Vol. 10 (2017) *Acta Physica Polonica B Proceedings Supplement* No 3

ENERGETIC SCANS OF MAREK GAŹDZICKI*

PETER SEYBOTH

Jan Kochanowski University in Kielce, Poland
and
Max-Planck-Institut für Physik, Munich, Germany

(Received April 26, 2017)

As an introduction to this special session on the occasion of Marek Gaździcki's imminent 60th birthday his main research activities are briefly reviewed.

DOI:10.5506/APhysPolBSupp.10.841

1. Introduction

Marek Gaździcki is turning 60 in a few days. For this occasion, this session is devoted to honoring him by a series of talks by friends and collaborators on subjects central to his research work. Having worked closely and with great pleasure with Marek for the past 30 years, I shall try to sketch the main subjects of his distinguished research activities.

2. Early years at Warsaw and Dubna 1980–1985

Marek studied at the University of Warsaw with Ewa Skrzypczak and proceeded to work on his Ph.D. investigating nucleus–nucleus collisions. His principle interest was the search for enhanced strangeness production as an indicator of hadron deconfinement during the early stage of the collisions. The experiment was performed with the SMK2000 streamer chamber at the Dubna Sychophasotron delivering light nuclei with energies of $4.5\,A\,\mathrm{GeV}$. Reactions C+C, C+Ne, C+Cu, C+Pb, O+Ne and O+Pb were studied and yields of π^-, K^0_{S} and Λ were obtained from the track measurements in the projected photographs of the reactions. The results were the basis of Marek's Ph.D., but unfortunately they did not show any statistically significant "unusual enhancement" of Λ and K^0_{S} production [1].

* Presented at the "Critical Point and Onset of Deconfinement" Conference, Wrocław, Poland, May 30–June 4, 2016.

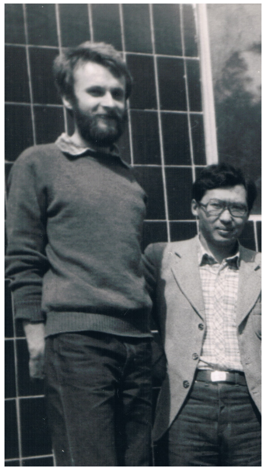


Fig. 1. Marek as a Ph.D. student at Dubna.

3. NA35 streamer chamber experiment at the CERN SPS 1986–1990

After completion of his Ph.D. at the University of Warsaw, Marek's interest remained with the study of strangeness production in nucleus–nucleus collisions and he moved to a postdoctoral position at the University of Heidelberg. After a short interlude (1989–1992) at the Warsaw Institute of Experimental Physics, Marek received, on account of his exceptional analysis contributions to NA35, a permanent research position at the University of Frankfurt. Later, he was appointed in addition to a visiting professorship at the University in Kielce.

Fig. 2. Marek at the University of Heidelberg (1986–1989).

The Heidelberg group collaborated in the NA35 experiment within the new CERN program searching for hadron deconfinement and ultimately evidence for the quark–gluon plasma (Ref. [2] was the first publication of NA35 with Marek). The new high-energy regime at the SPS made this a promising endeavor. Initially, beams of oxygen nuclei were accelerated to energies of $60\,A$ and $200\,A$ GeV in 1986, and sulphur nuclei of $200\,A$ GeV were provided in 1987 and 1990. Examples of NA35 streamer chamber pictures of reactions are shown in Fig. 3. Most of these pictures had to be measured manually by human scanners.

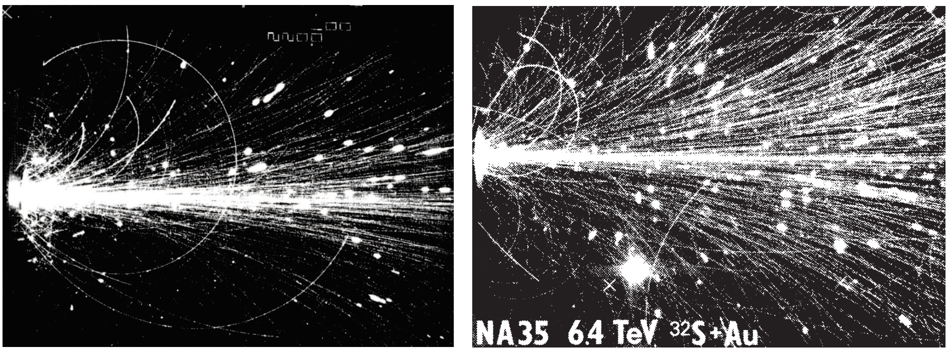


Fig. 3. Photographs of a O+Au (left) and S+Au (right) reaction at $200\,A$ GeV in the NA35 streamer chamber.

The results of NA35 on pion and strange particle production [3] clearly demonstrated a roughly factor 2 enhancement of strangeness production in S+S and S+Au reactions compared to p+A collisions. This was quantified by the strangeness suppression factor in terms of valence quarks by

$$\lambda_{\mathrm{S}} = \frac{\langle s\bar{s}\,\rangle}{0.5\ \left(\langle u\bar{u}\,\rangle + \langle d\bar{d}\,\rangle\right)}\,,$$

which can be estimated from measured particle yields by Wroblewski's procedure [4]. The value of λ_{S} was found to double from 0.17 to 0.35 between nucleon–nucleon and S+A reactions. Marek proposed a new measure of the strangeness content of the final state at SPS energies [5] which is easier to measure

$$E_{\mathrm{S}} = \frac{\langle \Lambda\rangle + 4\,\left\langle K^0_{\mathrm{S}}\right\rangle}{3\,\langle \pi^-\rangle} \approx \frac{\langle \Lambda\rangle + \left\langle K + \bar{K}\right\rangle}{\langle \pi^-\rangle}\,.$$

The value of E_{S} increases from 0.1 to 0.17 between nucleon–nucleon and S+A collisions confirming the strangeness enhancement.

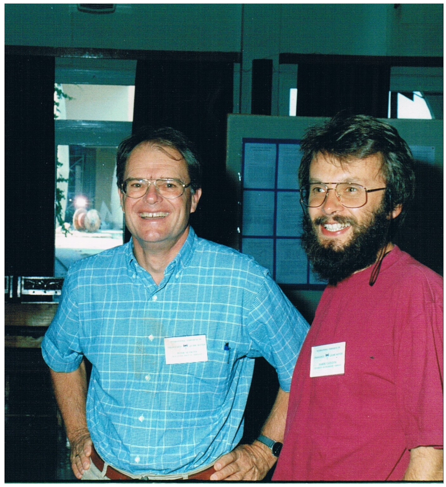


Fig. 4. SQM conference in Kolymbari 1994. Right: Marek, the main driving force of the NA35 strange particle analysis. Left: the spokesman of NA35 (myself).

4. The statistical model of the early stage SMES

Marek's long-standing interest in understanding particle production yields based on compilation of measurements (*e.g.* Ref. [5] with his long-time collaborator D. Röhrich) and his belief in deconfinement in $A+A$ collisions led to the development of the statistical model of the early stage SMES in collaboration with M. Gorenstein [6]. The high initial state energy density achieved at SPS energies suggested the assumption of a first order phase transition between hadrons and quarks and gluons during the early stage of

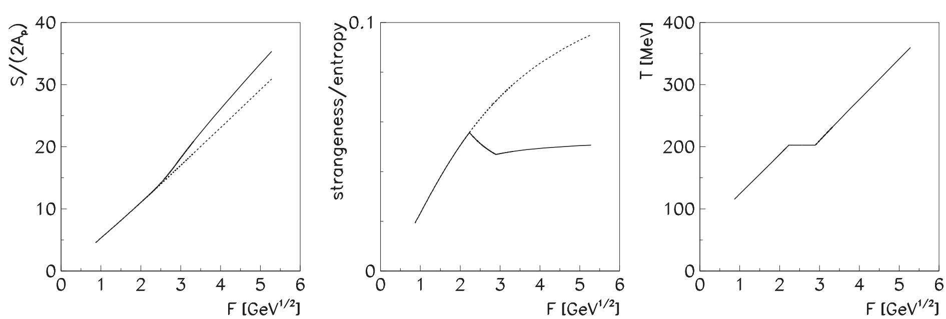


Fig. 5. SMES model predictions for the produced entropy density (left), the strangeness-to-entropy ratio (center) and the inverse slope parameter of the kaon spectrum (right) as a function of the Fermi energy variable $F \approx s_{NN}^{0.25}$. All these quantities change abruptly at the energy at which deconfinement starts.

the collisions in accordance with QCD-based models. This led to specific predictions for the produced entropy and strangeness as shown in Fig. 5, namely the "kink" (left), the "horn" (center) and the "step" (right). It was, moreover, shown that these features can be experimentally observed by the energy dependence of the following proxies: the ratio of pion multiplicity to the number of participants (excitation of quark and gluon degrees of freedom), the ratio of kaon to pion yield (change of strangeness content due to the decrease of the mass of strangeness carriers) and the inverse slope parameter of the kaon spectrum (stalling of radial expansion due to the softness of the equation of state in the mixed phase region).

5. NA49 time projection chamber experiment at the CERN SPS 1994–2002

Meanwhile, it had become clear that measurements of Pb+Pb collisions at the top SPS energy (see Fig. 6 (left)) were alone not sufficient to prove and locate the onset of deconfinement. Marek, therefore, convinced CERN to carry out an energy scan with Pb+Pb collisions. The final results of NA49 from the energy scan of central Pb+Pb collisions are plotted in Fig. 7. They clearly confirm the predictions of the SMES model, and indicate the onset of deconfinement at an energy near 30 A GeV [7].

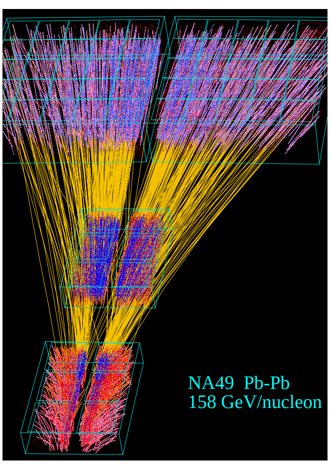


Fig. 6. Left: central Pb+Pb collision recorded by the NA49 TPC detector. Right: Marek at the University of Frankfurt in the late 1990s.

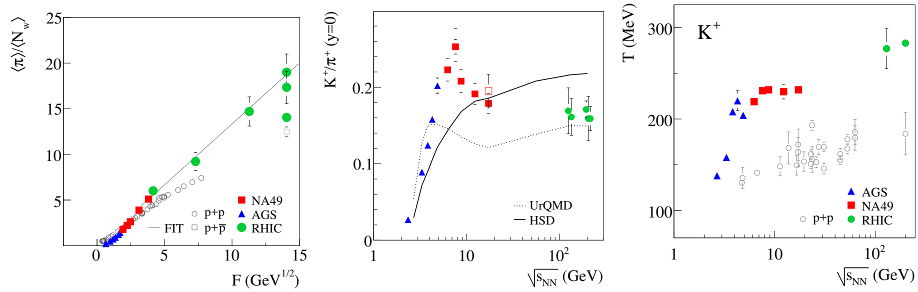


Fig. 7. Collision energy dependence of hadron production properties in central Pb+Pb collisions measured by the NA49 experiment. Left: ratio of pion multiplicity to the number of participants ("kink"). Center: ratio of kaon to pion yield at midrapidity ("horn"). Right: inverse slope parameter of the kaon spectrum at midrapidity ("step").

6. NA61/SHINE experiment at the CERN SPS 2007 to present

It has been realized that the phase diagram of strongly interacting matter has probably a rich structure. In particular, the phase transition between hadrons and quarks and gluons is believed to happen along a narrow strip of temperature T *versus* baryochemical potential μ_{B} as shown for the most popular scenario in Fig. 8 (left). Theoretical considerations suggested a first order transition (shaded band) which ends in a critical point. The latter might be observable in a maximum of fluctuations of various observables as shown schematically in Fig. 8 (center) ("hill of fluctuations"). Although the fluctuations might not fully develop due to the small size and lifetime of the fireballs, a search via a scan of the phase diagram offered an exiting possibility of discovery.

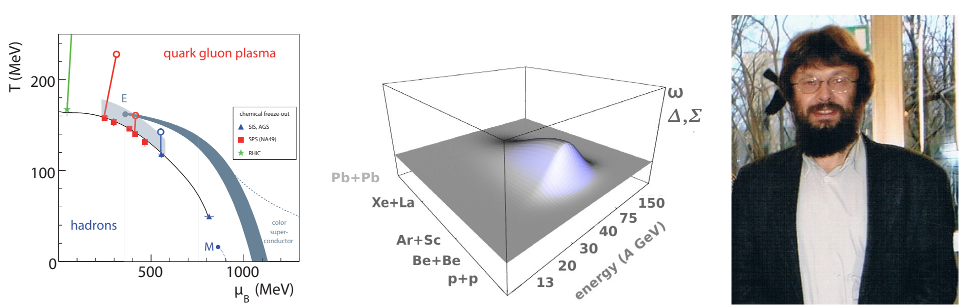
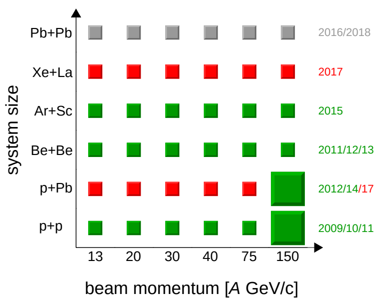


Fig. 8. Left: phase diagram of hadron matter showing phase transition region (shaded) and freezeout points of hadron composition. Center: strength of fluctuation signals near a critical point. Right: Marek in 2007, spokesperson of NA61/SHINE.

Marek proposed to achieve this by performing a systematic scan of hadron production by collisions of nuclei of different sizes at different energies using an upgraded version of the NA49 detector. Initially, he had to contend with great skepticism towards a new ion program at the SPS. Finally, after persuading groups from the T2K neutrino program to join for systematic particle production measurements with this uniquely suitable detector for the use in the precision calculations of ν-beam properties, the CERN committees gave the green light to the NA61/SHINE experiment [8]. Figure 9 (left) provides an overview of the beam energy and collision system size scan of the NA61/SHINE strong interaction program. Energy scans of p+p, Be+Be and Ar+Sc (Fig. 9 (right)) collisions have been completed, and Xe+La as well as a repeat of Pb+Pb reactions are foreseen for 2017–2018. The analysis of the collected data is in progress, but clear indications of fluctuations associated with a critical point have not yet been observed. Marek, of course, has more plans for the future: a high interaction rate experiment with an additional micro-vertex detector for the time (2020+) after the next long SPS shutdown.



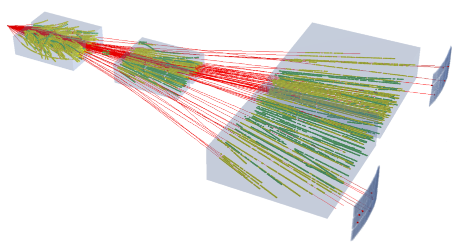


Fig. 9. (Color online) Left: program of NA61/SHINE with already recorded data shown in black/green. Right: display of a central Ar+Sc reaction.

7. CPOD conference series

The need for a specialized discussion forum focused on the experimental and theoretical exploration of the phase diagram was recognized by Marek a decade ago. He therefore initiated (with E. Shuryak and me) in 2004 the workshop "Tracing the Onset of Deconfinement in Nucleus–Nucleus Collisions" at the ECT in Trento. This launch event evolved into the conference series "Critical Point and Onset of Deconfinement" (CPOD) which started at Bergen in 2005. You are attending CPOD2016, the ninth in this series. It was preceded by the CPOD conferences at Florence (2006), GSI (2007), BNL (2009), Dubna (2010), Wuhan (2011), Napa Valley (2013) and Bielefeld (2014). Clearly, there is still plenty of work ahead of us to elucidate the phase diagram of strongly interacting matter, both in theory and experiment.

Fig. 10. S. Mrówczyński, Marek and M. Gorenstein at CPOD2005, Bergen.

8. Marek turns 60 on 9th of June 2016

Congratulations to Marek on the occasion of his 60th birthday on 9th of June!

Fig. 11. Marek chairs the NA61/SHINE collaboration meeting at Baku, May 2016.

May he

— maintain his remarkable energy and enthusiasm to pursue his projects,

— keep his ability to attract and motivate students and collaborators,

— be rewarded by finding experimental evidence for the critical point,

— and above all stay healthy and enjoy his family.

REFERENCES

[1] M.K. Anikina *et al.*, *Z. Phys. C* **25**, 1 (1984).
[2] A. Bamberger *et al.* [NA35 Collaboration], *Phys. Lett. B* **184**, 271 (1987).
[3] T. Alber *et al.* [NA35 Collaboration], *Z. Phys. C* **64**, 195 (1994).
[4] A. Wróblewski, *Acta Phys. Pol. B* **16**, 379 (1985).
[5] M. Gaździcki, D. Röhrich, *Z. Phys. C* **71**, 55 (1996).
[6] M. Gaździcki, M.I. Gorenstein, *Acta Phys. Pol. B* **30**, 2705 (1999).
[7] C. Alt *et al.* [NA49 Collaboration], *Phys. Rev. C* **77**, 024903 (2008).
[8] NA61/SHINE proposal, CERN-SPSC-2006-034.