New results from fluctuation analysis in NA49 at the CERN SPS

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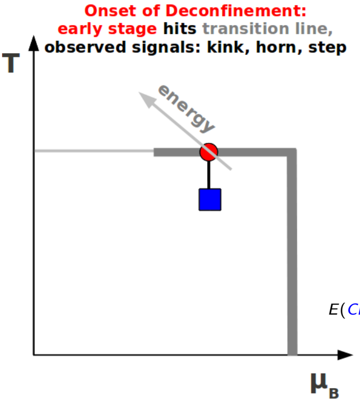
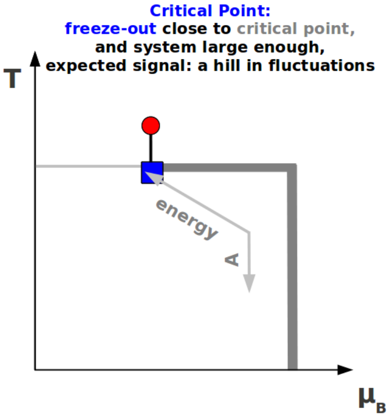
Fluctuations study for OD and CP



$E(CP) > E(OD)$



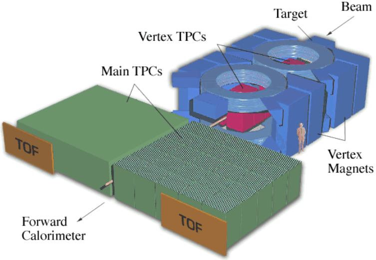
Fluctuations/correlations may serve as an additional evidence of OD

Fluctuations/correlations are basic signal of the critical point.

NA49 experiment

NA49 experiment

NA49 (fixed target) experiment at CERN SPS



- data taking 1994-2002
- p+p, C+C, Si+Si, Pb+Pb interactions at $\sqrt{s_{NN}} \in (6.3 - 17.3) GeV$

- Hadron spectrometer
  Four TPCs; two VTPCs (1/2) in the B field and two others MTPCs (R/L) outside; for a precise measurement of p and dE/dx
- Large acceptance $\sim$ 50%
- High momentum resolution

$$\frac{\sigma(p)}{p^2} \sim 10^{-4} (\frac{GeV}{c})^{-1}$$

- PID by dE/dx, TOF, decay topology, invariant mass

$$\sigma(dE/dx)/ < dE/dx > \sim 5\%$$

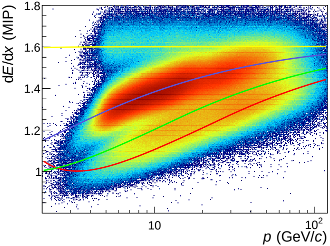
$$\sigma(TOF) \sim 60ps$$

$$\sigma(m_{inv}) \sim 5MeV$$

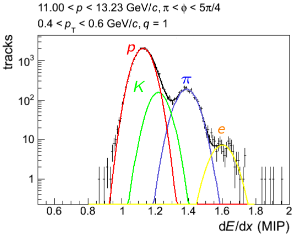
- Good centrality determination
  Forward Calorimeter (energy of projectile spectators)

E-by-e identified hadron multiplicities in NA49

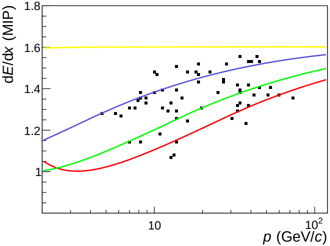
100k events:



Fit dE/dx spectra in each phase-space bin:



1 event:



Fit multiplicities of identified hadrons with maximum likelihood method in each event.

Correct fluctuation results for misidentification using mixed events method.

Measures of fluctuations

Fluctuation measures studied in NA49

σ_{dyn} - measure of dynamical particle ratio fluctuations (K/p,K/π,p/π)

- E-by-e fit of particle multiplicities required in NA49
- Mixed events used as reference
- $\sigma^2_{dyn} \sim \frac{1}{N_W}$, $\sigma^2_{dyn} \approx \nu_{dyn}$

$$\sigma_{dyn} = sign(\sigma^2_{data} - \sigma^2_{mix})\sqrt{|\sigma^2_{data} - \sigma^2_{mix}|}$$

$$\sigma = \frac{\sqrt{Var(A/B)}}{<A/B>} \cdot 100[\%]$$

ω - scaled variance of multiplicity distribution

- Intensive measure
- For Poissonian multiplicity distribution $\omega = 1$
- In wounded nucleon model: $\omega(AA) = \omega(NN) + \frac{1}{2} < n > \omega_W$
  where $w(NN)$ and $< n >$ are scaled variance and mean multiplicity in NN interactions; respectively
  ω_W - scaled variance of the number of wounded nucleons, N_W
  ω **depends on** N_W **fluctuations**

$$\omega = \frac{<N^2> - <N>^2}{<N>}$$

Φ_x - strongly intensive fluctuation measure (x=p_T,ϕ,Q)

- In superposition model $\Phi_x(AA) = \Phi_x(NN)$
- For independent particle emission $\Phi_x = 0$
- Φ_x is independent of volume and volume fluctuations (strongly intensive)

$$\Phi_x = \sqrt{\frac{<Z_x^2>}{<N>}} - \sqrt{\overline{z^2}},$$

$z_x = x - \overline{x}$, $\overline{x}$ - incl. aver.,

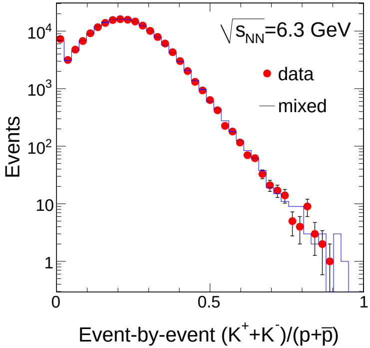
$$Z_x = \sum_{i=1}^{N}(x - \overline{x})$$

Intermittency analysis will be presented by F. Diakonos

Chemical fluctuations

E-b-e hadron ratios

Fitted event-by-event hadron ratios (e.g., K/p) from



● data events

— mixed events:

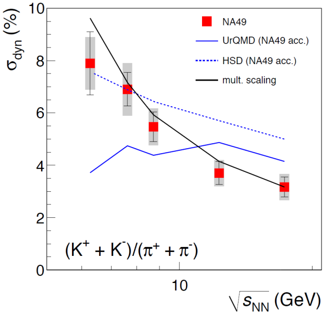
event mixing + maximum likelihood PID

Calculate from data and mixed events:

$$\sigma = \frac{\sqrt{Var(A/B)}}{<A/B>} \cdot 100[\%]$$

$$\sigma_{dyn} = sign(\sigma^2_{data} - \sigma^2_{mix})\sqrt{|\sigma^2_{data} - \sigma^2_{mix}|}$$

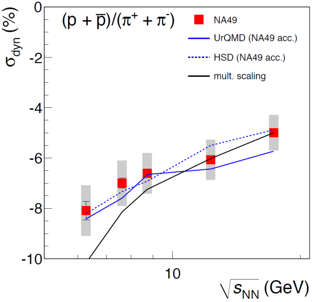
Energy dependence for central Pb+Pb



K/π: $\sigma_{dyn} > 0$

σ_{dyn} rises towards low SPS energies which is not reproduced by UrQMD. HSD catches the trend but over-predicts points at high SPS energies. Data are reproduced by multiplicity scaling.

NA49: PR**C79**, 044910 (2009)
HSD: PR**C79**, 024907 (2009)



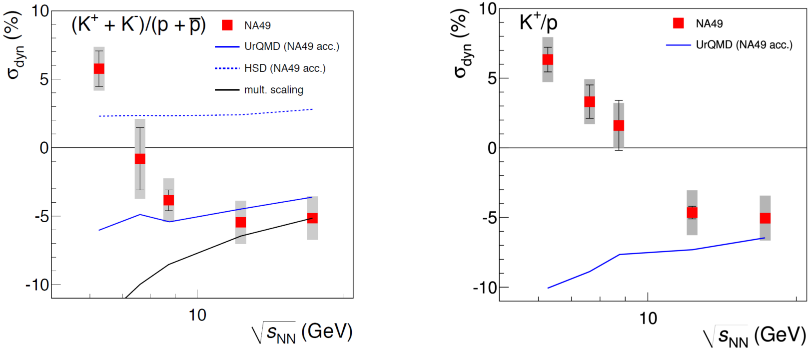
p/π: $\sigma_{dyn} < 0$

σ_{dyn} decreases towards low SPS energies which is reproduced by hadronic models and multiplicity scaling. The trend is understood in terms of correlations due to nucleon resonance decays.

NA49: PR**C79**, 044910 (2009)
HSD: J.Phys.**G36**, 125106 (2009)

Multiplicity scaling is expected in thermodynamic models for μ_B, T_{chem} = const [Koch, Schuster PRC81,034910(2010)]

Energy dependence for central Pb+Pb

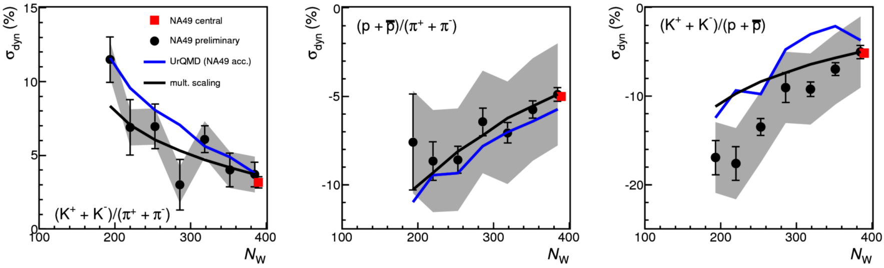


K/p: σ_{dyn} changes sign

The sign change is not reproduced by hadronic models (UrQMD and HSD) and by the multiplicity scaling.

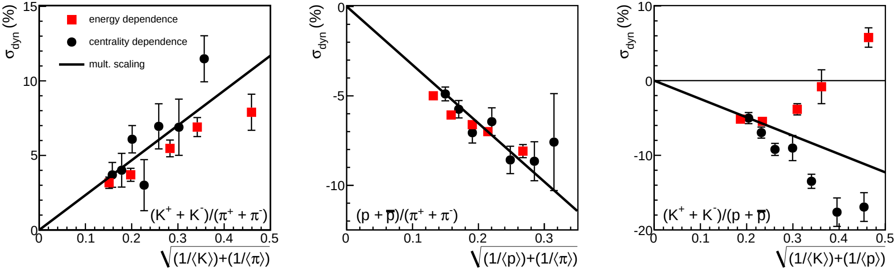
NA49: PR**C83**, 061902 (2011) [arXiv:1101.3250]; HSD: J.Phys.**G36**, 125106 (2009)

Centrality dependence of Pb+Pb at 17.3 GeV



σ_{dyn} does not change sign for K/p, K/π, p/π

Direct multiplicity scaling

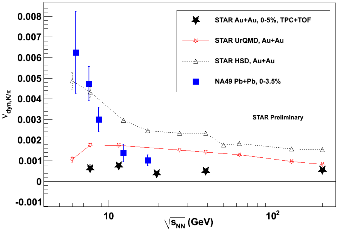


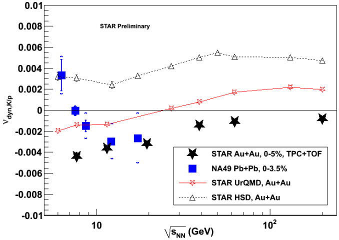
Multiplicity scaling ($\sigma_{dyn} \propto \sqrt{\frac{1}{<A>} + \frac{1}{<B>}}$) works for K/π and p/π fluctuations

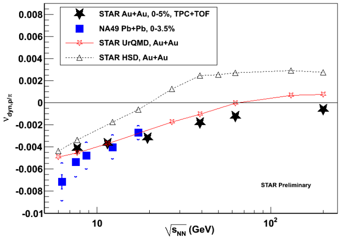
The same scaling does not work for K/p

Comparison between NA49 and STAR

Energy dependence for central Pb+Pb (Au+Au) collisions.







figures from T. Tarnowsky (STAR, SQM2011)
conversion via:

$$\nu_{dyn} = sign(\sigma_{dyn}) \cdot \sigma_{dyn}^2$$

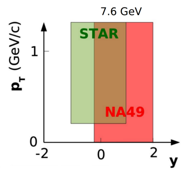
STAR results do not show increase towards low SPS energies for K/π and K/p

Possible sources of the difference

Analysis procedures were carefully checked, no problems found

NA49 and STAR acceptance and centrality selection differ significantly

Acceptance schematic sketch



Centrality selection:

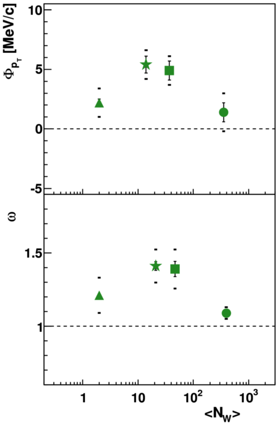
- NA49: energy of projectile spectators
- STAR: N_{ch} multiplicity

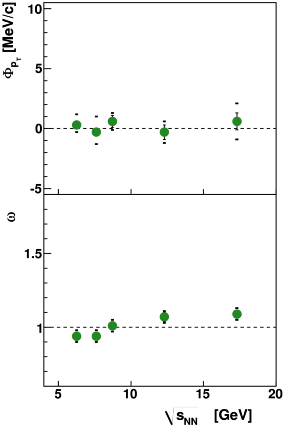
Further steps

- further checks of the used analysis methods
- a new analysis method (identity PRC**83**,054907(2011),PRC**84**,024902(2011)) and strongly intensive fluctuation measures will be used by NA49

N and average p_T fluctuations

Large fluctuations of multiplicity and mean transverse momentum expected at CP [Stephanov, Rajagopal, Shuryak, PR**D60**, 114028 (1999)]



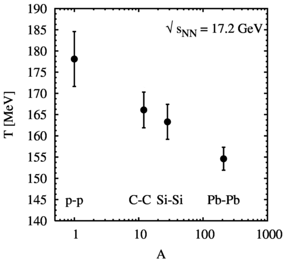


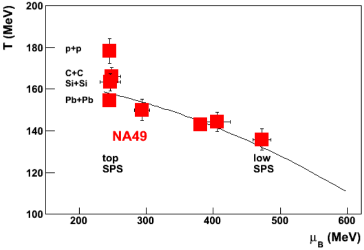
Maximum of Φ_{p_T} and ω for C+C and Si+Si

Weak, if any, energy dependence

Multiplicity and mean transverse momentum fluctuations

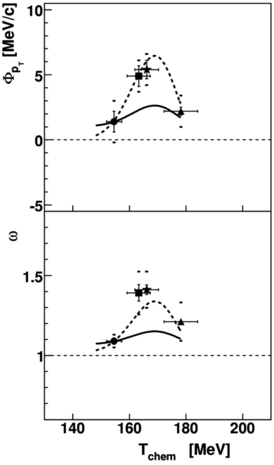
For the search of CP it is more convenient to use (T_{chem}, μ_B) instead of $(N_w, \sqrt{s_{NN}})$

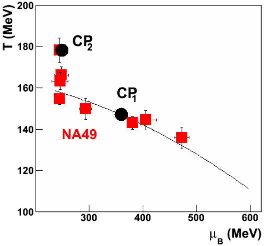




Chemical freeze-out points
[Becattini et al., PR**C73**, 044905 (2006)]

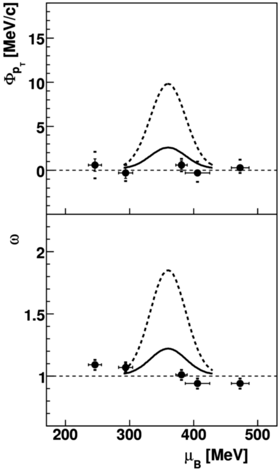
All charged:





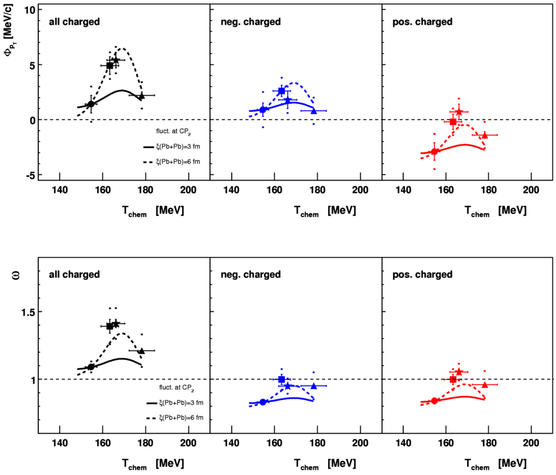
Maximum of Φ_{p_T} and ω observed for C+C and Si+Si

Data are consistent with the CP_2 predictions



[1] Stephanov et al., PR**D60** 114028 (1999), Hatta,Ikeda et al., PR**D67** 014028 (2003) for details see Grebieszkow et al., NP**A830**, 547C-550C (2009)

Results for same charged particles

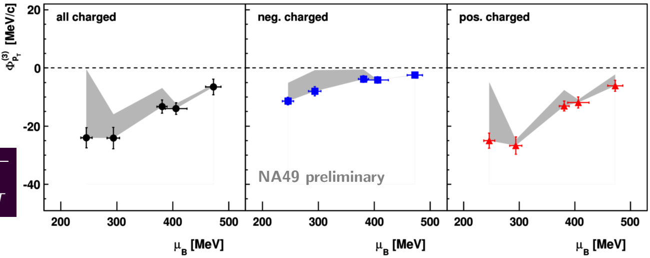


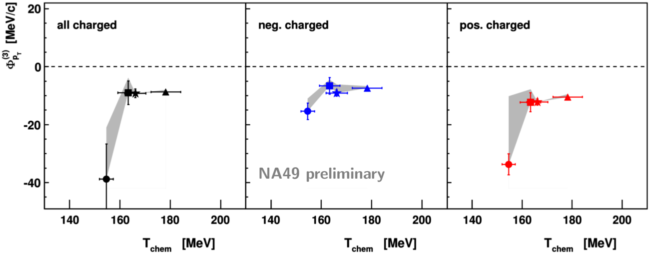
Increase about two times larger for all charged than for same charged particles (as predicted for CP)

3^{rd} moment of average p_T fluctuations

Higher moments are expected to be more sensitive to the CP fluctuations.

$$\Phi^{(3)}_{p_T} = \sqrt[3]{\frac{<Z^3_{p_T}>}{<N>}} - \sqrt[3]{\overline{z^3_{p_T}}}$$





No quantitative predictions for fluctuations at CP.

Azimuthal angle fluctuations

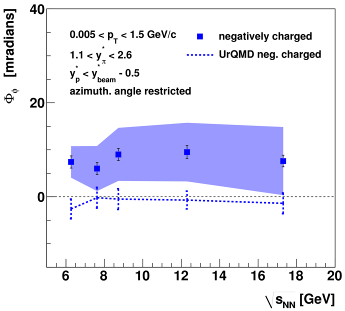
Energy dependence of azimuthal angle fluctuations

Azimuthal angle fluctuations may be sensitive to:

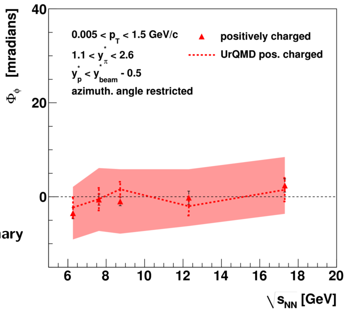
- plasma instabilities PLB**314**, 118 (1993)
- flow fluctuations APP**B34**, 4241 (2003); arXiv:nucl-ex/0312008

Background effects: resonance decays, momentum conservation, flow, (di-)jets, quantum statistics

Central Pb+Pb:



NA49 preliminary

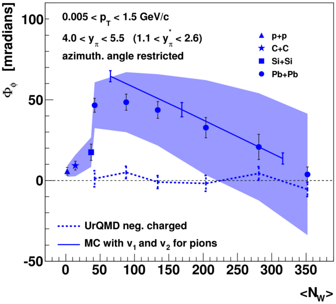


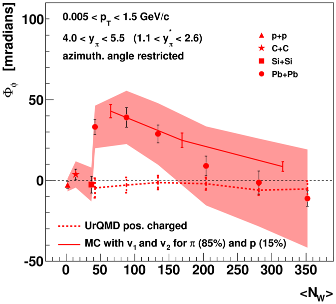
$\Phi_\phi(\textit{negative}) > 0$
- different than in UrQMD (1.3)

$\Phi_\phi(\textit{positive})$ consistent with zero

System size dependence at 17.3 GeV of azimuthal angle fluctuations

NA49 preliminary:





- $\Phi_\phi > 0$ for peripheral Pb+Pb
- UrQMD(3.3) does not reproduce the data
- the magnitude of Φ_ϕ reproduced by the effect of v_1 and v_2

Summary

- Energy and system size dependence of K/π **and** p/π **fluctuations** can be described in a **simple multiplicity scaling model**

- K/p **fluctuations** show a deviation from this scaling; is the underlying correlation physics changing with energy?

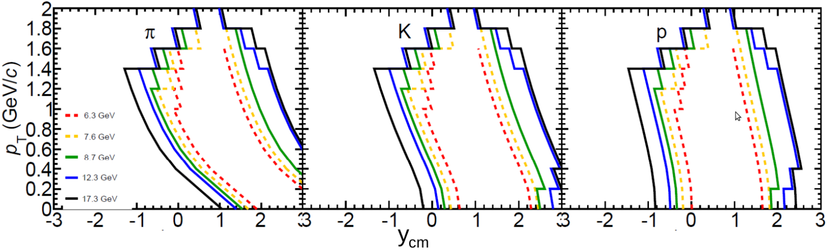
- The energy dependence of event-by-event K/p and K/π fluctuations measured by NA49 and STAR in central Pb+Pb/Au+Au is different. Both collaborations work on clarification of the observed differences

- **Fluctuations of average p_T and multiplicity are maximal in Si+Si collisions at 17.3 GeV**. This might be connected with the critical point at SPS energies $\rightarrow$ **strong motivation for future experiments**

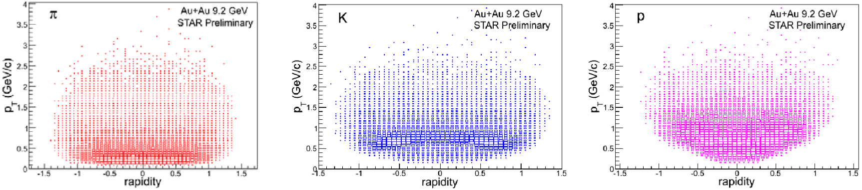
Back-up slides

Details of acceptance in NA49 and STAR

NA49:



STAR:

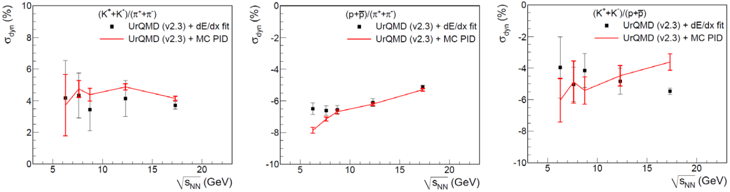


Test of the method

artificial correlations introduced by the fit procedure are quantified by applying the same analysis procedure to mixed events and subtracted

$$\sigma_{dyn} = \text{sign}(\sigma^2_{data} - \sigma^2_{mix})\sqrt{\left|\sigma^2_{data} - \sigma^2_{mix}\right|} \quad , \quad \sigma = \frac{\sqrt{Var(A/B)}}{\langle A/B \rangle}$$

UrQMD simulation demonstrates validity of the method:



differences mostly insignificant, taken into systematic errors

equivalence of σ_{dyn} and ν_{dyn}

$$\sigma^2_{dyn} \approx \left(\frac{\langle A(A-1)\rangle}{\langle A^2\rangle} + \frac{\langle B(B-1)\rangle}{\langle B^2\rangle} - 2\frac{\langle AB\rangle}{\langle A\rangle\langle B\rangle} \right) = \nu_{dyn}$$

generic multiplicity dependence

$$= \left(\frac{1}{\langle A\rangle} C_{AA} + \frac{1}{\langle B\rangle} C_{BB} - \frac{2}{\sqrt{\langle A\rangle\langle B\rangle}} C_{AB} \right)$$

Koch,Schuster PRC81,034910(2010)

Calculate ν_{dyn} in NA49

$$\nu = \frac{<A^2>}{<A>^2} + \frac{<B^2>}{<B>^2} - 2\frac{<AB>}{<A><B>}$$

The definition of ν_{dyn} assumes uncorrelated background

$\nu_{stat} = \frac{1}{<A>} + \frac{1}{<B>}$ $\nu_{dyn} = \nu - \nu_{stat}$

To subtract correlation present in mixed events, we instead define

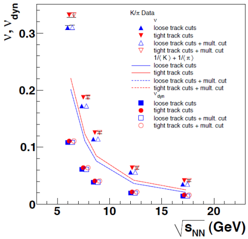
$$\Delta\nu = \nu_{data} - \nu_{mix}$$

K/π in central Pb+Pb

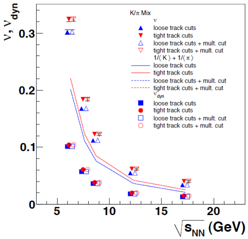
K/π fluctuations

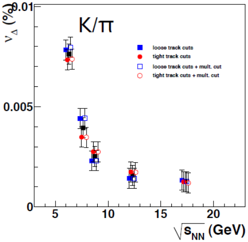
Results for ν_Δ

ν and ν_{dyn} (K,π) data



ν and ν_{dyn} (K,π) mix

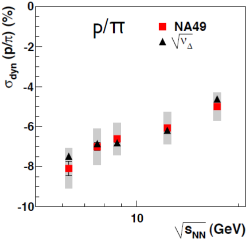


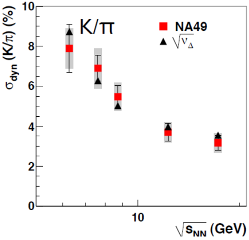


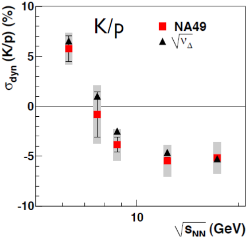
K/π in central Pb+Pb

Calculate ν_{dyn} in NA49

Compare to σ_{dyn} results

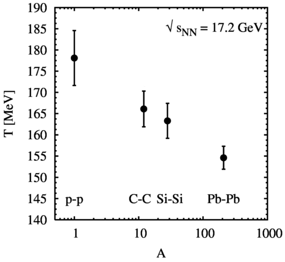


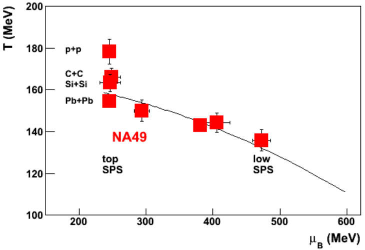




Multiplicity and mean transverse momentum fluctuations

Strategy to look for critical point in NA49:





Chemical freeze-out points [PR C73, 044905 (2006)]

- Energy scan (beams 20A-158A GeV) with central Pb+Pb collisions - μ_B extracted from the fits to particles multiplicities
- System size dependence (different ions) at 158A GeV (top SPS energy) - T_{chem} depends on system size

Estimates of effects due to the critical point

Correlation length ξ at the critical point not divergent but limited by finite size and lifetime of the fireball.

parameterization: $\xi = min(c_1 A^{1/3}, c_2 A^{1/9})$ (M. Stephanov, priv. comm.)

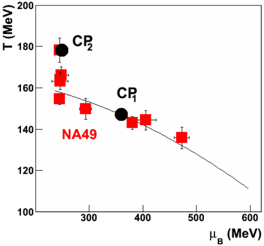
size lifetime

Suggesting: $\xi(Pb + Pb) = 3 \rightarrow 6 fm$

$\xi(p + p) = 1 \rightarrow 2 fm$

Range of correlation effect estimated from QCD calculations (Hatta,Ikeda,PRD67,014028(2003):

$\sigma(\mu_B) = 30$ MeV, $\sigma(T) = 10$ MeV



considered examples:

- CP1 - $\mu_B = 360$ MeV (lattice QCD,Fodor-Katz)
  T = 147 MeV (chem. freeze-out line)
- CP2 - $\mu_B = 250$ MeV (data 158A GeV)
  T = 178 MeV (fit of p+p data)