parameters extracted for central Pb+Pb collisions at the CERN SPS energies are plotted in the phase diagram of hadron matter, Fig. 3, together with the corresponding results for higher (RHIC) and lower (AGS, SIS) energies. With increasing collision energy the chemical freeze-out parameter  $T$  increases and  $\mu_B$  decreases. A rapid increase of temperature is observed up to mid SPS energies, then from the top SPS energy ( $\sqrt{s_{NN}} = 17.2$  GeV) to the top RHIC energy ( $\sqrt{s_{NN}} = 200$  GeV) the temperature increases only by about 10 MeV.

Fig. 3 also shows a sketch of the phases of strongly interacting matter in the  $(T, \mu_B)$  plane as suggested by QCD-based considerations [35, 36]. To a large extent these predictions are qualitative, as QCD phenomenology at finite temperature and baryon number is one of the least explored domains of the theory. More quantitative results come from lattice QCD calculations which can be performed at  $\mu_B = 0$ . They suggest a rapid crossover from the hadron gas to the QGP at the

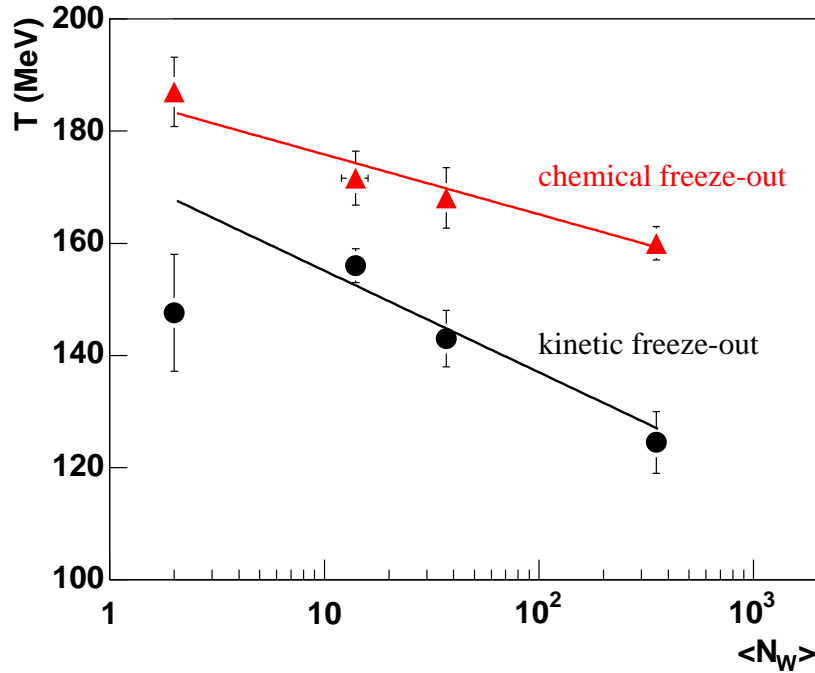


**Figure 3:** The hypothetical phase diagram of strongly interacting matter in the plane temperature,  $T$ , and baryonic chemical potential,  $\mu_B$ . The end point  $E$  of the first order transition strip is the critical point of the second order. The chemical freeze-out points extracted from the analysis of hadron yields in central Pb+Pb (Au+Au) collisions at different energies are plotted by the solid symbols. The region covered by the future measurements at the CERN SPS is indicated by the gray band.

temperature  $T_C = 170 - 190$  MeV [37, 38], which seems to be somewhat higher than the chemical freeze-out temperatures of central Pb+Pb collisions ( $T = 150 - 170$  MeV) [39] at the top SPS and RHIC energies.

The nature of the transition to QGP is expected to change with increasing baryo-chemical potential. At high potential the transition may be of the first order, with the end point of the first order transition domain, marked  $E$  in Fig. 3, being the critical point of the second order. Recently even richer structure of the phase transition to QGP was discussed within a statistical model of quark-gluon bags [40]. It was suggested that the line of the first order phase transition at high  $\mu_B$  is followed by a line of second order phase transition at intermediate  $\mu_B$ , and then by lines of "higher order transitions" at low  $\mu_B$ . A characteristic property of the second order phase transition (the critical point or line) is a divergence of the susceptibilities. Consequently an important signal of a second-order phase transition at the critical point are large fluctuations, in particular an enhancement of fluctuations of multiplicity and transverse momentum are predicted



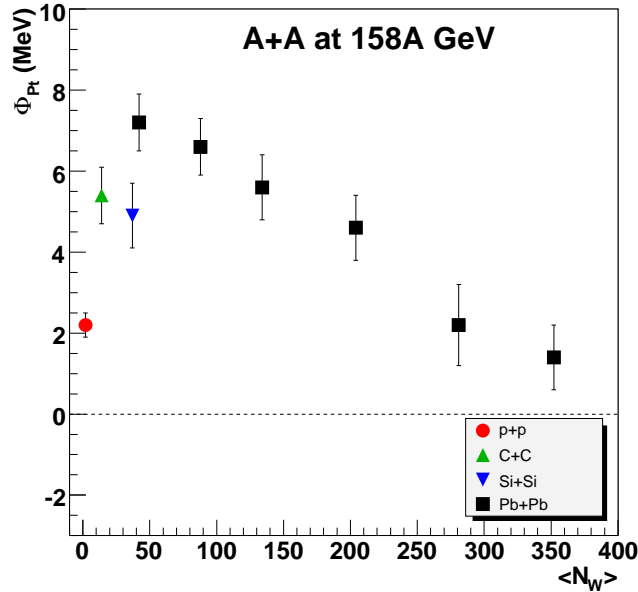


**Figure 4:** The dependence of the chemical and kinetic freeze-out temperatures on the mean number of wounded nucleons for p+p, C+C, Si+Si and Pb+Pb collisions at 158A GeV.

[34]. A characteristic feature of the second order phase transition is the validity of appropriate power laws in measurable quantities related to critical fluctuations. Techniques associated with such measurements in nuclear collisions are under development [41] with emphasis on the sector of isoscalar di-pions ( $\sigma$ -mode) as required by the QCD conjecture for the critical end point in quark matter [35]. Employing such techniques in a study of nuclear collisions at different energies at the SPS and with nuclei of different sizes, the experiment may test not only the existence and location of the critical point but also the size of critical fluctuations as given by the critical exponents of the QCD conjecture.

Thus when scanning the phase diagram a maximum of fluctuations located in a domain close to the critical point (the increase of fluctuations can be expected over a region  $\Delta T \approx 15$  MeV and  $\Delta\mu_B \approx 50$  MeV [42]) or the critical line should signal the second order phase transition. The position of the critical region is uncertain, but the best theoretical estimates based on lattice QCD calculations locate it at  $T \approx 158$  MeV and  $\mu_B \approx 360$  MeV [43, 44] as indicated in Fig. 3. It is thus in the vicinity of the chemical freeze-out points of central Pb+Pb collisions at the CERN SPS energies.

Pilot data [5] on interactions of light nuclei (Si+Si, C+C and p+p) taken by NA49 at 40A



**Figure 5:** The measure of transverse momentum fluctuations  $\Phi_{pT}$  versus mean number of interacting nucleons  $\langle N_W \rangle$  for nuclear collisions at 158A GeV. The results for all charged hadrons are presented. Only statistical errors are plotted, the systematic errors are smaller than 1.6 MeV.

and 158A GeV indicate that the freeze-out temperature increases with decreasing mass number,  $A$ , of the colliding nuclei, see Fig. 4. This means that a scan in the collision energy and mass of the colliding nuclei allows us to scan the  $(T, \mu_B)$  plane in a search for the critical point (line) of strongly interacting matter [34].

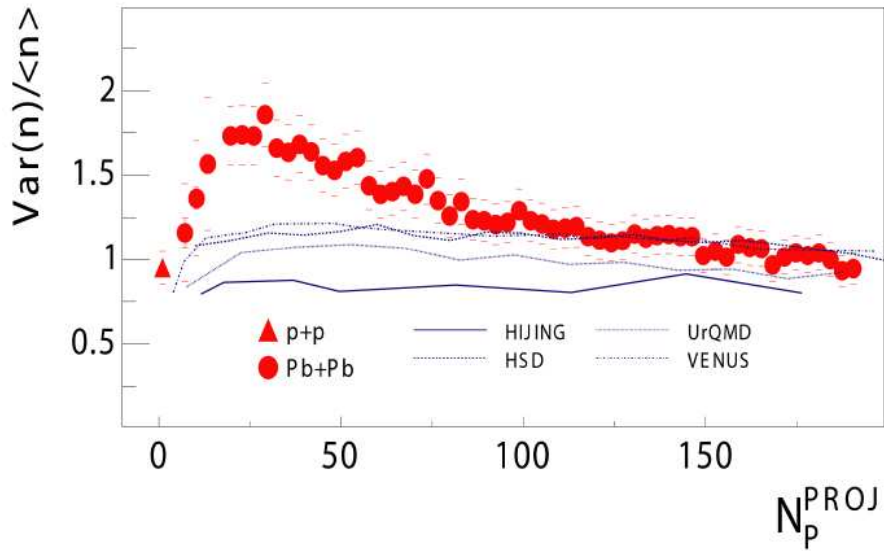
The experimental search for the critical point by investigating nuclear collisions is justified at energies higher than the energy of the onset of deconfinement. This is because the energy density at the early stage of the collision, which is required for the onset of deconfinement is higher than the energy density at freeze-out, which is relevant for the search for the critical point. The only anomalies possibly related to the onset of deconfinement are measured at 30A GeV ( $\sqrt{s_{NN}} \approx 8$  GeV) (see Fig. 1). This limits a search for the critical point to an energy range  $E_{lab} > 30A$  GeV ( $\mu_B(CP) < \mu_B(30A\text{GeV})$ ).

Fortunately, as discussed above and illustrated in Fig. 3, the best theoretical predictions locate the critical point in the  $(T, \mu_B)$  region accessible in nuclear collisions in this energy range (at about 80A GeV). There are, however, large and difficult to estimate systematic errors in these predictions.

Under the minimal assumption that the critical point is located with equal probability at  $\mu_B(CP) < \mu_B(30A\text{GeV})$  one can estimate a probability of 0.5 that it is reachable in the SPS energy range.

One of the first proposed signals of the critical point of strongly interacting matter was a maximum of the transverse momentum fluctuations in the (collision energy)-(system size) plane [34]. NA49 performed the system size scan at 158A GeV and, in fact, a maximum was observed

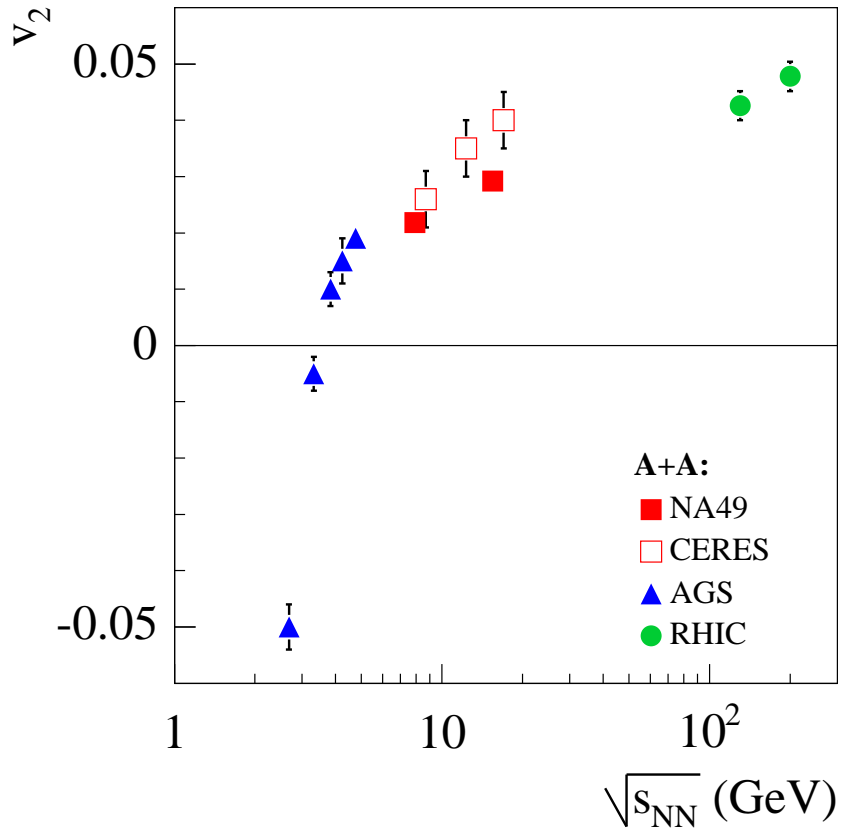
for collisions with a number of interacting nucleons of about 40 [45]. Qualitatively similar results were obtained by CERES [46]. The experimental results of NA49 are shown in Fig. 5, where the intensive fluctuation measure,  $\Phi_{P_T}$  is plotted against the mean number of interacting nucleons. The magnitude of the observed fluctuations,  $\Phi_{P_T} = 7 \pm 2$  MeV, is in approximate agreement with the predictions for the critical point,  $\Phi_{P_T} \approx 10$  MeV [47].



**Figure 6:** Scaled variance of the multiplicity distribution for negatively charged hadrons as a function of the number of projectile participants for Pb+Pb collisions at 158A GeV. The systematic errors due to a poor resolution in the measurement of the number of projectile spectators are indicated by the horizontal bars. The lines show predictions of string-hadronic models.

Onset of deconfinement and the critical point are also expected to lead to anomalies in the multiplicity fluctuations [29, 34]. The dispersion of the multiplicity distribution should increase by about 10-20% when crossing the energy domain in which the onset of deconfinement is located [29]. The scaled variance of the multiplicity distribution is expected to increase by about 10% in the vicinity of the critical point [34]. The identification of these effects is however non-trivial. This is mainly because the measured multiplicity fluctuations are directly sensitive to the fluctuations in the number of interacting nucleons caused by event-by-event changes in the collision geometry.

First results from NA49 on the scaled variance of the multiplicity distribution as a function of the number of interacting nucleons from the projectile nucleus are shown in Fig. 6. The measurements show an increase towards peripheral collisions similar to that seen for  $\Phi_{P_T}$ . This increase is not present in existing string-hadronic models [48]. It was recently suggested [49] that the large fluctuations for peripheral collisions may be caused by equilibration (mixing) of particle sources from the projectile and target nuclei. It is clear that clarification of the origin of the observed large increase of multiplicity fluctuations in peripheral collisions is a necessary first step in a search for the fluctuation signals of the critical point or onset of deconfinement. This requires new high



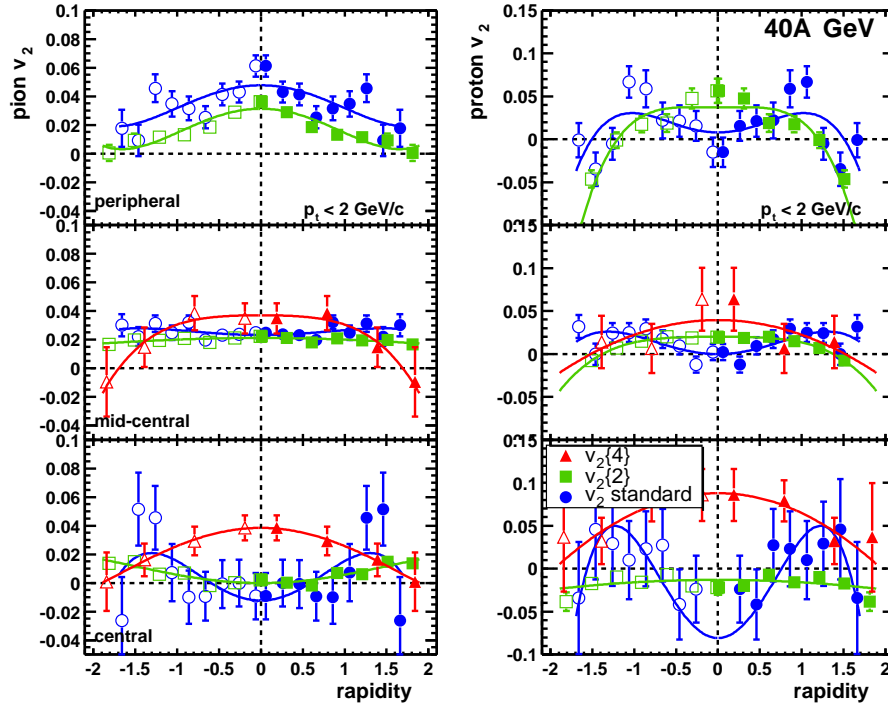
**Figure 7:** The energy dependence of elliptic flow of charged pions at mid-rapidity in Pb+Pb (Au+Au) collisions for mid-central events.

precision comprehensive data on multiplicity fluctuations and an improved forward calorimeter to reduce uncertainties in the determination of the collision geometry.

Whether the measured  $p_T$  and multiplicity fluctuations signal the vicinity of the critical point (line) remains an open question. This is mainly because systematic data on the energy and collision system size dependence of these fluctuation observables are missing. Only an observation of a maximum (or an onset) in the energy dependence will serve as a strong indication for the critical point (line).

The energy dependence of anisotropic flow is considered to be sensitive to both the onset of deconfinement [30] and the critical point [50]. The two can be distinguished by separate measurements of the flow for mesons and baryons. In the case of the onset of deconfinement the flow of both mesons and baryons should be reduced [51], whereas the critical point should lead to a decrease of the baryon flow and an increase of the meson flow [50]. However, the existing data [52] are inconclusive on whether the expected effects are present in the CERN SPS energy range. The main experimental results are summarized in Figs. 7 and 8. The energy dependence of the  $v_2$  parameter for pions in Pb+Pb (Au+Au) collisions is shown in Fig. 7. A rapid increase observed at low energies seems to weaken in the SPS energy range. In Fig. 8 the rapidity dependence of

the elliptic flow parameter,  $v_2$ , of pions and protons is plotted for Pb+Pb collisions at 40A GeV. The results from the standard analysis suggest the reduction of  $v_2$  for protons at mid-rapidity. This effect is, however, not observed in the results from the cumulant analysis and the 40A GeV data from NA49 are the only data on proton flow at low SPS energies. Thus the present data suggest the possibility of anomalies in the energy dependence of elliptic flow of mesons and baryons at the SPS energies, but they are too sparse to allow any firm conclusion.



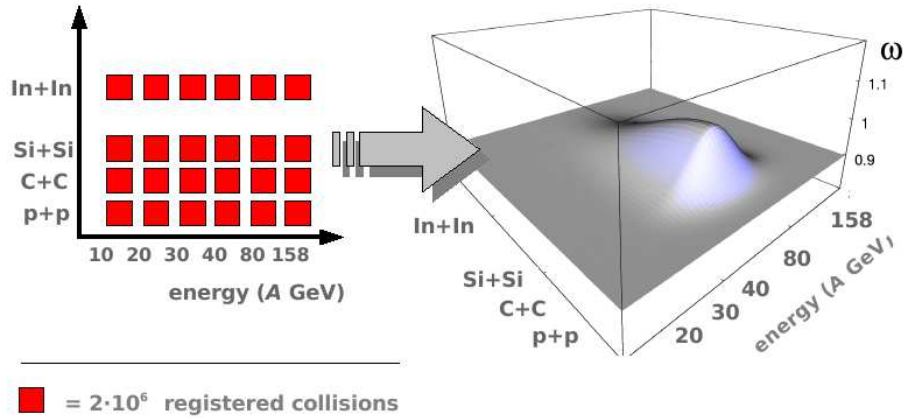
**Figure 8:** Elliptic flow of charged pions (left) and protons (right) obtained from the standard ( $v_2$  standard) and cumulant ( $v_2\{2\}$ ) methods as a function of the rapidity in Pb+Pb collisions at 40A GeV for three centrality bins. The open points have been reflected with respect to mid-rapidity. The solid lines are from polynomial fits.

It is thus clear that only the new measurements at the CERN SPS can answer the important question:

- **does the critical point of strongly interacting matter exist in nature and, if it does, where is it located?**

The qualitative progress in the experimental search which will be achieved by the proposed new measurements is illustrated in Fig. 9. The critical point is expected to manifest itself e.g. by a maximum of the scaled variance  $\omega$  of the produced particle multiplicity distribution. A detailed discussion of the requested reactions is given below.

In conclusion, the recent experimental and theoretical findings strongly suggest that a further study of nuclear collisions in the CERN SPS energy range is of particular importance. The new



**Figure 9:** An illustration of the impact of the new measurements of central collisions on the search for the critical point of strongly interacting matter.

measurements will dramatically improve the current experimental situation and they should allow to answer the key questions concerning the nature of the onset of deconfinement and the existence and location of the critical point.

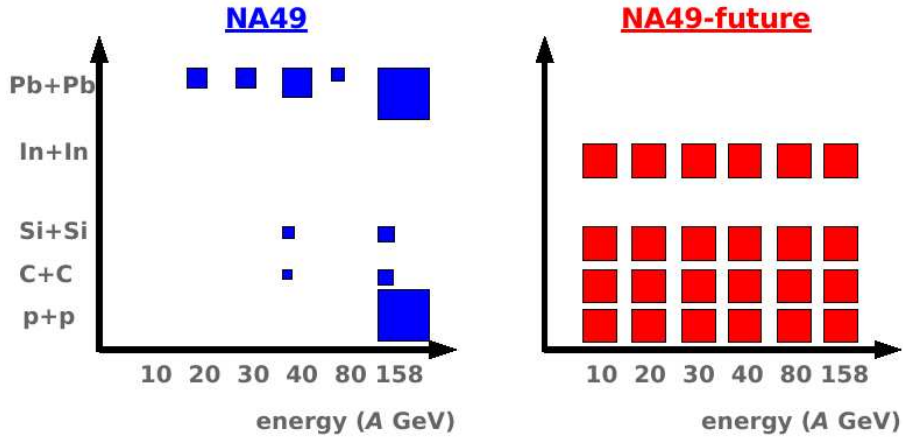
## 2.4 General requirements

The physics goals of the new experimental program with nuclear beams at the CERN SPS presented in the previous section require a comprehensive energy scan in the whole SPS energy range (10A-200A GeV) with light and intermediate mass nuclei. The NA49-future collaboration intends to register p+p, C+C, Si+Si and In+In collisions at 10A, 20A, 30A, 40A, 80A, 158A GeV and a typical number of recorded events per reaction and energy of  $6 \cdot 10^6$ .

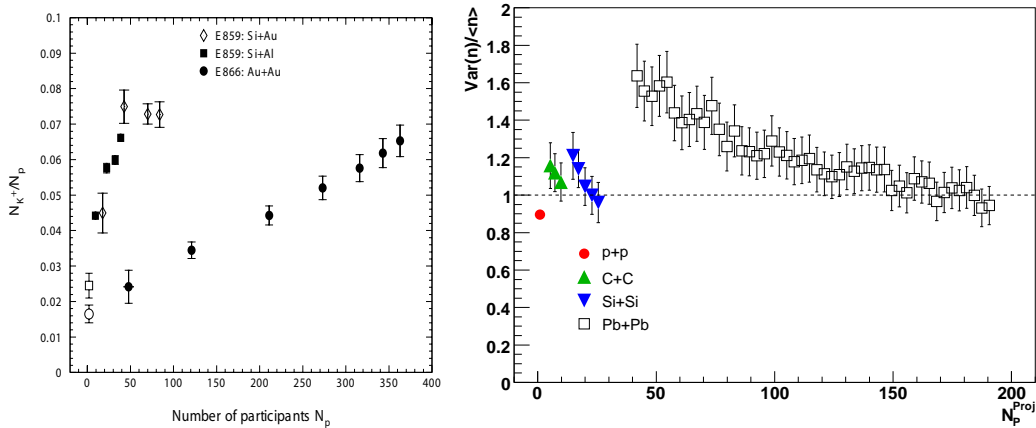
The data sets recorded by NA49 and those planned to be recorded by NA49-future are shown in Fig. 10. It is clear that the new measurements will lead to a very significant experimental progress.

It is important to underline that collisions of medium size and light nuclei can not be replaced by centrality selected collisions of heavy (e.g. Pb+Pb) nuclei. This point is illustrated in Fig. 11, where a large difference between hadron production properties in central collisions of light nuclei and peripheral Pb+Pb (Au+Au) interactions is clearly seen. This conclusion is valid both for mean values (Fig. 11 (left)) and for fluctuations (Fig. 11 (right)). Furthermore it has to be stressed that a hadronic final state produced in central collisions is much closer to the chemical and thermal equilibrium than a corresponding final state produced in peripheral collisions. Thus, for the planned study of the properties of the onset of deconfinement and the search for the critical point central collisions are of primary interest.

The future analysis should focus on the study of fluctuations and anisotropic flow. The first NA49 results on these subjects [52, 45, 53, 54] suggest, in fact, the presence of interesting effects for collisions with moderate number of participant nucleons and/or low collision energies. However, as discussed above, a very limited set of data and resolution limitations do not allow firm conclusions.



**Figure 10:** The data sets recorded by NA49 and those planned to be recorded by NA49-future. The area of the boxes is proportional to the number of registered central collisions, which for NA49-future will be  $2 \cdot 10^6$  per reaction.



**Figure 11:** Left: The mean number of  $K^+$  mesons per participant nucleon is plotted as a function of the number of participants for for Si+Al, Si+Au and Au+Au collisions at the top AGS energies (10A-14A GeV). Right: The scaled variance of the multiplicity distribution of negatively charged hadrons in the projectile hemi-sphere for p+p, C+C, Si+Si and Pb+Pb interactions is plotted versus the number of projectile participants.

Several upgrades of the current NA49 apparatus are necessary to reach the physics goals.

1. The event collection rate should be significantly increased in order to allow a fast collection of sufficient statistics for a large number of different reactions ( $A, \sqrt{s_{NN}}$ ).
2. The resolution in the event centrality determination based on the measurement of the energy of projectile spectator nucleons should be improved. This is important for high precision measurements of event-by-event fluctuations.

3. It is desirable to increase the acceptance for the measurements of charged hadrons.

The proposed hardware upgrades of the NA49 apparatus and the resulting improvements of its physics performance are presented in the proposal [1].

## 2.5 Experimental landscape

The SPS energy range is of particular importance for the study of nucleus-nucleus collisions for two reasons. Firstly, at the low SPS energies anomalies in the energy dependence of hadron production properties are observed. They are attributed to the onset of deconfinement. Secondly, at high SPS energies the critical point of strongly interacting matter can be discovered. This expectation is based on the recent estimate of the location of the critical point from lattice QCD and the freeze-out parameters determined from measured hadron yields using the hadron-resonance gas model.

Among other existing heavy ion accelerators only RHIC at BNL can potentially run in the SPS energy range. In March 2006 a RIKEN BNL workshop "Can the QCD critical point be discovered at the BNL RHIC" took place, where it was decided to start preparations for a low energy RHIC program. The first tests of the accelerator complex were performed in June 2006. Proton beams of 11 GeV/c ( $\sqrt{s_{NN}} = 22$  GeV) were successfully injected, circulated and collided at RHIC. The magnet currents for this test correspond to those required for Au+Au running at  $\sqrt{s_{NN}} \approx 8.8$  GeV, or equivalently with fixed target running at about 40A GeV. Tests at lower energies using ion beams are foreseen in 2007. The physics run with Au beams at several energies which correspond to the NA49 settings may be scheduled for 2009. The performance of the STAR and PHENIX detectors matches, in general, the physics requirements of running at low RHIC energies.

The SPS program proposed here and the suggested new RHIC program are to a large extent complementary. This is due to different collision kinematics and different priorities in data taking.

NA49-future at the SPS will take data in the fixed target mode. First, this gives the unique possibility to measure the number of projectile spectators for each collision, which, in turn, allows a precise study of event-by-event fluctuations, in particular, fluctuations of extensive quantities like multiplicity. Second, the NA49-future acceptance for identified hadrons covers a large part of the projectile hemi-sphere. This allows measurement of almost the full rapidity spectrum and total multiplicities of produced hadrons. NA49-future intends to perform the energy scan for collisions of light and medium size nuclei (p+p, C+C, Si+Si and In+In).

In contrast, it is planned to start the low energy RHIC program with the energy scan for Au+Au collisions. STAR and PHENIX at the RHIC will take data in the collider mode. This allows to perform measurements with full and uniform azimuthal angle acceptance and forward-backward symmetry with respect to mid-rapidity. This is crucial for a precise measurement of azimuthal flow and other measures of azimuthal correlations.

Starting from 2015 the study of nucleus-nucleus collisions at lower SPS energies (10A-40A) will be continued by the CBM experiment at SIS-300 (FAIR, Darmstadt). Low cross-section processes, like di-lepton as well as open and hidden charm hadron production will be the focus of these measurements.

Furthermore there is a discussion of the possibility to construct a heavy ion collider at JINR, Dubna, which would also cover the low SPS energy range.



### 3. Summary

There are numerous exciting physics questions which motivate a new experimental program to study hadron production in hadron-nucleus and nucleus-nucleus collisions at the CERN SPS which has been recently proposed by the NA49-future collaboration. The goals of the program are:

- search for the critical point of strongly interacting matter and a study of the properties of the onset of deconfinement in nucleus-nucleus collisions,
- measurements of correlations, fluctuations and hadron spectra at high  $p_T$  in proton-nucleus collisions needed as for better understanding of nucleus-nucleus results,
- measurements of hadron production in hadron-nucleus interactions needed for neutrino (T2K) and cosmic-ray (Pierre Auger Observatory and KASCADE) experiments.

The nucleus-nucleus program has the potential for an important discovery – the experimental observation of the critical point of strongly interacting matter. Other proposed studies belong to the class of precision measurements. The collaboration proposes to perform these measurements in the period 2007–2011 by use of the upgraded NA49 apparatus. Synergy of different physics programs as well as the use of the existing accelerator and detectors offer the unique opportunity to reach the ambitious physics goals in a very efficient and cost effective way.

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