

My adventures with Marek **event by event**

Stanisław Mrówczyński

Jan Kochanowski University, Kielce, Poland

&

National Centre for Nuclear Research, Warsaw, Poland



Happy Birthday!



Warsaw University 1975



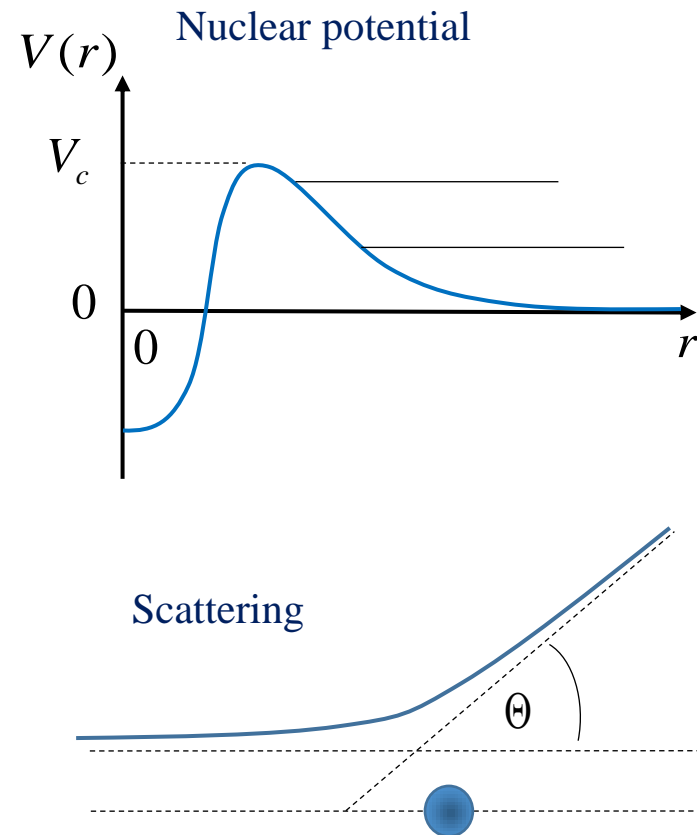
Faculty of Physics

Van de Graaff accelerator



„Lech” (1961 – 2014)

$p, d, {}^3\text{He}, {}^4\text{He}$ accelerated up to 3.2 MeV



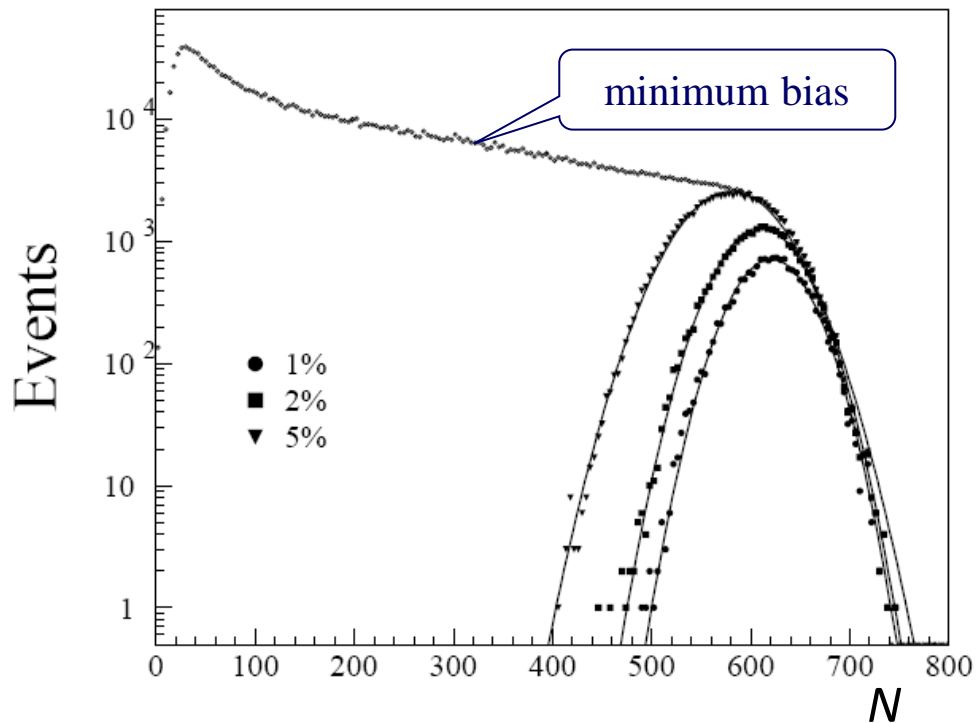
Rutherford cross section

$$\frac{d\sigma}{d\Omega} \propto \frac{1}{\sin^4\left(\frac{\Theta}{2}\right)}$$

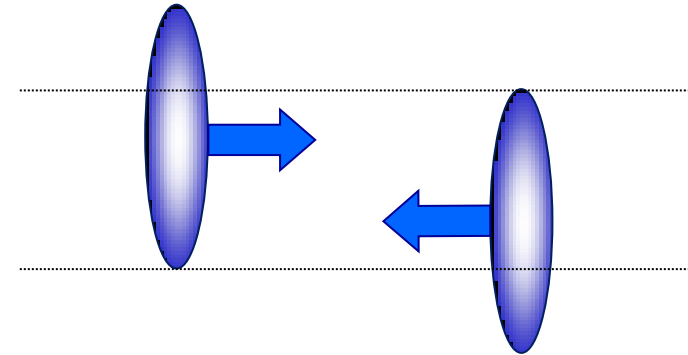
Effect of Coulomb barrier
was observed!

Fluctuations in nucleus-nucleus collisions

Multiplicity distribution in Pb-Pb @ 158 A GeV



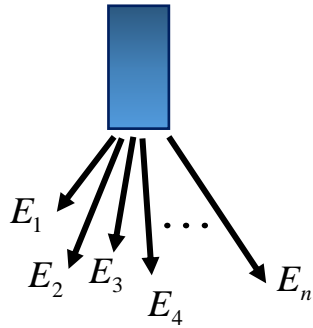
$\langle N \rangle$ & $\text{Var}(N)$ strongly depend on trigger conditions



Number of participants is never exactly known!

Problem

Single source of particles

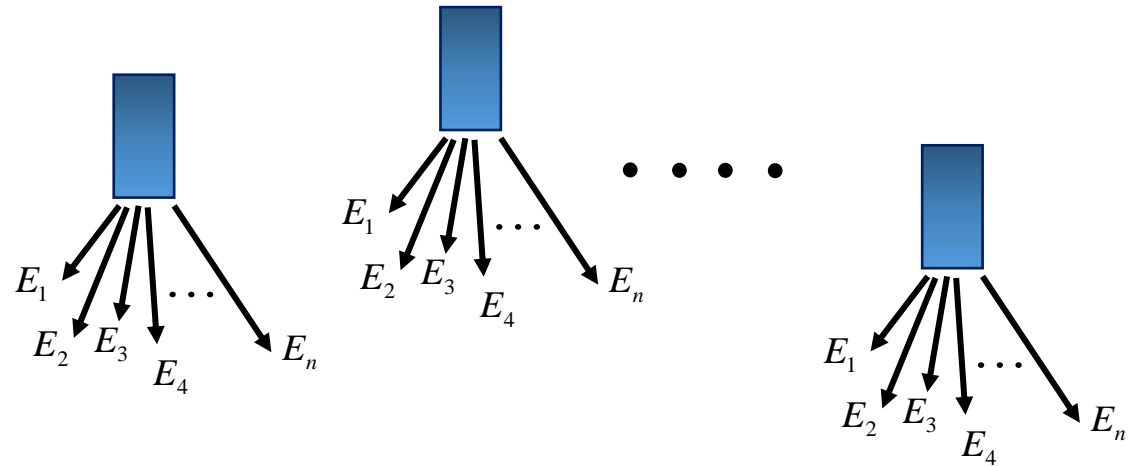


$P(E)$ - distribution of energy carried by particles

$$E = E_1 + E_2 + \dots + E_n$$

Analog of N-N collisions

k source of particles



$P_k(E)$ - distribution of energy carried by particles from k sources

For fluctuating number k :
$$\tilde{P}(E) = \sum_k p_k P_k(E_k)$$

Analog of A-A collisions

Is it possible to check whether $P(E) = P_1(E)$?

Solution

▶ one-particle variable $z \equiv E - \bar{E}$

... inclusive average $\bar{z} = 0$

▶ event variable $Z \equiv \sum_{i=1}^N z^i = \sum_{i=1}^N (E_i - \bar{E})$

$\langle \dots \rangle$ average over events $\langle Z \rangle = 0$

$$\frac{\langle Z \rangle^2}{\langle N \rangle} = \frac{\left\langle \left(\sum_{i=1}^N (E_i - \bar{E}) \right)^2 \right\rangle}{\langle N \rangle}$$

Exactly the same for a single source
and for k sources, even when k fluctuates!

Fluctuation measure Φ

$$\Phi = \sqrt{\frac{\langle Z \rangle^2}{\langle N \rangle} - \overline{z^2}}$$

$x = E, p_T, q, \dots$ one-particle variable

$$z \equiv x - \bar{x}$$

$\overline{\dots}$ inclusive average $\bar{z} = 0$

$$Z \equiv \sum_{i=1}^N z^i = \sum_{i=1}^N (x_i - \bar{x}) \quad \text{event variable}$$

$\langle \dots \rangle$ average over events $\langle Z \rangle = 0$

- ✓ Φ strongly intensive
- ✓ $\Phi = 0$ for no correlations (mixed events)

M. Gaździcki & St. Mrówczyński, Z. Phys. C **54**, 127 (1992)

Strongly intensive fluctuation measures

Multiplicity fluctuations in A-A collisions in wounded nucleon model

N – multiplicity in A-A collisions

$$\langle N \rangle = \langle k \rangle \langle n \rangle$$

k – number of wounded nucleons

n – multiplicity per wounded nucleon

$$\langle N^2 \rangle - \langle N \rangle^2 = \langle k \rangle (\langle n^2 \rangle - \langle n \rangle^2) + \langle n \rangle^2 (\langle k^2 \rangle - \langle k \rangle^2)$$

scaled variance:

$$\omega \equiv \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle} = \frac{\langle n^2 \rangle - \langle n \rangle^2}{\langle n \rangle} + \underbrace{\langle n \rangle \frac{\langle k^2 \rangle - \langle k \rangle^2}{\langle k \rangle}}$$

How to get rid of this term?

Strongly intensive fluctuation measures

$$\left\{ \begin{aligned} \omega_+ &\equiv \frac{\langle N_+^2 \rangle - \langle N_+ \rangle^2}{\langle N_+ \rangle} = \frac{\langle n_+^2 \rangle - \langle n_+ \rangle^2}{\langle n_+ \rangle} + \langle n_+ \rangle \frac{\langle k^2 \rangle - \langle k \rangle^2}{\langle k \rangle} \\ \omega_- &\equiv \frac{\langle N_-^2 \rangle - \langle N_- \rangle^2}{\langle N_- \rangle} = \frac{\langle n_-^2 \rangle - \langle n_- \rangle^2}{\langle n_- \rangle} + \langle n_- \rangle \frac{\langle k^2 \rangle - \langle k \rangle^2}{\langle k \rangle} \end{aligned} \right.$$

$$\frac{\langle N_+ \rangle \omega_- - \langle N_- \rangle \omega_+}{\langle N_{\pm} \rangle} = \frac{\langle n_+ \rangle}{\langle n_{\pm} \rangle} \frac{\langle n_-^2 \rangle - \langle n_- \rangle^2}{\langle n_- \rangle} - \frac{\langle n_- \rangle}{\langle n_{\pm} \rangle} \frac{\langle n_+^2 \rangle - \langle n_+ \rangle^2}{\langle n_+ \rangle}$$

No dependence on k !

Chemical fluctuations

Example: fluctuations K vs. π

x - particle's identity

$$x = \begin{cases} 1 & \text{- particle is a kaon} \\ 0 & \text{- particle is a pion} \end{cases}$$

$$\Psi \equiv \frac{\langle Z^2 \rangle}{\langle N \rangle} - \bar{z}^2$$

$$z \equiv x - \bar{x}$$

$$\dots \quad \text{inclusive average} \quad \bar{z} = 0$$

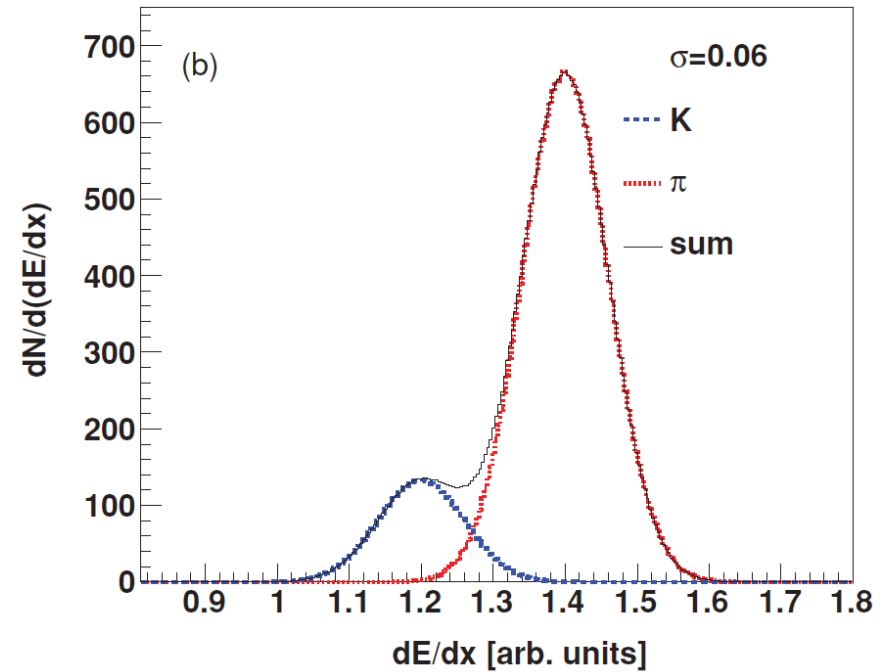
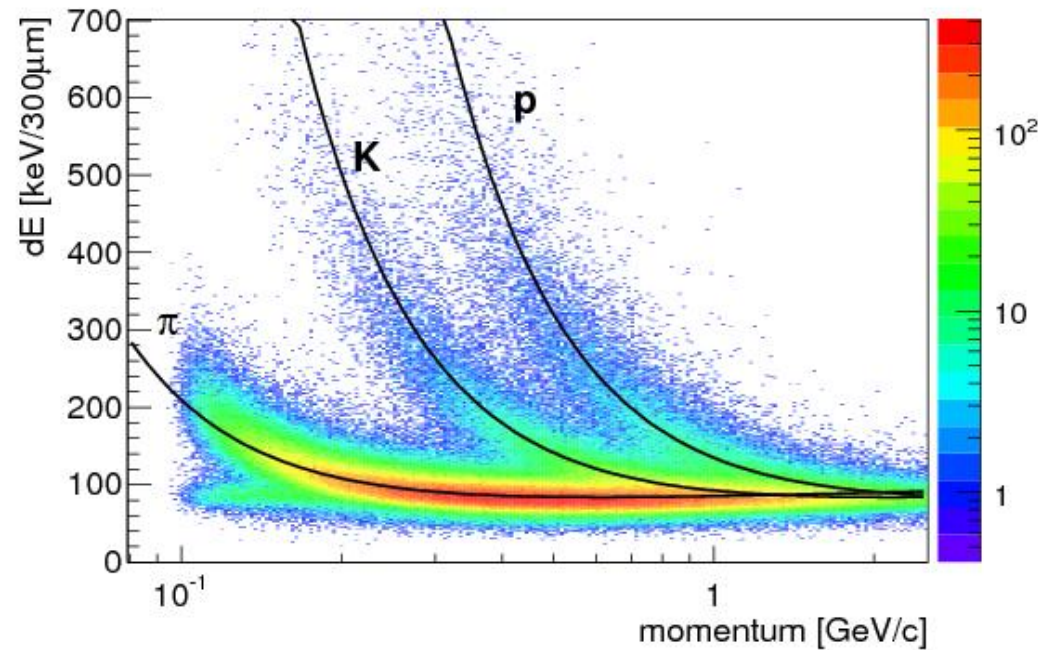
$$Z \equiv \sum_{i=1}^N z^i = \sum_{i=1}^N (x_i - \bar{x}) \quad \text{event variable}$$

$$\langle \dots \rangle \quad \text{average over events} \quad \langle Z \rangle = 0$$

$$\Psi \equiv \frac{1}{\langle N \rangle^3} \left[\langle N_\pi^2 \rangle \langle N_K \rangle^2 + \langle N_\pi \rangle \langle N_K^2 \rangle - 2 \langle N_\pi \rangle \langle N_K \rangle \langle N_\pi N_K \rangle - \langle N_\pi \rangle^2 \langle N_K \rangle - \langle N_\pi \rangle \langle N_K \rangle^2 \right]$$

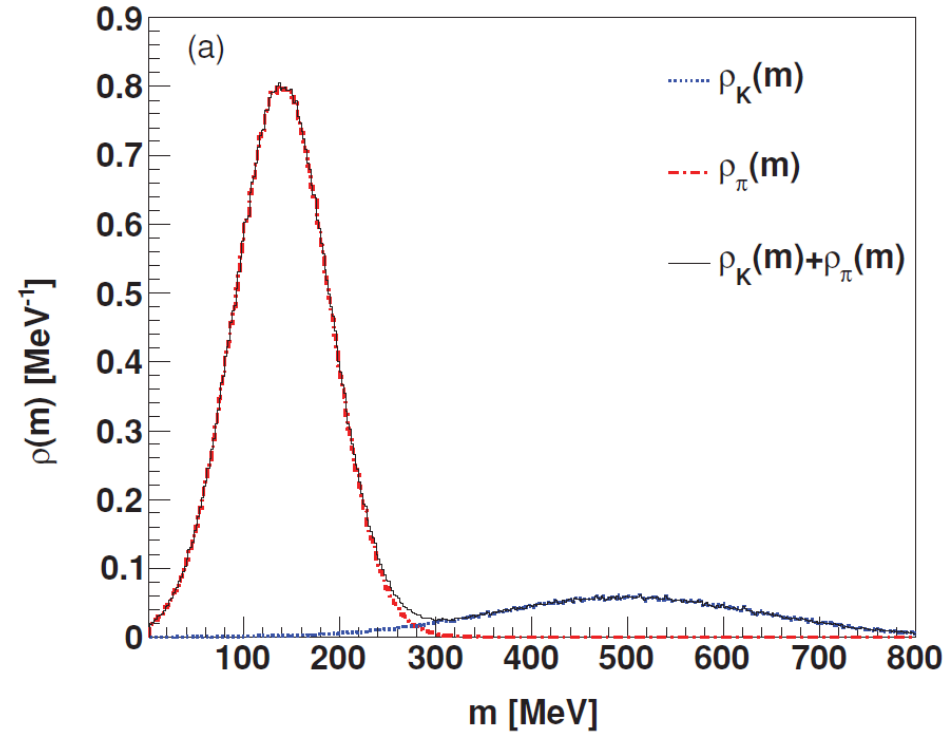
$$\langle N \rangle \equiv \langle N \rangle_K + \langle N \rangle_\pi$$

Particle identification



- Identification of an individual particle is never perfect!
- *Statistical* identification is typically exact!

Identity method



x - particle's identity

$$x(m) = \begin{cases} \frac{\rho_K(m)}{\rho(m)} & \text{- particle is a kaon} \\ 1 - \frac{\rho_K(m)}{\rho(m)} & \text{- particle is a pion} \end{cases}$$

$$\int dm \rho_K(m) = \langle N_K \rangle \quad \rho(m) \equiv \rho_K(m) + \rho_\pi(m)$$

$$\int dm \rho_\pi(m) = \langle N_\pi \rangle \quad \int dm \rho(m) = \langle N \rangle$$

Identity method

Ψ_{CI} is Ψ for complete identification

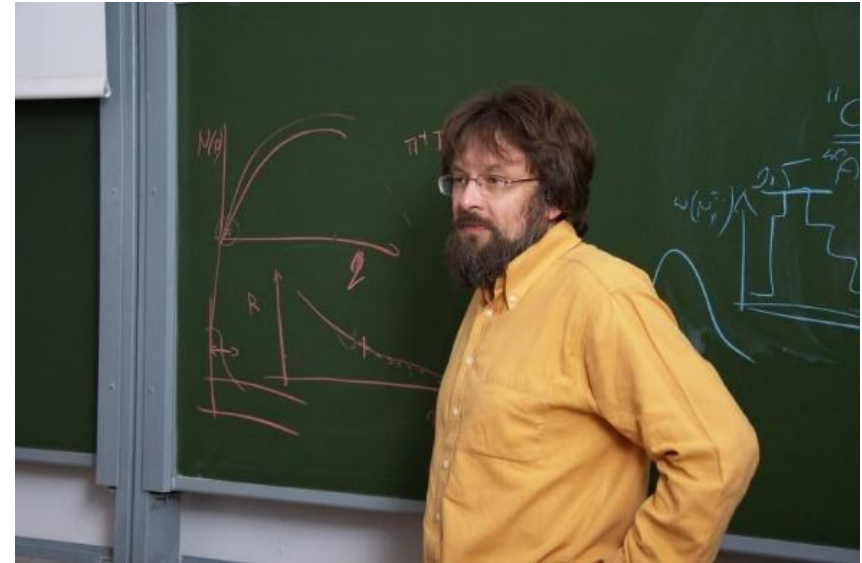
$$\Psi = \underbrace{\left(1 - \frac{\langle N \rangle (1 - \overline{u}_K)}{\langle N_\pi \rangle}\right)^2}_{\text{model independent correction factor}} \Psi_{\text{CI}}$$

model independent correction factor

$$\overline{u}_K \equiv \frac{1}{\langle N_K \rangle} \int dm \rho_K(m) x(m)$$

Chemical fluctuations
can be exactly measured!

There are still some adventures ahead!



Happy Birthday!