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Addendum to the proposal P330

Additional Information Requested in the Proposal Review Process

By NA49-future Collaboration
http://na49future.web.cern.ch

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This documents presents additional information on the proposal [1] requested by the SPSC referees during the review process.

1 Update of the author list

After submission of the proposal three new groups joined the collaboration, namely:

- the group from the University of Bern, Bern, Switzerland (group leader A. Ereditato),
- the group from the ETH, Zurich, Switzerland (group leader A. Rubbia) and
- the group from the Soltan Institute for Nuclear Studies, Warsaw, Poland (group leader E. Rondio).

Currently the collaboration consists of 106 physicist from 25 institutes and 15 countries. About 20 % of the collaboration members also participate in the ALICE (a dedicated heavy ion) experiment at the CERN LHC.

2 Comments on the run schedule

The proposed run schedule, proton runs in 2007-2008 for the T2K and cosmic-ray experiments and ion and proton runs in 2009-2011 for the study of strong interactions (see section 5.4 of the proposal [1]), aims to:
(1) fit the external constraints and
(2) maximize synergy effect between different physics programs.

add. (1) External constraints.

The ion beams for the fixed target program are expected to be available starting from 2009, whereas the proton beam starting from 2007. In order to test the prototypes of the detector upgrades (the TPC read-out electronics and the PSD) a minimum of 10 days of beam time are required in 2007.

To perform the measurements for T2K will require (at least) two years of data taking. We would like to measure these cross sections under different conditions (beam energy and target thickness) to a quality level that allows sufficient precision to the end of the T2K program and sequels.

A significant measurement could be achieved already in 2007, if sufficient data taking time (2 to 3 weeks) is granted. These data will be also used to understand the systematics of the measurement to the precision level required. We are requesting 30 days of beam time in 2007. About 2 weeks are needed for setup and test of the NA49-future apparatus and the prototypes. Two weeks would be dedicated to physics data taking. The cost of the experiment in 2007 outlined in Table 2 is largely independent of the running time.

If there is no run in 2007 the whole program will suffer a parallel shift by one year.

T2K will start data taking in 2009. It is important to take data for T2K now, since the resources (mainly manpower) available now to run NA49-future might be reduced once T2K starts taking data in 2009.

The RHIC physics runs with Au beams at several energies are expected to start in 2009. Thus it is highly recommended to run the complementary SPS ion program before or in parallel to the RHIC program.

add. 2 Synergy effect between different physics programs.

Runs with ion beams require all upgrades needed for the proton runs and, in addition, the introduction of the Projectile Spectator Detector and the beam pipe. The R&D and construction time for the PSD is estimated to be about 2 years. Thus the proposed sequence of runs, 2007-2008 proton runs and 2009-2011 ion and proton runs, allows to sequentially implement and test all necessary upgrades and take in parallel the requested physics data.

3 Resources provided by the collaborating institutes

This chapter gives detailed lists of the resources provided by the collaborating institutes.

Yearly common fund contributions of the NA49-future participating groups are presented in Table 1 for the whole running period.

Table 2 presents expected sources of money which will cover the cost of upgrades, maintenance and running of the experiment in the first three years (see Table 5 of the proposal [1]). During the last two years of the operation no upgrades are foreseen. The cost of running and maintenance will be about 100 kCHF per year and it will be covered from the common fund (see Table 1).

The presented list of contributions assumes approval of the NA49-future grant applications which are planned to be submitted by the participating groups.

4 Resources requested from CERN

In this chapter resources requested from CERN are presented.

4.1 Beams

Standard secondary hadron beams with a typical intensity of 10^6 particles per spill are requested in accordance with the running plan presented in section 5.4 of the proposal [1].

Primary ion beams with a typical intensity of 10^6 particles per spill are needed for the ion part of the program which will start in 2009. A detailed running plan is given in

Institute	Contribution (kCHF)
Athens	5
Bari	5
Bergen	5
Bern	5
Budapest	5
Cape Town	10
Cracow	5
Dubna	5
IKF Frankfurt	5
Geneva	5
Karlsruhe	10
Kielce	5
Paris	5
Pusan	1
Sofia	1
St. Petersburg	3
Stony Brook	10
KEK Tsukuba	5
WUT Warsaw	5
WU Warsaw	5
SINS Warsaw	5
Zagreb	5
ETH Zurich	5
total	120

Table 1: Expected yearly common fund contributions for the running period 2007-2011.

section 5.4 of the proposal [1]. Secondary ion beams as used by NA49 are not suitable for NA49-future running due to two reasons:

- the NA49 studies show that only low mass nuclei (up to about silicon) can be produced via fragmentation of the Pb beam, thus a secondary In beam is excluded,
- for a given Z/A setting of the beam line only a small fraction (of the order of several %) of all nuclei has the requested nuclear mass number. Thus the required intensity of light nuclei implies a very high overall intensity of the secondary beam leading to a delta-electron background larger by more than one order of magnitude than in the case of using a primary light ion beam.

Item	Cost (kCHF)	Covered by
2006/2007		
pool electronics	60	CF(15),SG(45)
TPC maintenance and gas	30	PG(10), SG(20)
upgrade of the TPC cooling system	20	SG(20)
upgrade of the TOF read-out	20	CF(20)
TPC slow control and monitoring	33	PG(10), SG(23)
DAQ+CDR upgrade	5	CF(5)
BPDs	10	PG(10)
Graphite target	15	KEK(15)
PSD super-module	70	Bergen(30), CF(40)
Safety	10	CF(10)
technician (500h)	30	CF(30)
total	303	
2007/2008		
TPC DAQ upgrade	440	Budapest(220), SG(220)
TPC gas	30	CF(30)
PSD production	350	Bergen(200), Stony Brook(150)
technician (500h)	30	CF(30)
total	850	
2008/2009		
TPC gas	30	CF(30)
PSD production	350	PG(200), Stony Brook(150)
He beam pipe	30	CF(30)
technician (500h)	30	CF(30)
total	440	

Table 2: Estimate of the cost of upgrades, maintenance and running for the first 3 years of the NA49-future operation and the expected sources of money. The used abbreviations are: CF - common fund, PG - Polish groups (UJ Cracow, AS Kielce, UW Warsaw, WUT Warsaw and SINS Warsaw), SG - Swiss groups (UB Bern, ETH Zurich, UG Geneva). The numbers in brackets indicate the expected contributions in kCHF.

The following information concerning ion beams for NA49-future was provided by D. Kuechler (CERN AB/ABP). With the present source there is experience in the production of lead ion beams. The predecessor source delivered lead, indium, oxygen and helium ions. So one does not expect any technical obstacles that would prevent production of beams of carbon, sulphur (or something in the same mass range) and indium. However, these beams

Institute	Seniors	Students (Ph. D and M. Sc.)
Athens	3	1.5
Bari	2	1
Bergen	0.5	1
Bern	1	0
Budapest	4	2
Cape Town	0.5	1
Cracow	3	1.5
Dubna	3	1.5
FH Frankfurt	0.5	-
IKF Frankfurt	2	1.5
Geneva	1	1
Karlsruhe	0.5	1
Kielce	3	1.5
Moscow	1.5	-
Paris	1	1
Pusan	0.5	1
Sofia	1	1
St. Petersburg	1	1
Stony Brook	1	1
KEK Tsukuba	0.5	-
WUT Warsaw	1.5	3
WU Warsaw	1	2
SINS Warsaw	0	0.5
Zagreb	1	1
ETH Zurich	1	1
total	34.5	20.5

Table 3: Expected yearly manpower devoted to NA49-future averaged over the running period 2007-2011.

have to be studied first (the production in the source, the transport in the machines, beam properties, beam reliability). This needs manpower and resources which are not foreseen at the moment.

4.2 NA49-future magnets

All requested runs will require operation of the two superconducting NA49-future magnets. In the past NA49 running the operation and maintenance of the magnets was done by the corresponding CERN groups and the cost was covered by CERN. The same service is requested for NA49-future.

Year	O&M cryogenics plants (kCHF)	Electrical power (kCHF)	O&M power converters (kCHF)
2007	120	40	5
2008	120	60	5
2009	120	80	5
2010	120	80	5
2011	120	80	5
All years	600	340	25

Table 4: Estimated costs of the operation and maintenance (O&M) and electrical power related to the two NA49-future superconducting magnets resulting from the NA49-future runs requested in section 5.4 of the proposal [1].

According D. Delikaris (CERN-AT-ECR group) the operation and maintenance cost for both helium cryogenic plants associated to the two NA49 magnets is approximately 120 kCHF per year (CERN AT Department budget). The electrical power needed for operating the cryogenic plants (global CERN budget under TS Department supervision) costs approximately 40 kCHF per one month of running (1 MW electrical power for both cryogenic plants and a mean cost of 55 CHF per MW·hour are assumed).

An estimate by F. Bordry (CERN AB-PO group) of the annual maintenance and operation cost for the two magnet power converters is 5 kCHF. The main cost is driven by the annual maintenance and commissioning time at the start of the run. The operation during the year is performed by the standby service taking care of the North Area.

The costs are summarized in Table 4.

4.3 IT resources

The requested IT resources are related to:

- transfer of the raw data from the experiment to the IT storage media,
- storage of the raw data, dsts and mini-dsts,
- reconstruction and subsequent analysis of the taken data.

Table 5 shows year-by-year the expected volume of the raw data, dsts and mini-dsts.

In order to transfer the raw data from the experiment to the IT storage medium an optical Gigabit Ethernet link is requested by August 2007. Furthermore a wireless access

Year	Raw data (TB)	DST (TB)	Mini-DST (TB)	Sum (TB)
2007	2.1	1.5	0.03	3.63
2008	52.5	30	0.7	83.2
2009	74.8	42.8	2.5	120
2010	73.1	50.4	1.4	125
2011	53	37	0.9	91
All years	255	162	5.5	423

Table 5: An estimate of the volume of the raw data, dsts and ROOT mini-dsts resulting from the NA49-future runs requested in section 5.4 of the proposal [1]
.

point is needed in the NA49-future counting houses to allow effective work during the running periods.

The incremental requested IT storage volume is given in the last column of Table 5.

The IT batch time needed for event reconstruction and analysis is presented in Table 6. Note that the requested resources consist only a small fraction of the resources needed for the LHC experiments.

Year	Reconstruction (KSI2K)	Analysis (KSI2K)
2007	1	1
2008	20	1
2009	550	30
2010	1900	180
2011	1300	240
2012	800	280
2013	-	280
2014	-	280
2015	-	280

Table 6: Estimated IT batch time in KSI2K units needed for reconstruction and analysis of the data resulting from the NA49-future runs requested in section 5.4 of the proposal [1].

5 List of NA49 data and publications

A summary of the data taken by NA49 is presented in Table 7 together with the references to the papers where the corresponding physics results are presented. In the reference list the publications with final results are marked (final), whereas the conference contributions with preliminary data are marked (preliminary).

The analysis and publishing of existing NA49 data, in particular on p+p and p+A reactions, is continuing. However, we want to stress that the recorded NA49 data sets in Table 7 will not fulfill the requirements of the NA49-future programme as summarized in Table 8. The T2K and cosmic ray measurements need different energies and targets. The high p_T program must extend the p_T range for p+p and p+Pb collisions and therefore aims at an order of magnitude higher event statistics (the justification is discussed in more detail below). Finally, the study of the onset of deconfinement and the search for the critical point require p+p and p+Pb collision data at the energies below 158 GeV for baseline comparisons which are not available from NA49 (the 100 and 40 GeV p+p data sets of NA49 are not usable for this purpose due to non-functioning of part of the detector). The energy scan for p+p and p+Pb collisions planed during 2009 and 2011 runs will be complemented by the runs at 158 GeV. These data will be taken in the same run as the data at lower energies in order to minimize relative systematic errors in the study of energy dependence of hadron production properties.

6 NA49-future physics versus data sets

A summary of all data sets planned to be registered by NA49-future are given in Table 8 marked by acronyms of physics which motivates them. In the following the physics cases are briefly explained.

- Data for T2K. High precision measurements of the differential cross-section (momentum and polar angle) for charged pion and kaon production in p+C interactions at 30, 40 and 50 GeV. These data are needed by the T2K neutrino experiment for a detailed simulation of the initial neutrino flux which is necessary to achieve the required precision on the neutrino oscillation parameters. For more details see chapter 2.1.1 of the proposal [1].

- Data for C-R. High precision measurements of the differential cross-section of identified hadrons in p+C interactions at 30, 40, 50 and 400 GeV. These data are needed by the cosmic-ray experiments (KASCADE and Pierre Auger Observatory) in order to reduce uncertainties of hadron production models used in the analysis of data on high energy cosmic-ray reactions. The new results will significantly improve the resolution of cosmic-ray experiments. For more details see chapter 2.1.2 of the proposal [1].

- High p_T. Large statistics measurements of hadron production in p+p and p+Pb interactions at 158 GeV needed as reference data for better understanding of hadron spectra at high transverse momenta in nucleus-nucleus reactions. Suppression of

System	Energy (A GeV)	Centrality	Event statistics	(References to the results) /Comments/
Pb+Pb	158	central	4000k	([2]-[35])
...	...	min. bias	720k	([2]-[35])
...	80	central	300k	([2]-[35]) + ([37]-[54])
...	40	central	700k	([2]-[35]) + ([37]-[54])
...	...	min. bias	800k	([2]-[35]) + ([37]-[54])
...	30	central	450k	([2]-[35]) + ([37]-[54])
...	...	semi central	450k	([2]-[35]) + ([37]-[54])
...	20	central	360k	([2]-[35]) + ([37]-[54])
...	...	semi central	320k	([2]-[35]) + ([37]-[54])
Si+Si	158	semi central	460k	([56]-[58]) + ([29]-[31])
...	40	semi central	250k	+ ([59]-[60])
C+C	158	semi central	410k	([56]-[58]) + [29]-[31])
...	40	semi central	140k	+ ([59]-[60])
p+Pb	158	semi central	2600k	([64]-[65])
...	100	semi central	470k	/no results/
p+Al	158	min. bias	360k	/no results/
p+C	158	min. bias	570k	([62])
...	100	min. bias	200k	/no results/
p+p	158	min. bias	3900k	([28]-[61]) + ([29]-[31]) + ([23],[18],[25], [63])
...	100	min. bias	640k	/incomplete event information/
...	40	min. bias	410k	/incomplete event information/
d+p	158	min. bias	300k	([63])
π+p/Pb	158	min. bias	3300k	([66])

Table 7: Data sets taken by NA49 and references to the corresponding physics results. In 27 publications the final results are presented, whereas in 37 the preliminary data are shown. The event statistics corresponds to the total number of events registered on tape. For reactions with hadrons and light nuclei a fraction of non-target, background, events reaches up to 50%.

hadron yield at high transverse momenta in central heavy ion collisions relative to the p+p and p+A interactions is one of the most important RHIC results. It reflects properties of high energy density matter created in the collisions. The discriminating power of the corresponding results at SPS is poor due to the absence of high statistic measurements in p+p and p+Pb interactions. For more details see chapter 2.2 of the proposal [1] and chapter 7 of this document.

- CP&OoD. Measurements of hadron production in nucleus-nucleus collisions in the

SPS energy range with the aim to identify the properties of the onset of deconfinement and find evidence for the critical point of strongly interacting matter. 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, will be performed.

The new data can answer the questions:
- what is the nature of the transition from the anomalous energy dependence measured in central Pb+Pb collisions at SPS energies (interpreted as evidence of the onset of deconfinement), to the smooth dependence suggested by the existing p+p results ? and
- does the critical point of strongly interacting matter exist in nature and, if it does, where is it located ?
For more details see chapter 2.3 of the proposal [1].

- $\overline{\text{CP\&OoD}}$ Measurement of energy dependence of hadron production in p+p and p+Pb interactions at SPS. These results are needed to test alternative explanations of the effects which are, or will be, considered as signals of the onset of deconfinement and the critical point. The alternative interpretations are based on string-hadronic approaches which use as input results from p+p and p+Pb reactions. The attempts to understand production of strange hadrons by extrapolation of the results measured in p+p and p+Pb collisions serve as a well known example [68, 69]. For more details see chapter 2.2 of the proposal [1].

Reaction	Energy (A GeV)	Year	Event statistics	Physics
p+C	30	2007	$3 \cdot 10^6$	Data for T2K, C-R
p+C	30, 40, 50	2008	$25 \cdot 10^6$	Data for T2K, C-R
p+ C	400	2008	$5 \cdot 10^6$	Data for C-R
p+p/Pb	158	2008	$55 \cdot 10^6$	High p_T
p+p	158	2010	$60 \cdot 10^6$	High p_T
In+In	10, 20, 30, 40, 80, 158	2009	$36 \cdot 10^6$	CP&OoD
Si+Si	10, 20, 30, 40, 80, 158	2010	$36 \cdot 10^6$	CP&OoD
C+C	10, 20, 30, 40, 80, 158	2011	$36 \cdot 10^6$	CP&OoD
p+p	10, 20, 30, 40, 80, 158	2009	$36 \cdot 10^6$	CP&OoD, $\overline{\text{CP\&OoD}}$
p+Pb	10, 20, 30, 40, 80, 158	2011	$36 \cdot 10^6$	$\overline{\text{CP\&OoD}}$

Table 8: Summary of the data sets to be taken and the physics which motivates them.

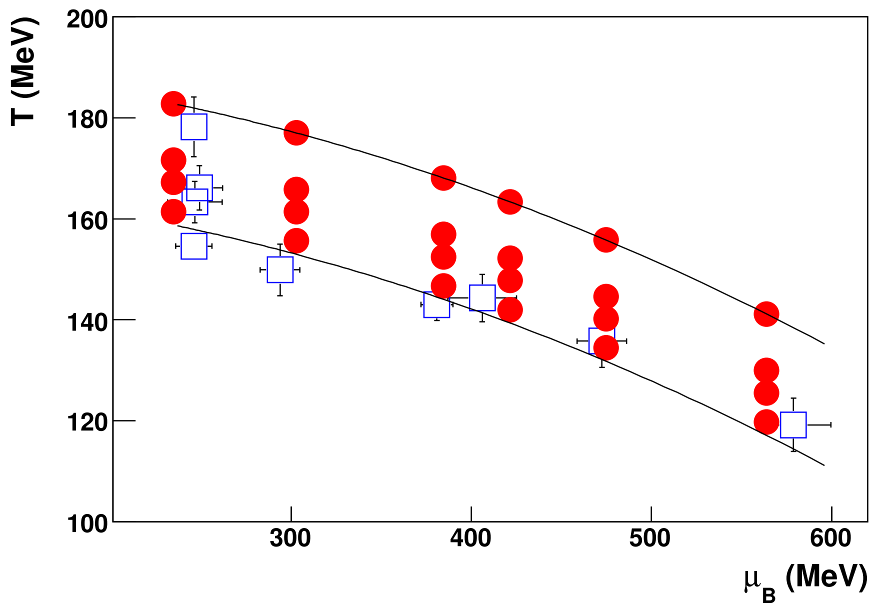

Figure 1: Hypothetical positions of the chemical freeze-out points of the reactions (In+In, S+S, C+C and p+p from bottom to top at 158A, 80A, 40A, 30A, 20A and 10A GeV from left to right) to be studied by NA49-future in the (temperature)-(baryo-chemical potential) plane are shown by full dots. The open squares show the existing data. For more details see text.

The proposed physics 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 critical point is expected to be found by a measurement of a maximum of fluctuations in transverse momentum and multiplicity in the two dimensional plane of system size and collision energy (see e.g. Fig. 23 of the proposal [1]). In the physics of the critical point the relevant parameters are the temperature and the baryo-chemical potential at the freeze-out of strongly interacting matter. These parameters vary under changes of the system size and collision energy. The hypothetical positions of the chemical freeze-out points for central In+In, S+S and C+C collisions (full dots from bottom to top) at 158A, 80A, 40A, 30A, 20A and 10A GeV (full dots from left to right) are shown in Fig. 1. These positions are calculated using a parametrization [67] of the dependence of T and μ_B on collision energy and system size based on the existing data. These data are shown in Fig. 1 by the open squares. The upper open and the corresponding full dots indicate the upper limit of the temperature obtained for p+p interactions. Note that for these collisions the grand canonical approximation is not valid and thus baryo-chemical potential and temperature are not well defined. The lower solid line shows the parametrization for the central Pb+Pb collisions.

7 Critical point search strategy

This chapter summarizes basic elements of the NA49-future strategy in a search for the critical point of strongly interacting matter. The details are given in the proposal [1].

1. The critical point is expected to lead to an increase of multiplicity and transverse momentum fluctuations [70] provided the freeze-out of the matter takes place in its vicinity ($\Delta T \approx 10$ MeV and $\Delta \mu_B \approx 50$ MeV [71]).

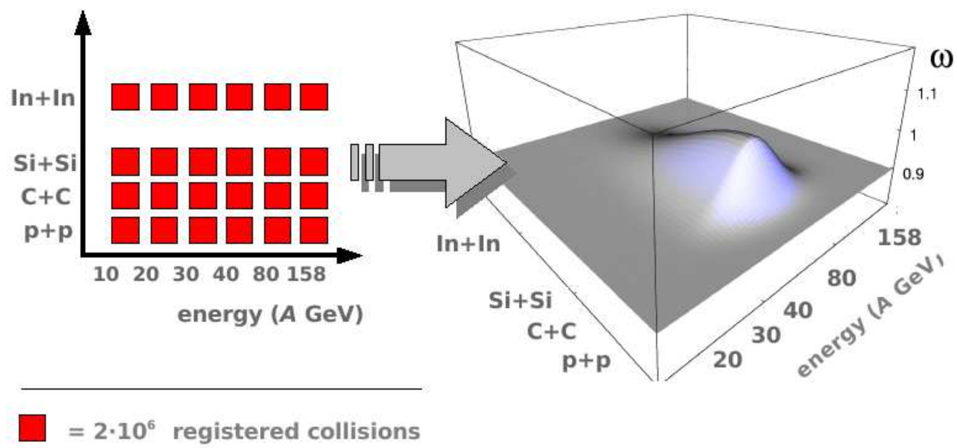

Figure 2: An qualitative illustration of the NA49-future strategy in search for the critical point of strongly interacting matter. For details see text.

2. Freeze-out parameters, the temperature T and baryo-chemical potential μ_B, depend on the collision energy and the size of the colliding nuclei (see Fig. 1).

3. NA49-future plans to perform a first comprehensive scan in energy and the system size (see Table 8) which will allow for a detailed study of matter properties as a function of T and μ_B.

4. Thus, if the critical point is located in the scanned region of the phase diagram as suggested by the lattice QCD calculations [72], it should be signaled by a "hill" of fluctuations over smoothly varying background in the (collision energy)-(system size) plane. This qualitative prediction (see Fig. 2 for its graphical illustration), if

confirmed by the data, will serve as a strong argument [73] for the existence of the critical point and its location in the phase diagram of strongly interacting matter.

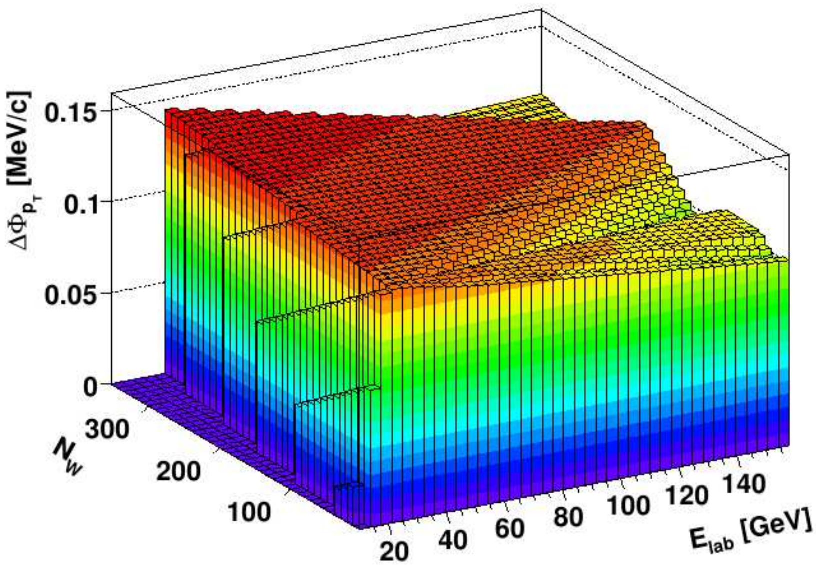

Figure 3: The expected statistical error of the Φ_{p_T} measure of transverse momentum fluctuations for $2{\cdot}10^6$ events as a function of the system size and collision energy.

5. The QCD-inspired calculations [70] predict that the critical point should lead to an increase of the scaled variance of the multiplicity fluctuations by about 10% and an increase of the Φ_{p_T} measure of the transverse momentum fluctuations by about 10 MeV/c. NA49-future will measure the scaled variance and Φ_{p_T} in central A+A collisions and p+p interactions with statistical errors smaller than 0.5% and about 0.15 MeV/c, respectively. The expected statistical error of Φ_{p_T} as a function of the system size and collisions energy is shown in Fig. 3. The corresponding systematic errors will be about 1% and 0.5 MeV/c. The above estimates are performed based on the NA49 results. Thus clearly NA49-future has the required sensitivity for a search for the critical point.

6. The background fluctuations are influenced by several physics phenomena. In particular these are a variation in the collision geometry, conservation laws, quantum statistics, resonances decays and production of mini-jets. The resulting fluctuations are expected to vary smoothly with collision energy and the system size. Quantitative predictions of these fluctuations depend on the models used.

7. The pioneering NA49 results on fluctuations show several unexpected effects:
   -non-monotonic centrality and system size dependence of the transverse momentum fluctuations at 158A GeV [29],
   -non-monotonic centrality dependence of the multiplicity fluctuations in Pb+Pb collisions at 158A GeV [31] and
   -an increase of the kaon to pion ratio fluctuations with decreasing collision energy in central collisions [49].
   An interpretation of these results and their possible relation to the critical point is unclear. This is because comprehensive precision measurements of fluctuations are missing.

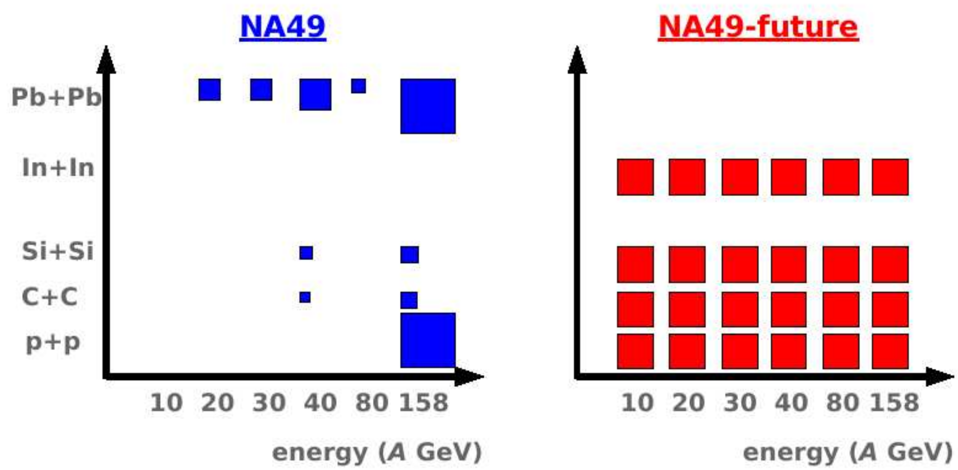

Figure 4: The data sets recorded by NA49 and those planned to be recorded by NA49-future in the CP&OoD program. The area of the boxes is proportional to the number of registered central collisions, which for NA49-future will be $2{\cdot}10^6$ per reaction.

8. The proposed NA49-future measurements with the upgraded NA49 detector would qualitatively improve the experimental situation (see Fig. 4 for a graphical illustration) and consequently allow for a quantitative understanding of fluctuations and at the same time would give the opportunity to discover the critical point of strongly interacting matter.

8 Additional information concerning high p_T physics

As discussed in Section 2.2 of the proposal [1] the interpretation of the inclusive particle spectra produced in nucleus-nucleus collisions at medium and high transverse momenta

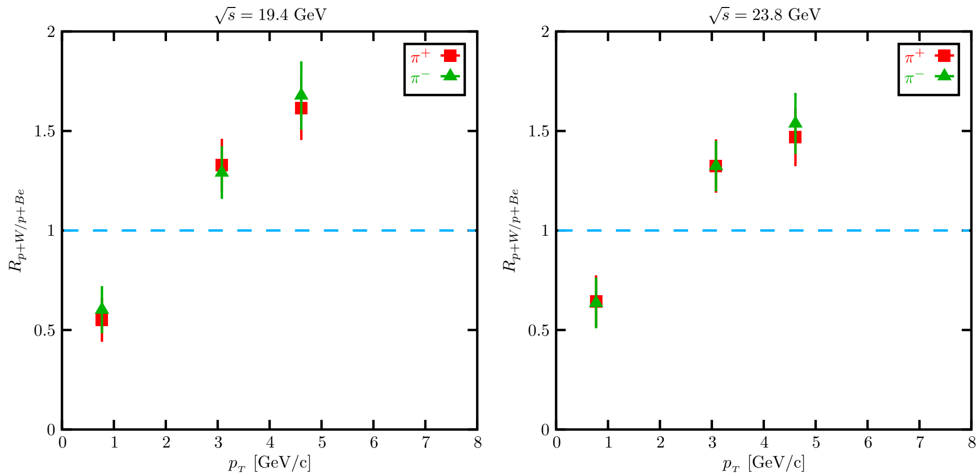

Figure 5: The Cronin enhancement in p+W relative to p+Be collisions [74, 75, 76]. The points above one indicate the Cronin enhancement.

requires a precise knowledge of the inclusive spectra in p+p and p+A reactions. Here additional information concerning this subject is given.

The change of the medium and high p_T spectra in A+A collisions relative to suitably normalized p+p and p+A interactions are due to an interplay of

- mechanisms leading to an enhancement of the relative particle yield and
- effects causing a suppression of the relative particle yield.

The enhancement was first observed in high energy p+A collisions (Fig. 5) and is referred to as the *Cronin effect*. It is interpreted as due to initial multiple scattering of the colliding particles (partons or hadrons), which transports energy from the longitudinal motion to the transverse motion and thus results in the particle yield excess at medium and high transverse momentum. The suppression was first observed in central Au+Au collisions at RHIC (Fig. 6), and is referred to as *high p_T suppression effect*. It is interpreted as due to energy loss of the produced particles (partons or hadrons) in the high density matter created at the early stage of the collisions. The measured spectra in Pb+Pb (Au+Au) collisions are affected by both effects and thus their understanding requires reference data on particle spectra in p+p (both Cronin and suppression effects are absent) and p+Pb (the Cronin effect only) interactions.

The aim of the high p_T NA49-future program is to measure hadron spectra at medium and high p_T in p+p and p+Pb interactions at the top SPS energy (158 GeV). This new data should allow to understand already existing spectra in central Pb+Pb collisions. This measurement is of special interest, because of the RHIC results for d+Au and Au+Au reactions at $\sqrt{s_{NN}} = 62.4, 130$ and 200 GeV (Fig. 6). Namely at RHIC energies there is a remarkable Cronin enhancement in d+A interactions, and there is a strong high p_T

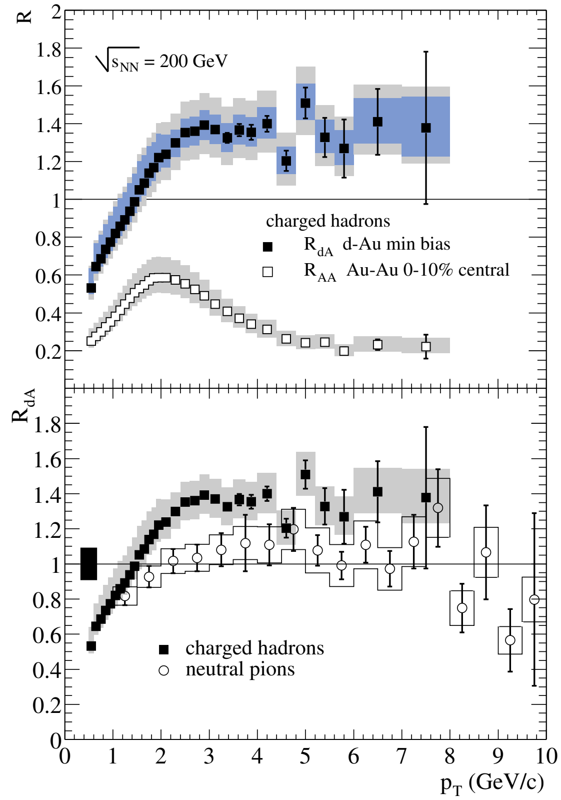

Figure 6: The high p_T suppression of charged hadrons in central Au+Au collisions relative to p+p interactions and Cronin enhancement in d+Au interactions at 200 GeV (for details see [77]).

suppression in central Au+Au collisions. The final interpretation of the current RHIC data clearly requires systematic high precision data on high p_T production at different energies and for various colliding systems.

In the near future experiments at CERN could play a crucial role in this field. First, high statistics results at LHC energies are expected within the next years. Second NA49-future can significantly improve the accuracy of the data at the top SPS energy. These results are of particular interest as they will yield information on the properties of matter at energy densities close to the phase transition. This is a very important but poorly understood region. In the farther future it will be possible to complement the SPS results by corresponding measurements at even lower energies with the CBM experiment at FAIR.

The understanding of the effect of the hadronic medium on particle production is the main motivation to study the energy dependence of high p_T spectra in A+A collisions with respect to the corresponding spectra in p+p and p+Pb interactions at the CERN

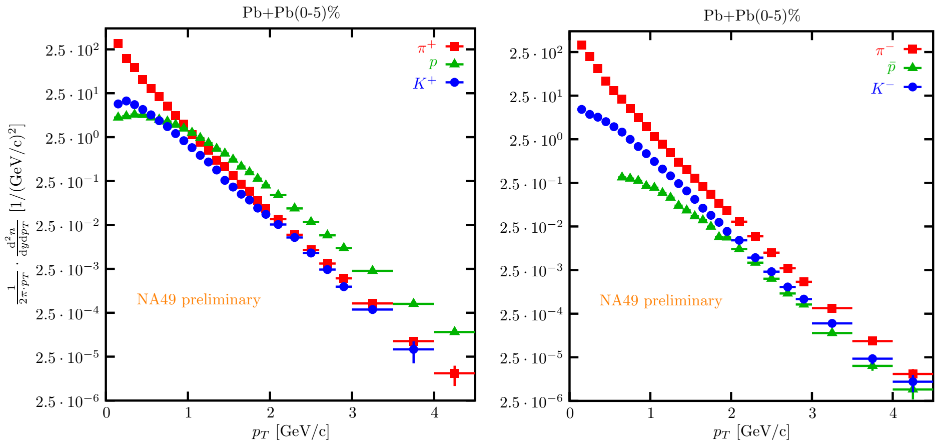

Figure 7: The identified charged particle invariant yields integrated on the rapidity domain $-0.3 \leq y \leq 0.7$; at 17.3 GeV/nucleon Pb+Pb collisions, at (0-5)% centrality (presented at Quark Matter 2005).

SPS. The accuracy of the current results at the top SPS energy in the interesting p_T range is poor because of the low statistics of existing data on p+p and p+Pb. Thus the main effort should go to the precision measurements of high p_T spectra in p+p and p+Pb reactions.

The Cronin and suppression effects are quantified via the measurement of the so called *nuclear modification* factor, defined by the ratio:

$$R_{A+A/p+p} = \frac{N_{p+p}}{N_{A+A}} \cdot \frac{(\text{Invariant yield})_{A+A}}{(\text{Invariant yield})_{p+p}},$$

where N_{A+A} and N_{p+p} denote the average number of binary collisions in A+A and p+p reactions, respectively. They are calculated within the Glauber-type models.

The heavy ion experiments at the CERN SPS (WA98 [81], NA45 [82], NA49 and NA57 [83]) already provided some remarkable information on the nuclear modification factor at top SPS energy. Namely, the experiment were able to measure identified particle spectra in Pb+Pb reaction at 17.3 GeV/nucleon c.m. energy up to 4.5 GeV/c in transverse momentum (for an example see Fig. 7).

However, the corresponding data for p+p and p+Pb reactions were either not recorded or low statistics limit the spectra to the low p_T domain ($p_T < 2.5$ GeV/c). In the case of NA49 data on p+p [61] and p+Pb interactions were recorded, but for both reactions the p_T spectra end at about 2.5 GeV/c (see Fig. 8). The high p_T range ($p_T > 3$ GeV/c) in which the suppression of pion spectra at RHIC energies is fully established (see Fig. 6) is not reached at the CERN SPS energies. Due to limited statistics in peripheral Pb+Pb

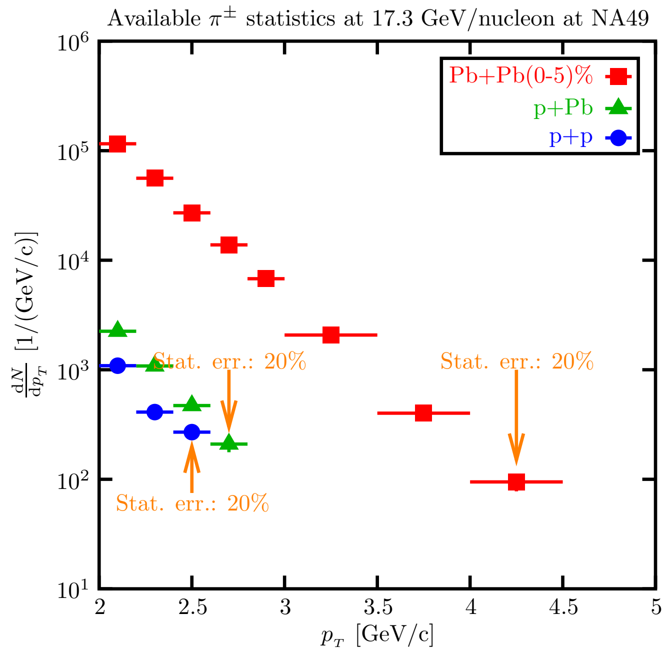

Figure 8: Statistics of identified charged pions registered by NA49 in p+p, p+Pb, and Pb+Pb(0-5)% central interactions ($4 \cdot 10^6$, $2 \cdot 10^6$ and $1 \cdot 10^6$ events, respectively). (Uncorrected spectra.)

p_T interval (GeV/c)	Event statistics for p+p interactions	Event statistics for p+Pb interactions
2.2-2.4	$5{\cdot}10^6$	$1{\cdot}10^6$
2.4-2.6	$11{\cdot}10^6$	$2{\cdot}10^6$
2.6-2.8	$22{\cdot}10^6$	$4{\cdot}10^6$
2.8-3.0	$44{\cdot}10^6$	$8{\cdot}10^6$
3.0-3.5	$57{\cdot}10^6$	$11{\cdot}10^6$
3.5-4.0	$296{\cdot}10^6$	$56{\cdot}10^6$

Table 9: Event statistics for p+p and p+Pb interactions at 158 GeV required to register 100 charged pions by NA49-future in a given interval of transverse momentum.

collisions, the $R_{\rm CP}$ central-to-peripheral modification factor (shown in Fig. 11 of the proposal) extends only to $p_T \approx 3$ GeV/c. Thus the low statistics of p+p, p+Pb and peripheral Pb+Pb interactions limits conclusions concerning central Pb+Pb collisions. Furthermore, published measurements of high p_T particle production in p+p and p+Pb interactions at

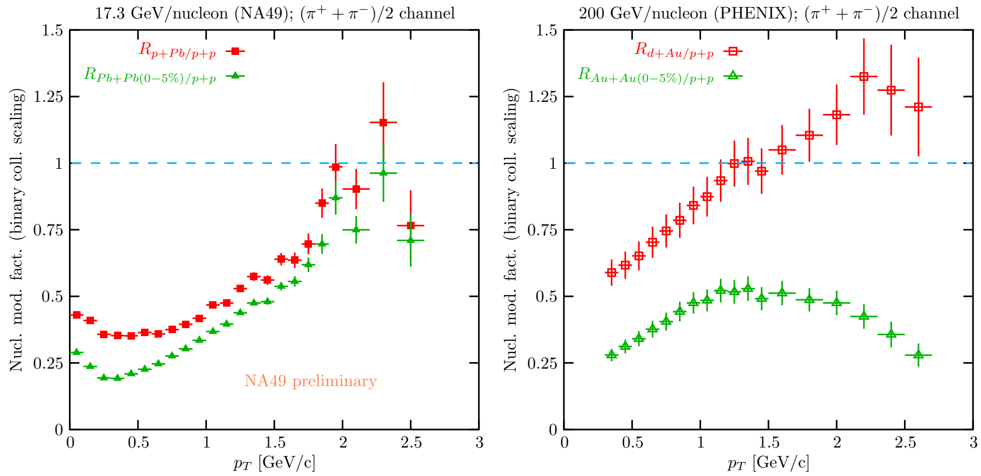

Figure 9: Left panel: the nuclear modification factor of 17.3 GeV/nucleon p+Pb and Pb+Pb(0-5)% central charged pion spectra relative to that of p+p reaction (NA49). Right panel: the same at 200 GeV/nucleon, but for d+Au and Au+Au(0-5)% central yields (PHENIX). As can be seen, our $p + p$ statistics ends at the beginning of the interesting domain. (Presented at Quark Matter 2006.)

energies close to the top SPS energy are not sufficient for a reliable interpolation (see Figs. 12 and 13 of the proposal). Therefore it is necessary to perform new high statistics measurements of p_T spectra in p+p and p+Pb interactions at 158 GeV.

The average multiplicity in p+Pb interactions at high transverse momentum (above 2 GeV/c) is about 5 times larger than the corresponding yield in p+p interactions. Thus the number of collected p+Pb events should be at least 1/5-th of the number of collected p+p events, in order to provide equivalent track statistics at high transverse momentum. The statistics of p+p and p+Pb interactions needed to reach a given transverse momentum interval is presented in Table 9. The estimate was performed under assumption that the ratio of the p_T spectra in p+p(Pb) and Pb+Pb collisions is p_T independent for $p_T > 2$ GeV/c. The future data will allow (with about 20-30% statistical error in the last p_T bin) to measure the p_T spectra for π^+ and π^- mesons up to 4.0 GeV/c and 4.5 GeV/c in p+p and p+Pb interactions, respectively. The systematic error is estimated to be below 5%.

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