Recent results from NA49 and NA61/SHINE

Anar Rustamov for the NA49 and NA61/SHINE Collaborations
a.rustamov@cern.ch

- Outline
  - Experimental setup
  - Physics program
  - Results from NA49
  - Results from NA61
  - Summary

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

QM 12 QuarkMatter

The NA49 experiment

- four TPCs with two of them inside the magnetic field
- large acceptance: ≈ 50%
- high momentum resolution:

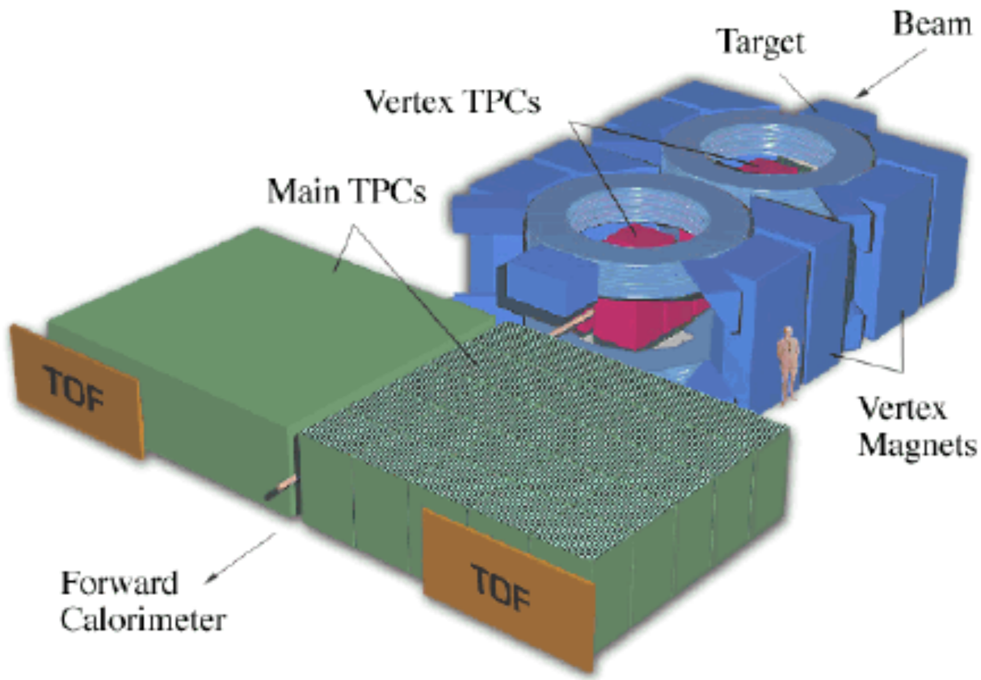
$$\frac{\sigma(p)}{p^2} \approx 10^{-4}[1/(GeV/c)]$$

- precise particle identification:

$$\frac{\sigma(dE/dx)}{\langle dE/dx \rangle} \approx 4\%$$

$$\sigma(tof) \approx 60\,ps$$

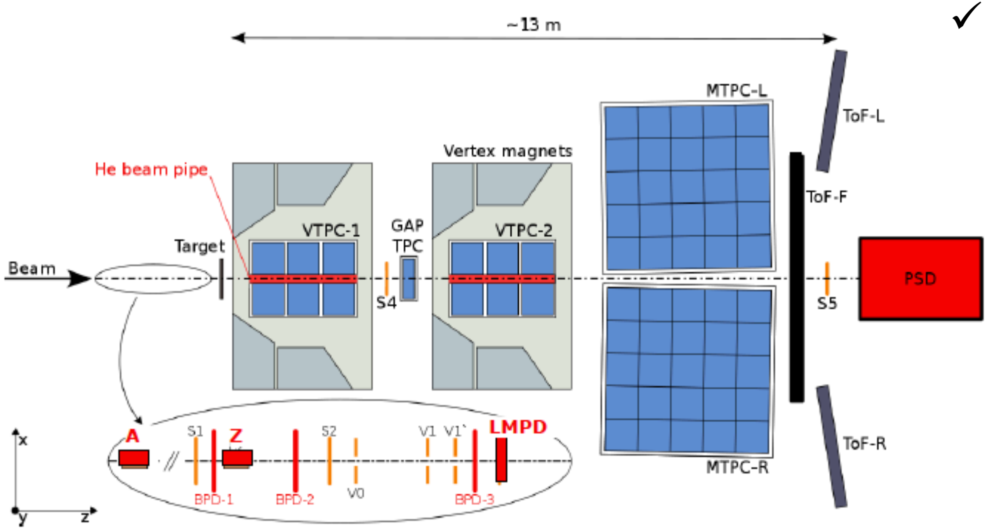
- Operated from 1994 to 2002 recorded data on: p+p, C+C, Si+Si and Pb+Pb



NA61 at the CERN SPS

"successor" of NA49 with numerous upgrades

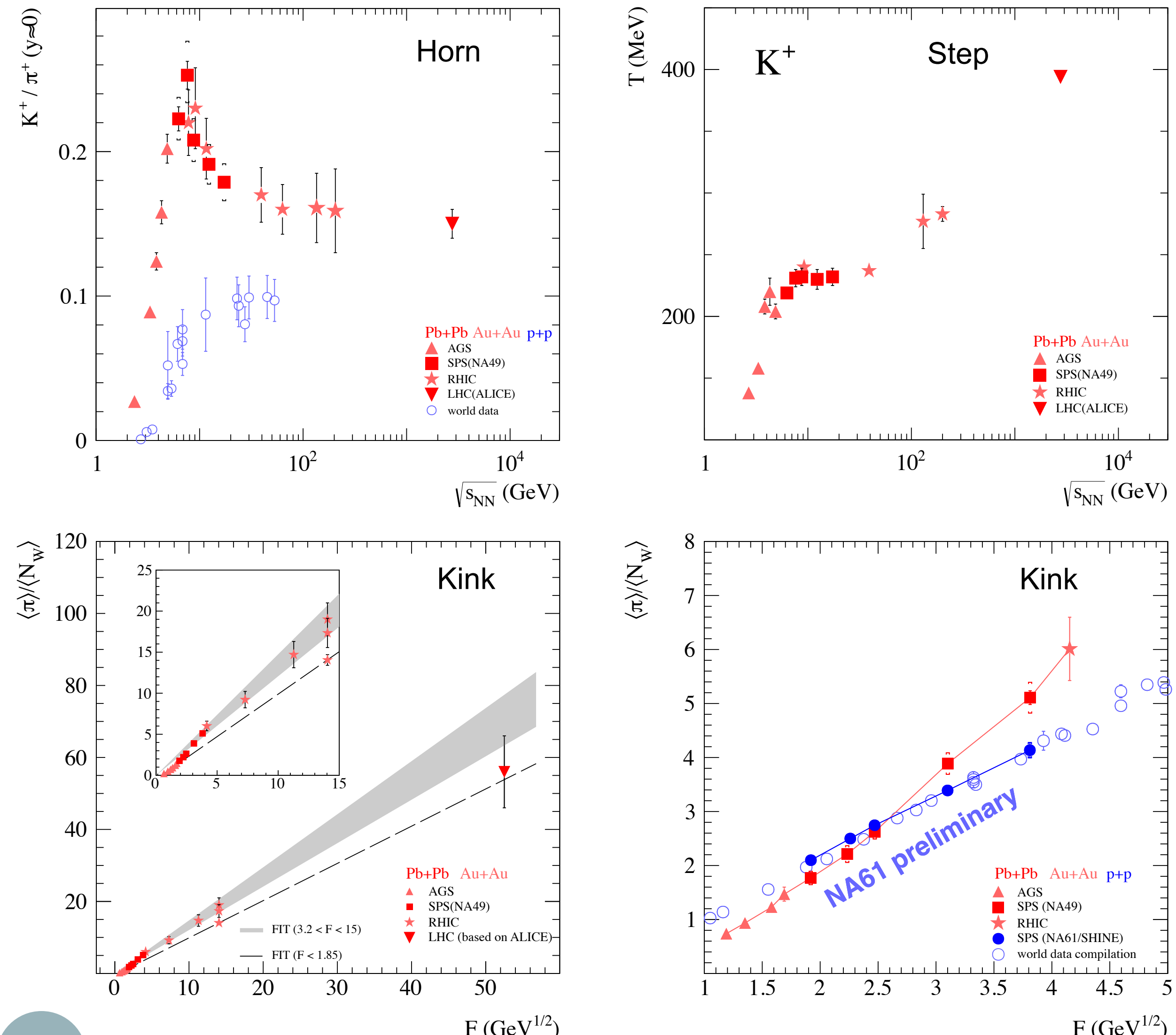
SPS Heavy Ion and Neutrino Experiment (3 different comunities)



operates since 2007

- ✓ 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

Onset of Deconfinement



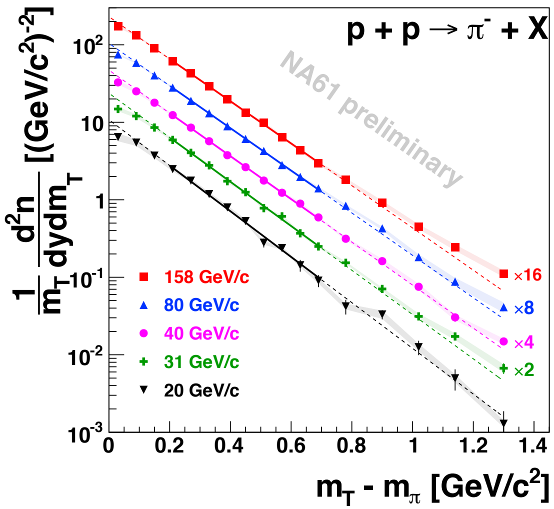
NA49 findings are confirmed by STAR and ALICE

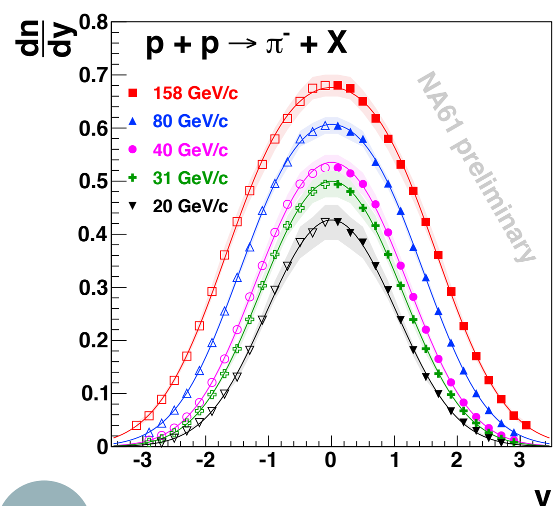
STAR: QM2011 proceedings
ALICE: QM2011 proceedings
A. Rustamov arXiv:1201.4520v1

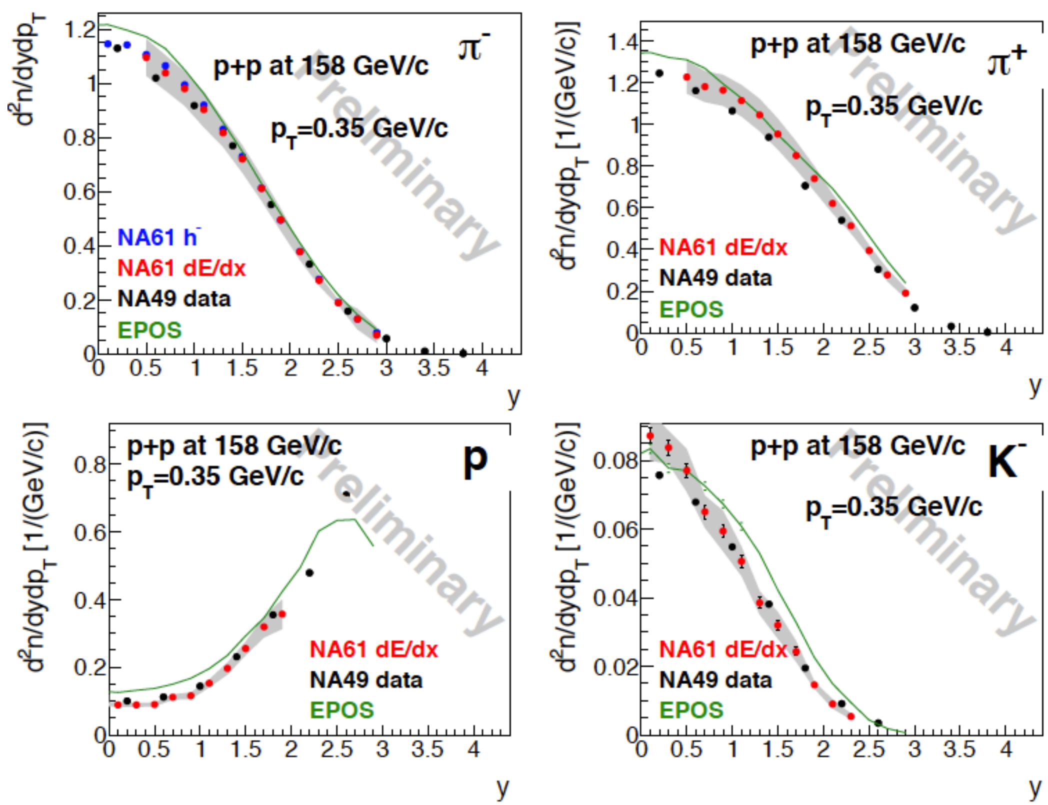
NA61/SHINE has successfully started the study of the onset signals

Particle Spectra

NA61/SHINE results on p+p data

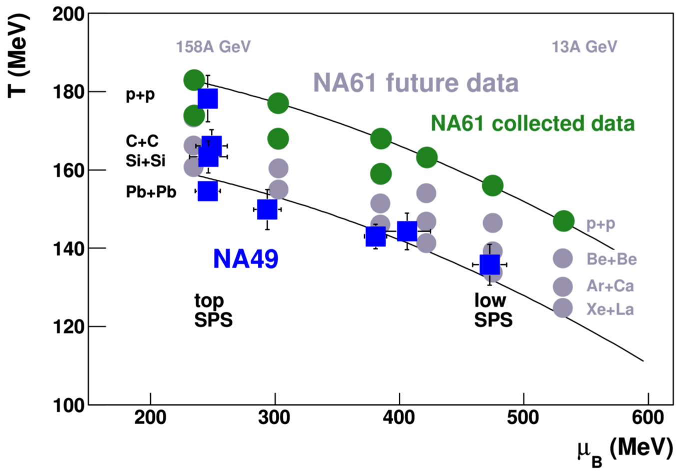




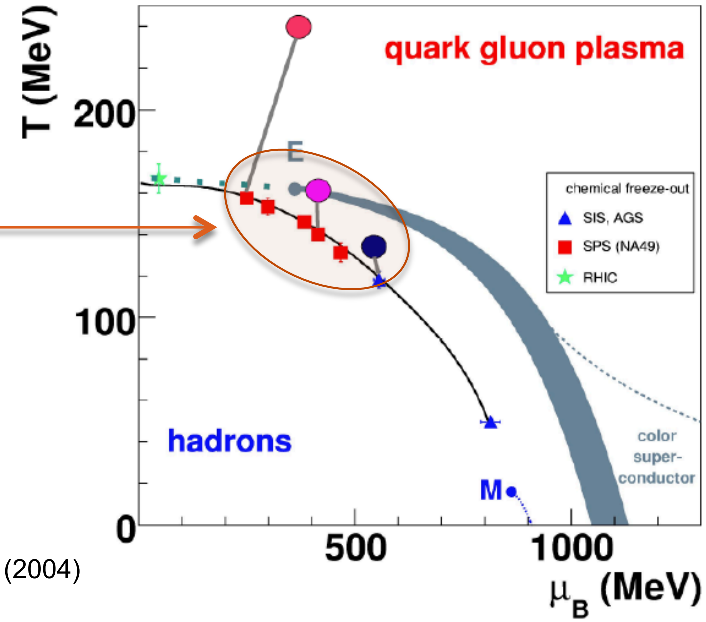


S. Puławski, this conference, poster session

Search for the CEP



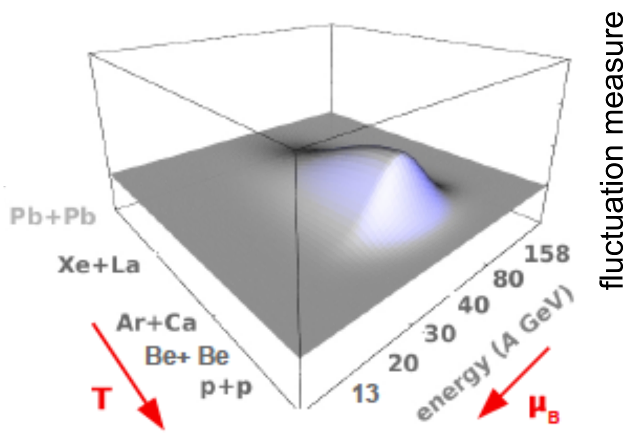
probes an interesting region on the phase diagram



for example:

$T_c = 162 \pm 2$ MeV
$\mu_c = 360 \pm 40$ MeV

Z. Fodor S. D. Katz, JHEP 0404, 050 (2004)



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

Multiplicity fluctuations

$$\omega = \frac{\langle N^2\rangle - \langle N\rangle^2}{\langle N\rangle} = \frac{Var(N)}{\langle N\rangle}$$

Poisson case: $\langle N^2\rangle = \langle N\rangle^2 + \langle N\rangle, \quad \omega = 1$

Chemical (particle composition) fluctuations

NA49: $\sigma_{dyn} = \mathrm{sgn}\left(\sigma^2_{data} - \sigma^2_{mixed}\right)\sqrt{\left|\sigma^2_{data} - \sigma^2_{mixed}\right|}$

$$\sigma = \frac{\sqrt{Var(A/B)}}{\langle A/B\rangle} \qquad \frac{A}{B} = \frac{K}{\pi}, \frac{p}{\pi}, \frac{K}{p}$$

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

$$\nu_{dyn} \approx \mathrm{sgn}(\sigma_{dyn})\sigma^2_{dyn}$$

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

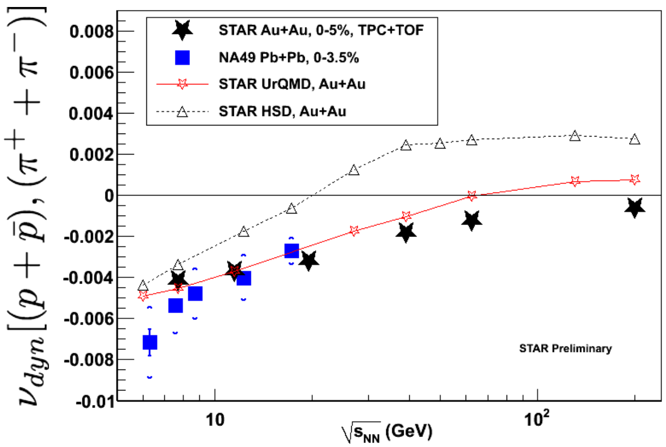
Intermittency

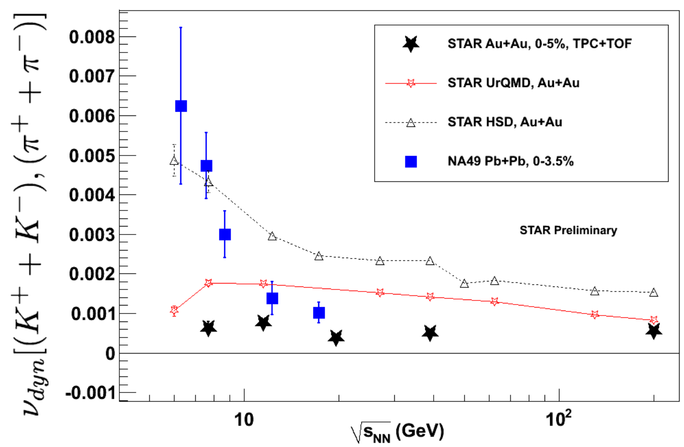
Experimental observable: factorial moments in transverse momentum space.

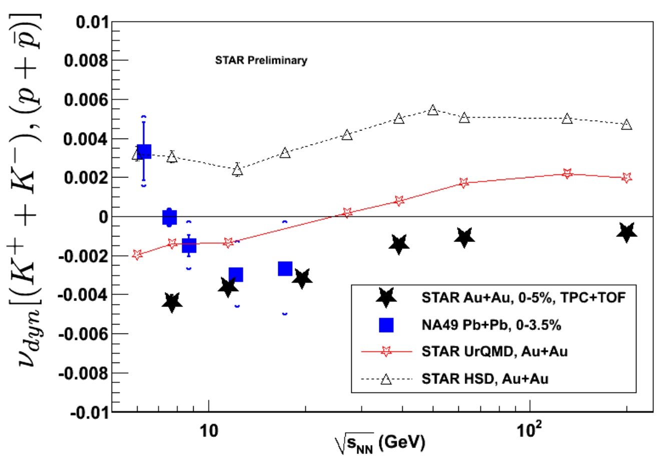
Power low (intermittency) prediction for CEP:

$$\Delta F_2(M) = F_2^{data}(M) - F_2^{mixed}(M) \propto \left(M^2\right)^{\phi_2}$$

NA49 vs. STAR







[K,p] and [K,π] results from NA49 and STAR are significantly different at low energies.

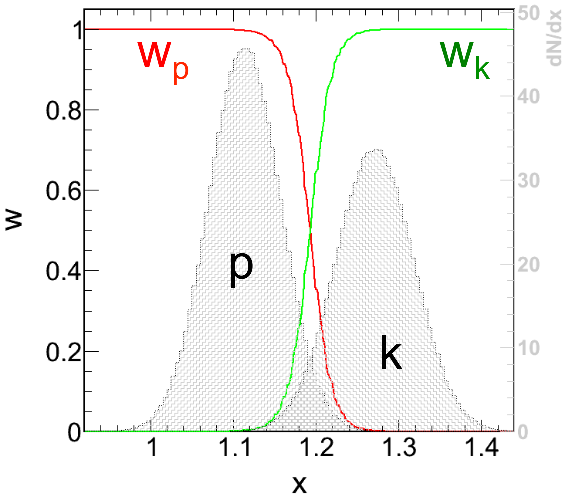
What is the reason for this difference?

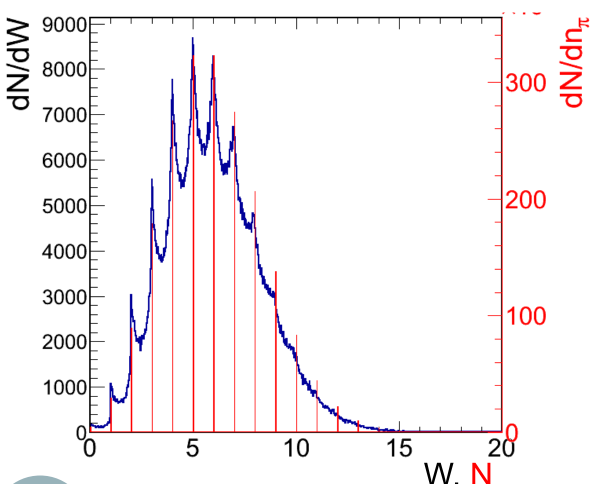
✓ bias in the used methods
✓ acceptance effects

Figures from: T. Tarnowsky, proceedings of Quark Matter 2011

Identity Method

2 particle example





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

Identity Method

The Identity Method relates corresponding moments of W and multiplicity distributions through a set of linear equations. An example for the second moments:

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

3 equations, 3 unknowns
(unique solution)

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

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

- 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, M. I. Gorenstein, arXiv:1204.6632, third moments

Results from Identity Method

second moments for central Pb+Pb data

input: rows $\langle N_p \rangle$, $\langle N_\pi \rangle$, $\langle N_K \rangle$

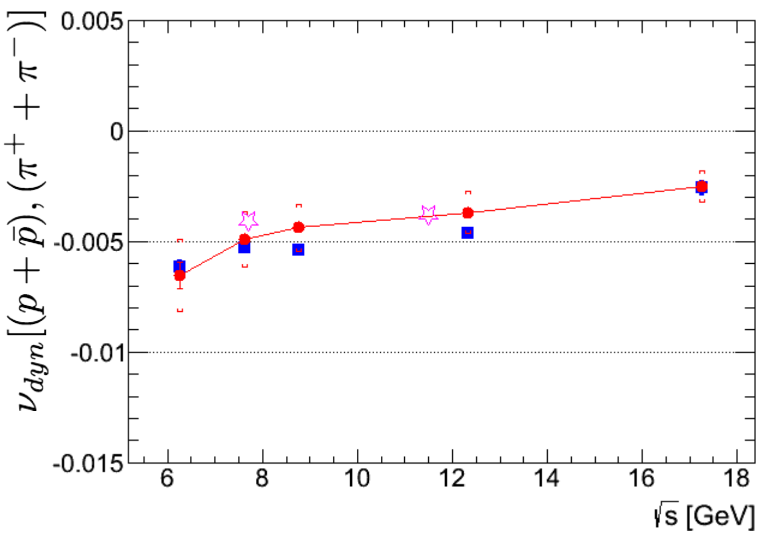
output: rows $\langle N_p^2 \rangle$ through $Cov[N_K N_\pi]$

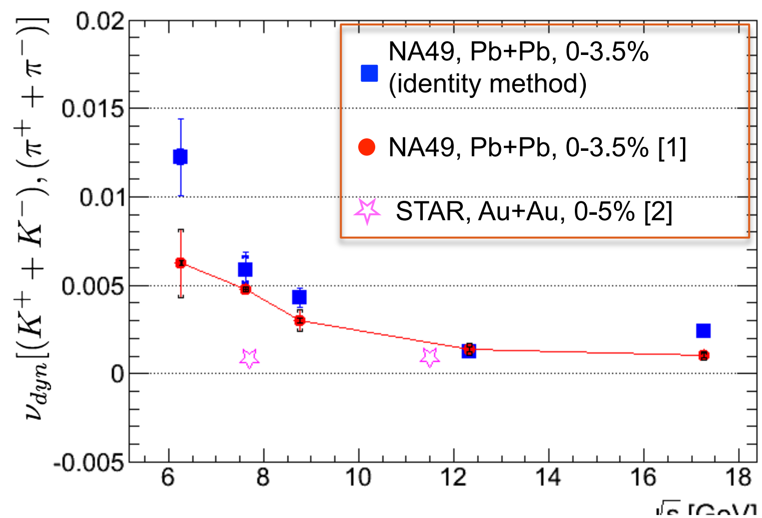
	20A GeV/c	30A GeV/c	40A GeV/c	80A GeV/c	158A GeV/c
$\langle N_p \rangle$	27.1786	34.876	38.186	47.5179	70.1685
$\langle N_\pi \rangle$	30.5385	66.4564	103.046	226.819	413.295
$\langle N_K \rangle$	4.5723	9.2489	13.6526	31.042	56.8712
$\langle N_p^2 \rangle$	764.277	1248.27	1493.64	2304.68	4969.01
$\langle N_\pi^2 \rangle$	964.311	4487.12	10737.9	51850.7	172014
$\langle N_K^2 \rangle$	25.395	94.9134	200.563	997.228	3312.25
$Cov[N_p N_\pi]$	2.12232	4.29659	9.15544	39.03744	32.00979
$Cov[N_p N_K]$	-0.73635	-0.62464	0.41682	3.48935	7.5732
$Cov[N_K N_\pi]$	-1.01266	-1.2876	0.30418	15.6246	110.6174

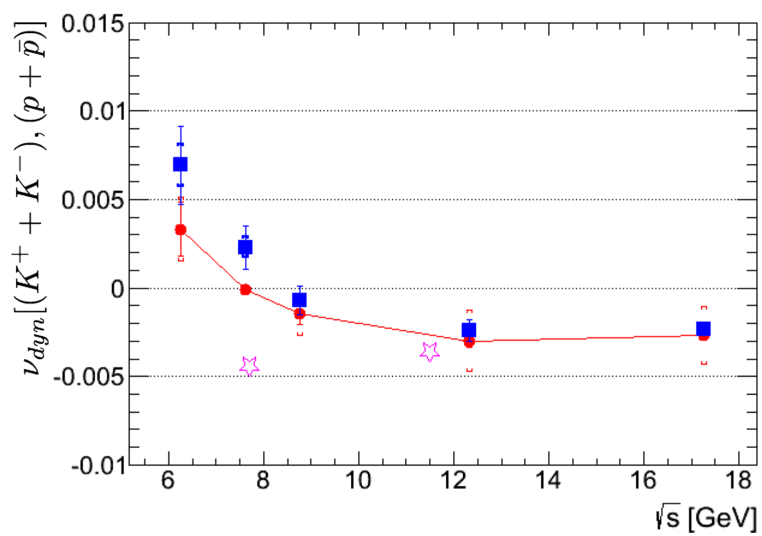
What is the reason for negative covariance?

$Cov[N_1,N_2] = \langle N_1 N_2 \rangle - \langle N_1 \rangle * \langle N_2 \rangle$

Results from Identity Method







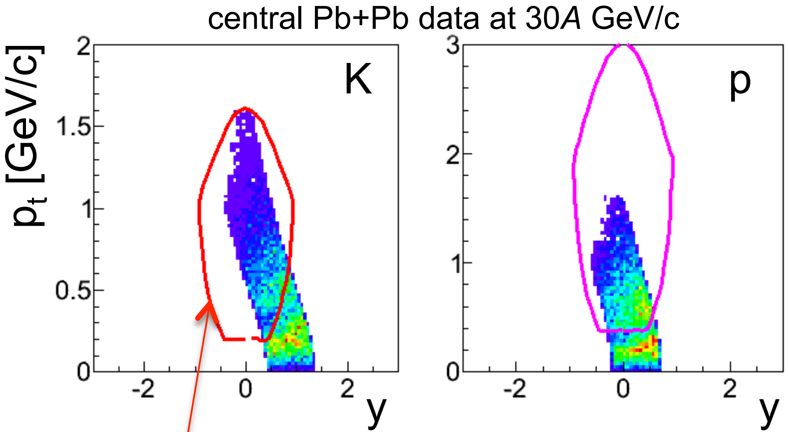
[p,π]: agreement with both, published results of NA49, and STAR

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

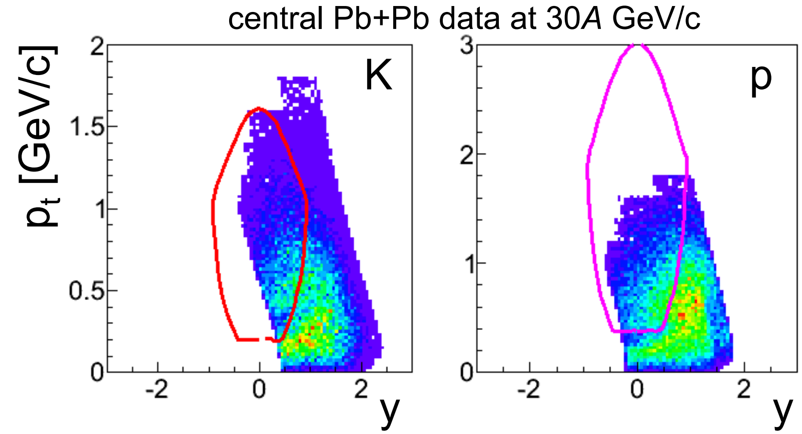
[K,p]: increasing trend at low energy published by NA49 is reproduced. Difference with STAR remains!

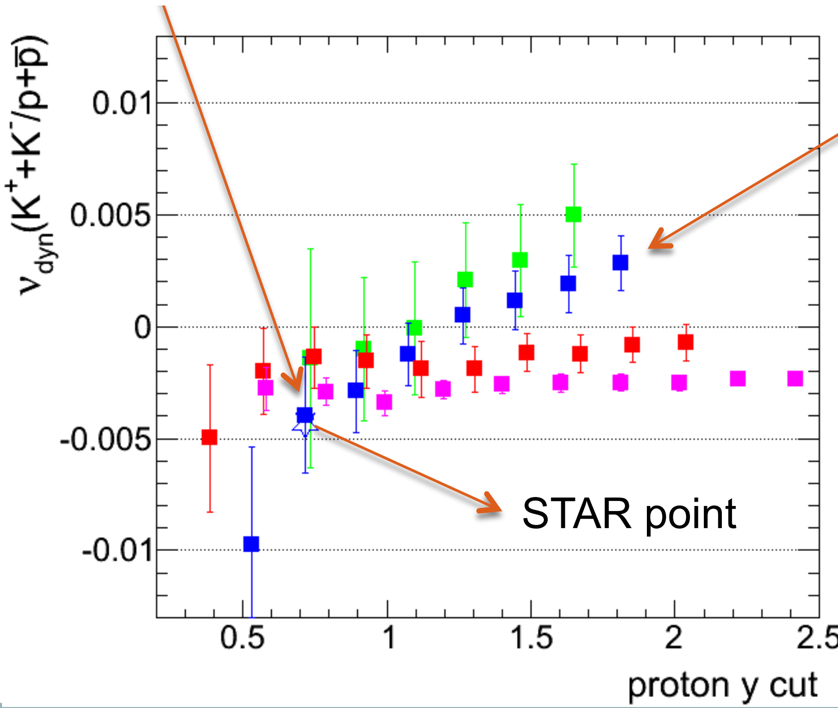
[1] NA49 Collaboration, PRC 79, 044910 (2009), PRC 83, 061902(R) (2011)
[2] T. Tarnowsky, proceedings of Quark Matter 2011

Dependence on acceptance



STAR acceptance



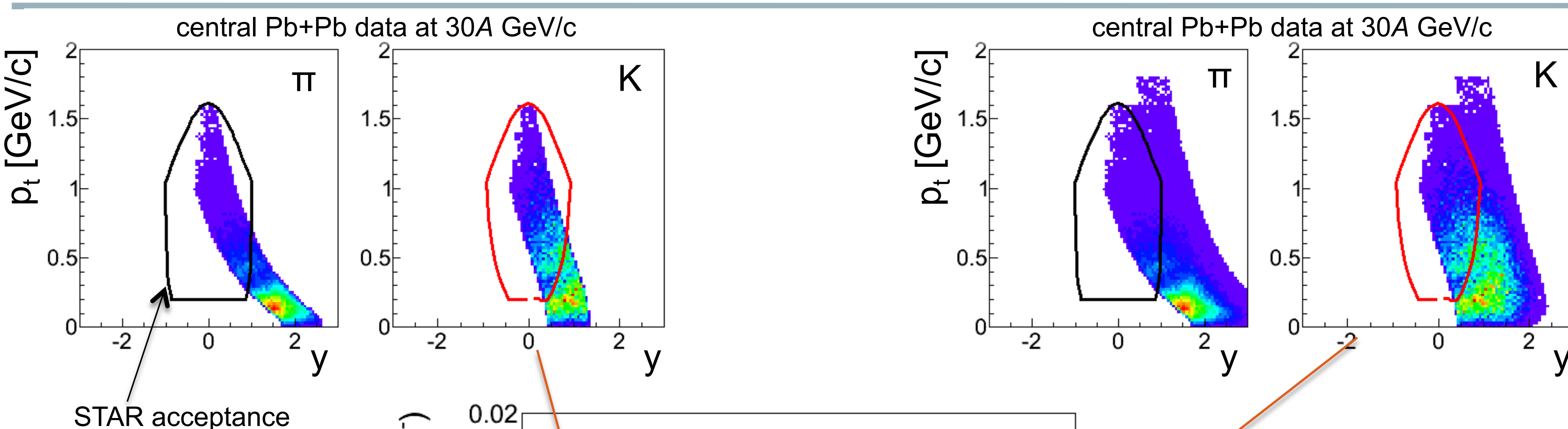


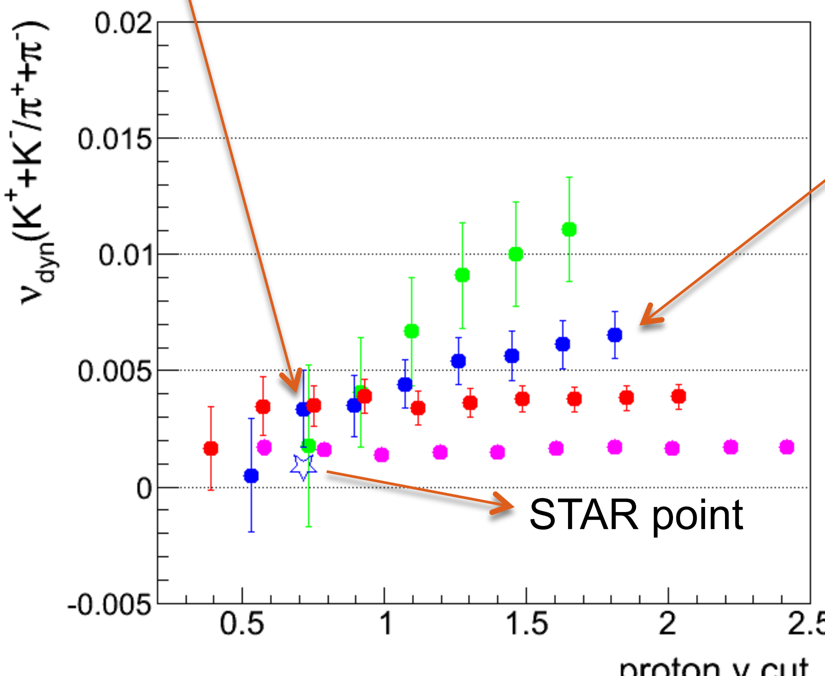
NA49, Pb+Pb at:
20*A* GeV/c
30*A* GeV/c
40 *A* GeV/c
158*A* GeV/c

at 20*A* and 30*A* GeV/c there is a strong acceptance dependence.

acceptance coverage appears to explain the difference with STAR

Dependence on acceptance



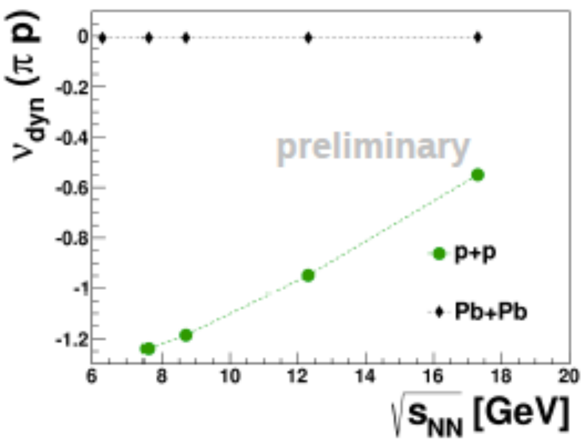


NA49, Pb+Pb at:
20*A* GeV/c
30*A* GeV/c
40 *A* GeV/c
158*A* GeV/c

at 20*A* and 30*A* GeV/c there is a strong acceptance dependence.

acceptance coverage appears to explain the difference with STAR

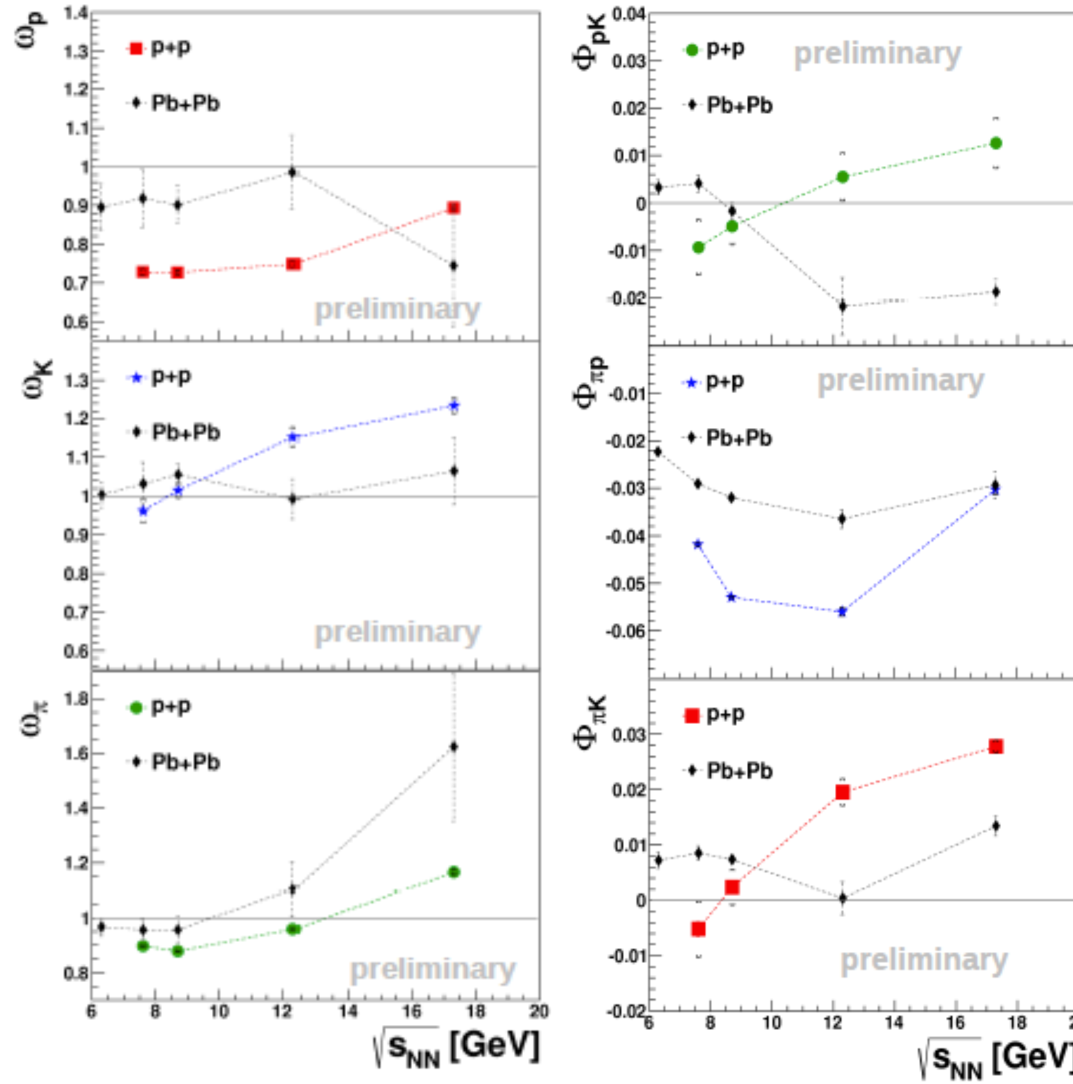
Pb+Pb vs. p+p



v_{dyn} depends on system volume
(not an intensive measure)

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

Φ_{ij} is an intensive quantity and does
not depend on volume fluctuations.
In a superposition model:
Φ_{ij} (A+A) = Φ_{ij} (N+N)

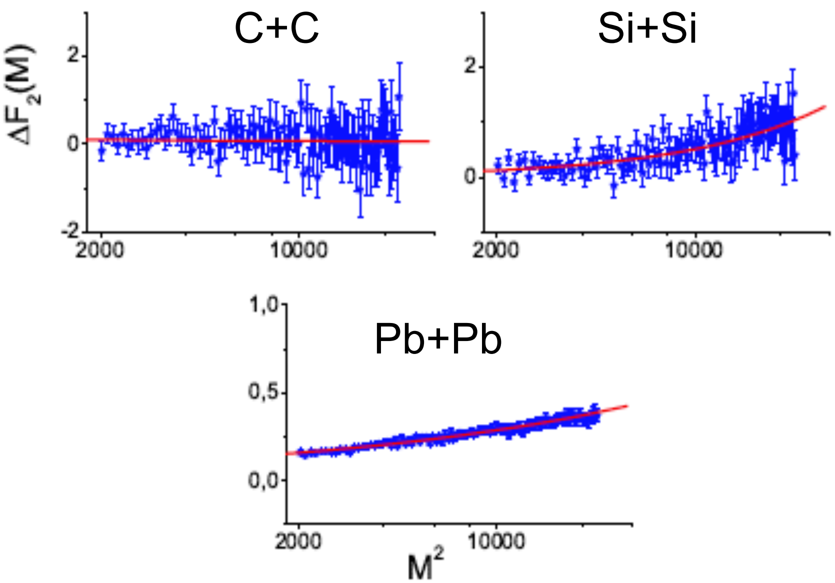


M. I. Gorenstein and M. Gazdzicki, PRC 84, 014904 (2011)

M. Maćkowiak this conference, poster session

Intermittency at 158*A* GeV/c

protons at mid rapidity



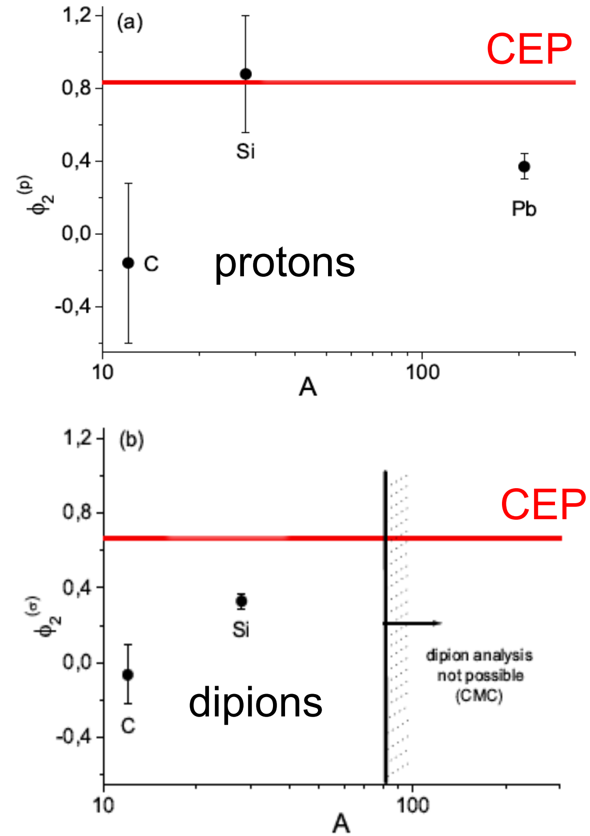
$$F_2(M)=\left\langle \frac{1}{M^2}\sum_{i=1}^{M^2} n_i\left(n_i-1\right)\right\rangle \Big/ \left\langle \frac{1}{M^2}\sum_{i=1}^{M^2} n_i\right\rangle^2$$

$$\Delta F_2(M)=F_2^{data}(M)-F_2^{mixed}(M)\propto\left(M^2\right)^{\phi_2}$$

M^2 – number of bins in p_t space

n_i number of protons in cell i

intermittency index



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

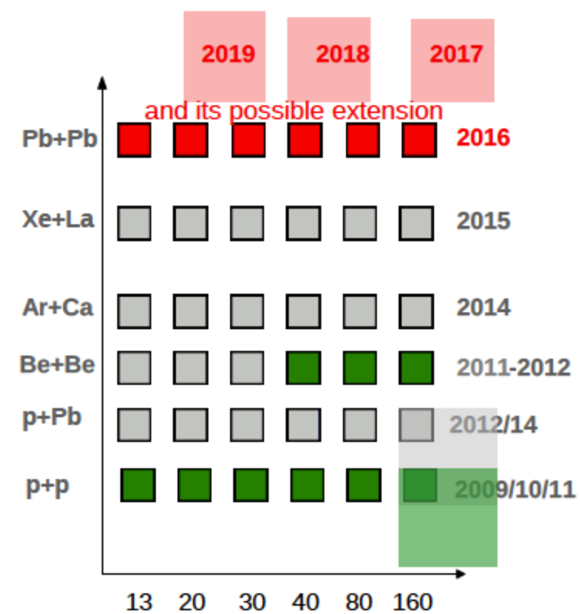
(i) net proton density

(ii) low mass ππ pairs

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

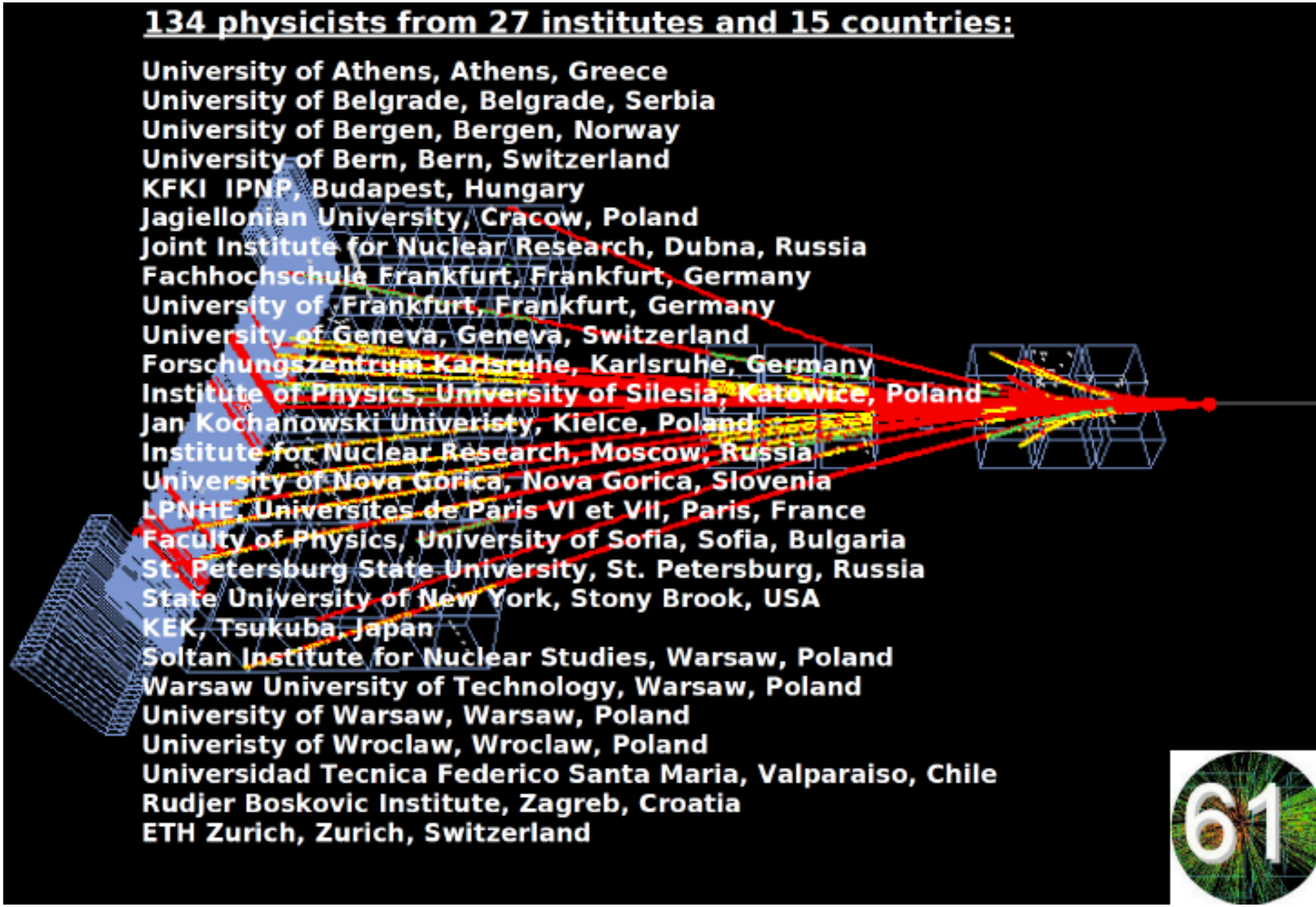
Summary

- NA49: chemical fluctuations in central Pb+Pb collisions
  - the increasing trend in $\nu_{dyn}[K,\pi]$ and $\nu_{dyn}[K,p]$ 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 π, K, p spectra
  - scaled variance and chemical fluctuations at 31, 40, 80 and 158 GeV/c.



NA61/SHINE schedule

NA61/SHINE Collaboration



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 Karlsruhe, Karlsruhe, Germany
Institute of Physics, University of Silesia, Katowice, Poland
Jan Kochanowski Univeristy, 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
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

NA49 Collaboration

78 physicists from 23 institutes and 12 countries:

NIKHEF, Amsterdam, Netherlands
University of Athens, Athens, Greece
Comenius University, Bratislava, Slovenia
Eotvos Lorand University, Budapest, Hungary
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