Can we discover the critical point at RHIC?

Experimental Overview

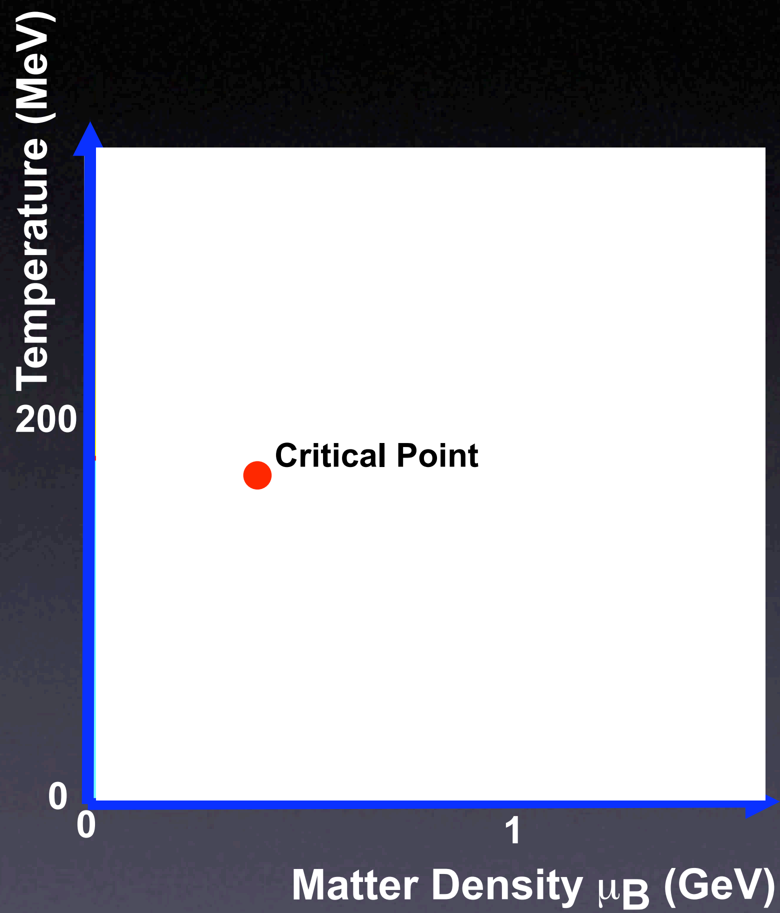
BNL

March 9 2006

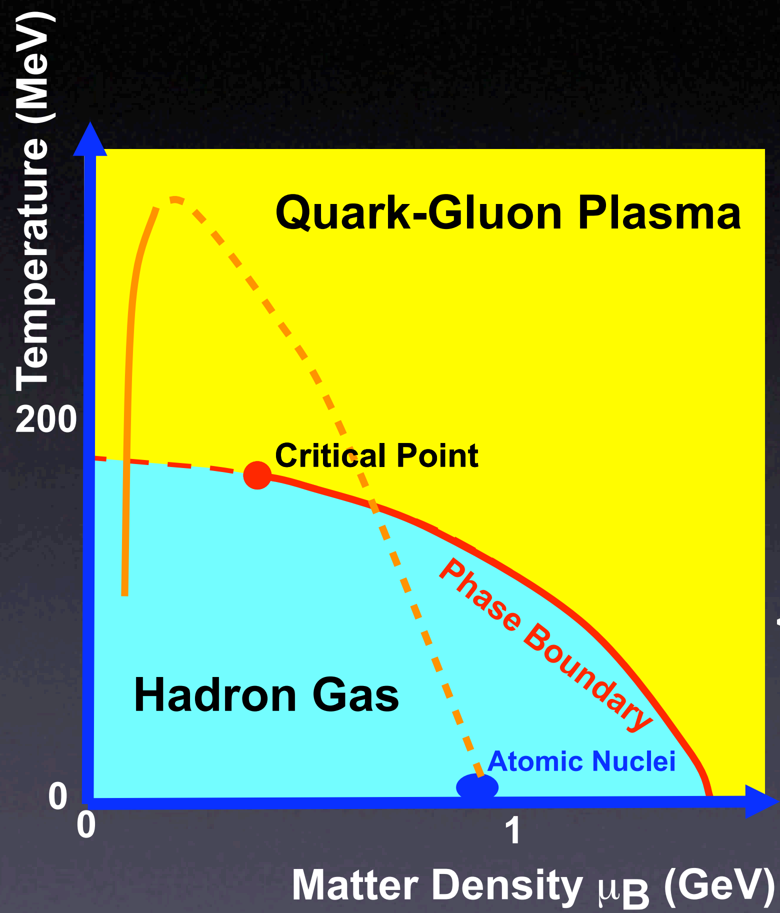
Gunther Roland

Thanks to
Burak Alver, Ed Wenger,
Siarhei Vaurynovich, Wei LI

Exploring the QCD Phasediagram

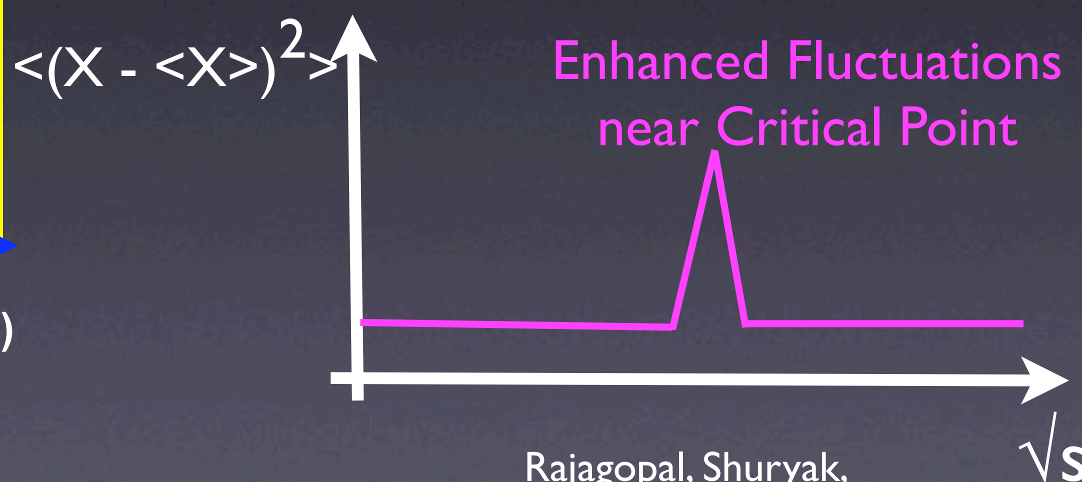


Exploring the QCD Phasediagram



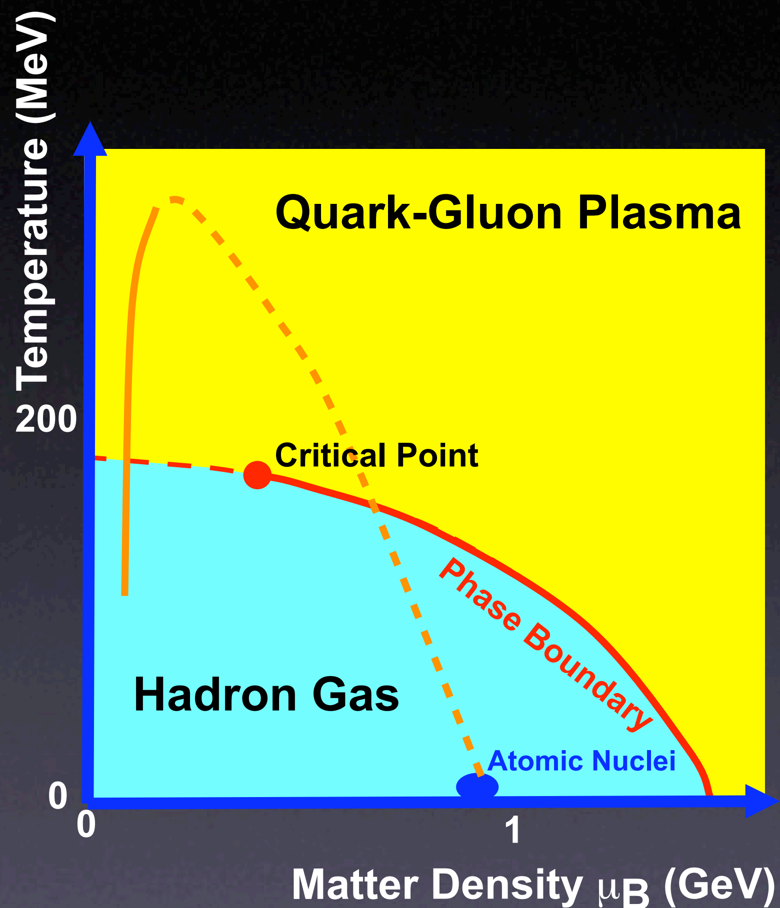
Susceptibilities diverge near critical point

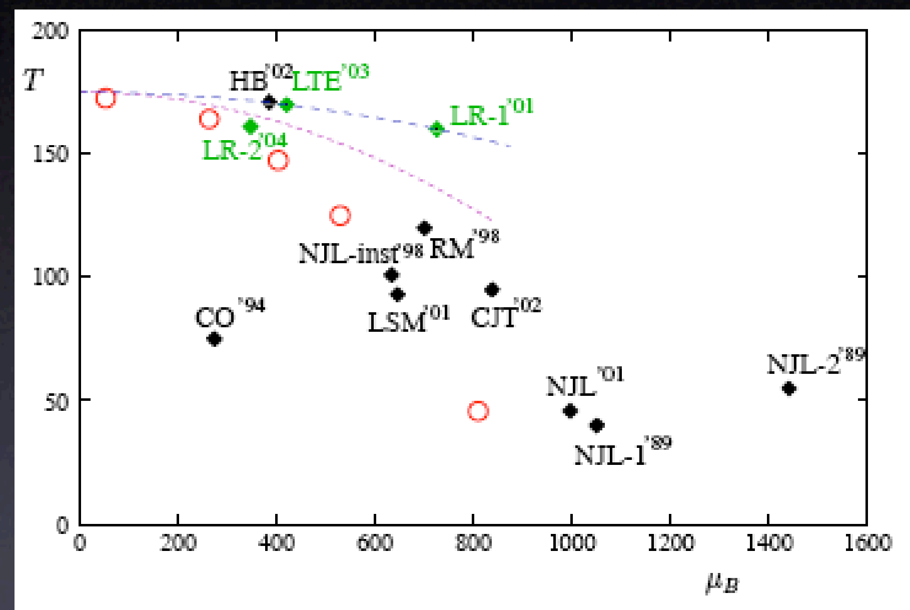
Locate the critical point using correlation/fluctuation measurements



Rajagopal, Shuryak, Stephanov

Exploring the QCD Phasediagram





Plot from M. Stephanov, Correlations '05

Challenge: Guidance on exact location and strength of correlation signals is limited

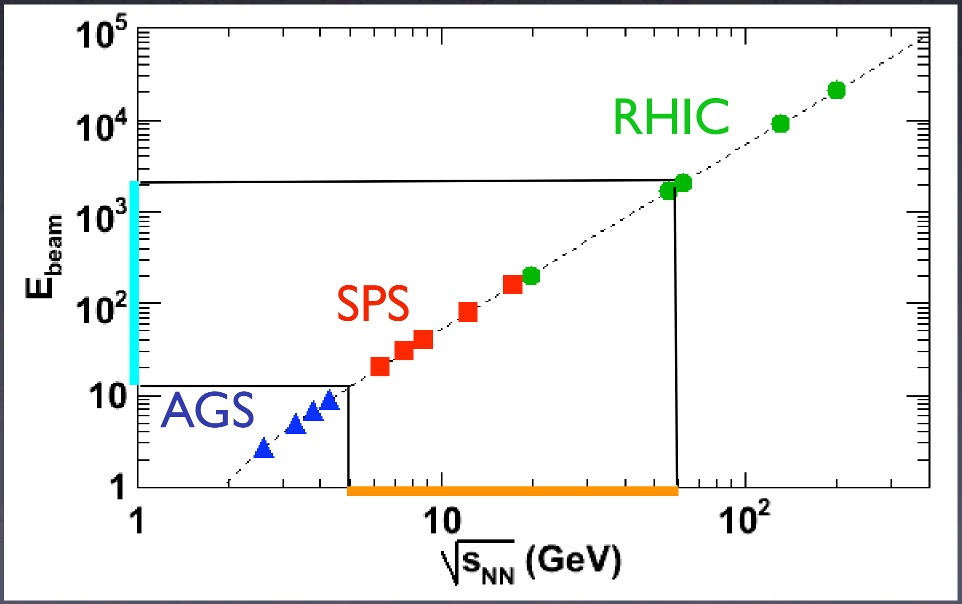
Experimental Search for the Critical Point

- Theoretical guidance is limited
- Experimental strategy:
  - Search in different observables, correlate observables ➔NA49
  - Maximize experimental sensitivity
  - Fine grained exploration of μ_B, T space
- Side effect:
  - Sensitivity to critical phenomena at 1st order transition, Onset of Deconfinement, EOS softest point, changes in bulk dynamics etc

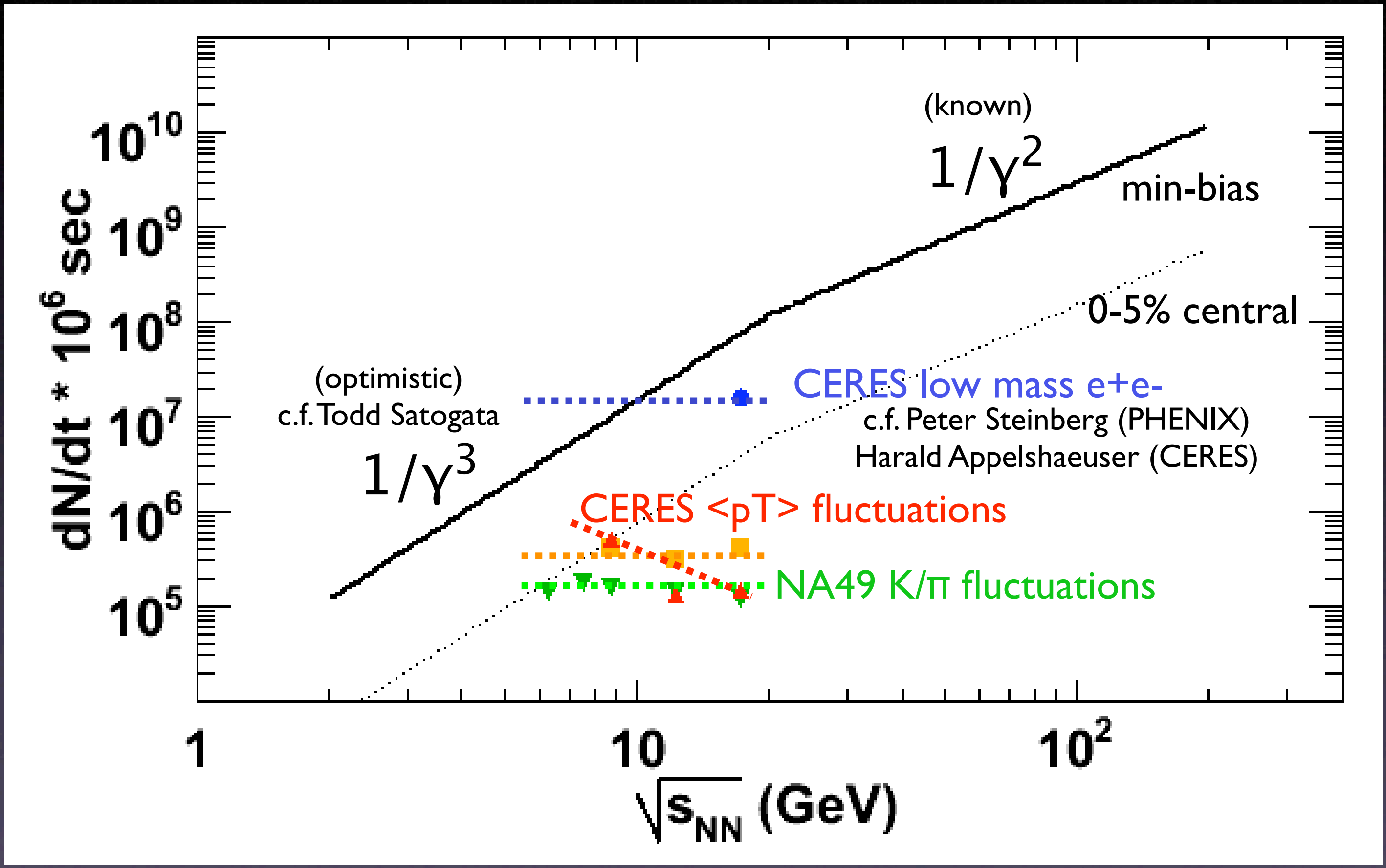
Experimental Search for the Critical Point

- This idea/strategy is not new
- This talk (this workshop)
  - What is known from excitation functions?
  - What could be done better at RHIC (and how good)?

First of many experimental talks



Fixed target vs collider experiments

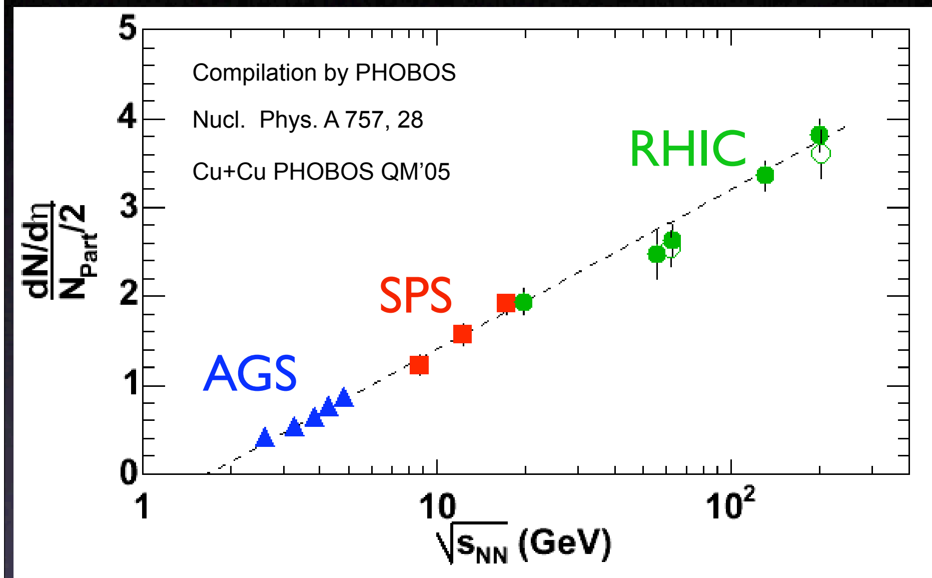


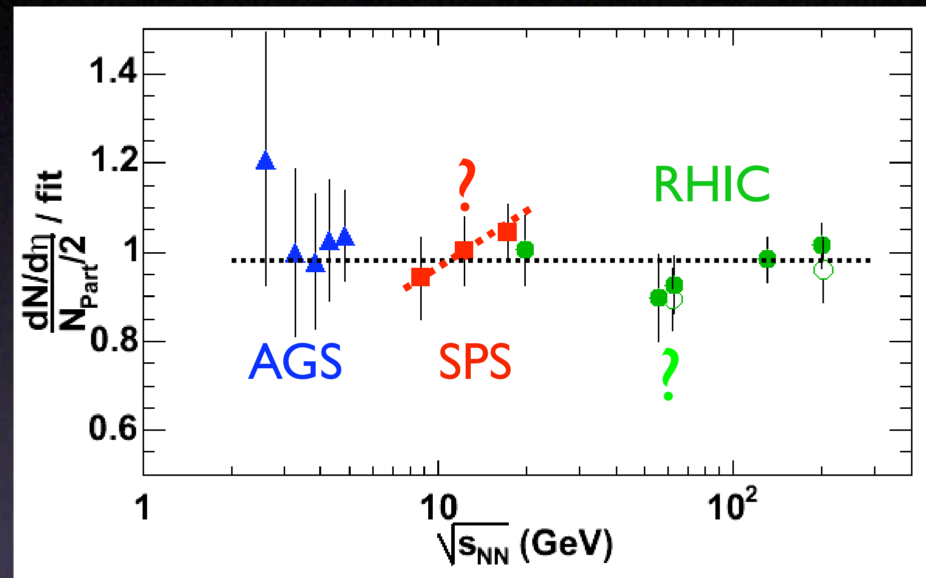
If rates O(1Hz) or greater:
√s scan of hadronic observables feasible

Suitable hadronic observables

- Here: Simple observables
  - Multiplicities and multiplicity correlations
  - Spectra and momentum correlations
  - Net charge correlations
  - Elliptic flow
  - Particle ratios and ratio fluctuations

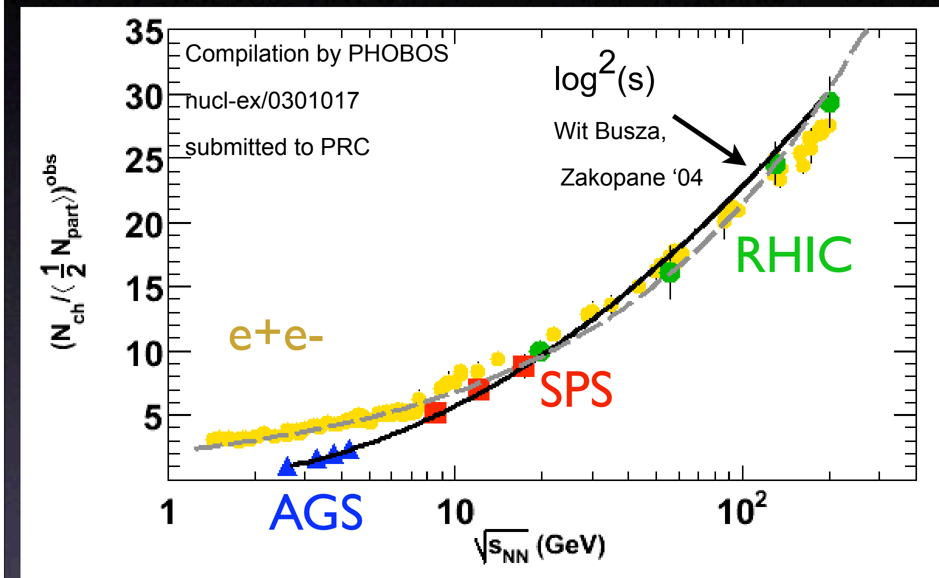
Excitation Function: Mid-rapidity Multiplicities

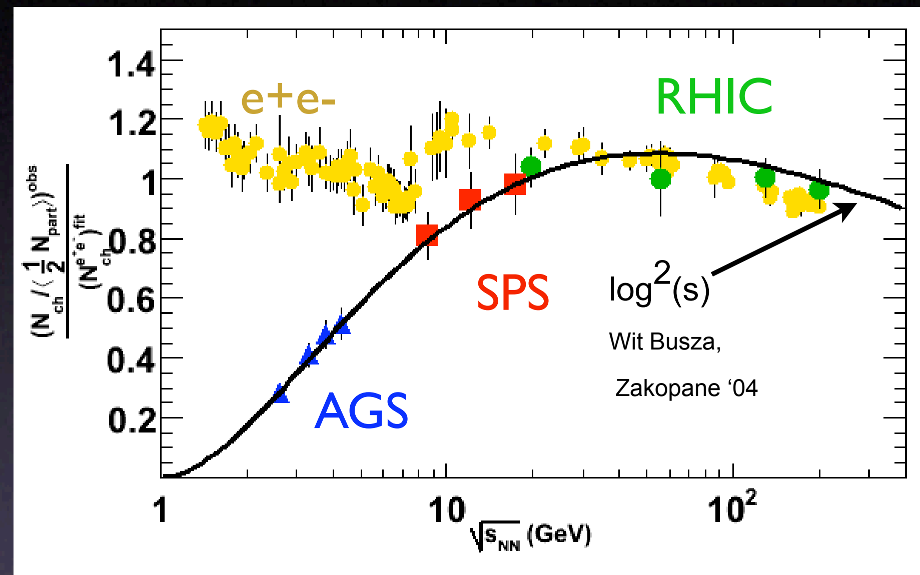




- Logarithmic growth of mid-rapidity particle density
- Structure at SPS energy range and/or around √s ≈ 60 GeV?
- Precision of ≈ 5-10% - better if doing relative scan in single experiment (≈ 3%)?

Excitation Function: Total Multiplicities



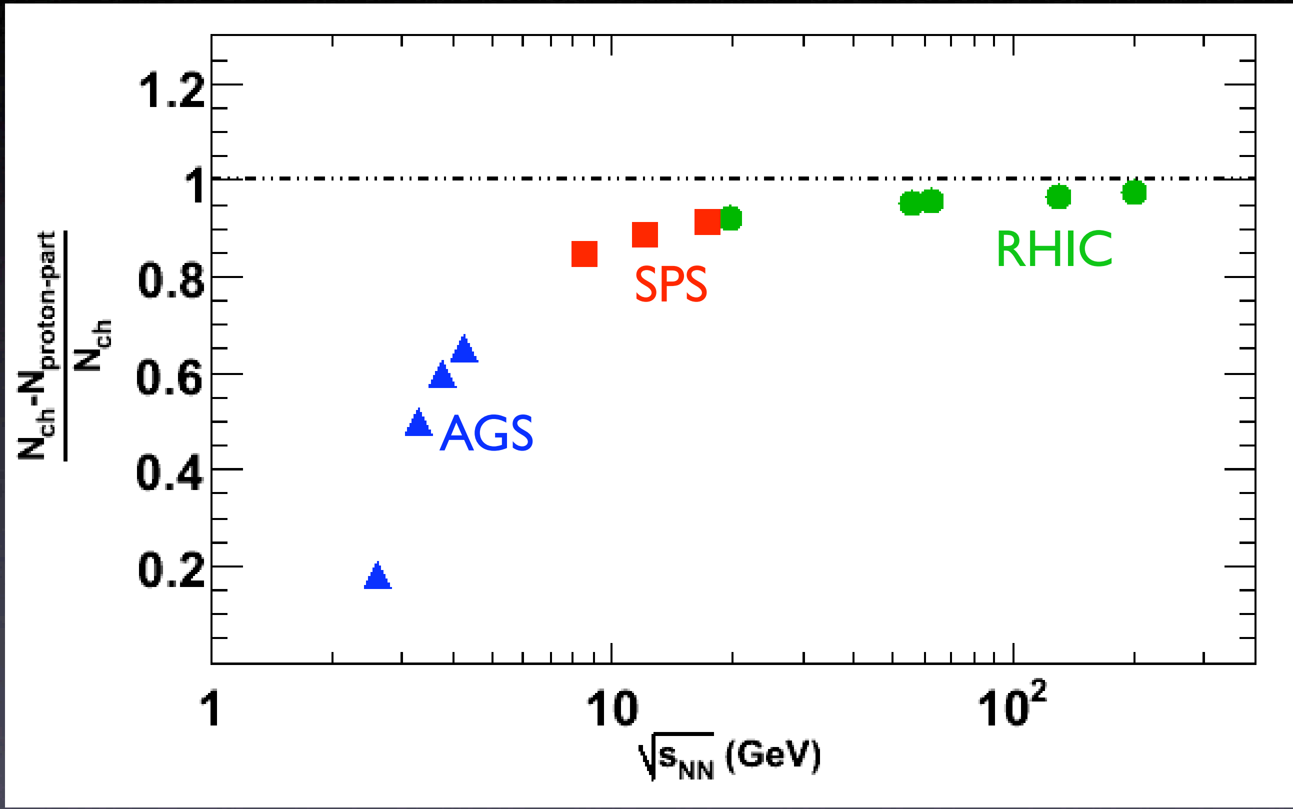


c.f. Gazdzicki, Steinberg

- A+A N_{ch}/participant pair approaches N_{ch} in e+e-
- A+A by itself can be fit with log^2(s)
- Structure at SPS energy *IF* compared to e+e- or p+p

Excitation Function: Total Multiplicities

Fraction of produced hadrons in N_{ch}

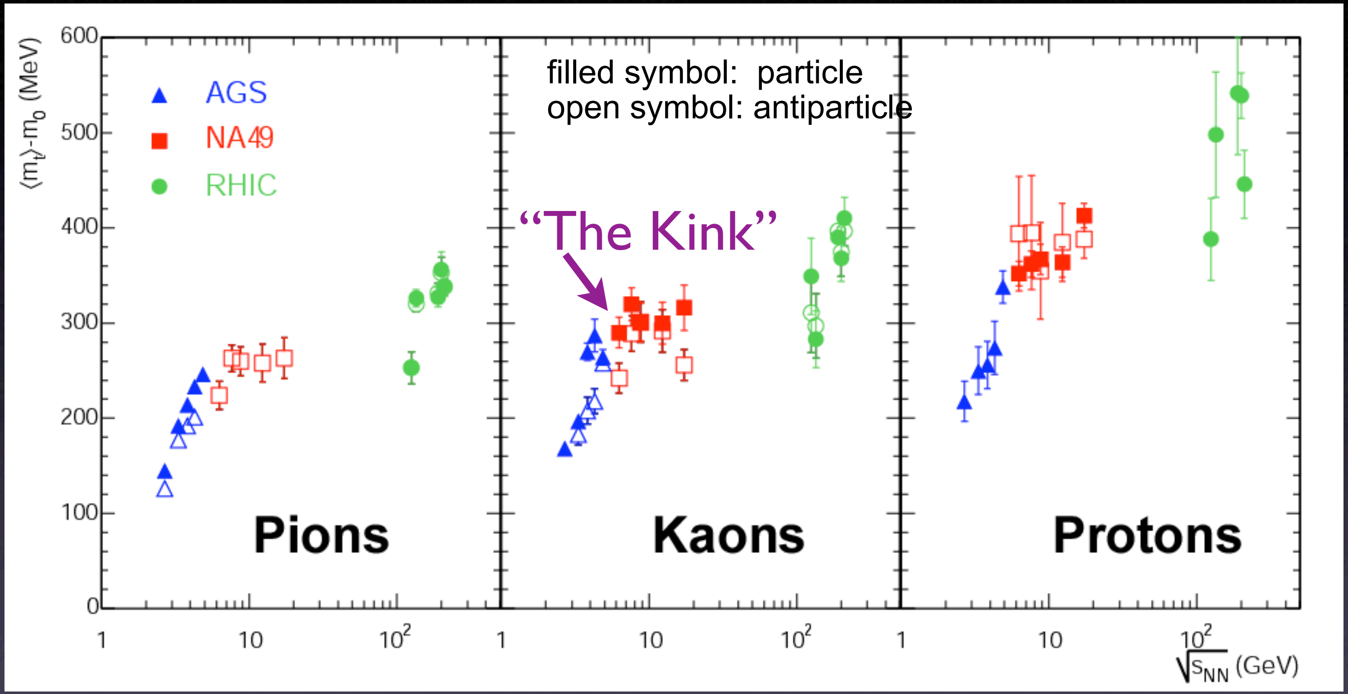


c.f. Gazdzicki, Steinberg

Change from baryon- to meson dominated system over the energy range of interest!

Excitation Function: Momentum Spectra

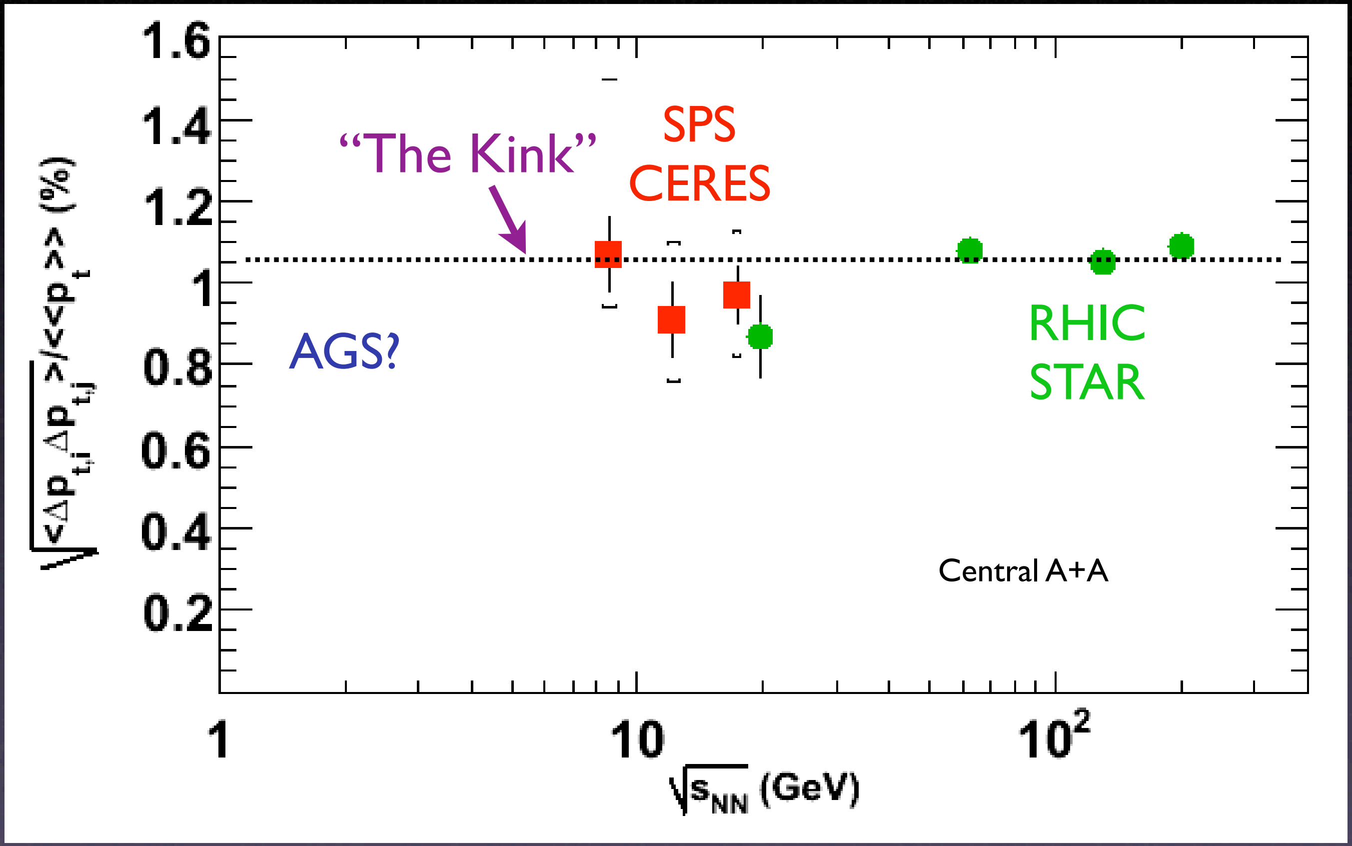
Compilation by NA49
Plot from Claudia Hoehne, QM'05



- Structure in energy dependence of <mT>
- Reminiscent of Van Hove's T vs ϵ prediction (1982)
- Surprisingly difficult measurement
    - Decay corrections, PID acceptance

Excitation Function: Momentum Fluctuations

Compilation by STAR
STAR PRC 72 044902 (2005)

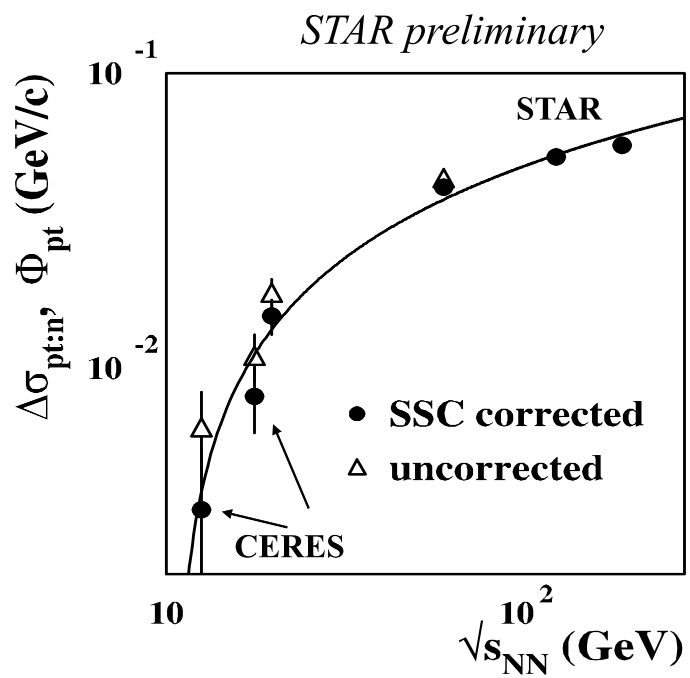


Monotonic energy dependence over measured range
No results near "kink" region

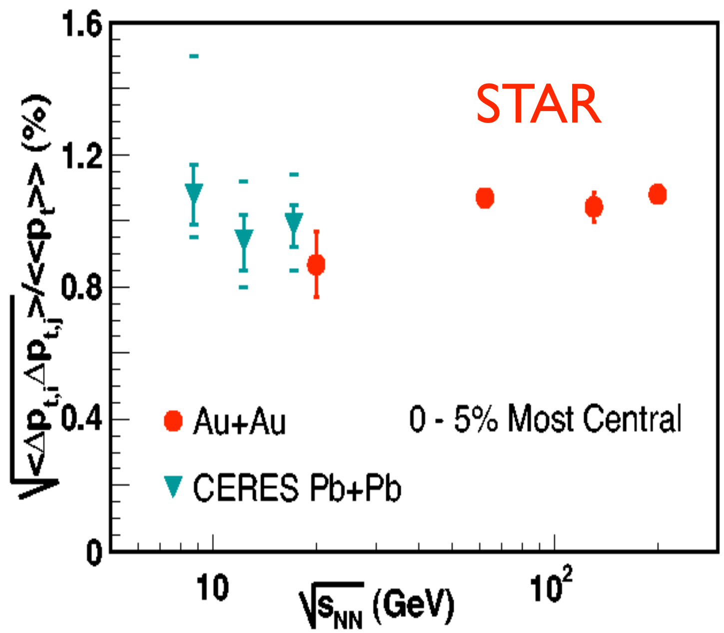
Excitation Function: Momentum Fluctuations

$$\Sigma_{p_T} \simeq \sqrt{\frac{2\Phi_{p_T}\sqrt{\sigma^2_{\hat{p}_T}}}{\overline{N}\bar{p}_T^2}}$$

Scaling: Connection between <pT>, N, fluctuations?



$\Sigma_{pT} \approx$

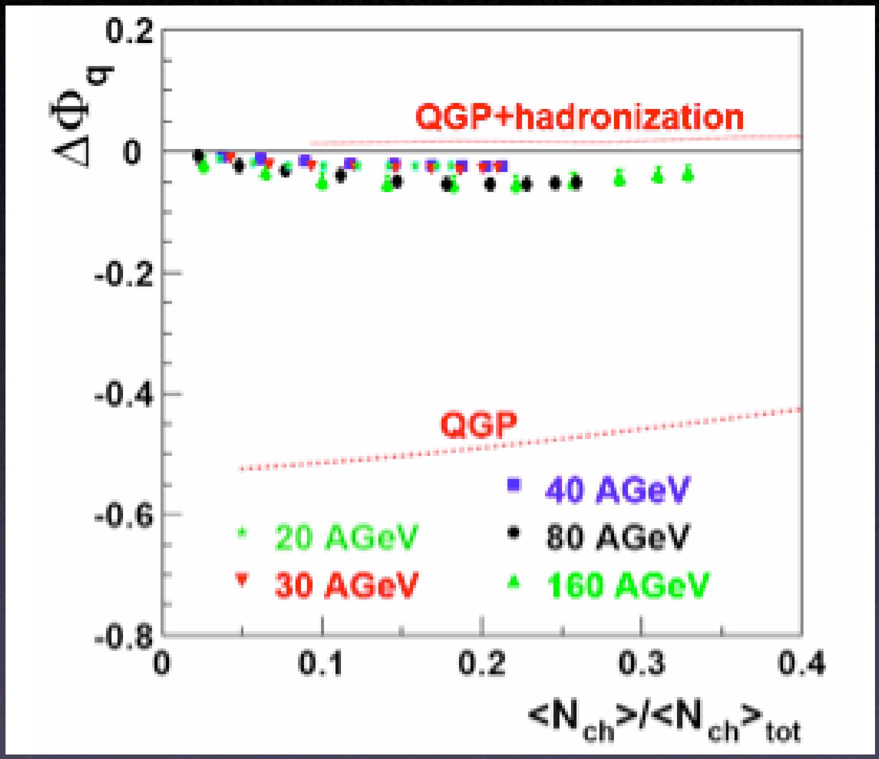


Connection to 2-particle correlations

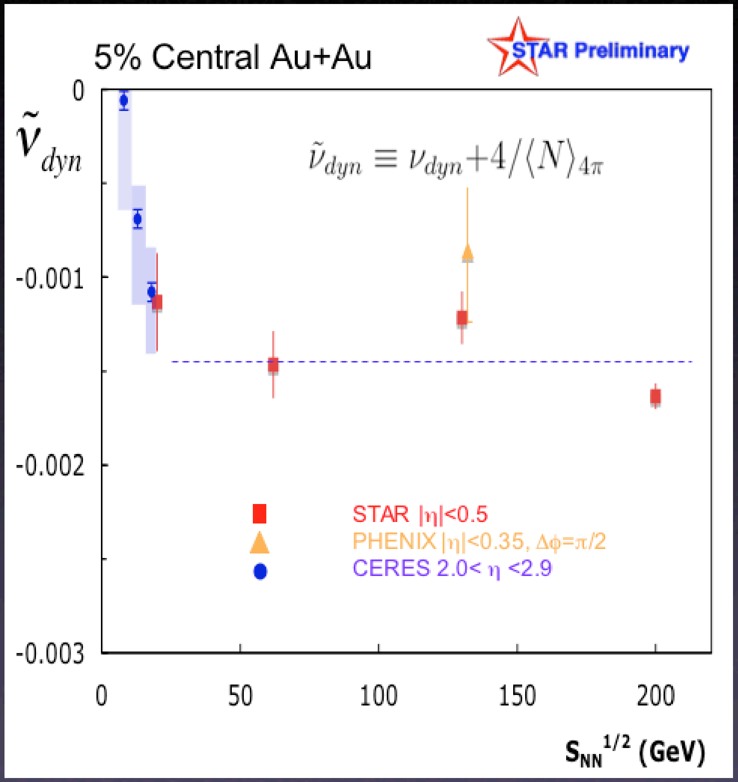
Interpretation connected to choice of variables

Excitation Function: Charge Fluctuations

NA49, PRC 70 064903 (2004)



Plot from Claude Pruneau
RHIC Users meeting workshop '04
PHENIX: PRL 89 082301 (2002)

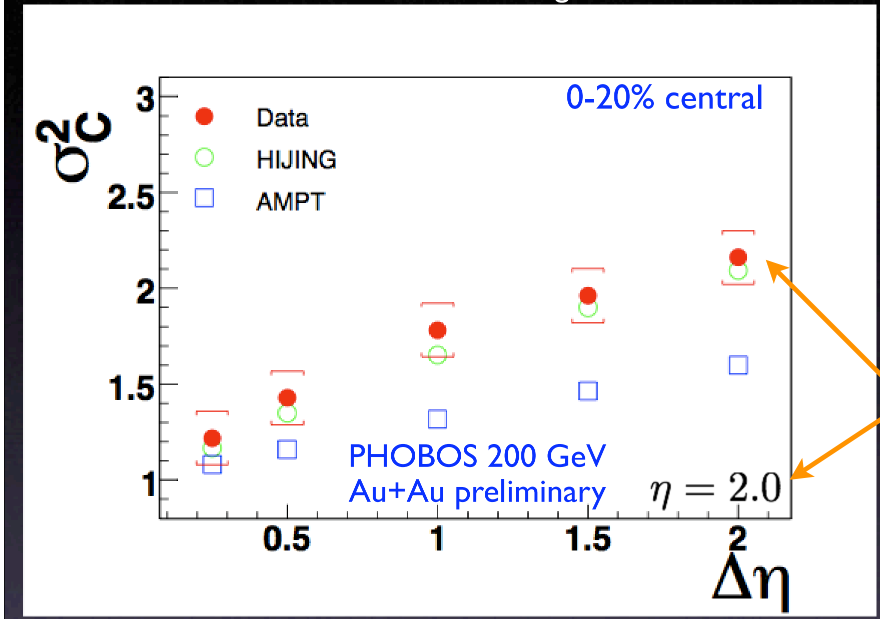


QGP ↓

Little (no) √s dependence of charge fluctuations

N.B. Multiplicity Fluctuations

PHOBOS, Peter Steinberg, QM'05



Particles produced independently:

$\sigma^2{}_C = 1$

Particles produced in clusters of size *K*:

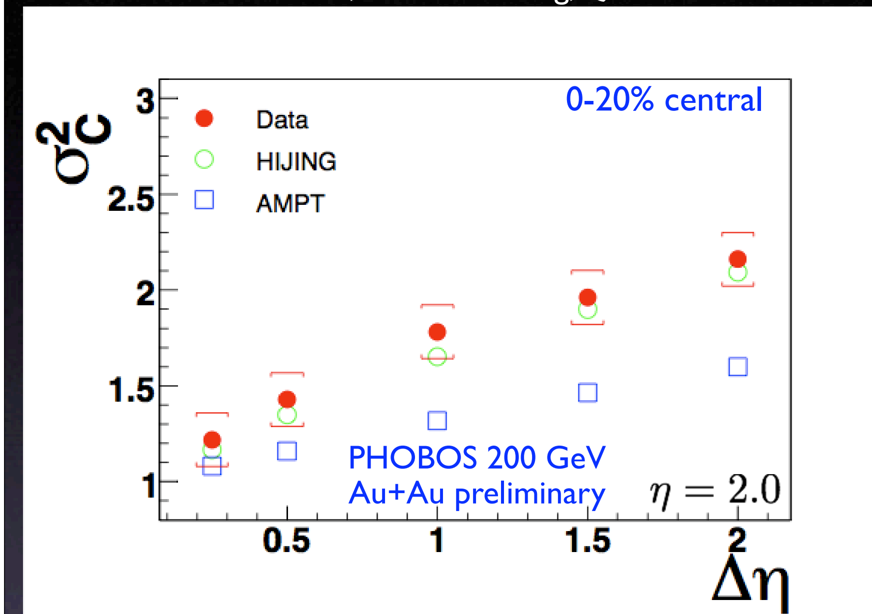
$$C \rightarrow \sqrt{K}C$$
$$\sigma^2_C \rightarrow K\sigma^2_C$$

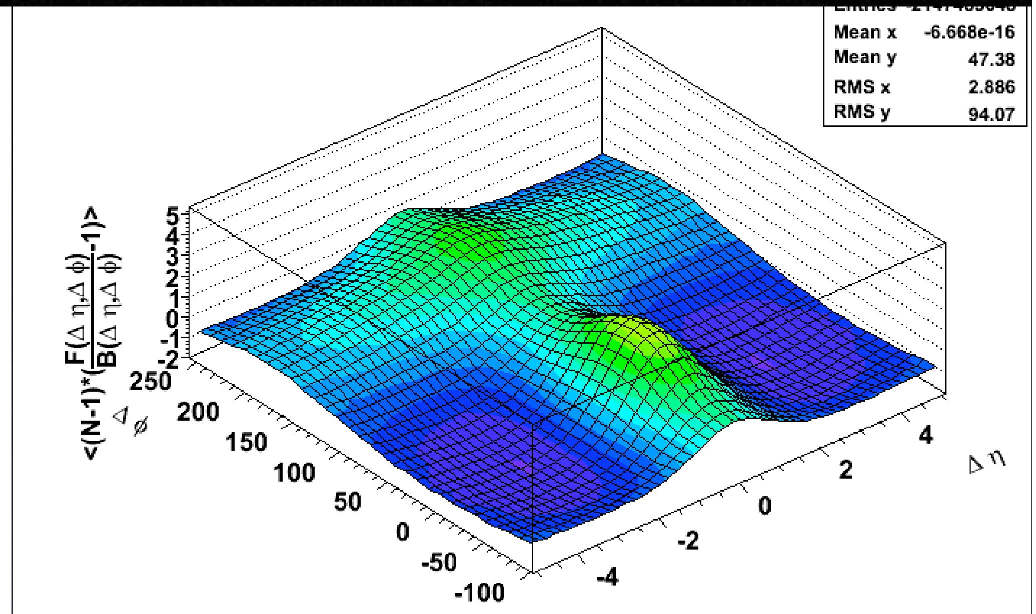
effective cluster size ≈ 2-2.5
for 200 GeV Au+Au

Analysis of forward/backward multiplicity correlations
Particles are produced in clusters of 2-3

N.B. Multiplicity Fluctuations

PHOBOS, Peter Steinberg, QM'05





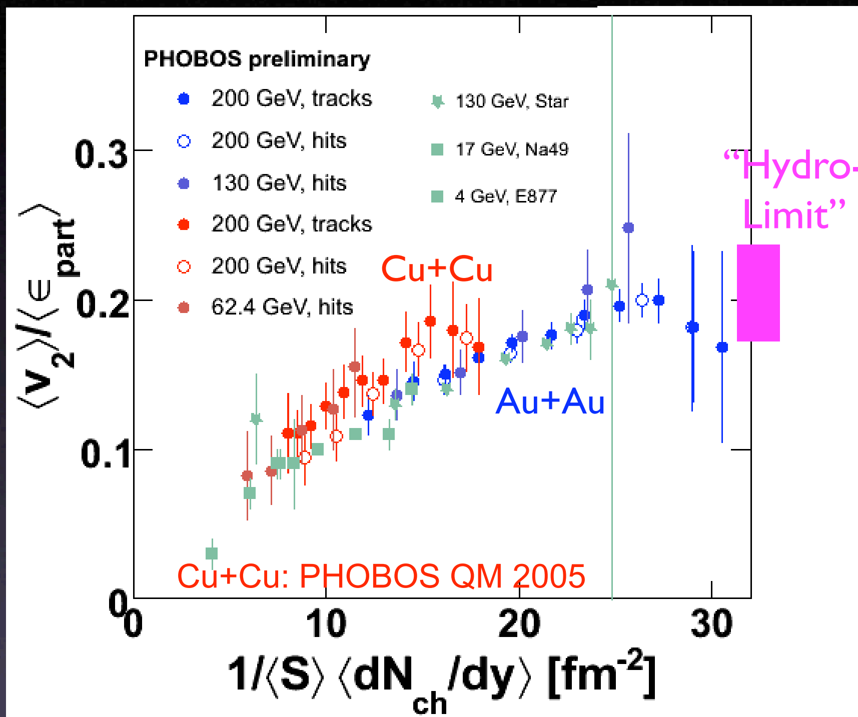
effective cluster size ≈ 2-2.5
for 200 GeV Au+Au

"Cluster" in Δη,Δφ space via
2-particle correlations
(pythia p+p @200 GeV, η<3)

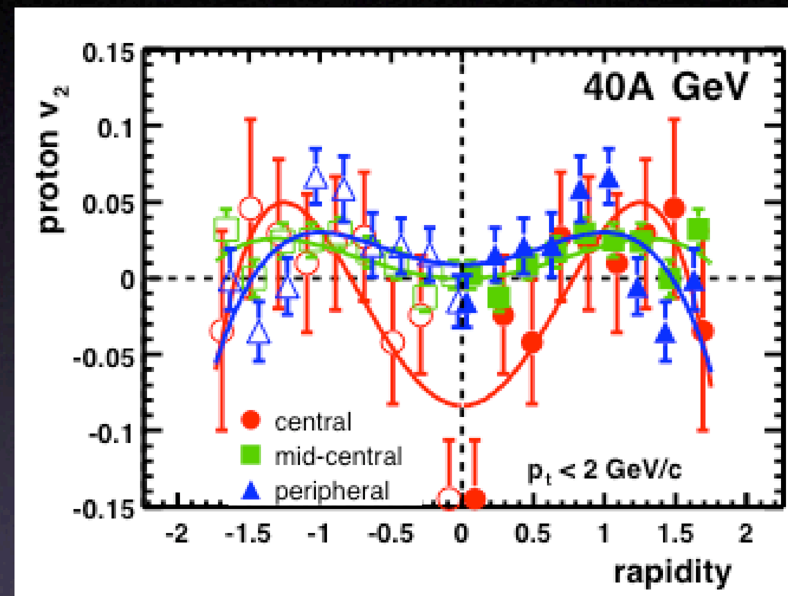
Lesson:
Hadronization cannot be ignored in
discussion of early stage fluctuations

Excitation Function: Elliptic flow

Low Density Limit:
STAR, PRC 66 034904 (2002)
Voloshin, Poskanzer, PLB 474 27 (2000)
Heiselberg, Levy, PRC 59 2716, (1999)



NA49 PRC C68 034903 (2003)



"Participant Eccentricity" provides universal scaling

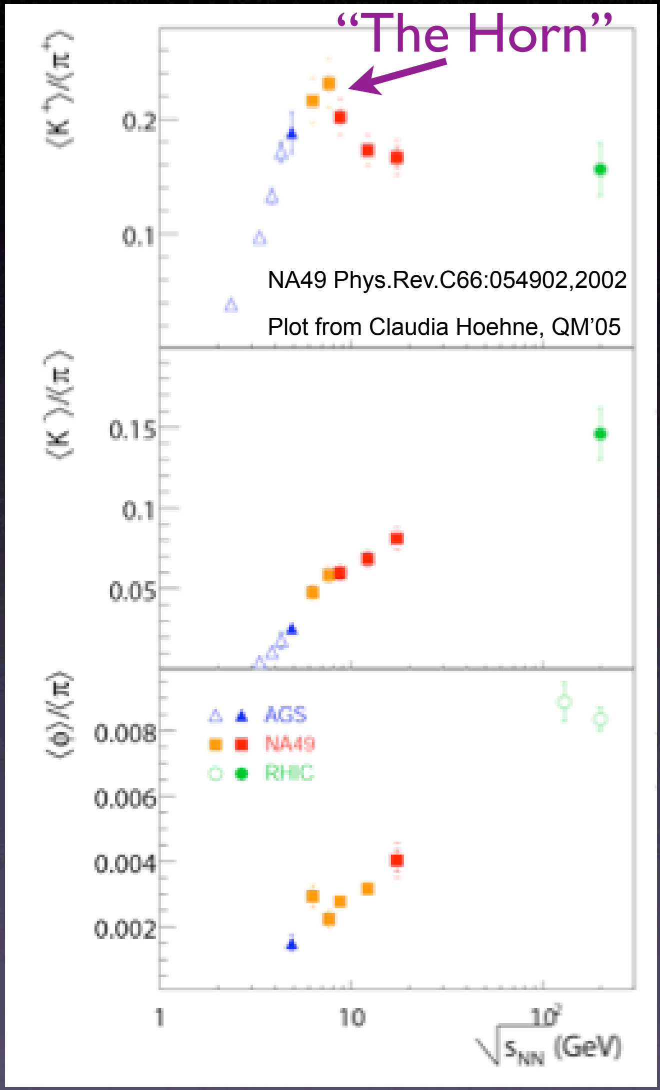
Collapse of proton flow at 40AGeV? provides universal scaling

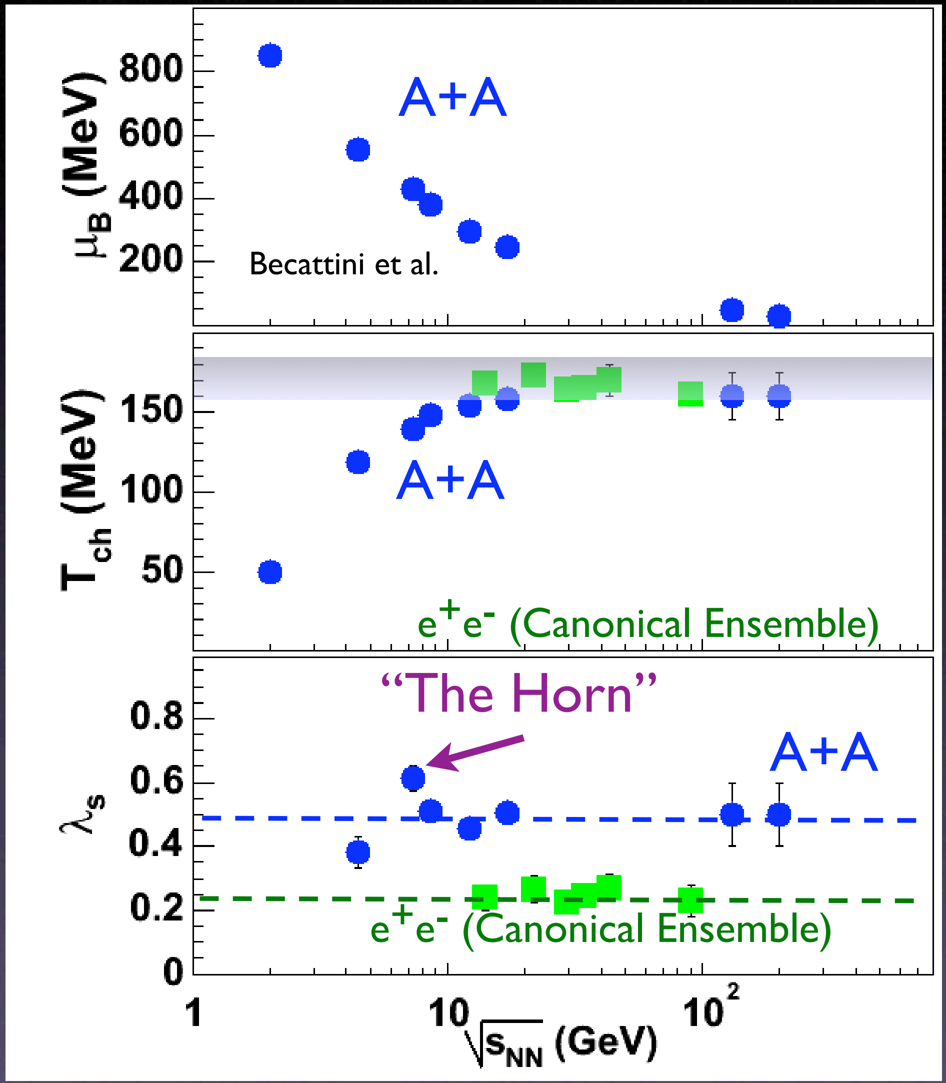
Approach to equilibrium or sampling different regions of EOS?

c.f. Shuryak, Stoecker

Now to the main event.....

Excitation Function: Particle Ratios

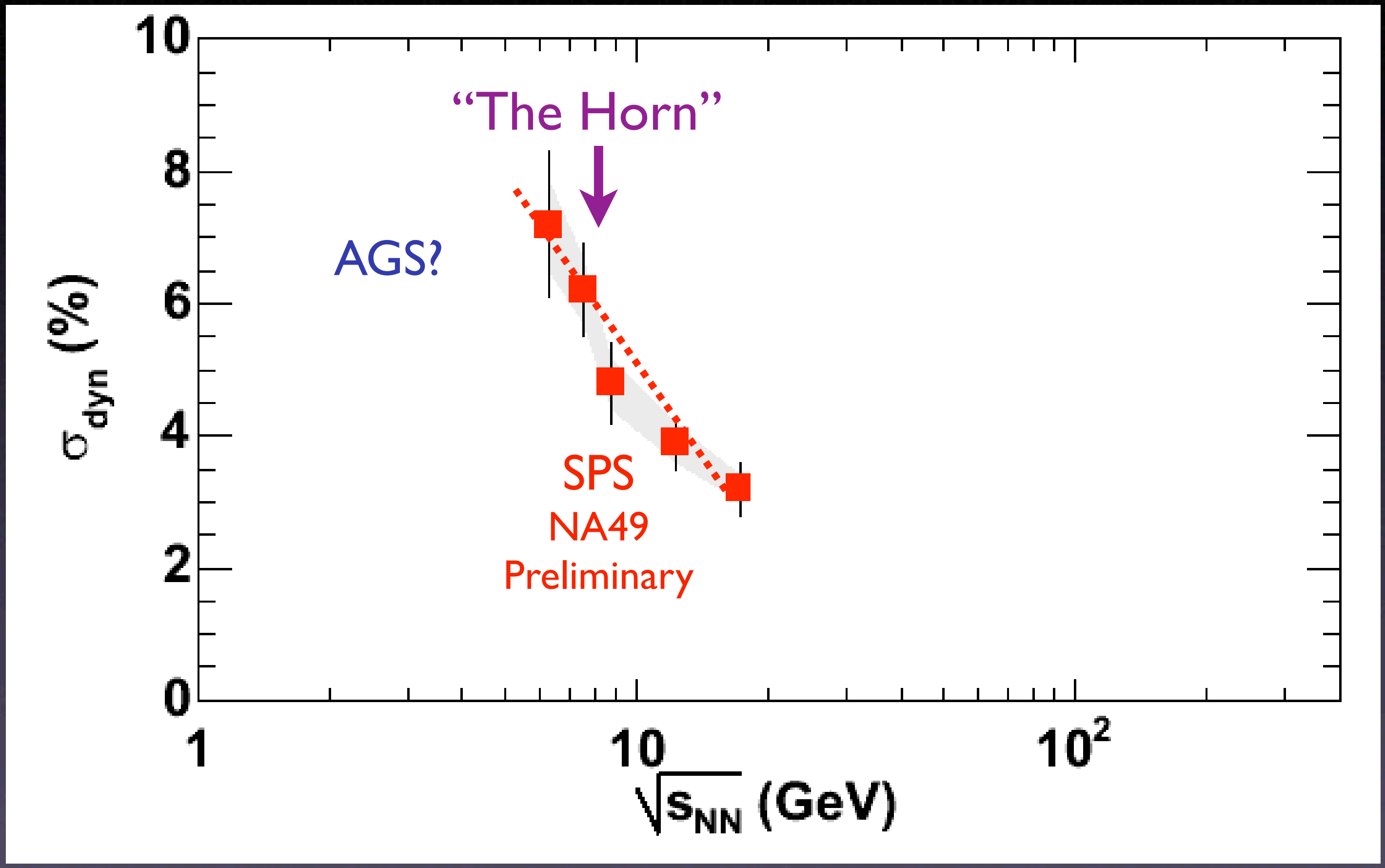




Non-monotonic behavior at AGS/SPS boundary

Excitation Function: K/π Fluctuations

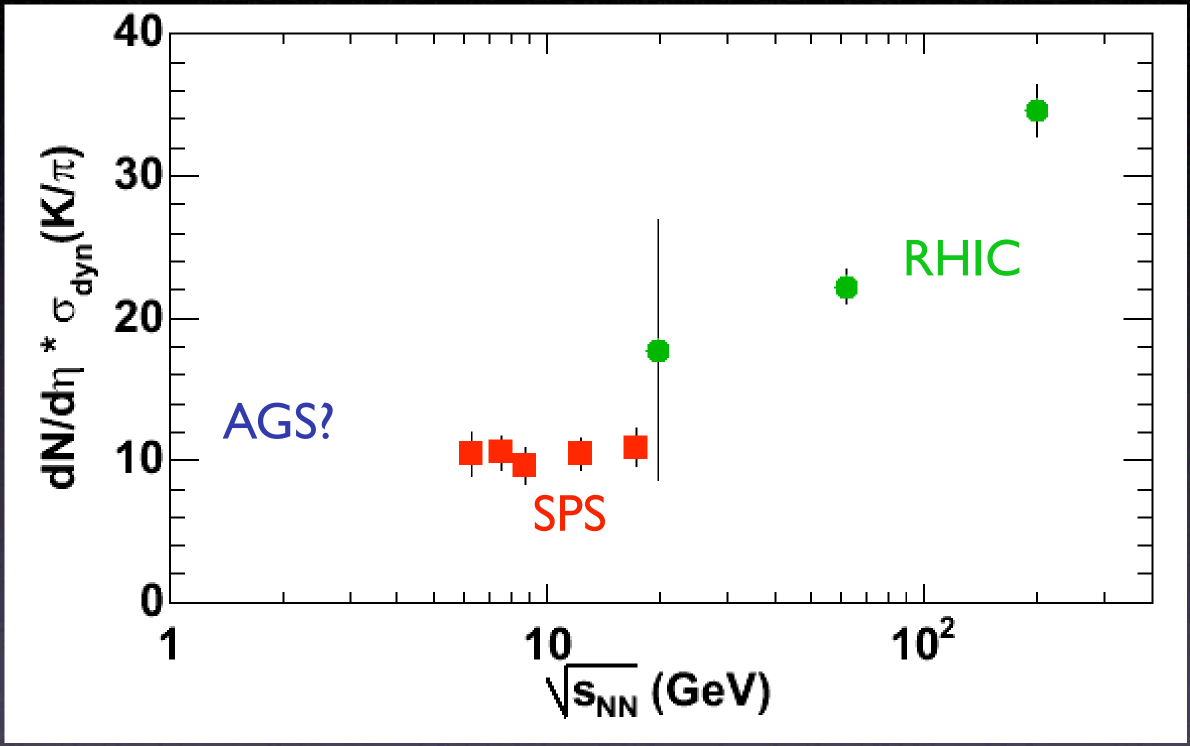
NA49, Christof Roland, QM'04   STAR, Supriya Das, VI Workshop '05



Lesson: Keeping acceptance/experimental technique constant is essential for precision studies

Excitation Function: K/π Fluctuations

Normalized by dN/dy

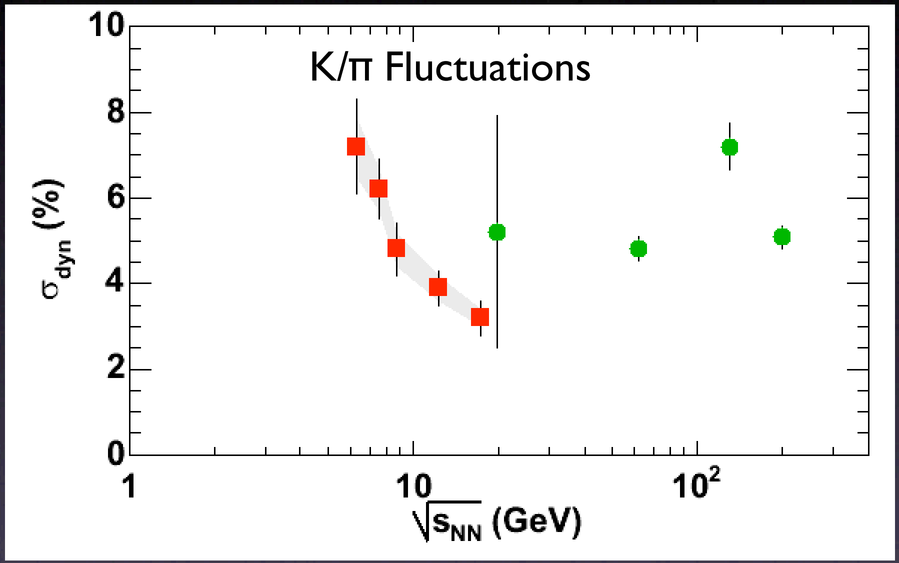


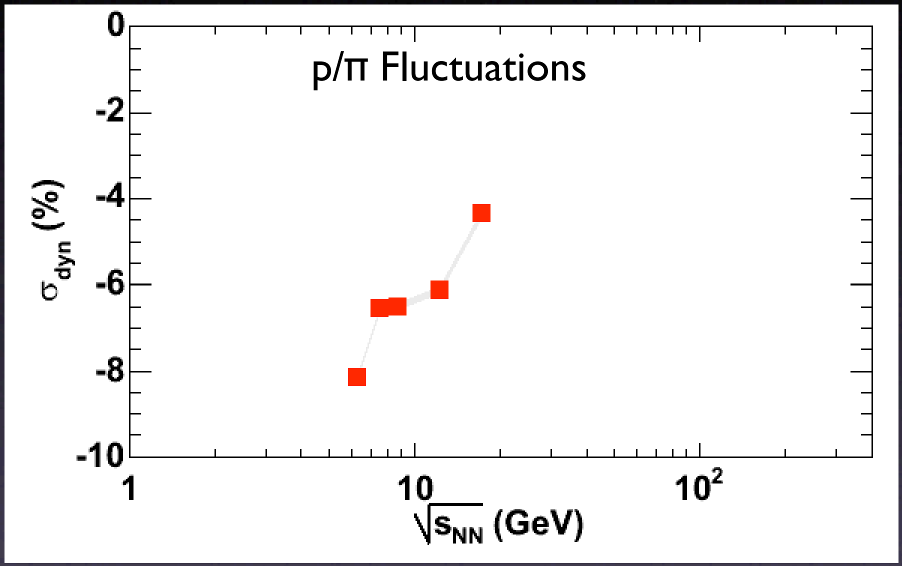
Scaling by dN/dy or $(dN/dy)^{1/2}$ does not work over full energy range

Why use a collider?

Can RHIC low-√s scan improve on SPS measurements?

NA49, Christof Roland, QM'04

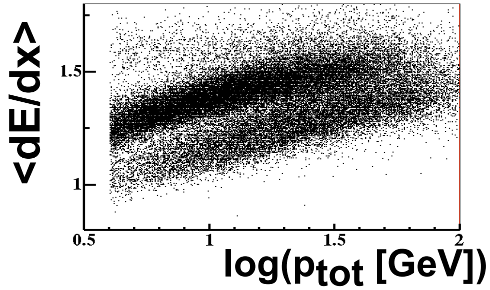




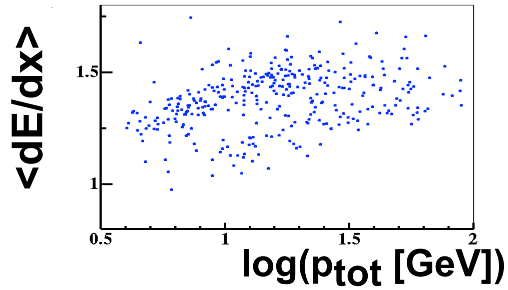
Use particle ratio fluctuations as case study

Event-by-event fit of K/π (NA49)

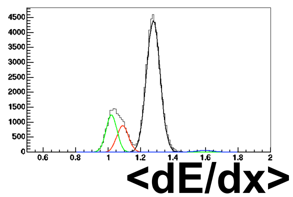
Event Ensemble:



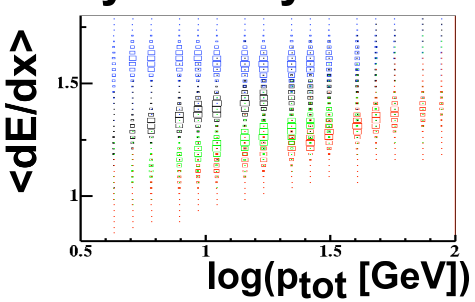
One Event:



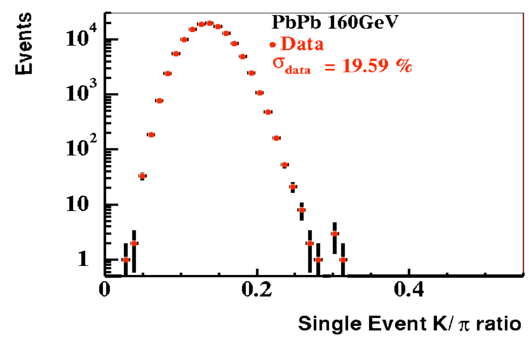
Fit dE/dx spectra in 4D binning



Probability density function:



- **Vary relative normalization of the particle species (K/π,p/π) in the PDF**
- **Extract ratios with maximum likelihood fit**

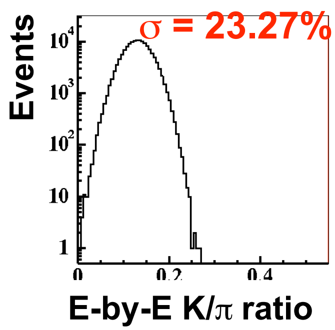


Slide from Christof Roland, Correlations ‘05, MIT

Extracting dynamical fluctuations (NA49)

Process the relative widths of the distributions: σ **= RMS/Mean * 100 [%]**

"Data" Events



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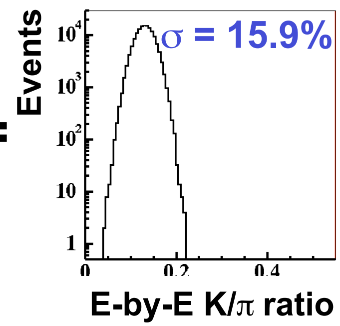
Finite Number Statistics



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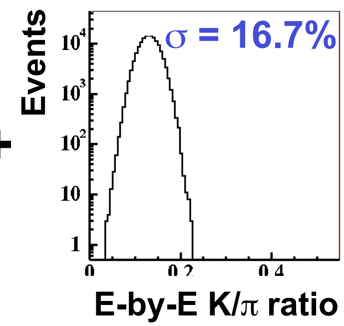
Experimental Resolution



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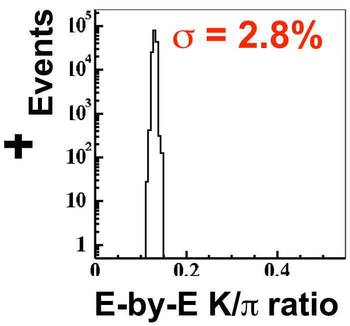
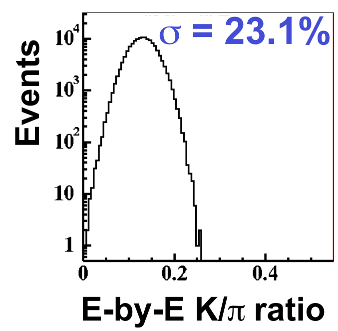
Dynamical Fluctuations



Statistical fluctuations

=

"mixed" Events

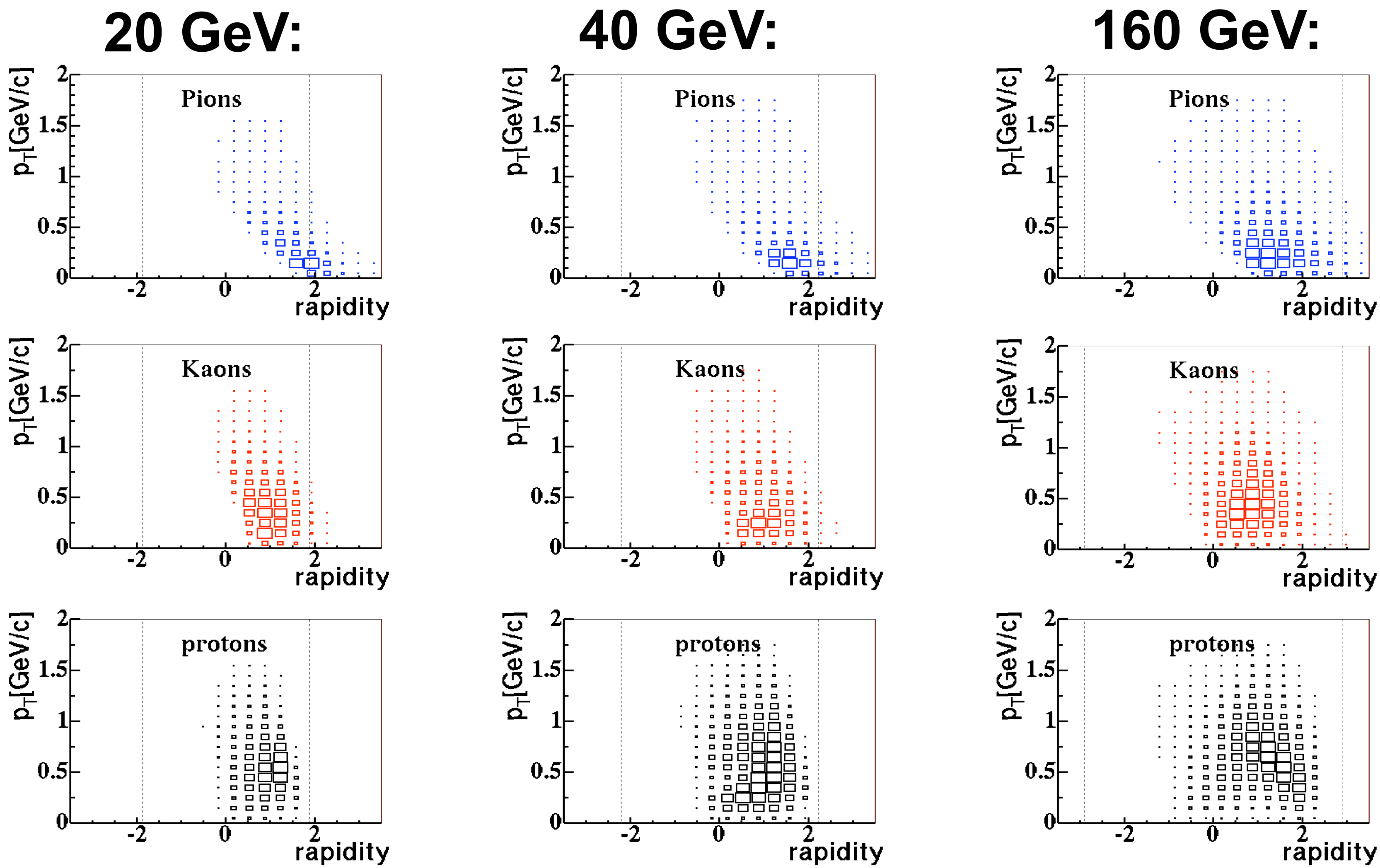


Compare data to mixed events:

$$\sigma^2_{data} - \sigma^2_{mix} = \sigma^2_{dynamic}$$

Slide from Christof Roland, Correlations '05, MIT

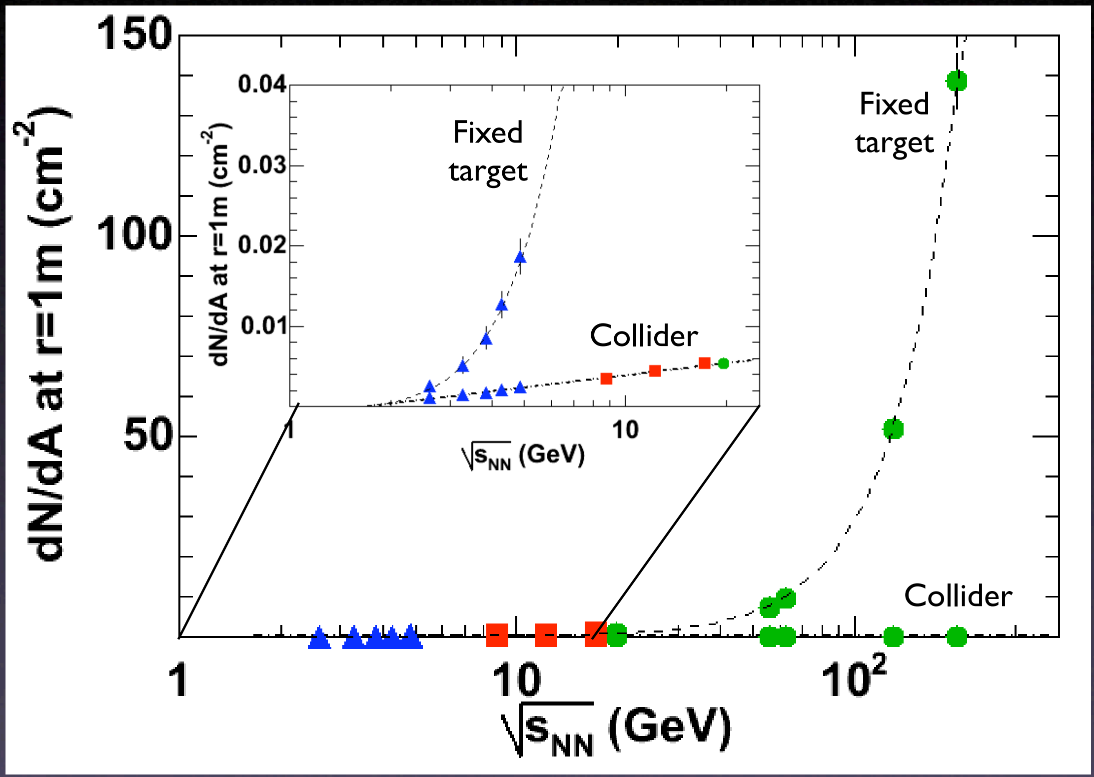
Challenge: Changing acceptance (NA49)



Slide from Christof Roland,
Correlations ‘05, MIT

Mid-rapidity spatial track density

"You prefer your collider"
Les Horribles Cernettes

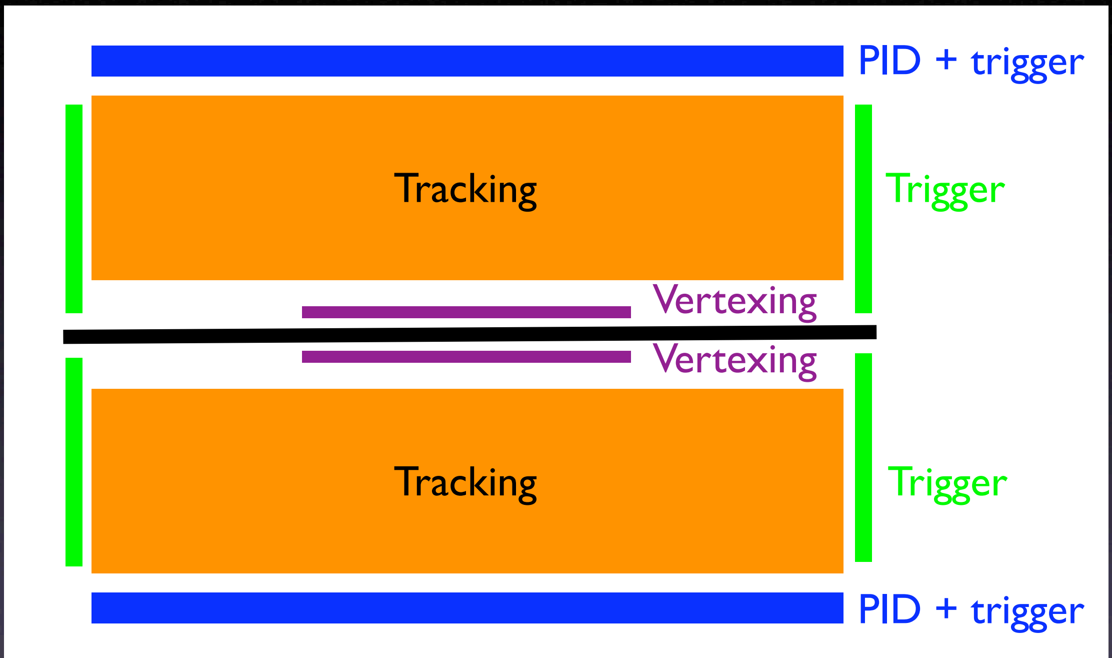


from this:
Occupancy
Double hits
Space Charge
Baseline shifts etc

Track density only rise logarithmically at collider

What can be achieved at RHIC?

“Ideal Detector”



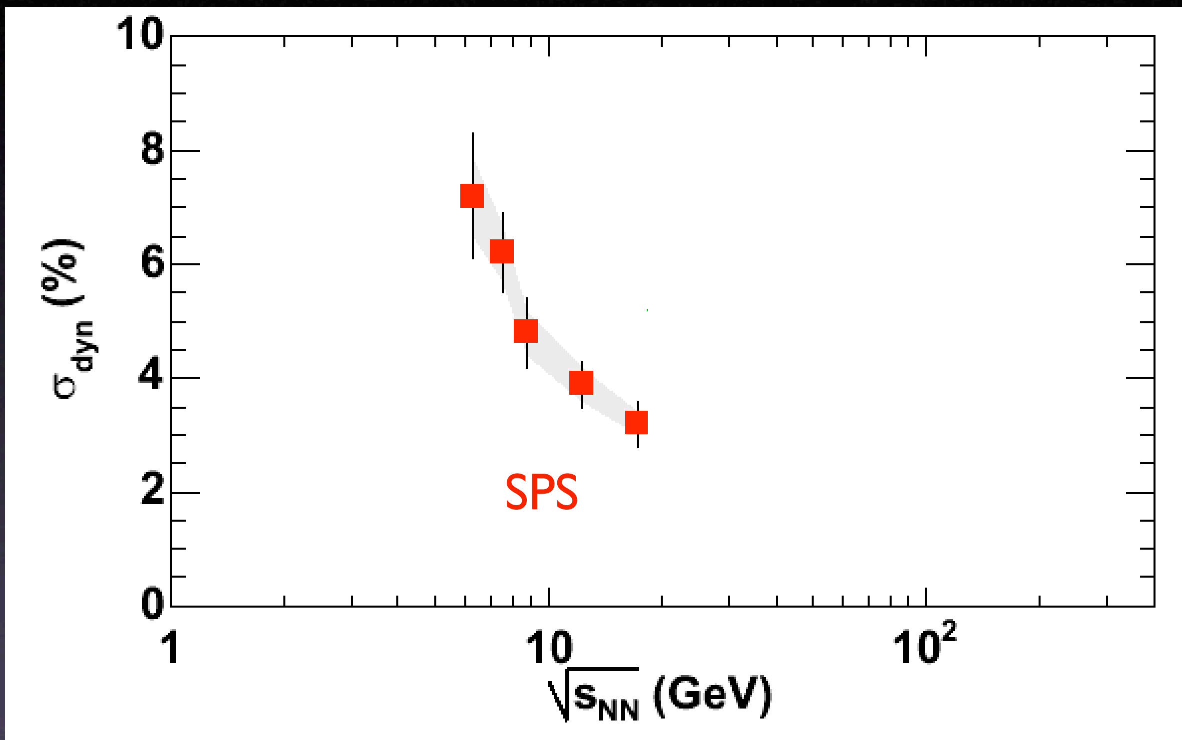
* >80% tracking + PID efficiency from 0.1 < pT < 2.0 GeV/c, over 2+ units of rapidity
* Large acceptance trigger/centrality counters
* High resolution vertexing

Assume 100k central sample at each $\sqrt{s}$

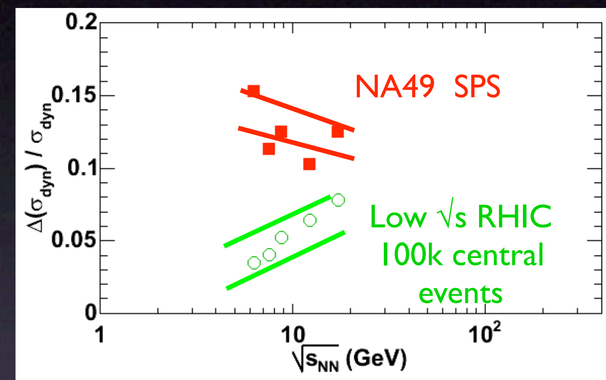
* 2π ToF PID coverage near y=0 possible
* Acceptance in (pT,y) independent of $\sqrt{s}$
* Track density grows logarithmically with $\sqrt{s}$
* Consistent centrality determination from N_{ch}

But: give up very low p_T , luminosity vs fixed target

K/π fluctuations at low-√s RHIC



Relative error on K/π fluctuations



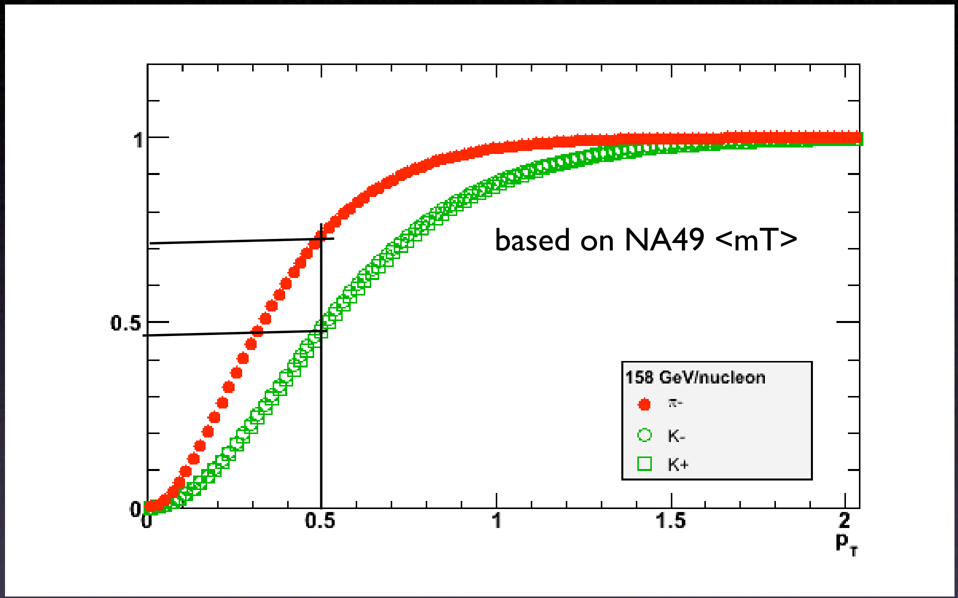
Estimate that RHIC low-√s scan could allow reduction of statistical errors to ~ 1/4 of NA49

Significant reduction of systematics of √s dependence

What about low p_T?

Critical fluctuations:
Long Wavelength
➡ look at low p_T

Fraction of particles below pT



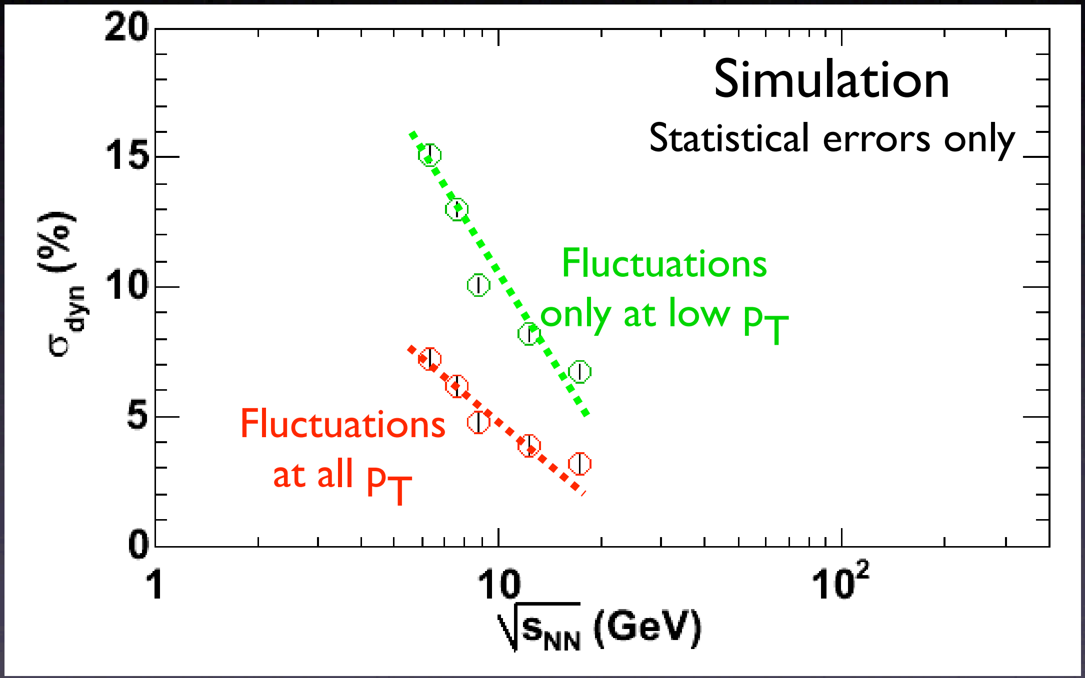
Median Kaon p_T ~ 0.5 GeV

(constant over SPS range)

A low p_T measurement (0.1 - 0.5 GeV/c) would capture ~ 45% (75%) of all kaons (pions)

Low p_T K/π Fluctuations at √s RHIC

Assumptions:
* Ideal RHIC detector (see above)
* 100k central Au+Au at each √s
* K/π Fluctuations from NA49 are correct
* $0.1 < p_T < 0.5$ GeV/c



Conclusion:
RHIC low-√s scan should allow precision measurement of (low p_T) K/π fluctuations

Summary

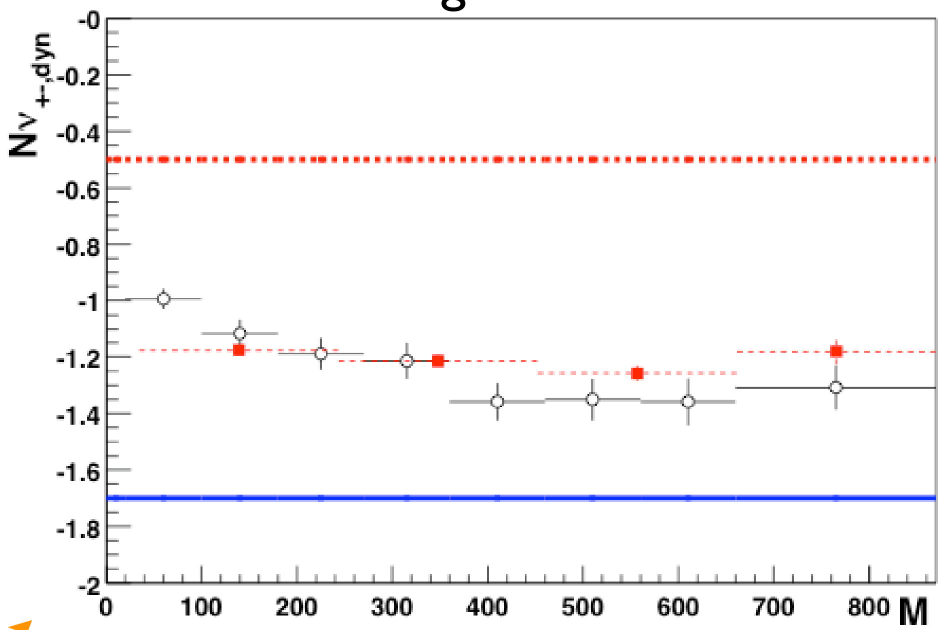
- Strong theoretical motivation for A+A at √s from 5-50 GeV
- Rich existing data set in this range
  - Non-trivial structure/change in yields, ratios, fluctuations/correlations
- Limited statistical/systematic significance
- Low-√s scan at RHIC could confirm and <u>improve</u> experimental results

Summary cntd

- To improve on SPS, low-$\sqrt{s}$ run needs to be done right
  - Sufficient run time (e.g. 1 RHIC run)
  - Large acceptance ToF PID
  - High resolution vertexing
  - Careful event selection/triggering
  - Sufficient number of energies (≥ 5)

Correlations and Fluctuations, revisited

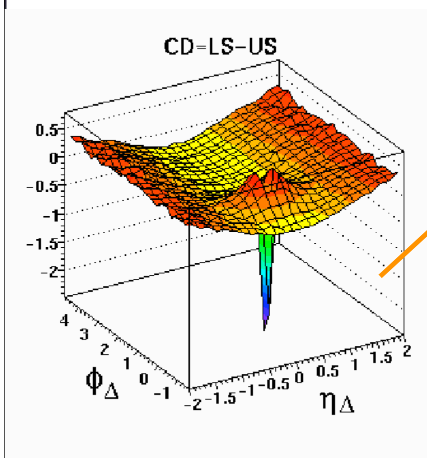
Net-charge Fluctuations



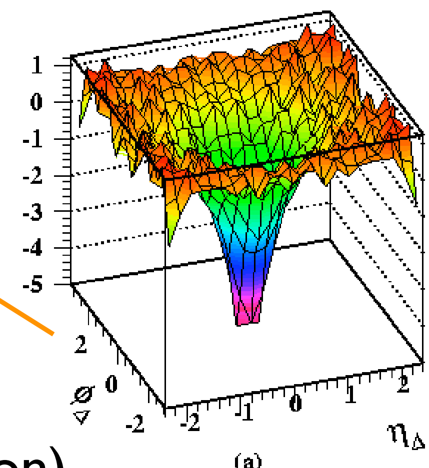
centrality →

Global scaling, even though underlying correlations change

p+p



Central A+A



Net-charge correlations (c.f. Balance Function)