NA49/NA61: results and plans on beam energy and system size scan at the CERN SPS

M. Gazdzicki, Frankfurt, Kielce for the NA49 and NA61 Collaborations

- Onset of deconfinement:
- NA49 evidence
- NA61 systematic study



Critical point:

- NA49 pilot results
- NA61 systematic search





Onset of deconfinement: AGS SPS RHIC ...LHC NA49 evidence in single 25 $\langle \pi \rangle / \langle N_w \rangle$ (A+A)-(p+p)_ particle yields and spectra 20 15 hadron production properties **Onset of Deconfinement:** F (GeV 10 early stage hits transition line, observed signals: kink, horn, step **Kink Predictions SMES:** Results: APP B30 2705 (99), PR C77 024903 (08) $\langle K^{+} \rangle \! / \langle \pi^{+} \rangle$ collision energy Т QGP 0.2 0.1 Horn early stage - 300-K⁺ freeze-out 200 **Hadrons** A+A: NA49 Step 100 AGS RHIC o p+p 10 15 5 0 $F(GeV^{1/2}) \approx S_{NN}^{1/4}$ collision energy

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Evidence: single particle yields



- π yield related to entropy production
- steeper increase in A+A suggests
3-fold increase of early stage d.o.f

 5% Pb+Pb
 $<\pi > / < N_w >$

 ALICE (Toia)+MG
 56 ± 10

 SPS+RHIC (SMES fit)
 70 ± 7

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 - E_s related to strangeness/entropy ratio
 - plateau consistent with prediction for deconfinement

Evidence: single particle spectra



softening of EoS due to mixed phase influence transverse (left) and longitudinal (right) expansion

> 5% Pb+Pb at 2.76 TeV (ALICE, Toia): kaon $< p_{T} > 20\%$ higher than at RHIC: the step structure becomes better defined

Verification of the NA49 evidence by STAR in progress



NA49 search for the onset signal in fluctuations

Multiplicity fluctuations in central (1%) Pb+Pb collisions (*PR C78 034914*)



Collisions with a fixed number of participants have to be selected. This is impossible in collider experiments. Verification by STAR impossible. Onset of deconfinement: an increase at about 80A GeV by about 0.01 (*PL B585 115*). Predicted effect smaller than the systematic errors

NA49 search for the onset signal in fluctuations

Energy dependence of chemical fluctuations in central (3.5%) Pb+Pb collisions (*arXiv:1101.3250*) (*T. Schuster, talk, D. Kresan, P100*)



Dynamical K/p fluctuations change sign at the onset energy. This is not described by hadronic models. Is this observation related to the onset of deconfinement?

Comparison between NA49 and STAR requires new analysis from both experiments in the common acceptance.

NA61 systematic study of the onset of deconfinement



Search for the onset of the signals in collisions of light nuclei

Progress and plans in data taking for CP&OD (central events only)



NA61 preliminary results on p+p and p+C collisions

Pion spectra at 31 GeV/c (arXiv:1101.3250 and (A. Aduszkiewicz and T. Palczewski, Thu. P153)

Comparison between p+C (NA61) and central Pb+Pb (NA49) at 30A GeV





Critical point: NA49 pilot results



Search for the critical point makes sense only at energies larger than the onset one (30A GeV)

Critical point: NA49 pilot results



First hint of the fluctuation hill?

PR C78:034914 PR D60:114028



$\frac{Critical \ point: \ NA49 \ pilot \ results}{3^{rd} \ moment \ of \ p_{_{T}} \ fluctuations} \\ \Phi_{_{pT}}^{(3)} \ has \ strongly \ intensive \ property \ like \ \Phi_{_{pT}}$



Higher moments are expected to be more sensitive to fluctuations, but no theoretical predictions yet. Data systematic errors are large.

<u>Critical point: NA49 pilot result</u> Intermittency of low-mass pion pairs at 158A GeV (PR C81:064907)



Critical point: NA61 systematic search



<u>Critical point: NA61 systematic search</u> Experimental techniques: upgraded NA49 facility



<u>Summary</u>



NA49: Onset of deconfinement:

- strong evidence in single particle yields and spectra,
- new: possible signal in kaon to proton fluctuations,
- first LHC data seem to confirm the interpretation,
- comparison between NA49 and STAR in progress
- NA49: Critical point:
- pilot results on system size scan at 158A GeV show enhanced fluctuations in Si+Si collisions, they are consistent with expectations for the critical point.



- NA61: Onset of deconfinement and critical point:
- scan in beam energy and system size started
- with p+p interactions at six momenta (13-158 GeV/c),
- first results are being released,
- energy scan with secondary Be beam will start this year

NA49:

78 physicists from 23 institutes and 12 countries:

NIKHEF, Amsterdam, Netherlands University of Athens, Athens, Greece **Comenius University, Bratislava, Slovenia** Eotvos Lorand University, Budapest, Hungar **KFKI IPNP, Budapest, Hungary** MIT, Cambridge, USA **INP, Cracow, Poland** Joint Institute for Nuclear Research, Dubna, Russia **GSI, Darmstadt, Germany** University of Frankfurt, Frankfurt, Germany **CERN, Geneva, Switzerland** Jan Kochanowski Univeristy, Kielce, Poland University of Marburg, Marburg, Germany MPI, Munich, Germany Charles University, Prag, Czech Republic University of Washington, Seattle, USA Faculty of Physics, University of Sofia, Sofia, Bulgaria Sofia University, Sofia, Bulgaria INR&NE, BAS, Sofia, Bulgaria State University of New York, Stony Brook, USA Soltan Institute for Nuclear Studies, Warsaw, Poland Warsaw University of Technology, Warsaw, Poland University of Warsaw, Warsaw, Poland Rudjer Boskovic Institute, Zagreb, Croatia



NA61: 134 physicists from 27 institutes and 15 countries:

University of Athens, Athens, Greece University of Belgrade, Belgrade, Serbia University of Bergen, Bergen, Norway University of Bern, Bern, Switzerland **KFKI IPNP**Budapest, Hungary Jagiellonian University, Cracow, Poland Joint Institute for Nuclear Research, Dubna, Russia Fachhochschule Frankfurt, Frankfurt, Germany University of Frankfurt, Frankfurt, Germany University of Geneva, Geneva, Switzerland Forschungszentrum Karlsr Karlsruhe, German Institute of Physics, University of Silesia, Katov Jan Kochanowski Univeristy, Kielce, Poland Institute for Nuclear Research, Moscow, Russia University of Nova Gorica, Nova Gorica, Slovenia PNHE, Universites de Paris VI et VII, Paris, France University of aculty of Physics, University of Sofia, Sofia, Bulgaria St. Petersburg State University, St. Petersburg, Russia State University of New York, Stony Brook, USA K, Tsukuba, Japan 🔫 Soltan Institute for Nuclear Studies, Warsaw, Poland Warsaw University of Technology, Warsaw, Poland University of Warsaw, Warsaw, Poland Univeristy of Wroclaw, Wroclaw, Poland Universidad Tecnica Federico Santa Maria, Valparaiso, Chile Rudjer Boskovic Institute, Zagreb, Croatia ETH Zurich, Zurich, Switzerland



Additional slides

NA61 preliminary results on p+p and p+C collisions

Pion spectra at 31 GeV/c (arXiv:1101.3250 and (A. Aduszkiewicz and T. Palczewski, Thu. P153)

Comparison between p+C (NA61) and central Pb+Pb (NA49) at 30A GeV



<u>Critical point: NA61 systematic search</u> Advances in analysis methods

Two families of strongly intensive quantities were identified (quantities which are independent of volume and volume fluctuations with the grand canonical ensemble and wounded nucleon model, *arXiv:1101.4865*) Their use should significantly reduce uncertainties due to fluctuations in collision geometry.

Use of the identity method to study chemical fluctuations (*PRC83:054907*) should significantly reduce uncertainties introduced by the currently used methods (NA49: event-by-event maximum likelihood fit, STAR: particle counting in *dE/dx-tof* windows).



In particular important for low multiplicity events studied by NA61

Particle identification





Secondary Berillium beam: basic idea



Secondary Berillium beam: fragment separator



500 m

H2 Beam Line for Fragmented Ion Beam

Secondary hadron beams

NA61 beam and trigger counters





Experimental landscape of complementary programs of nucleus-nucleus collisions around the SPS energies

Facility:	SPS	RHIC	NICA	SIS-100 (SIS-300)
Exp.:	NA61	STAR PHENIX	MPD	CBM
Start:	2010	2010	2015	2017 (2019)
Pb Energy: (GeV/(N+N))	5.1-17.3	7.6-50	4-11	<pre><2013) </pre> ≤5 (<8.5)
Event rate: (at 8 GeV)	70 Hz	3-30 Hz	≤10 kHz	≤10 MHz
Physics:	CP&OD	CP&OD	OD&HDM	HDM (OD)

under consideration: U70 in IHEP Protvino

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

