New results on event-by-event ratio fluctuations in Pb+Pb collisions at CERN SPS energies

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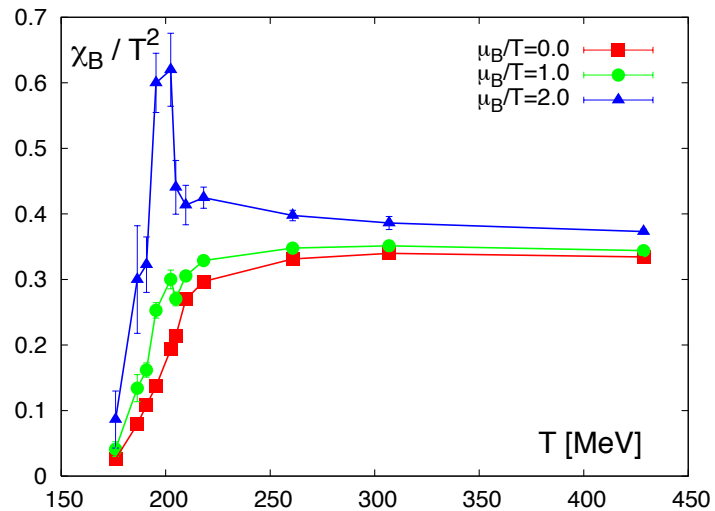
Quark Matter 2011
Annecy 23-28 May 2011

Hadron Ratio Fluctuations

- Hadron Ratios characterize the chemical composition of the fireball
  → fluctuations sensitive to the phase transition?

- Lattice QCD:
  quark number susceptibilities
  $\chi \sim \langle N^2 \rangle$

- Baryon-strangeness correlation:
  Reflected in K/p fluctuations?
  Koch et al. Phys. Rev. Lett. 95, 182301 (2005)

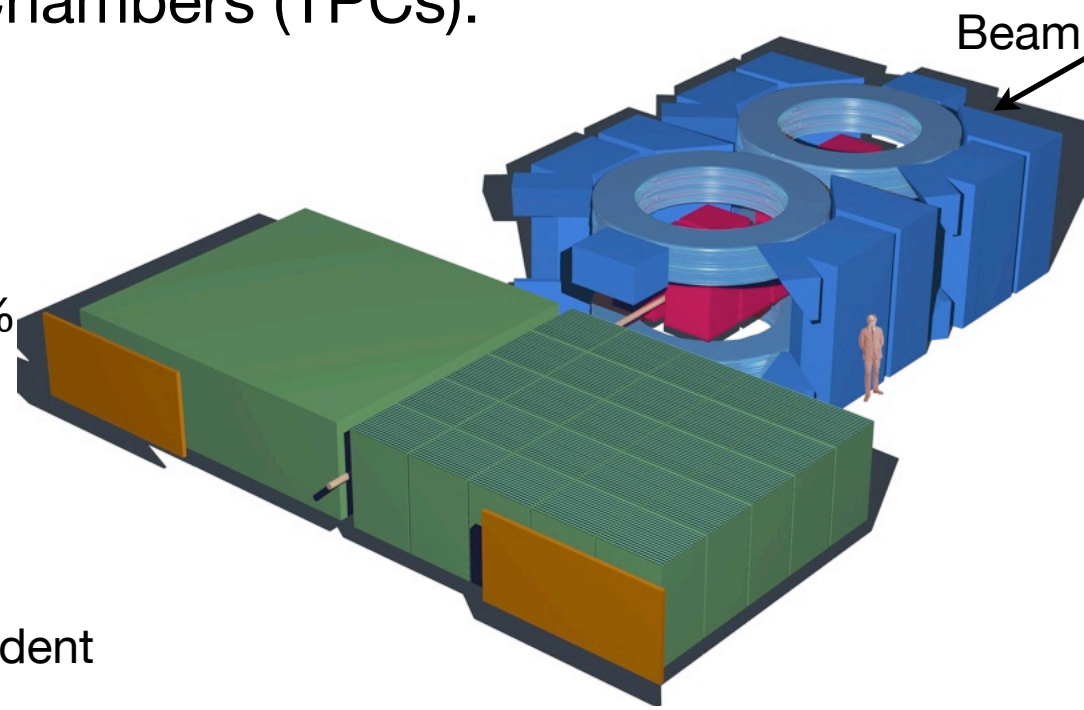


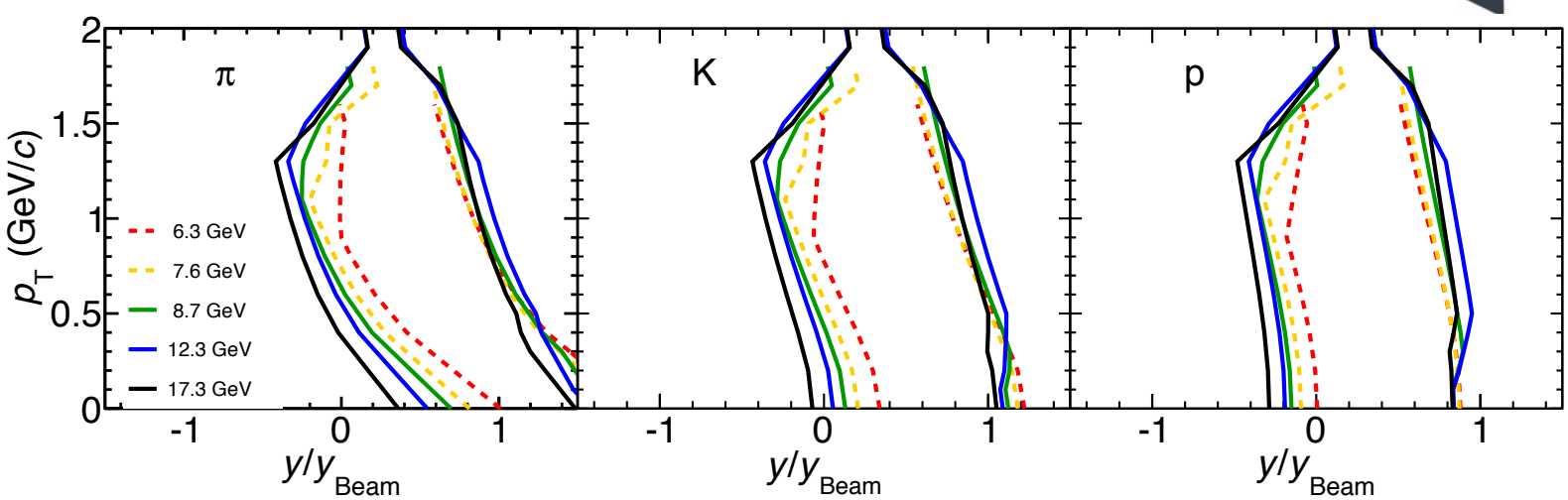
F. Karsch: PoS (CPOD07) 026
PoS (Lattice 2007) 015

- New NA49 Results:
  - Centrality dependence of K/π, p/π and K/p fluctuations at $\sqrt{s_{NN}}$ = 17.3 GeV:
    Complementary to energy dependence to understand systematics
  - Energy dependence of K/p fluctuations:
    Probe baryon-strangeness correlation

NA49 Fixed Target Experiment at CERN-SPS

- Large volume Time Projection Chambers (TPCs):
  - Tracking in magnetic field
    → momentum, charge
  - Specific energy loss dE/dx
    → PID of p, K, π, ... : Resolution 3-4%
  - Acceptance:
    - Mainly $y > 0$
    - Full p_T range
    - Limited φ acceptance; p_T, y dependent

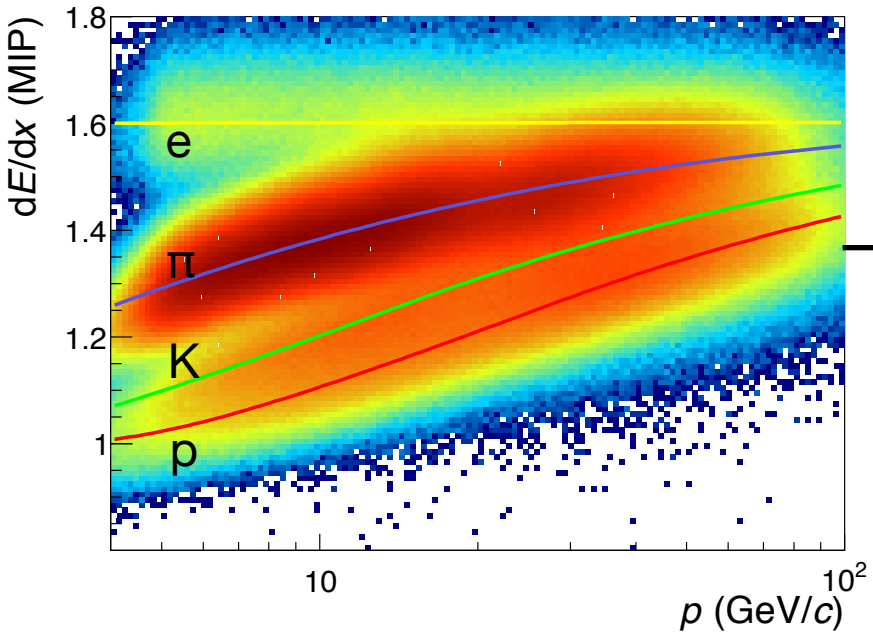




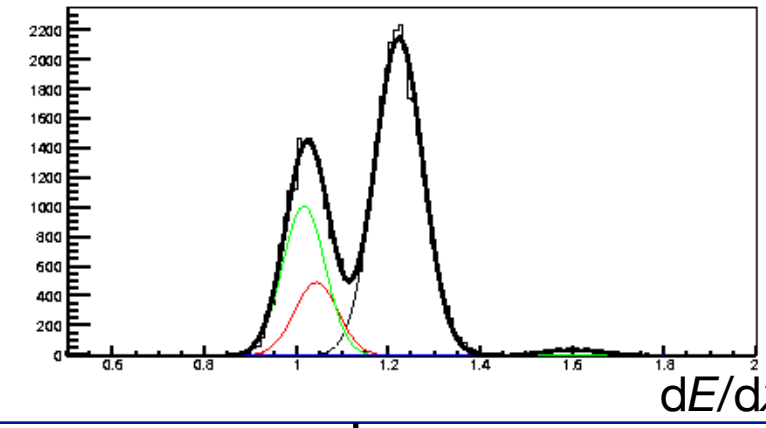
  - Fluctuation measures in general depend on acceptance
    → must be taken into account in model comparisons

NA49 E-by-e Particle Identification by dE/dx

~100k events:



Fit d*E*/d*x* spectra in phase space bins

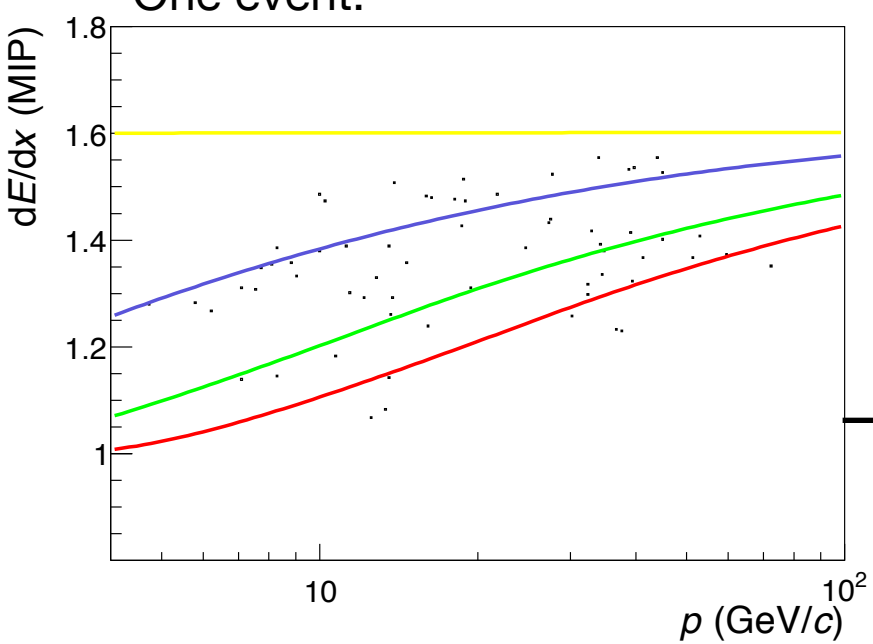


Inclusive probability density function (*p*,d*E*/d*x*)

$$F\left(\vec{p},\left(\mathrm{d}E/\mathrm{d}x\right)|\Theta\right) = \Sigma_{(m)} r^{(m)}\left(\vec{p}|\Theta^{(m)}\right) f_p^{(m)}\left(\mathrm{d}E/\mathrm{d}x\right)$$

(*m* = π,K,p,...)

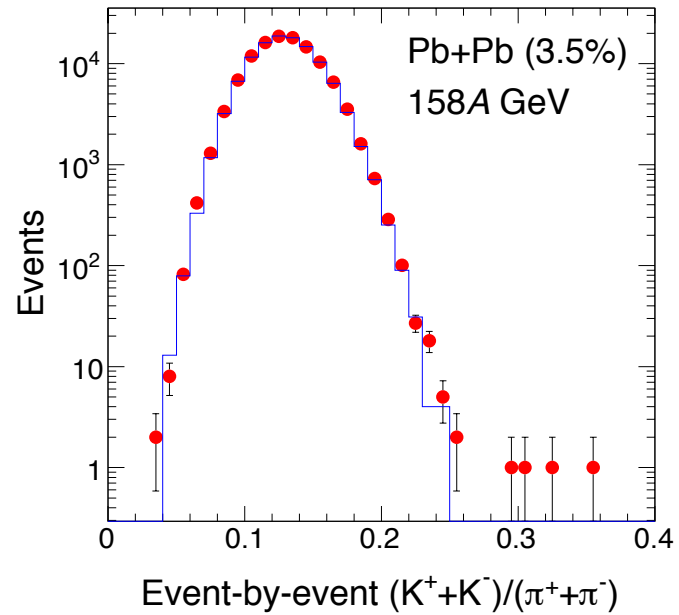
One event:



Extract hadron multiplicities with maximum likelihood from each event

Dynamical Ratio Fluctuations

- Extract event-by-event hadron ratios (e.g. K/π) from
  - Real data events
  - Reference events:
    event mixing + maximum likelihood PID

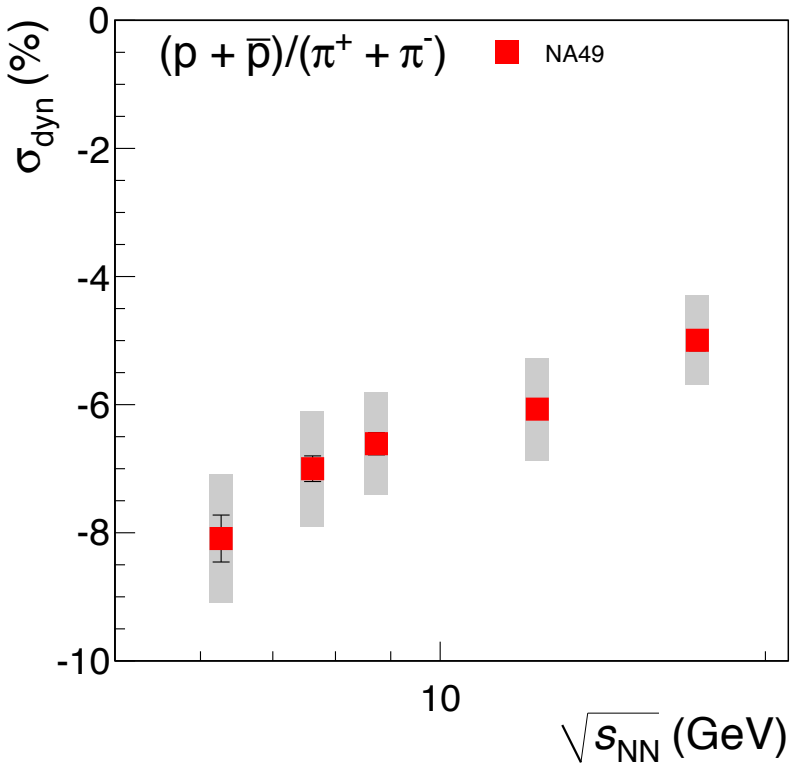


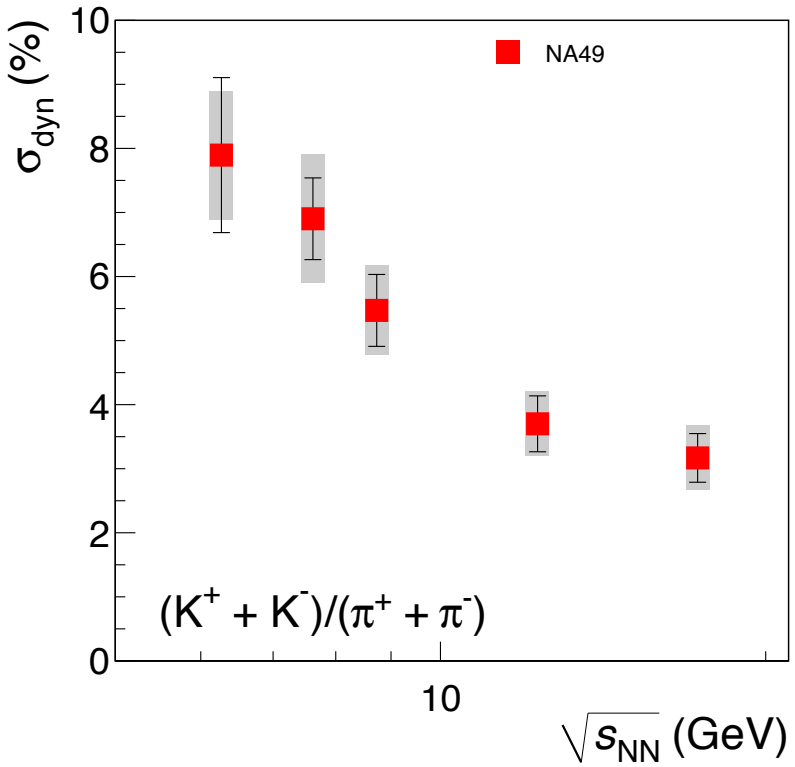
- Quantify the *dynamical* fluctuations:

$$\sigma_{\mathrm{dyn}} = \mathrm{sign}\left(\sigma^2_{\mathrm{data}} - \sigma^2_{\mathrm{mix}}\right)\sqrt{\left|\sigma^2_{\mathrm{data}} - \sigma^2_{\mathrm{mix}}\right|},\ \sigma^2 = \frac{\mathrm{Var}\left(K/\pi\right)}{\langle K/\pi\rangle^2}$$

- Alternative "identity" method under investigation in NA49
  Phys. Rev. C 83, 054907 (2011)

p/π and K/π Fluctuations



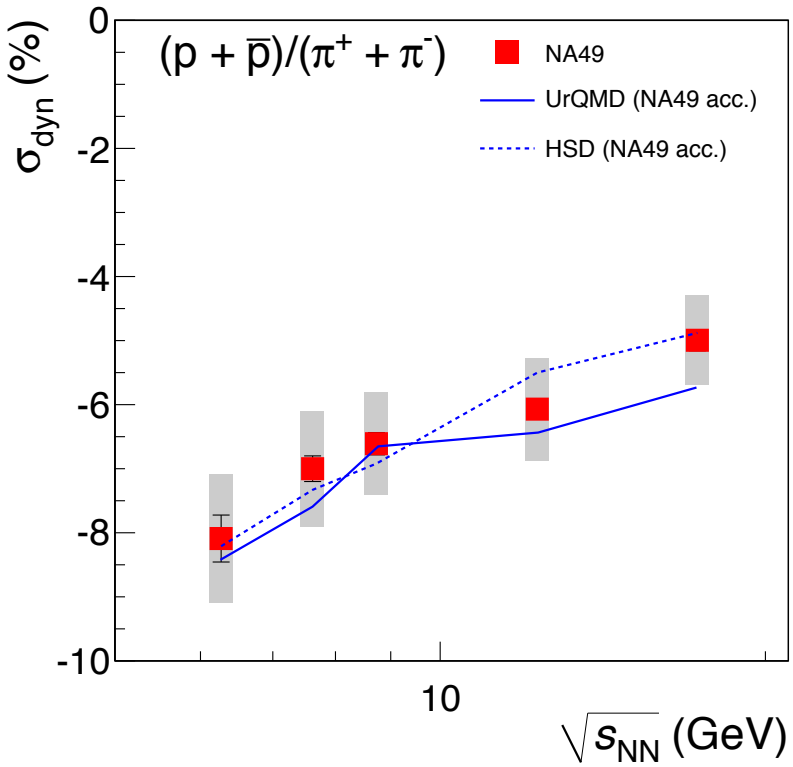


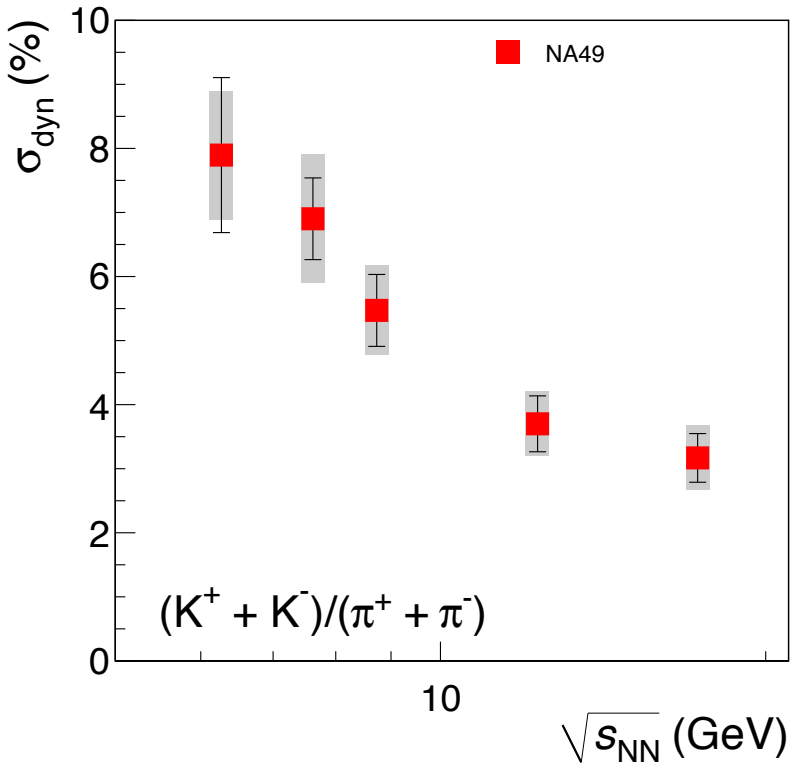
Pb+Pb central (3.5%)

NA49: Phys.Rev.C79, 044904 (2009)

- p/π: $\sigma_{dyn} < 0$, correlation due to resonance decay
- K/π: $\sigma_{dyn} > 0$, anti-correlation

p/π and K/π Fluctuations





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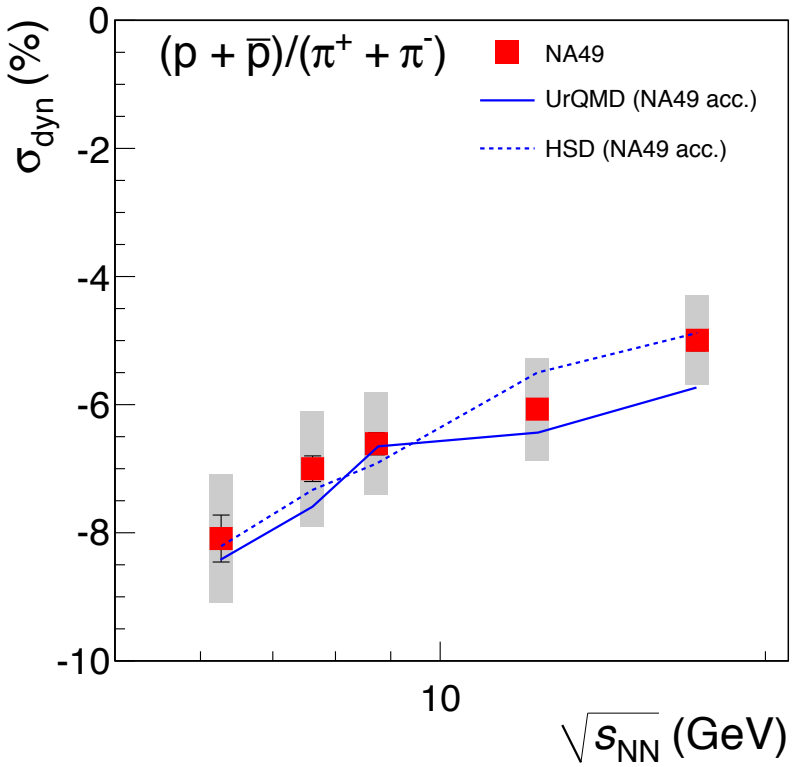
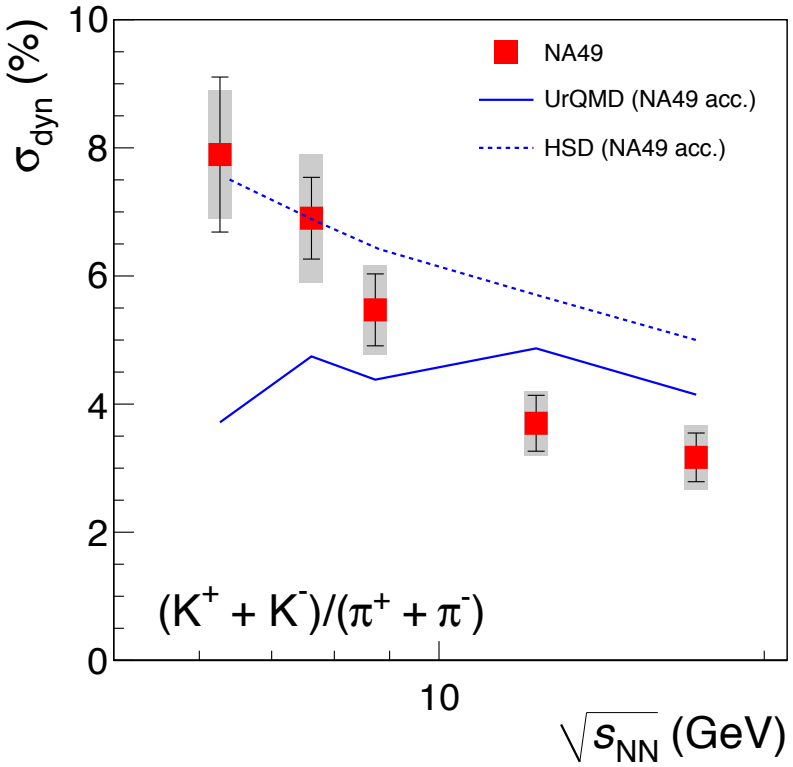
p/π and K/π Fluctuations





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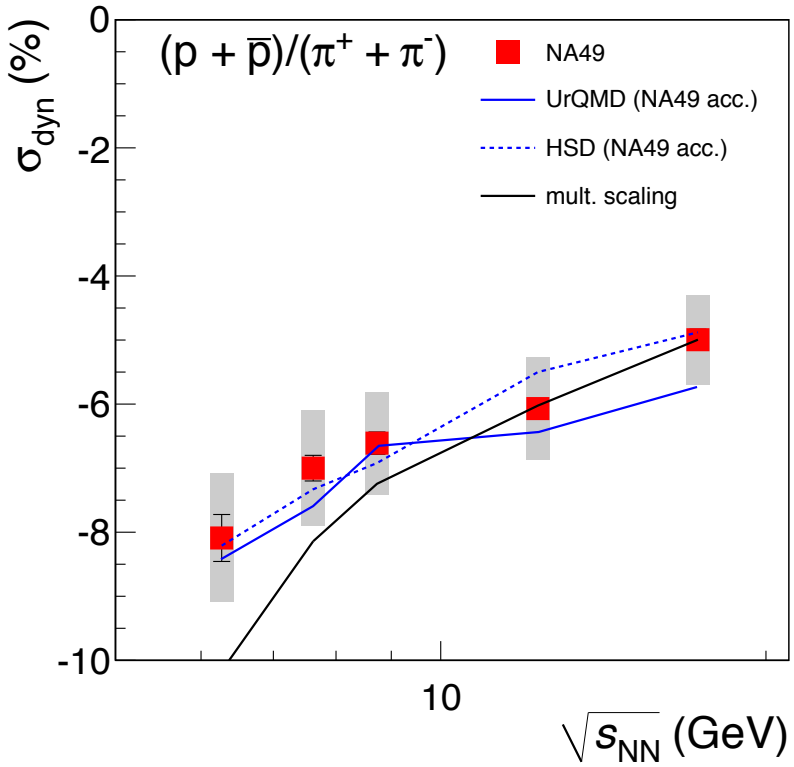
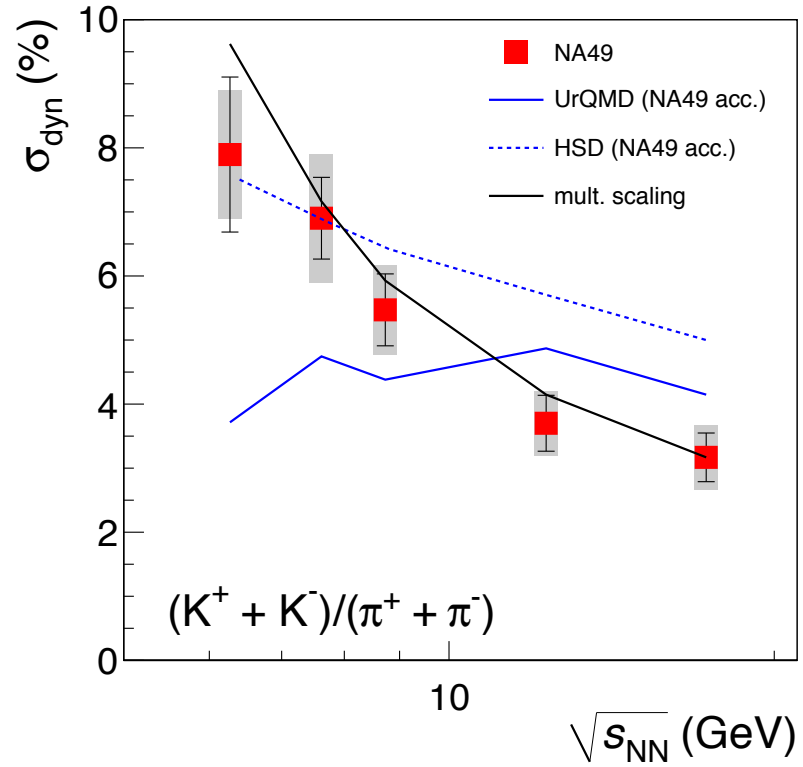
- p/π: $\sigma_{dyn} < 0$, correlation due to resonance decay
- Reproduced by hadronic transport models
- K/π: $\sigma_{dyn} > 0$, anti-correlation
- UrQMD and HSD are contradictory, neither describes the data

p/π and K/π Fluctuations





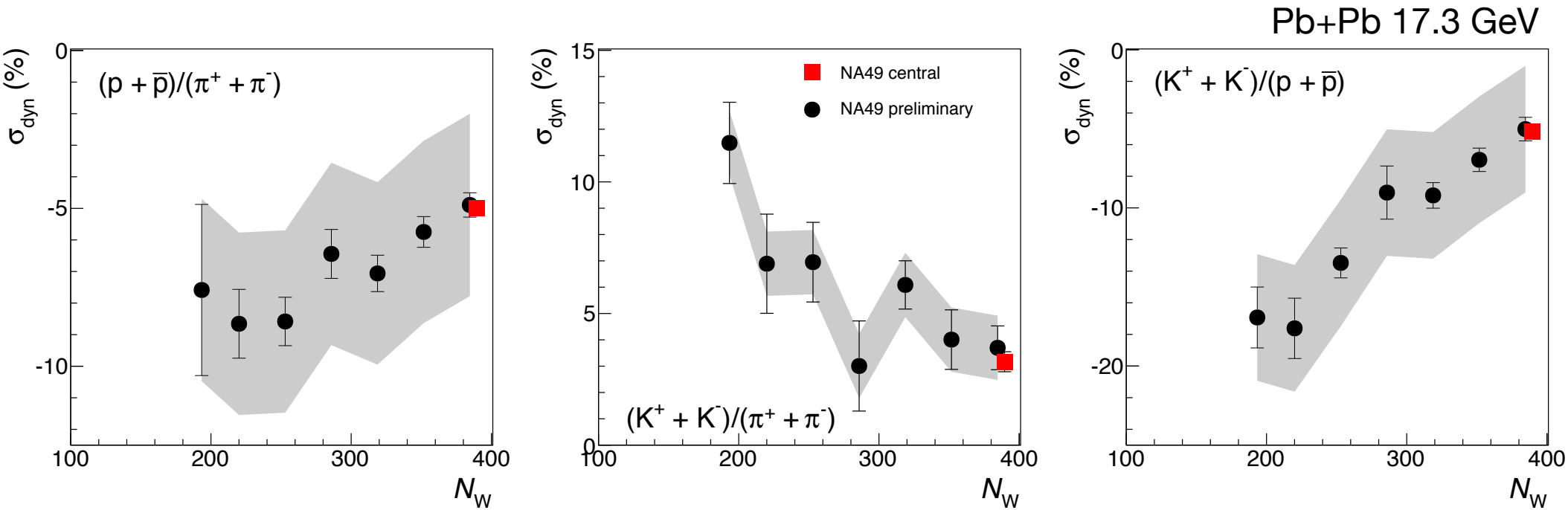
Pb+Pb central (3.5%)

NA49: Phys.Rev.C79, 044904 (2009)

Scaling: Koch, Schuster Phys.Rev.C81 034910 (2010)

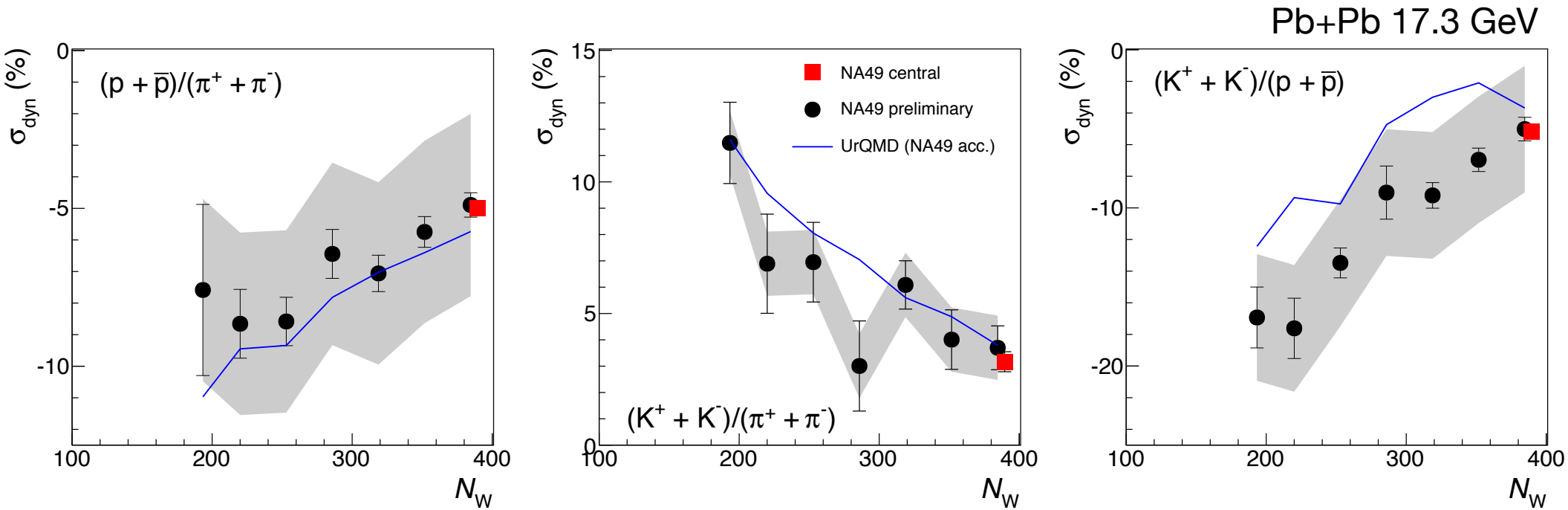
- σ_{dyn} can be expressed via
  - correlation strength
  - inherent multiplicity dependence
- In case of unchanged correlation strength, e.g. in the grand-canonical ensemble, $\sigma_{\mathrm{dyn}} \propto \sqrt{\frac{1}{\langle A \rangle} + \frac{1}{\langle B \rangle}}$

Fluctuations vs. Centrality



- Complementary study: Centrality dependence at $\sqrt{s_{NN}}$ = 17.3 GeV
  - Fix energy, vary system size
  - Cf. STAR: K/π at $\sqrt{s_{NN}}$ = 62 and 200 GeV, Phys.Rev.Lett.103 092301 (2009)
  - NA49 Poster: D. Kresan, board #100
- Increase in $|\sigma_{dyn}|$ towards peripheral collisions

Fluctuations vs. Centrality



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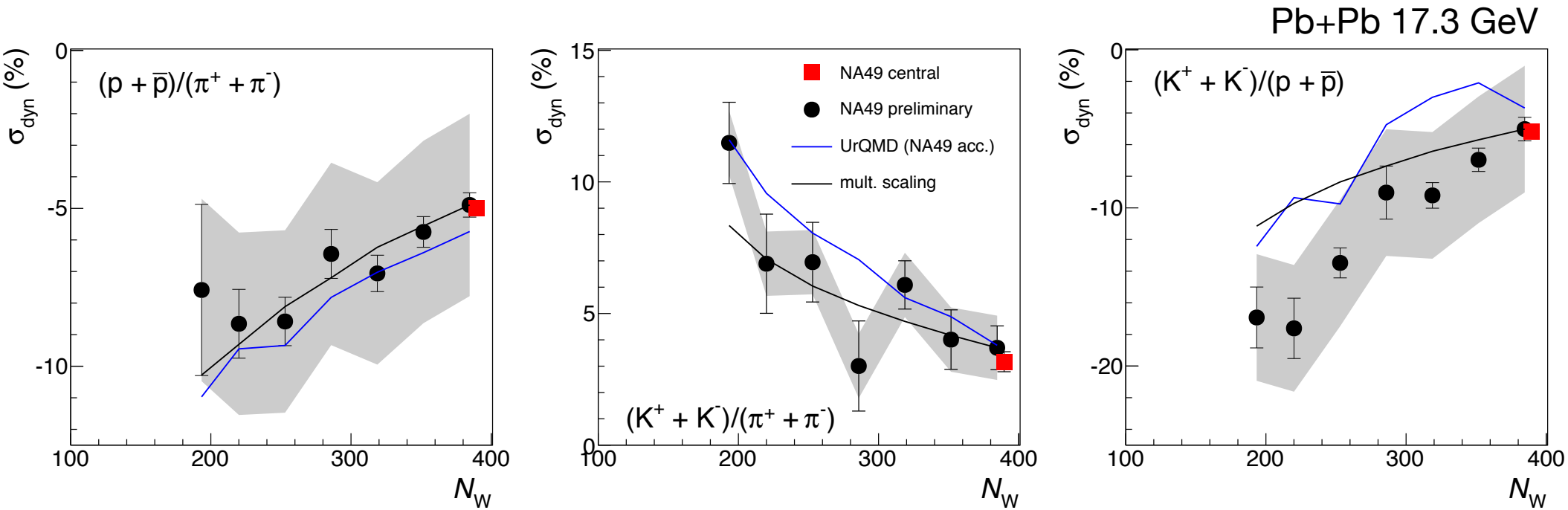

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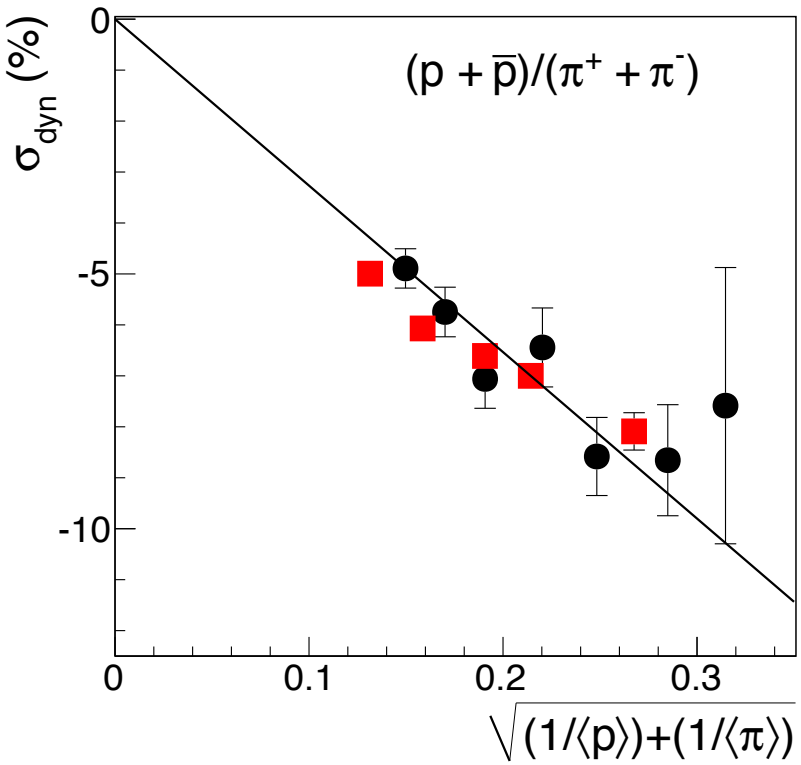
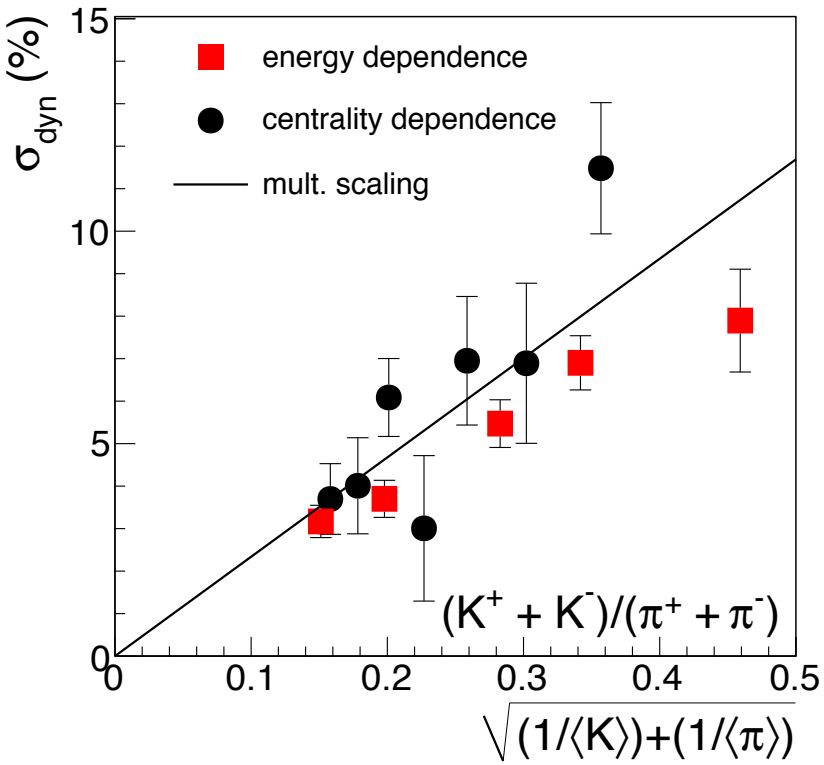
- Increase in $|\sigma_{dyn}|$ towards peripheral collisions as in UrQMD
- $\sigma_{\mathrm{dyn}} \propto \sqrt{\frac{1}{\langle A \rangle} + \frac{1}{\langle B \rangle}}$ holds → system size doesn't change physics

p/π and K/π Fluctuations

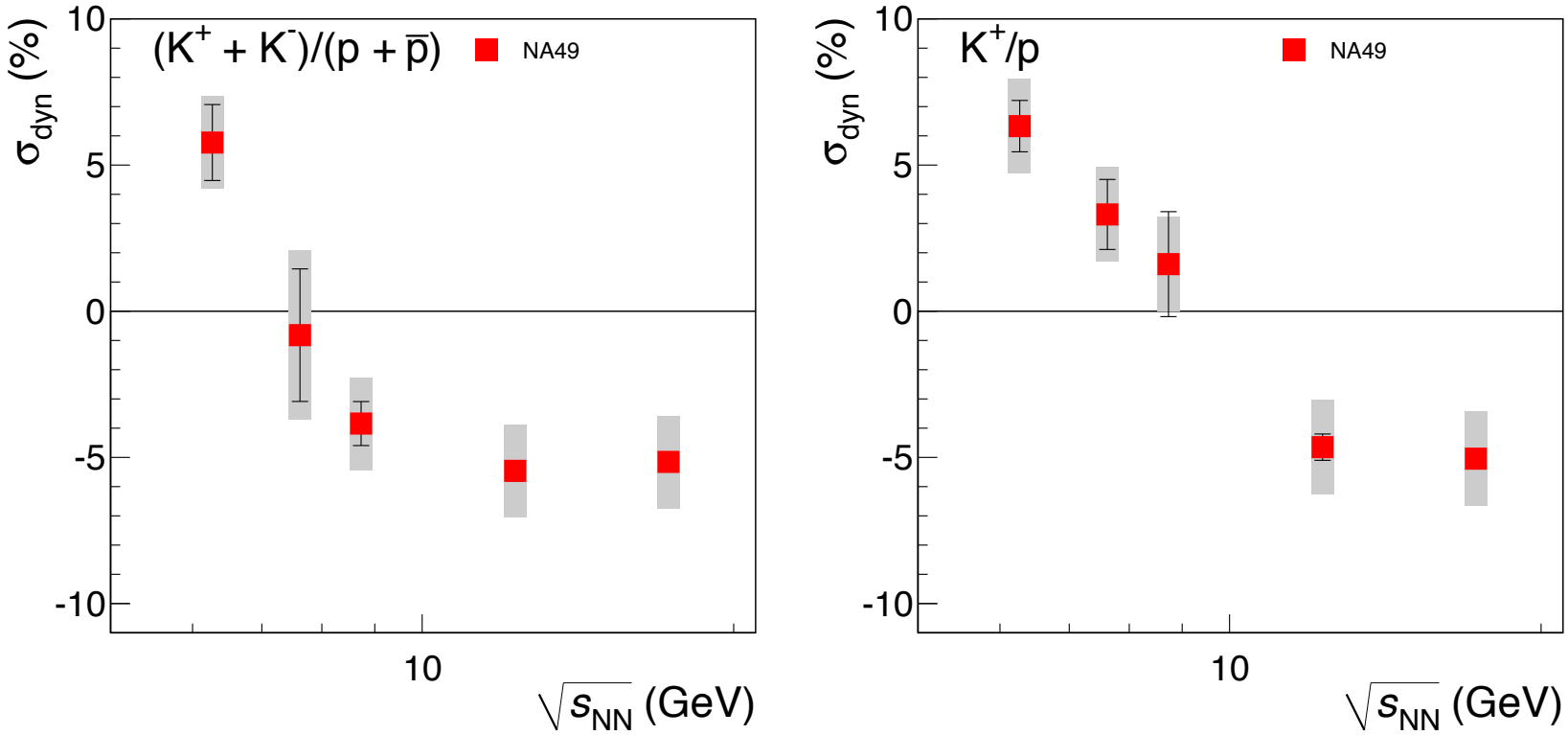




- Energy and centrality dependence together on one scale
- The same dependence on multiplicities is observed:

$$\sigma_{\mathrm{dyn}} \propto \sqrt{\frac{1}{\langle A\rangle} + \frac{1}{\langle B\rangle}}$$

K/p Fluctuations

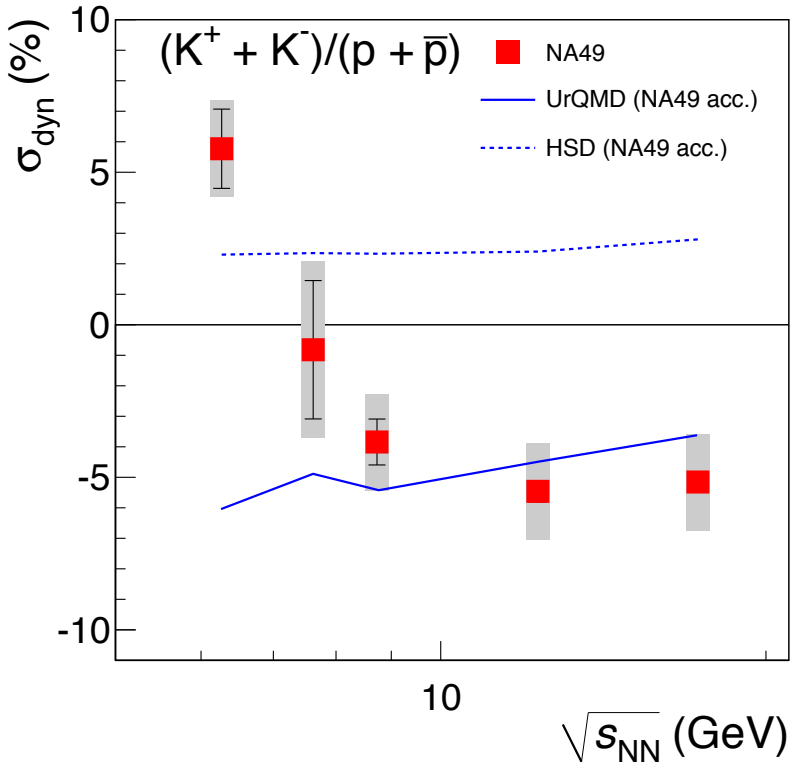


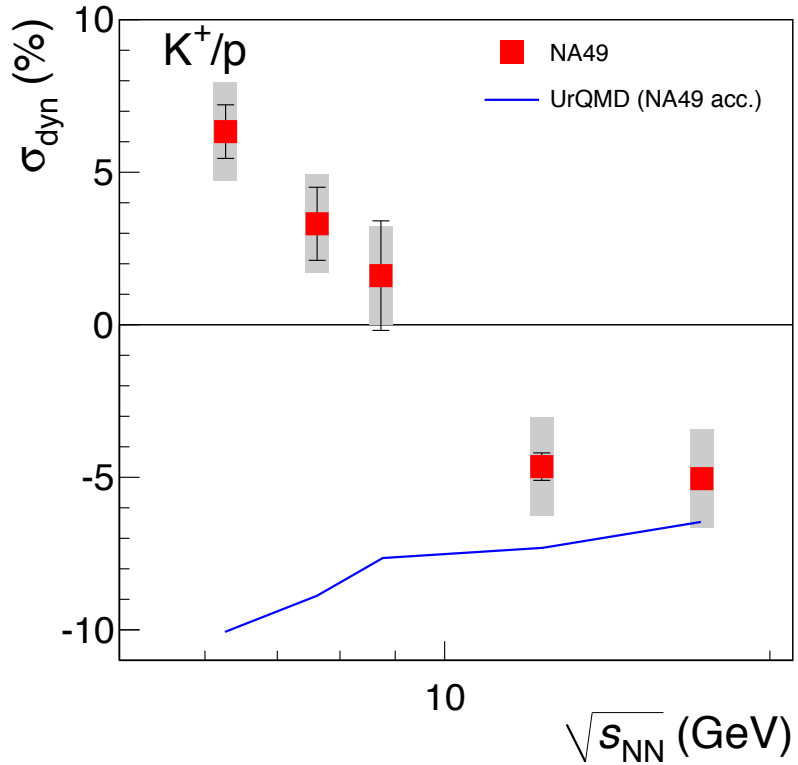
Pb+Pb
central (3.5%)

NA49: in print at
Phys.Rev.C,
arXiv:1101.3250

- New NA49 data on K/p fluctuations:
  potential connection to baryon-strangeness correlation
- Separate positive charged ratio: No resonance contribution

K/p Fluctuations





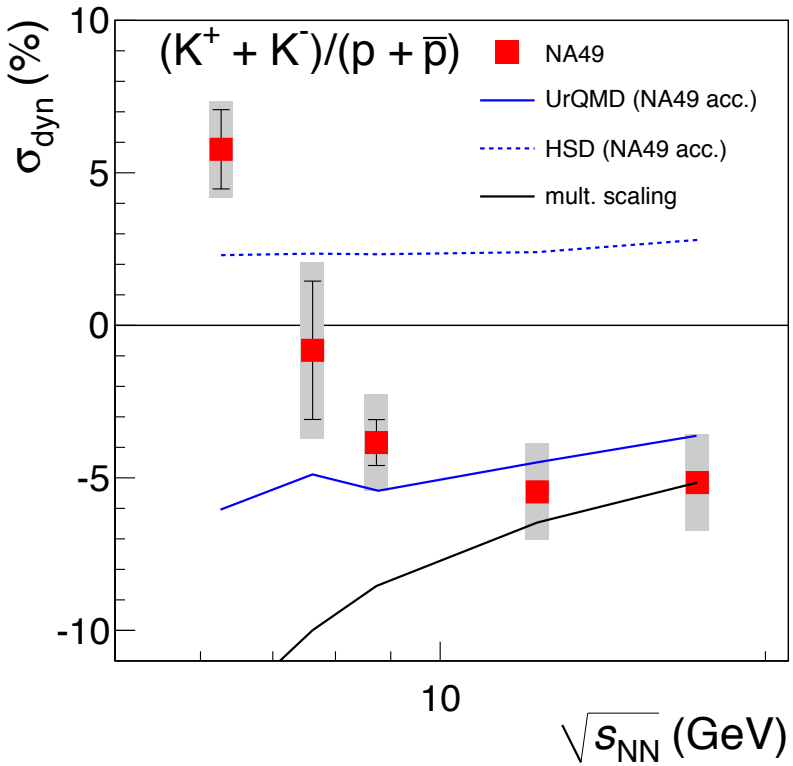
Pb+Pb
central (3.5%)

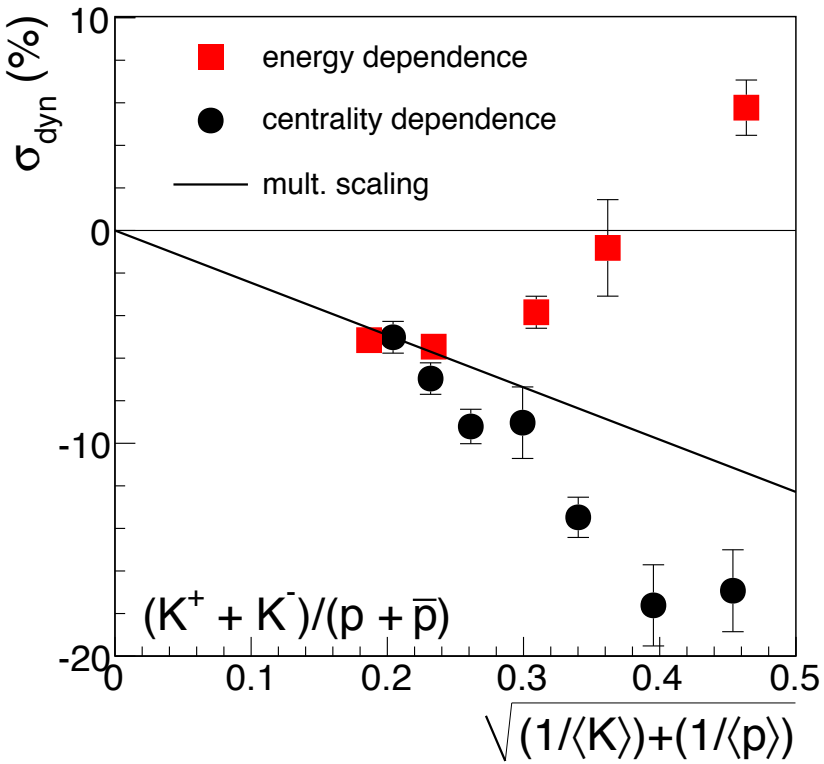
NA49: in print at
Phys.Rev.C,
arXiv:1101.3250

HSD:
J.Phys.G36
125106 (2009)

- New NA49 data on K/p fluctuations:
  potential connection to baryon-strangeness correlation
- Separate positive charged ratio: No resonance contribution
- UrQMD and HSD disagree and don't describe the trend (as for K/π)

K/p Fluctuations





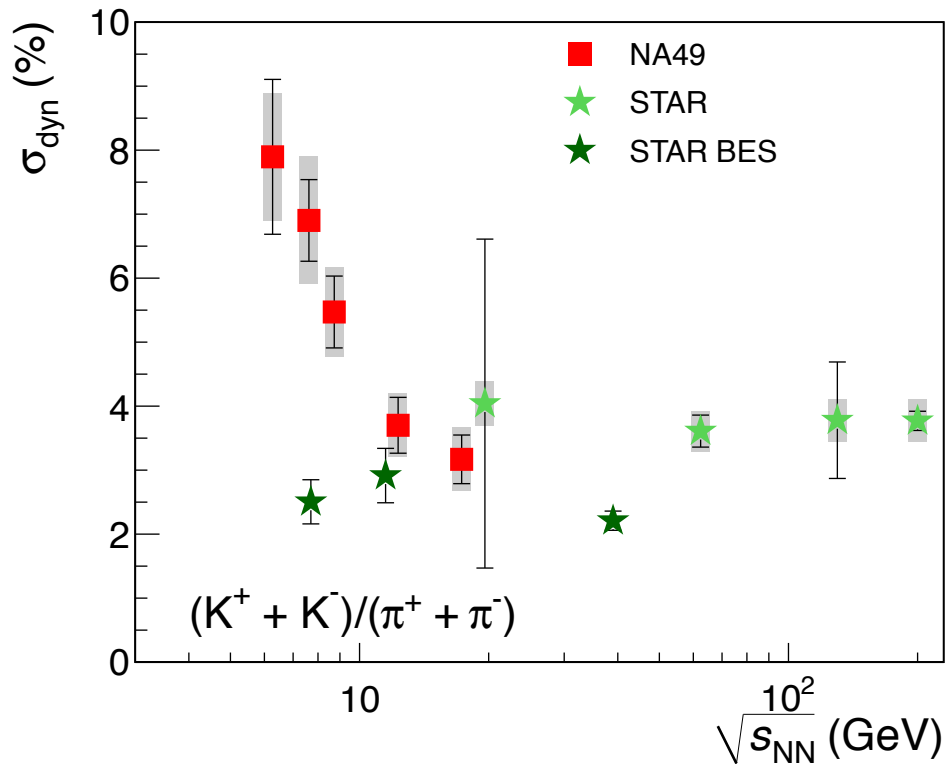
Pb+Pb
central (3.5%)

NA49: in print at
Phys.Rev.C,
arXiv:1101.3250

Scaling:
Koch, Schuster
Phys.Rev.C81
034910 (2010)

- The change of sign in the energy dependence excludes any scaling with multiplicities, e.g $\sigma_{\rm dyn} \propto \sqrt{\frac{1}{\langle K\rangle} + \frac{1}{\langle p\rangle}}$
- No common scaling of energy and centrality dependence (as seen for p/π and K/π) can be found in the case of K/p
- Is the underlying correlation physics changing with energy?

STAR Beam Energy Scan



Pb+Pb/Au+Au central (3.5%/5%)

NA49: Phys.Rev.C79, 044904 (2009)

STAR: Phys.Rev.Lett.103 092301 (2009), WWND2011

- Relation to STAR data under discussion ($\sigma_{dyn} = \sqrt{\nu_{dyn}}$)
- NA49-STAR task force set up to check
  - Approximation $\sigma_{dyn} = \sqrt{\nu_{dyn}}$
  - Effect of different acceptances
  - Experimental procedures

Summary

- NA49 results on K/π, p/π and K/p ratio fluctuations:
  - Energy dependence in central (3.5%) Pb+Pb collisions, $\sqrt{s_{NN}}$ = 6.3 to 17.3 GeV
  - Centrality dependence in min. bias Pb+Pb collisions at $\sqrt{s_{NN}}$ = 17.3 GeV
- K/π and p/π fluctuations:
  Energy and system size dependence can be described in a simple multiplicities scaling model
- K/p fluctuations show a deviation from this scaling:
  Change in underlying correlations with energy?