Recent results from NA49 and NA61/SHINE

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Outline

- Experimental setup
- Physics program
- Results from NA49
- Results from NA61
- Summary
The NA49 experiment

- four TPCs with two of them inside the magnetic field
- large acceptance: $\approx 50\%$
- high momentum resolution:
  \[
  \frac{\sigma(p)}{p^2} \approx 10^{-4}[1/(\text{GeV/c})]
  \]
- precise particle identification:
  \[
  \frac{\sigma(dE/dx)}{\langle dE/dx \rangle} \approx 4\% \\
  \sigma(\text{tof}) \approx 60\text{ps}
  \]
- Operated from 1994 to 2002
  recorded data on: p+p, C+C, Si+Si and Pb+Pb

A. Rustamov, QM2012, August 13-18, Washington D.C, USA
NA61 at the CERN SPS

“successor” of NA49 with numerous upgrades

SPS Heavy Ion and Neutrino Experiment
(3 different communities)

- program
  - neutrino program
    - precise hadron production data for the T2K experiment
  - cosmic rays program
    - precise hadron production data for the Pierre Auger Observatory
  - heavy-ion program:
    - study of Onset of Deconfinement
    - search for Critical End Point

operates since 2007
Onset of Deconfinement

NA49 findings are confirmed by STAR and ALICE

STAR: QM2011 proceedings
ALICE: QM2011 proceedings
A. Rustamov arXiv:1201.4520v1

NA61/SHINE has successfully started the study of the onset signals

A. Rustamov, QM2012, August 13-18, Washington D.C, USA
Particle Spectra

NA61/SHINE results on p+p data

\[ p + p \rightarrow \pi^- + X \]

\[ \frac{d^2 n}{d\eta dy} m_T - m_{\pi} \text{[GeV/c]}^2 \]

\[ p + p \rightarrow \pi^- + X \]

\[ \frac{d^2 n}{d\eta dy} m_T \text{[GeV/c]} \]

S. Pułaski, this conference, poster session
Search for the CEP

by varying the energy and/or size of the colliding system the CEP might be localized (CEP = freeze-out)

**Observables:**

Event-by-Event fluctuations

M. Stephanov, K. Rajagopal, E. V. Shuryak, PRD 60, 114028 (1999)
Selected fluctuation measures

\[ \omega = \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle} = \text{Var}(N) \]

**Multiplicity fluctuations**

Poisson case: \( \langle N^2 \rangle = \langle N \rangle^2 + \langle N \rangle \), \( \omega = 1 \)

**Chemical (particle composition) fluctuations**

NA49:
\[ \sigma_{\text{dyn}} = \text{sgn} \left( \sigma_{\text{data}}^2 - \sigma_{\text{mixed}}^2 \right) \sqrt{\sigma_{\text{data}}^2 - \sigma_{\text{mixed}}^2} \]
\[ \sigma = \frac{\sqrt{\text{Var}(A / B)}}{\langle A / B \rangle} \]
\[ \frac{A}{B} = \frac{K}{\pi} \cdot \frac{p}{\pi} \]

STAR:
\[ \nu_{\text{dyn}} = \frac{\langle N_1^2 \rangle}{\langle N_1 \rangle^2} + \frac{\langle N_2^2 \rangle}{\langle N_2 \rangle^2} - 2 \frac{\langle N_1 N_2 \rangle}{\langle N_1 \rangle \langle N_2 \rangle} - \left( \frac{1}{\langle N_1 \rangle} + \frac{1}{\langle N_2 \rangle} \right) \]

Independent Poisson distributions:
\[ \langle N_i^2 \rangle = \langle N_i \rangle^2 + \langle N_i \rangle, \quad \langle N_1 N_2 \rangle = \langle N_1 \rangle \langle N_2 \rangle \equiv \nu_{\text{dyn}} = 0 \]

**Intermittency**

Experimental observable: factorial moments in transverse momentum space.

Power low (intermittency) prediction for CEP:
\[ \Delta F_2(M) = F_2^{\text{data}}(M) - F_2^{\text{mixed}}(M) \propto (M^2)^{\phi_2} \]
[K,p] and [K,π] results from NA49 and STAR are significantly different at low energies.

What is the reason for this difference?

- bias in the used methods
- acceptance effects
Identity Method

- Available information:
  - inclusive distribution of PID variable, $\rho_j(x)$
  - mean multiplicities: $\langle N_p \rangle = \int \rho_p(x) \, dx$, $\langle N_k \rangle = \int \rho_k(x) \, dx$, ...

- The Problem:
  - how to find the moments of multiplicity distributions?

- The strategy:
  - for each measurement $x$ and particle $j$ in an event one defines
    \[ w_j(x) = \frac{\rho_j(x)}{\sum_j \rho_j(x)} \]
  - for each event one constructs:
    \[ W_j = \sum_i w_j(x_i) \]
  - finally one calculates moments of $W$ distribution

- The idea:
  - find moments of the multiplicity distributions from known moments of $W$ quantities
The Identity Method relates corresponding moments of $W$ and multiplicity distributions through a set of linear equations. An example for the second moments:

$$
\begin{pmatrix}
\langle N_p^2 \rangle \\
\langle N_k^2 \rangle \\
\langle N_p N_k \rangle
\end{pmatrix}
= \begin{pmatrix}
\bar{w}_{pp}^2 & \bar{w}_{pk}^2 & 2\bar{w}_{pp} \bar{w}_{pk} \\
\bar{w}_{kp}^2 & \bar{w}_{kk}^2 & 2\bar{w}_{kp} \bar{w}_{kk} \\
\bar{w}_{pp} \bar{w}_{kp} & \bar{w}_{pk} \bar{w}_{kk} & \bar{w}_{pp} \bar{w}_{kk} + \bar{w}_{pk} \bar{w}_{kp}
\end{pmatrix}^{-1}
\begin{pmatrix}
\langle W_p^2 \rangle - b_p \\
\langle W_k^2 \rangle - b_k \\
\langle W_p W_k \rangle - b_{pk}
\end{pmatrix}
$$

3 equations, 3 unknowns (unique solution)

$$b_i = \sum_{j=p,k} \langle N_j \rangle (\bar{w}_{ij}^2 - \bar{w}_{ij}^2), \quad b_{pk} = \sum_{j=p,k} \langle N_j \rangle (\bar{w}_{pkj} - \bar{w}_{pj} \bar{w}_{kj})$$

$$\bar{w}_{ij} = \frac{\int w_i(m)\rho_j(m)dm}{\int \rho_j(m)dm} \quad \bar{w}_{ij}^2 = \frac{\int w_i^2(m)\rho_j(m)dm}{\int \rho_j(m)dm} \quad \bar{w}_{ikj} = \frac{\int w_i(m)w_k(m)\rho_j(m)dm}{\int \rho_j(m)dm}$$

**Advantages:**
- Event-by-Event fits of PID variable is not needed
- Also no need for event mixing
- Mathematically proven

M. Gazdzicki et al., PRC 83, 054907 (2011)
M. I. Gorenstein, PRC 84, 024902 (2011), second moments

A. Rustamov, QM2012, August 13-18, Washington D.C, USA
## Results from Identity Method

### second moments for central Pb+Pb data

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>( &lt;N_p&gt; )</td>
<td>27.1786</td>
<td>34.876</td>
<td>38.186</td>
<td>47.5179</td>
<td>70.1685</td>
</tr>
<tr>
<td>( &lt;N_\pi&gt; )</td>
<td>30.5385</td>
<td>66.4564</td>
<td>103.046</td>
<td>226.819</td>
<td>413.295</td>
</tr>
<tr>
<td>( &lt;N_K&gt; )</td>
<td>4.5723</td>
<td>9.2489</td>
<td>13.6526</td>
<td>31.042</td>
<td>56.8712</td>
</tr>
<tr>
<td>( &lt;N_p^2&gt; )</td>
<td>764.277</td>
<td>1248.27</td>
<td>1493.64</td>
<td>2304.68</td>
<td>4969.01</td>
</tr>
<tr>
<td>( &lt;N_\pi^2&gt; )</td>
<td>964.311</td>
<td>4487.12</td>
<td>10737.9</td>
<td>51850.7</td>
<td>172014</td>
</tr>
<tr>
<td>( &lt;N_K^2&gt; )</td>
<td>25.395</td>
<td>94.9134</td>
<td>200.563</td>
<td>997.228</td>
<td>3312.25</td>
</tr>
<tr>
<td>Cov[N_pN_\pi]]</td>
<td>2.12232</td>
<td>4.29659</td>
<td>9.15544</td>
<td>39.03744</td>
<td>32.00979</td>
</tr>
<tr>
<td>Cov[N_pN_K]]</td>
<td>-0.73635</td>
<td>-0.62464</td>
<td>0.41682</td>
<td>3.48935</td>
<td>7.5732</td>
</tr>
<tr>
<td>Cov[N_KN_\pi]]</td>
<td>-1.01266</td>
<td>-1.2876</td>
<td>0.30418</td>
<td>15.6246</td>
<td>110.6174</td>
</tr>
</tbody>
</table>

**What is the reason for negative covariance?**

\[
\text{Cov}[N_1,N_2] = <N_1N_2> - <N_1> \ast <N_2>
\]
Results from Identity Method

[p,π]: agreement with both, published results of NA49, and STAR

[K,π]: increasing trend at low energy published by NA49 is reproduced. Difference with STAR remains!

[K,p]: increasing trend at low energy published by NA49 is reproduced. Difference with STAR remains!

Dependence on acceptance

At 20A and 30A GeV/c there is a strong acceptance dependence. Acceptance coverage appears to explain the difference with STAR.

STAR acceptance

NA49, Pb+Pb at:
- 20A GeV/c
- 30A GeV/c
- 40 A GeV/c
- 158A GeV/c
Dependence on acceptance

NA49, Pb+Pb at:
- 20 A GeV/c
- 30 A GeV/c
- 40 A GeV/c
- 158 A GeV/c

at 20 A and 30 A GeV/c there is a strong acceptance dependence. Acceptance coverage appears to explain the difference with STAR.
$v_{dyn}$ depends on system volume (not an intensive measure)

scaled variance, does not depend on volume however depends on volume fluctuations.

$\Phi_{ij}$ is an intensive quantity and does not depend on volume fluctuations.

In a superposition model:

$\Phi_{ij} (A+A) = \Phi_{ij} (N+N)$

M. I. Gorenstein and M. Gazdzicki, PRC 84, 014904 (2011)

M. Maćkowiak this conference, poster session
Intermittency at 158A GeV/c

protons at mid rapidity

C+C
Si+Si
Pb+Pb

intermittency index

\[ \Delta F_2^2 (M) = \frac{F_2^2 (M) - F_2^2_{\text{mixed}} (M)}{\left( \frac{1}{M^2} \sum_{i=1}^{M^2} n_i \right)^2} \]

\[ \Delta F_2 (M) = F_2^\text{data} (M) - F_2^\text{mixed} (M) \propto (M^2)^{\phi_2} \]

M^2 – number of bins in p_t space
n_i number of protons in cell i

near CEP fluctuations of \( \langle q\bar{q} \rangle \) are transferred to:

(i) net proton density
(ii) low mass \( \pi\pi \) pairs

N. G. Antoniou et al., this conference, poster session

A. Rustamov, QM2012, August 13-18, Washington D.C, USA
Summary

- NA49: chemical fluctuations in central Pb+Pb collisions
  - the increasing trend in $\nu_{dy}[K,\pi]$ and $\nu_{dy}[K,p]$ at low SPS energies is confirmed by the Identity Method
  - difference with the STAR results appears to be due to different acceptance coverage
- NA49: proton Intermittency
  - strong intermittency observed in Si+Si collisions at 158A GeV/c is consistent with the predictions for the CEP
- NA61/SHINE: identified hadron production in p+p
  - energy dependence of pion yield follows literature and further supports the “kink” signal
  - precise measurement of $\pi$, K, p spectra
  - scaled variance and chemical fluctuations at 31, 40, 80 and 158 GeV/c.

A. Rustamov, QM2012, August 13-18, Washington D.C, USA
NA61/SHINE Collaboration

134 physicists from 27 institutes and 15 countries:

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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 Karlsruhe, Karlsruhe, Germany
Institute of Physics, University of Silesia, Katowice, Poland
Jan Kochanowski University, Kielce, Poland
Institute for Nuclear Research, Moscow, Russia
University of Nova Gorica, Nova Gorica, Slovenia
LPNHE, Universites de Paris VI et VII, Paris, France
Faculty of Physics, University of Sofia, Sofia, Bulgaria
St. Petersburg State University, St. Petersburg, Russia
State University of New York, Stony Brook, USA
KEK, Tsukuba, Japan
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