

Review of Signals of Deconfinement

Critical Point and Onset of Deconfinement
Florence
March 9 2006

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

Gunther Roland

Review of Signals of Deconfinement

(\sqrt{s} Excitation Functions of Bulk Observables)

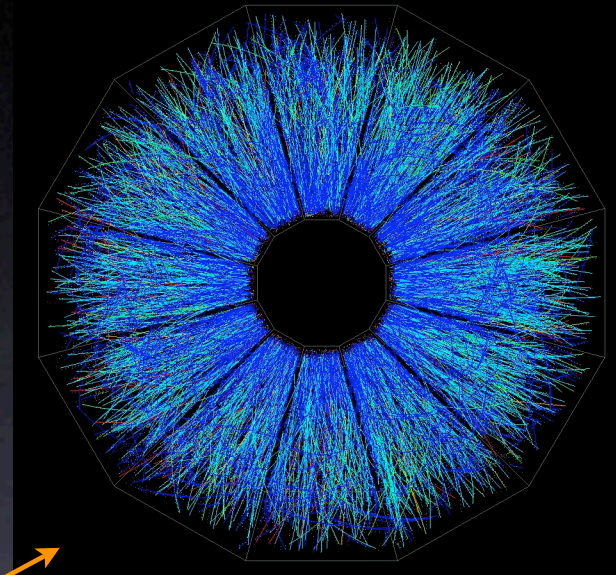
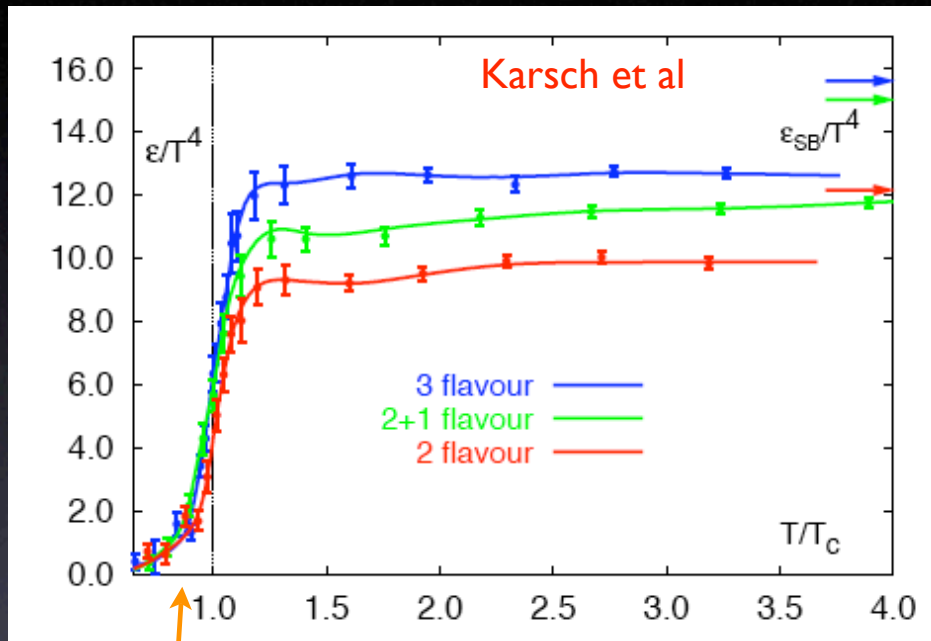
c.f. D. Silvermyr (J/ψ),
E. Scomparin (Leptons)

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Onset of Deconfinement



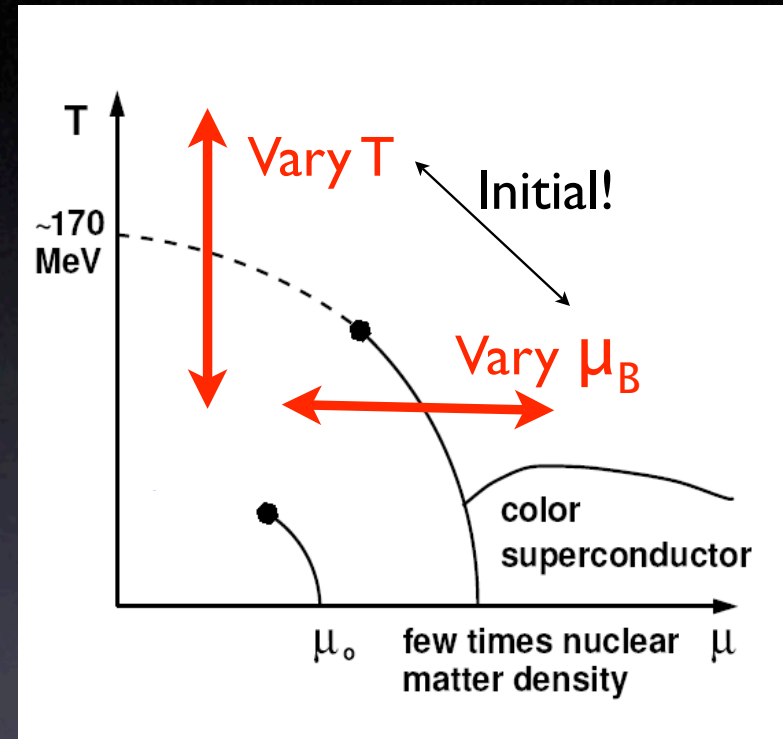
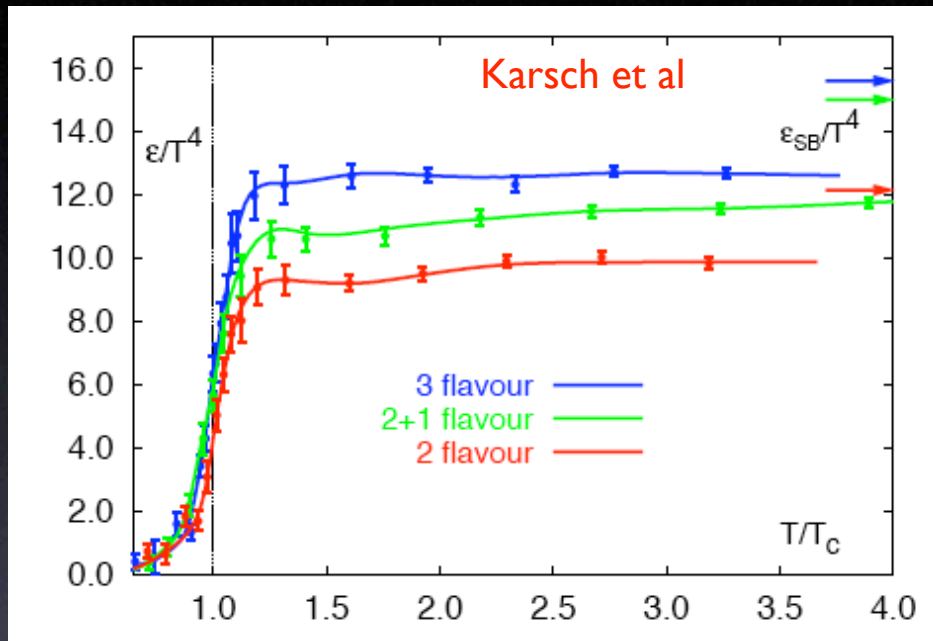
Can this be traced in experiment?

➔ What are the conceptual challenges?

➔ Selection of results

(some exciting, some boring)

Onset of Deconfinement



Can this be traced in experiment?

➔ What are the conceptual challenges?

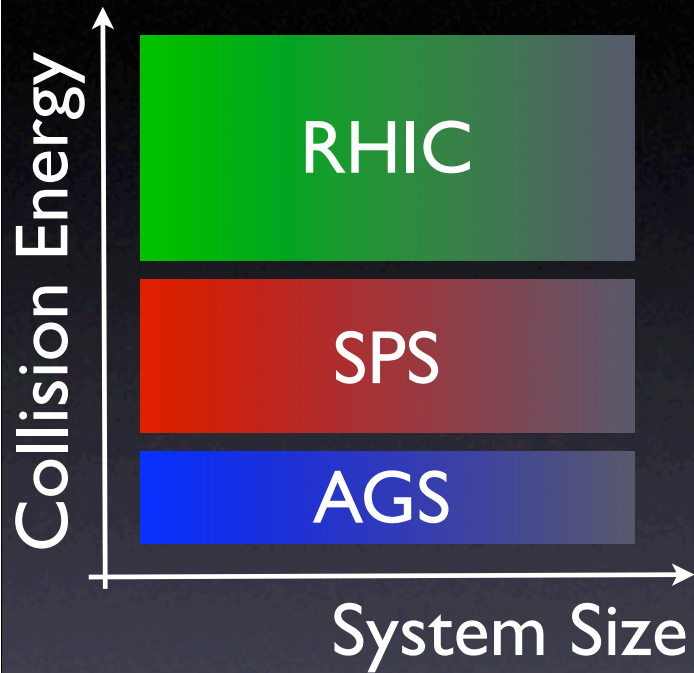
➔ Selection of results

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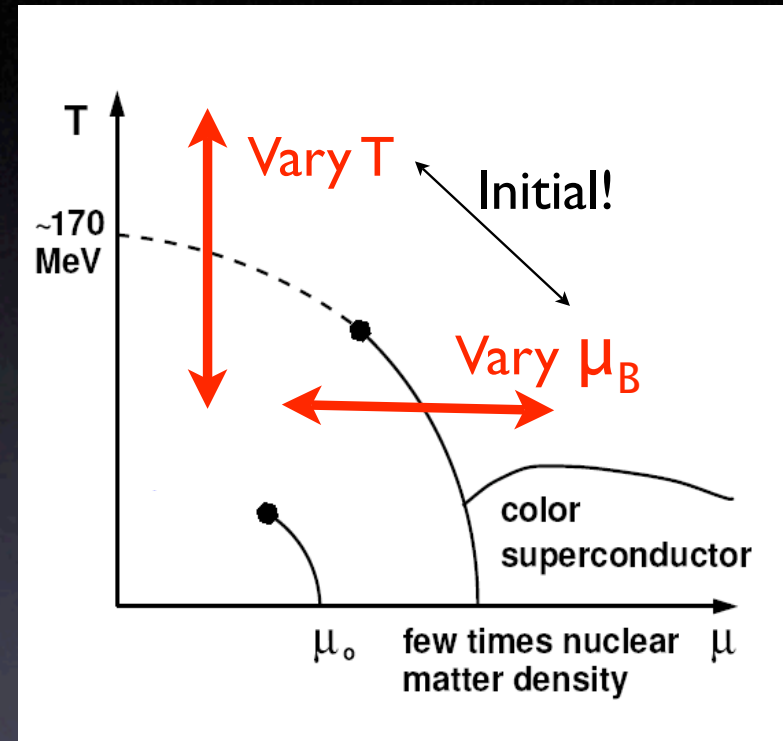
Phase diagram is 2-dimensional

Vary T and/or μ_B to enter QGP

Onset of Deconfinement



Two control parameters to vary initial conditions:
Energy and **System Size**

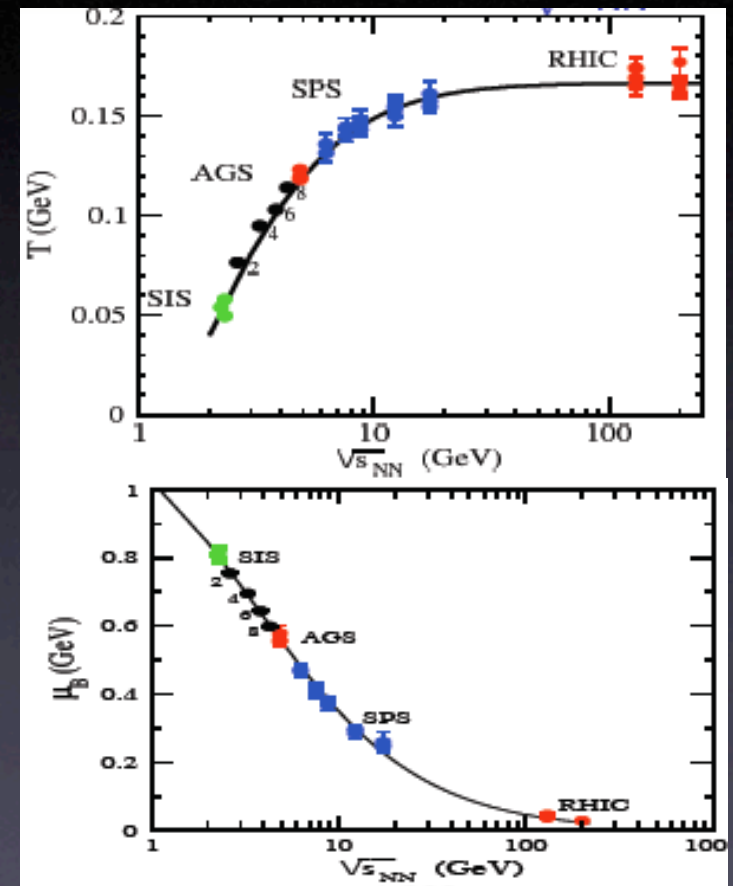
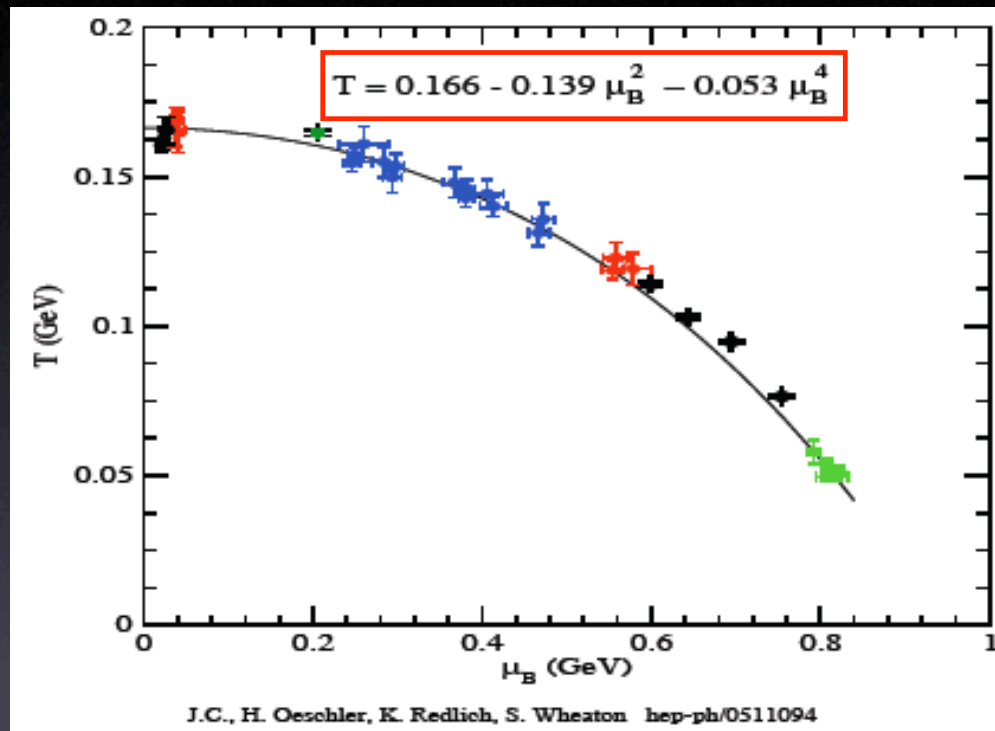


Phase diagram is 2-dimensional

Vary **T** and/or **μ_B** to enter QGP

1st Challenge: Moving across the phase diagram

T_{chem} and μ_B at **chemical freeze-out**

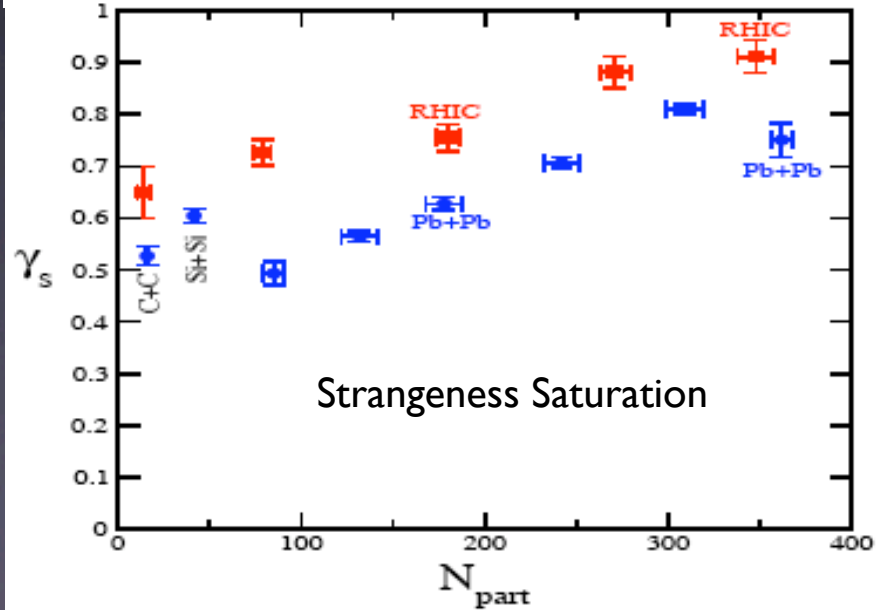
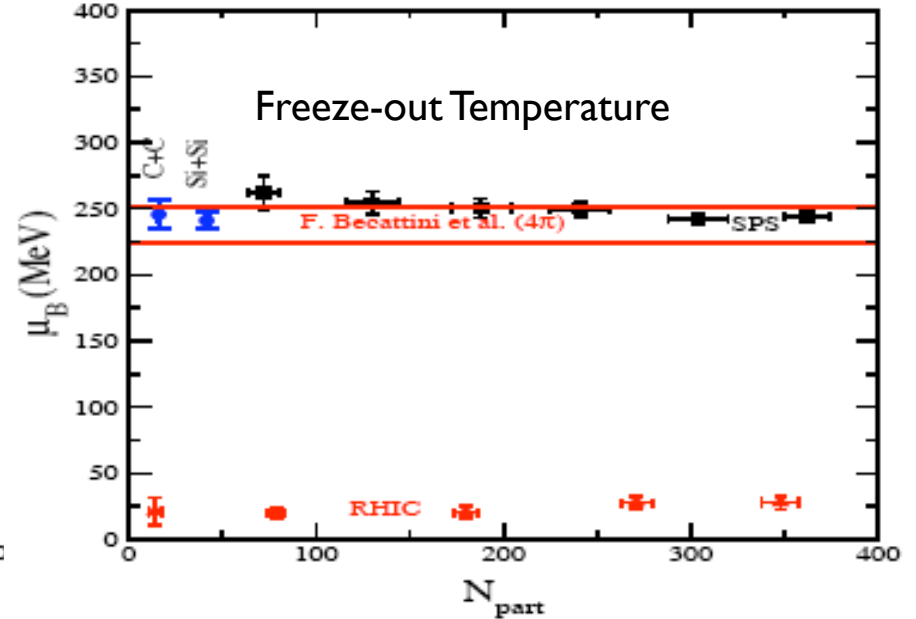
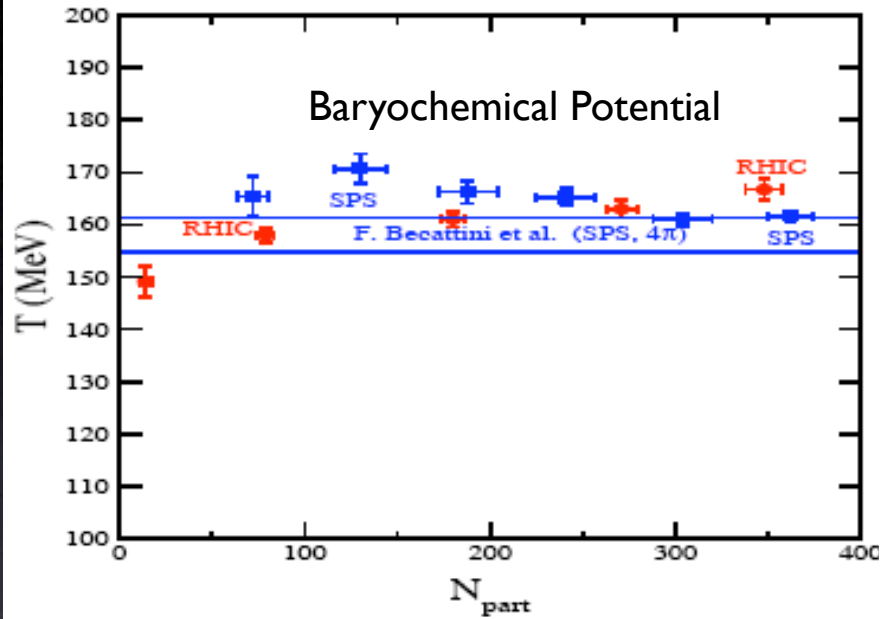


Collision energy varies
 T_{chem} and μ_B **simultaneously**

c.f. Manninen, J. Cleymans

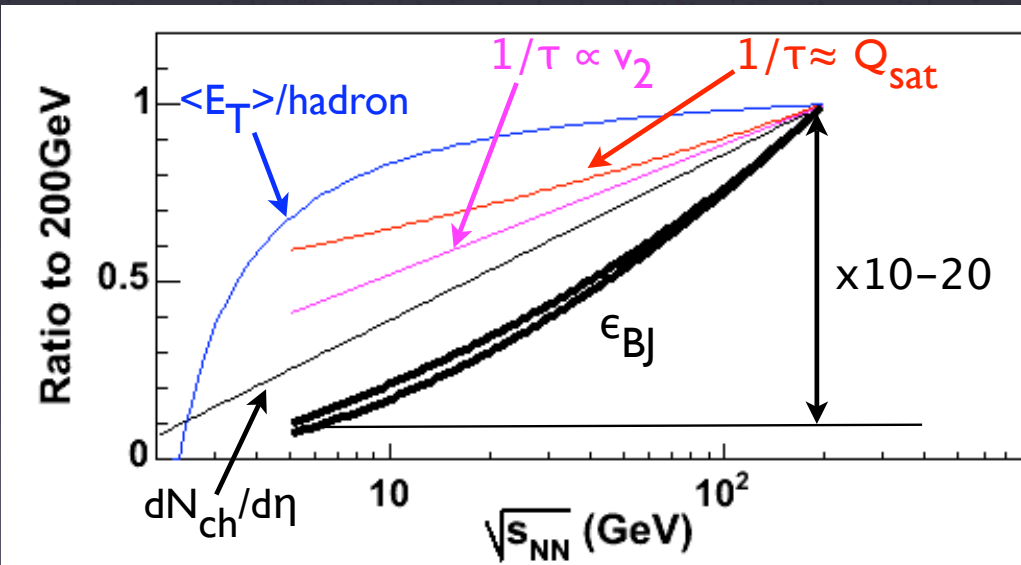
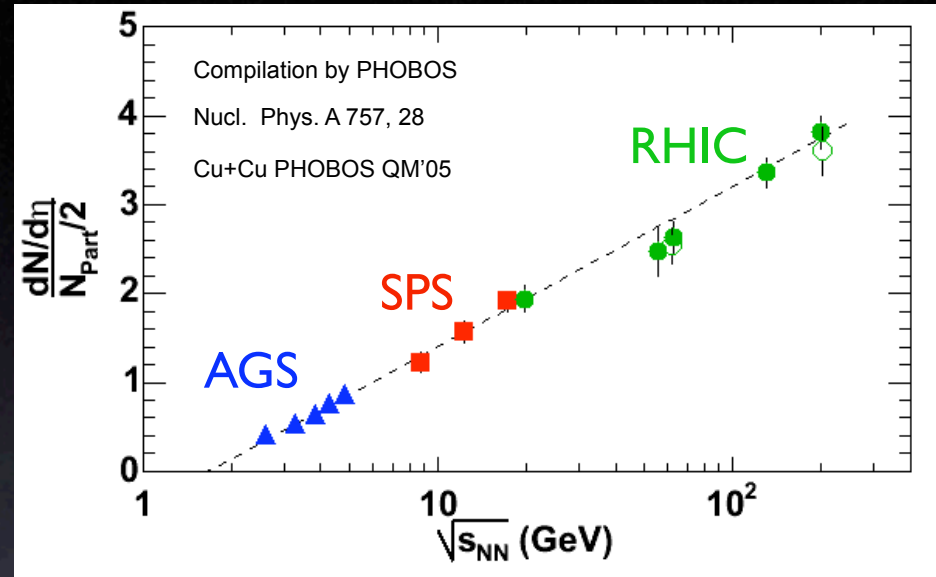
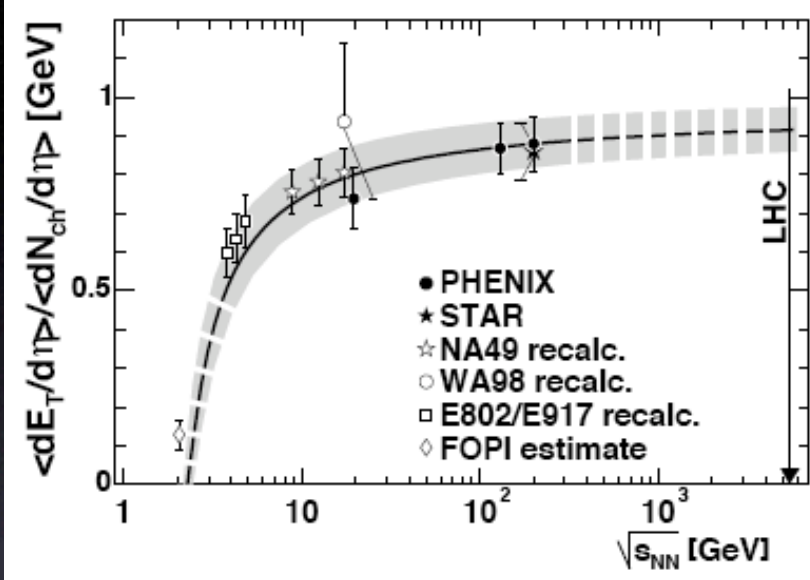
Varying μ_B at fixed \sqrt{s} ?

hep-ph/0311020, Cleymans et al



Variation of initial energy density

PHENIX nucl-ex/0409015 (PRC)

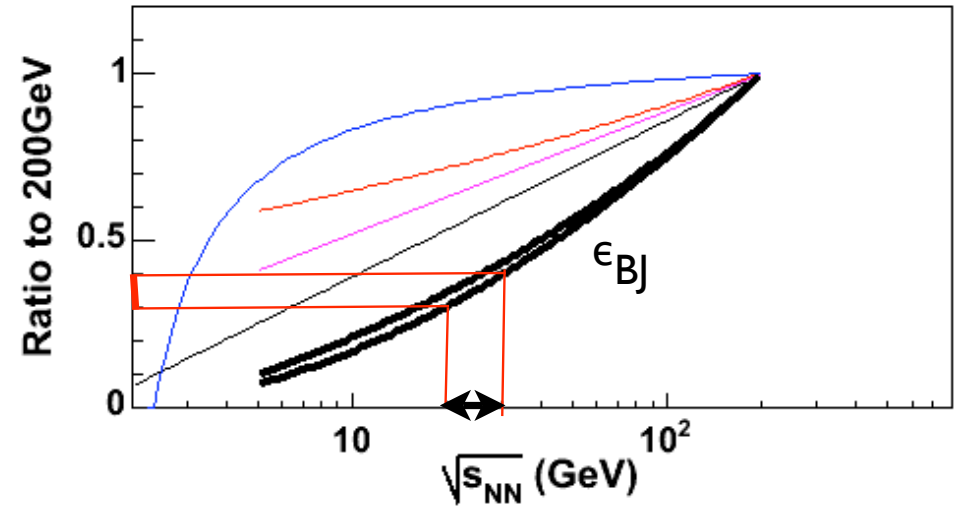
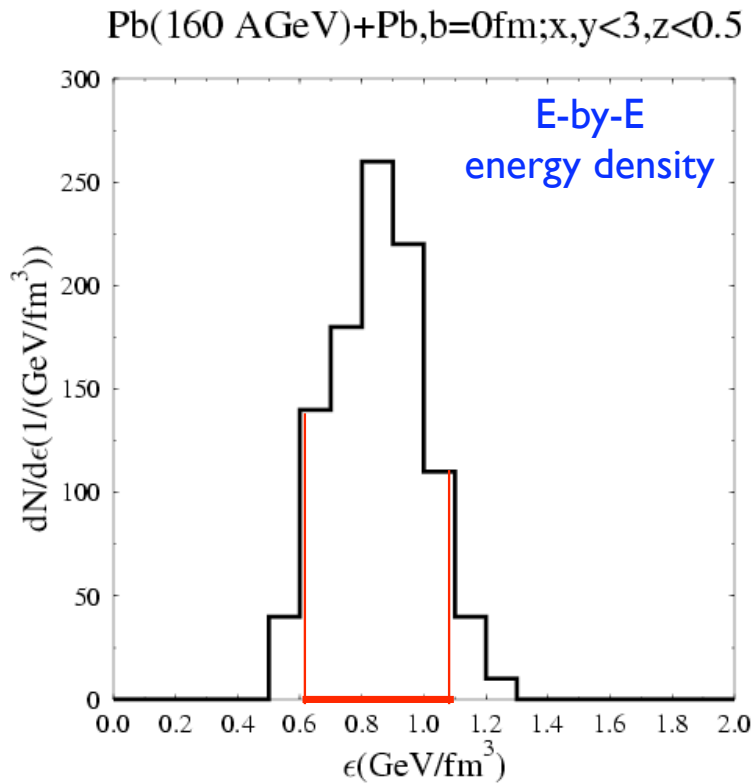


$$\epsilon = \frac{dN/dy \langle m_T \rangle}{\tau_o \times \pi R^2}$$

Bjorken 1982

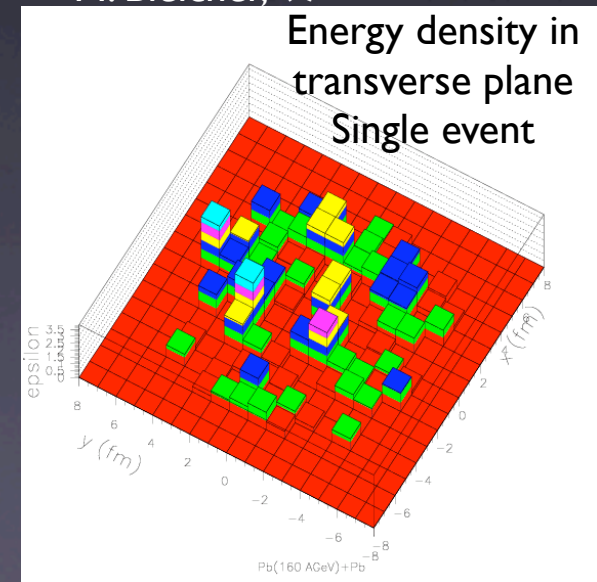
2nd Challenge: Structures in \sqrt{s} vs Fluctuations

M. Bleicher, '97



M. Bleicher, '97

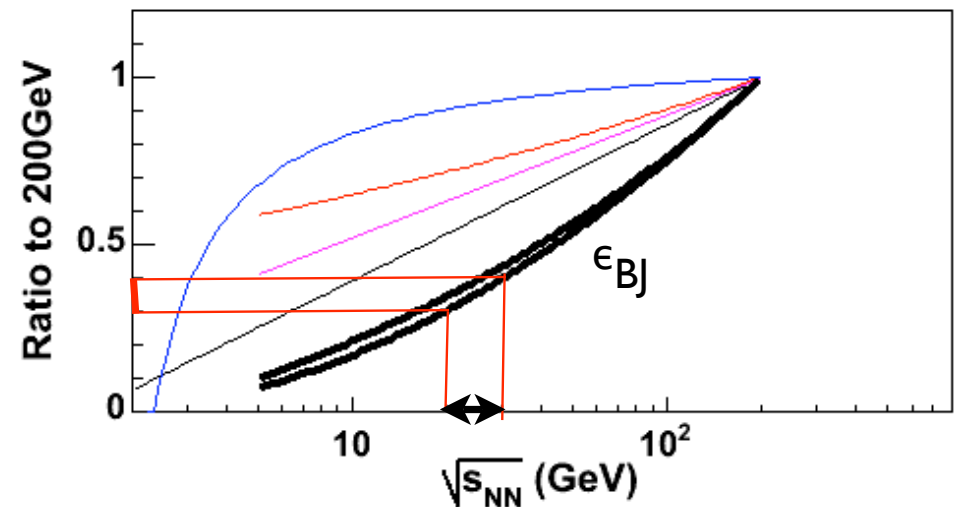
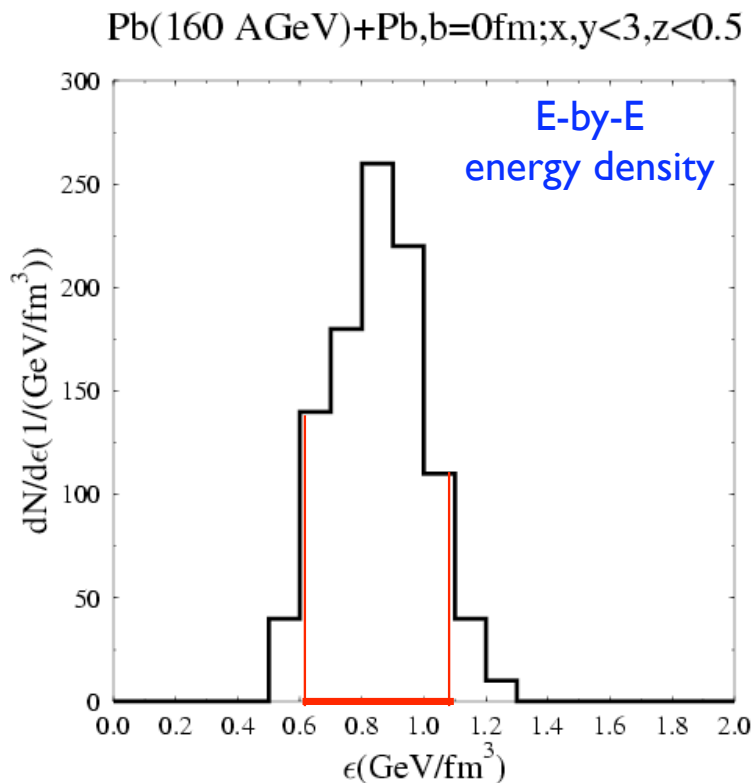
Energy density in
transverse plane
Single event



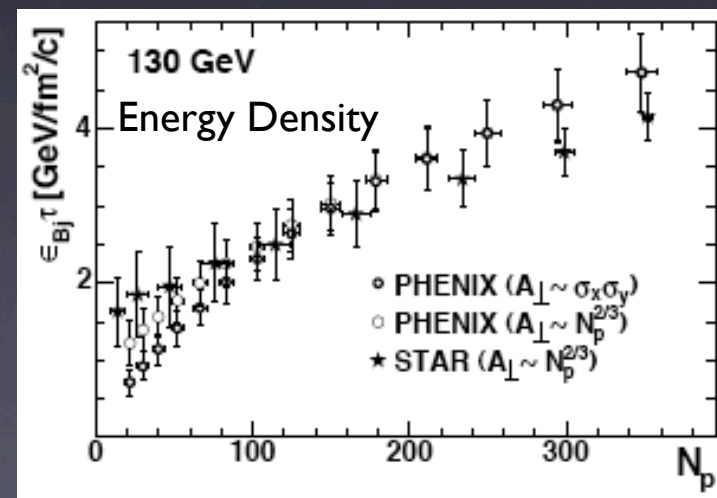
Fluctuations in initial conditions
limit 'sharpness' of structures
vs collision energy

2nd Challenge: Structures in \sqrt{s} vs Fluctuations

M. Bleicher, '97



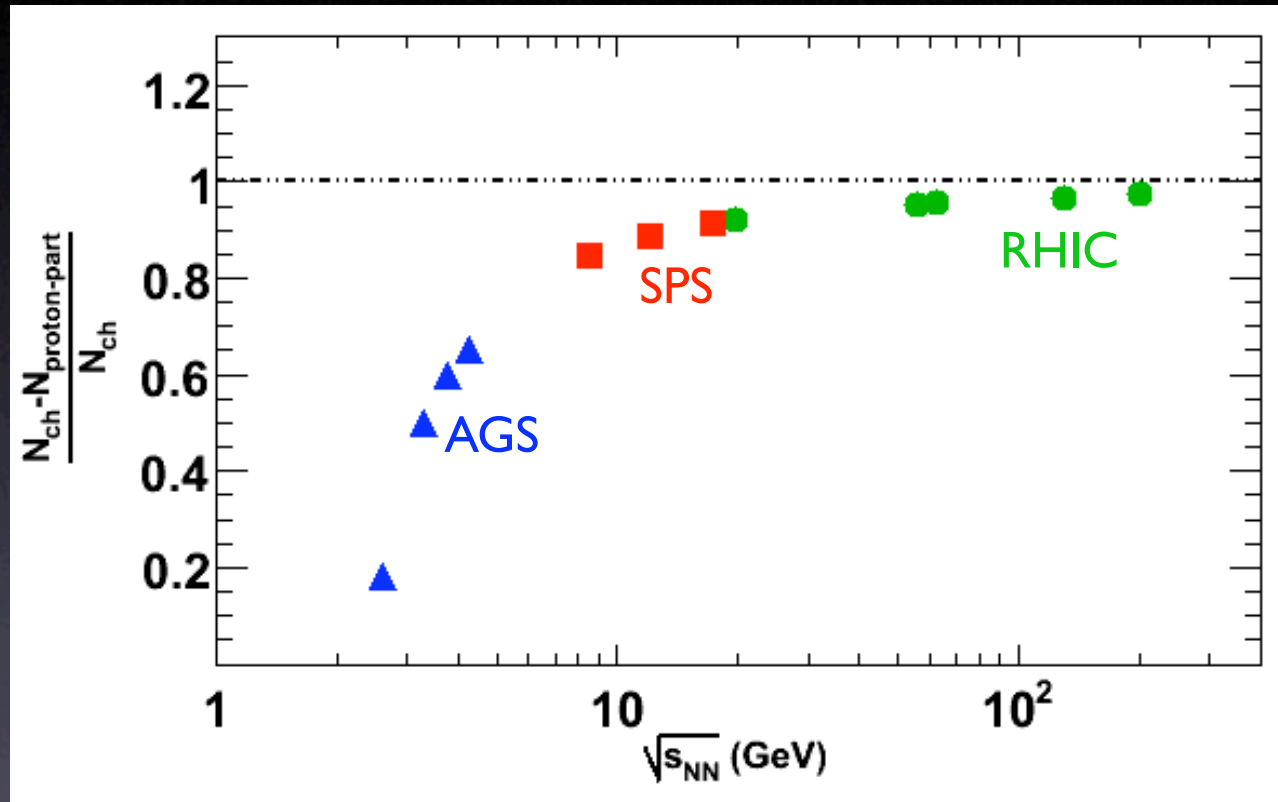
Fluctuations in initial conditions
limit 'sharpness' of structures
vs collision energy



PHENIX nucl-ex/0409015 (PRC)

3rd Challenge: Net-Baryon/Meson Balance

Fraction of produced hadrons in N_{ch}

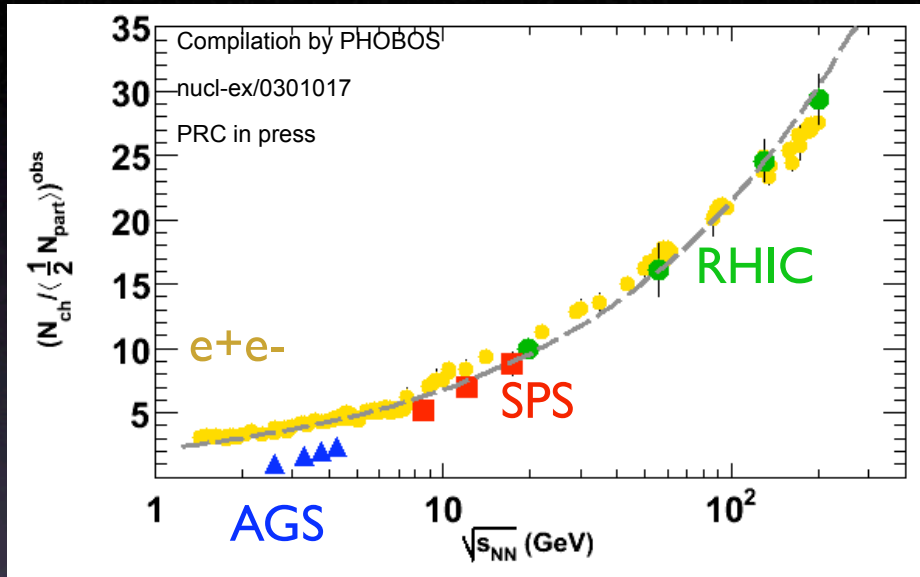


Change from baryon- to meson dominated system
over the energy range of interest!

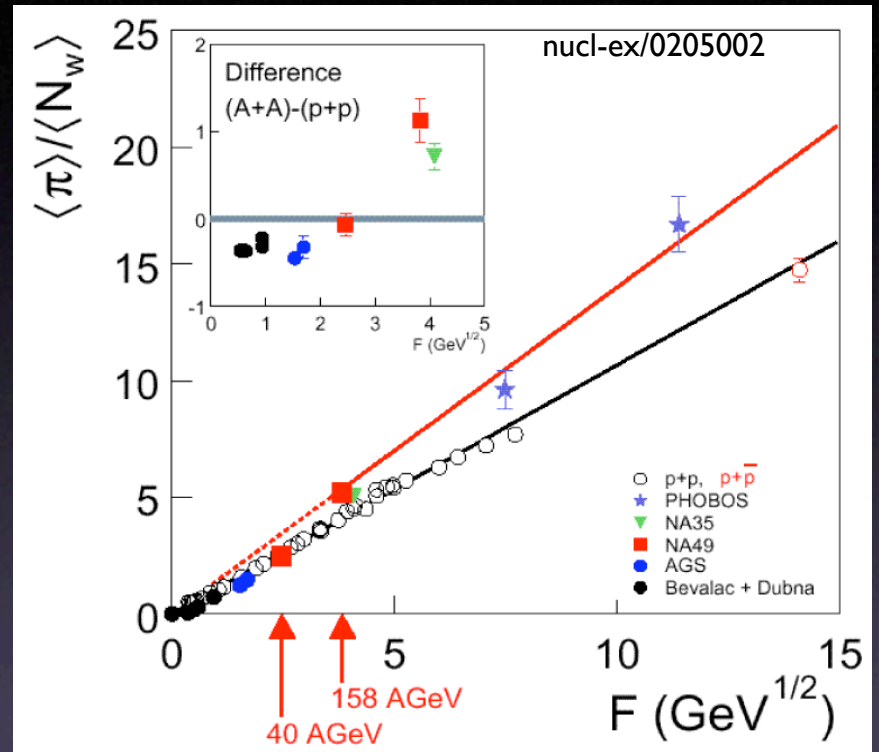
Excitation Function: Total Multiplicities

$$\langle N_{ch} \rangle$$

$$\langle N_{ch} \rangle - (\langle K \rangle + \langle p \rangle)$$



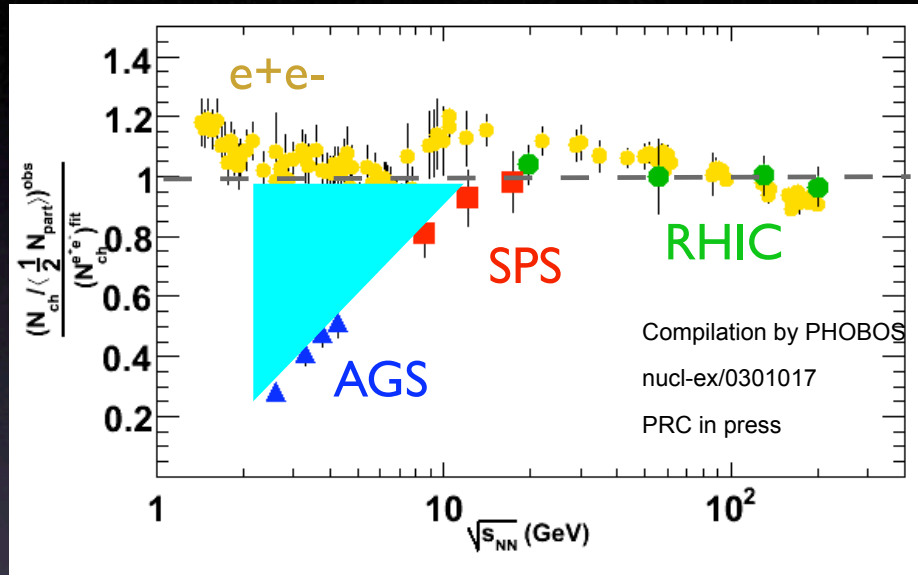
c.f. P. Steinberg



c.f. C. Blume, M. Gazdzicki

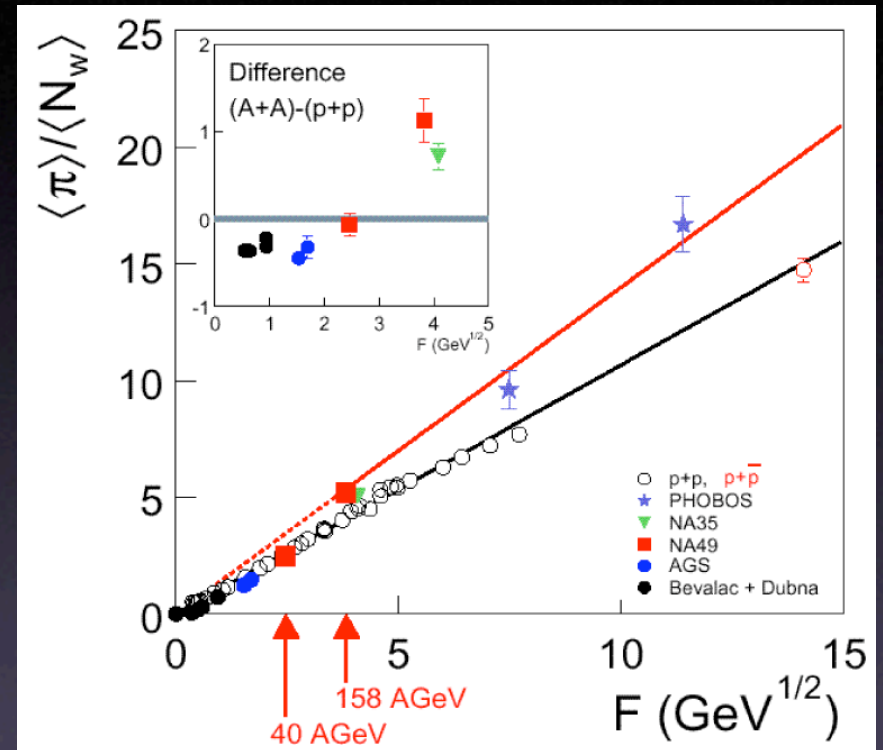
Excitation Function: Total Multiplicities

$$\langle N_{ch} \rangle / e+e- \text{ fit}$$



“Universality” of entropy production
At low energy, baryons carry away
difference

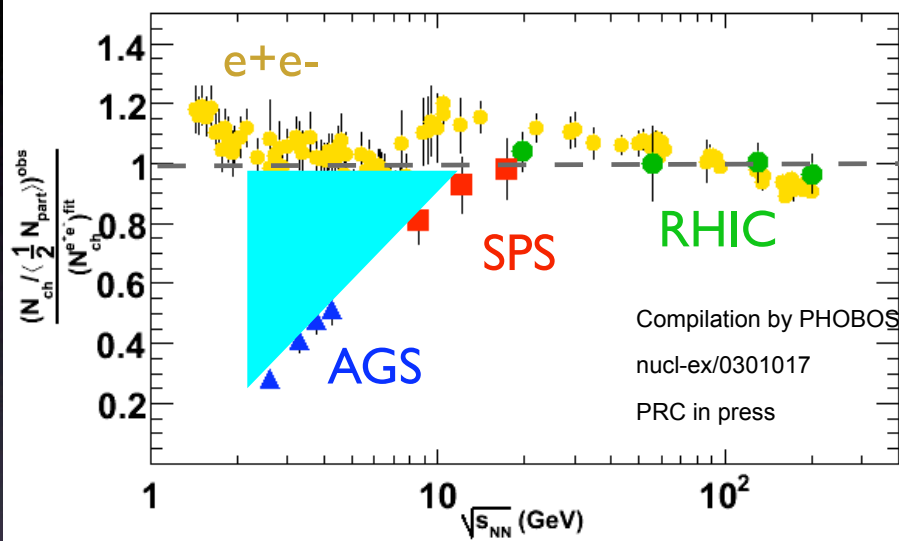
$$\langle N_{ch} \rangle - (\langle K \rangle + \langle p \rangle)$$



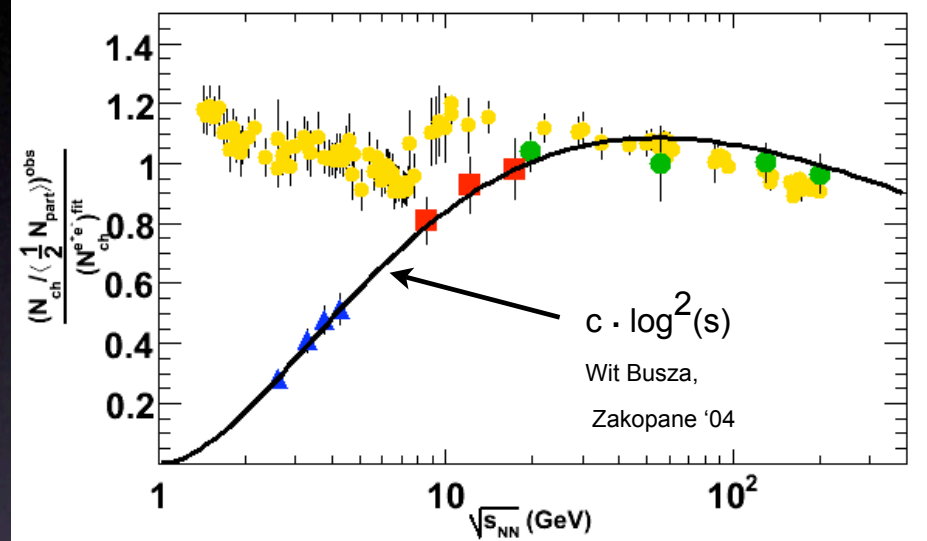
Increase in pion production due to
change in DoF
At low energy, baryons “eat”
some of the pions

Excitation Function: Total Multiplicities

$\langle N_{ch} \rangle / e+e- \text{ fit}$



$\langle N_{ch} \rangle / e+e- \text{ fit}$



A+A by itself can be fit with $\log^2(s)$

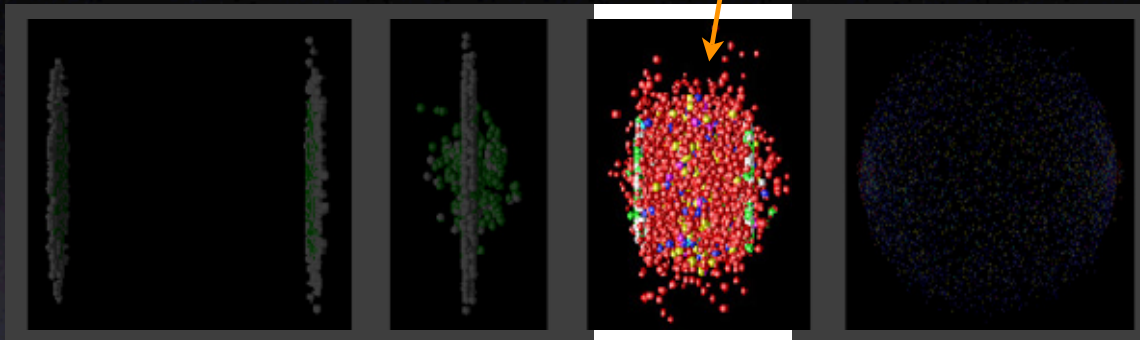
Structure at SPS (and therefore interpretation) depends on **context** (e.g. comparison to $e+e-$, treatment of baryons)

Fluctuations as Deconfinement Signal

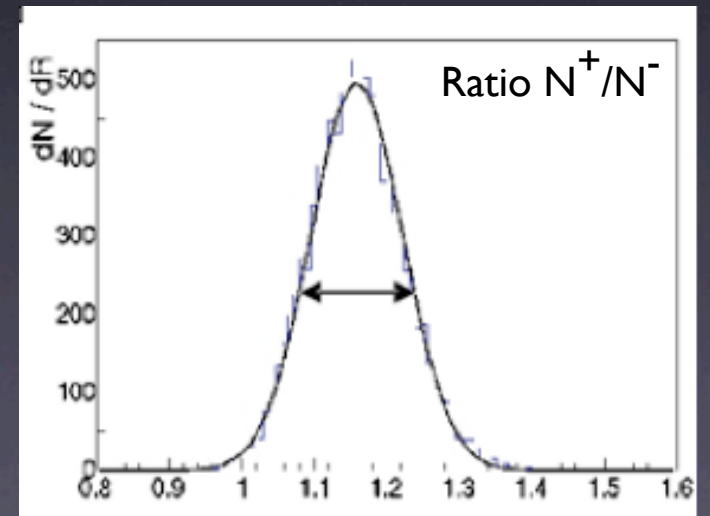
DoF of Medium?

Jeon, Koch PRL (2000) hep-ph/0003168

Asakawa, Heinz, Mueller PRL (2000) hep-ph/0003169



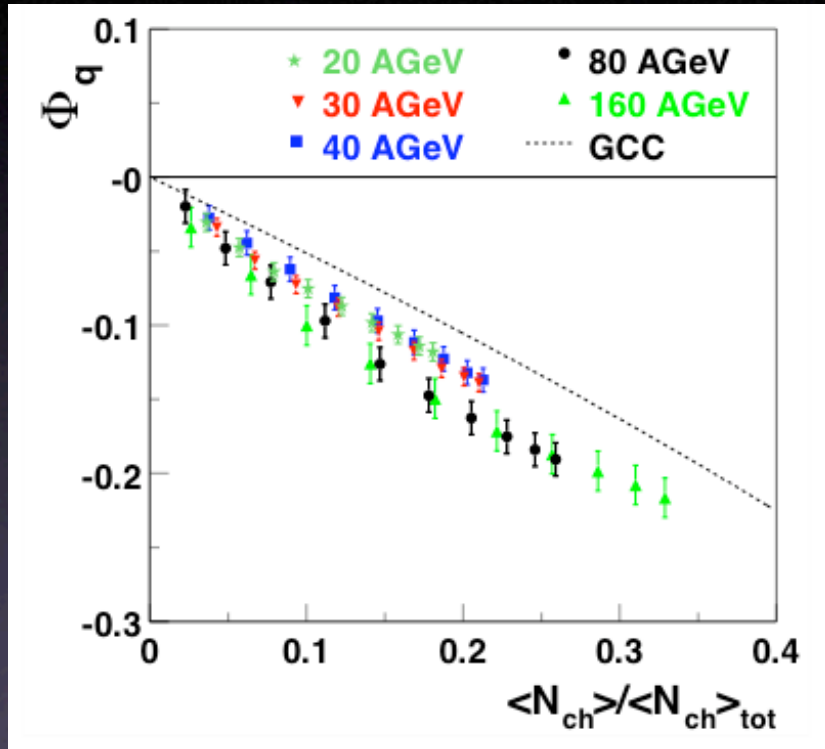
- **Net Charge/ Δy Fluctuations \Leftrightarrow Charge/DoF**
 - Fluc's change from **1-2 (QGP)** to **4 (Pion Gas)**
- **Fluctuations frozen b/c charge conservation**
 - Diffusion vs Expansion timescale



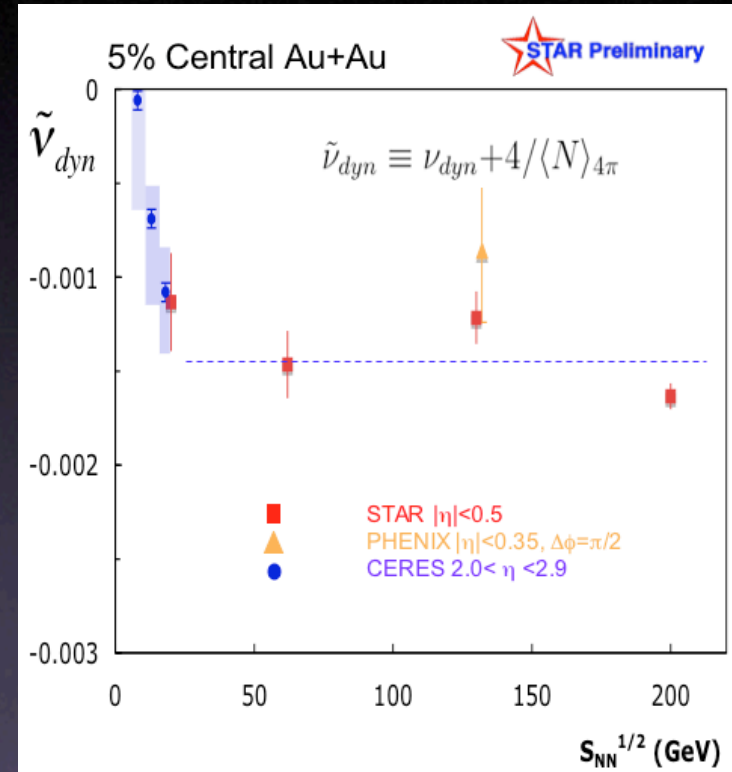
Event-by-event distribution of net charge ratio

Excitation Function: Charge Fluctuations

NA49, PRC 70 064903 (2004)



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



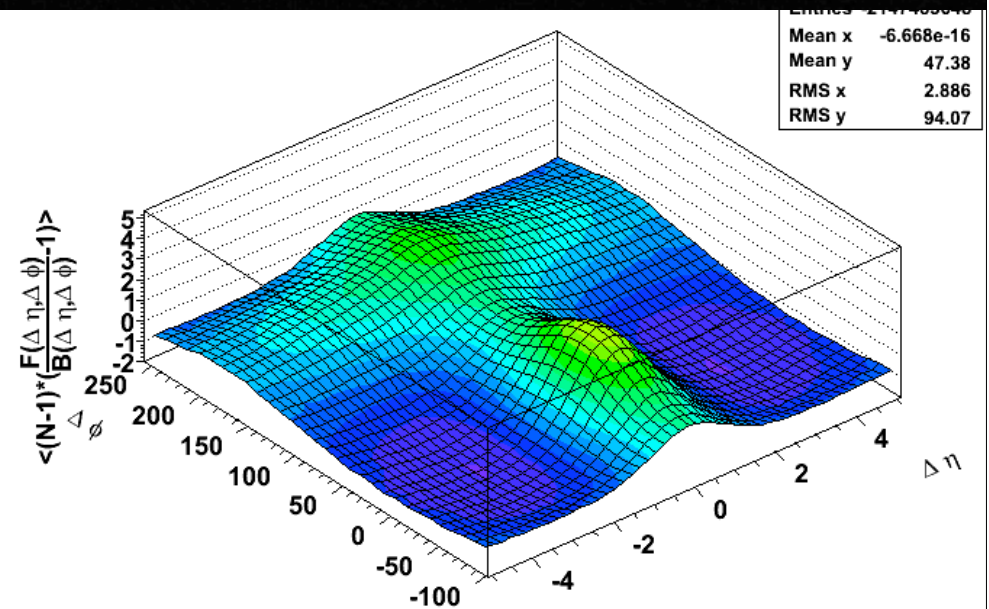
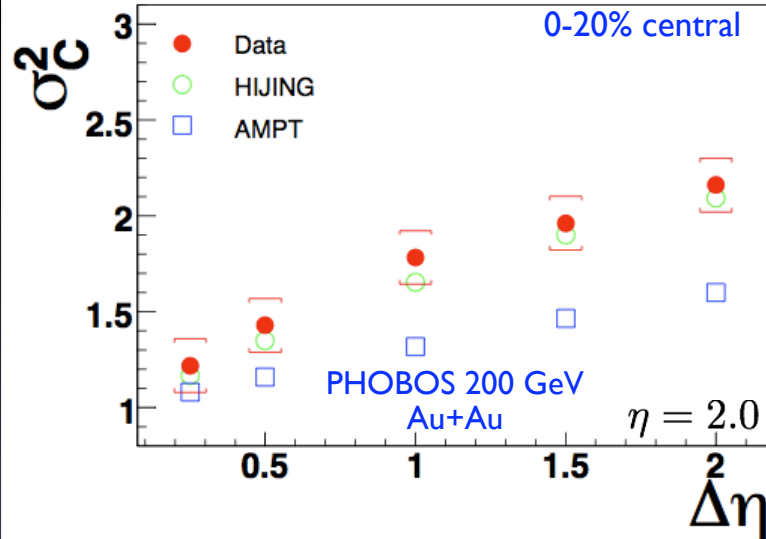
Little (no) \sqrt{s} dependence of charge fluctuations

QGP
↓

Hadron Production in Clusters

PHOBOS, PRC in press

c.f. C. Loizides, W. Li



effective cluster size $\approx 2-2.5$
for 200 GeV Au+Au

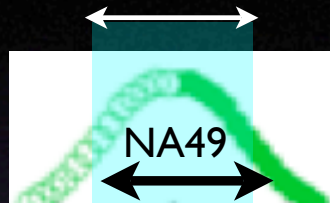
“Cluster” in $\Delta\eta, \Delta\phi$ space via
2-particle correlations
(pythia p+p @200 GeV, $\eta < 3$)

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

4th Challenge: Rapidity Scales

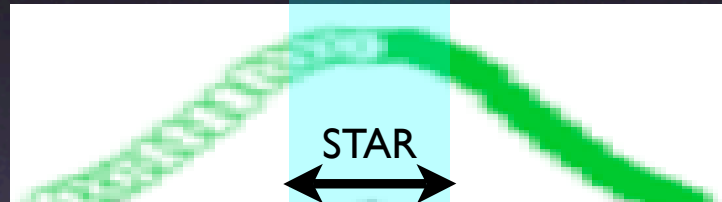
“Clustersize” $\Delta y \approx 2$

SPS



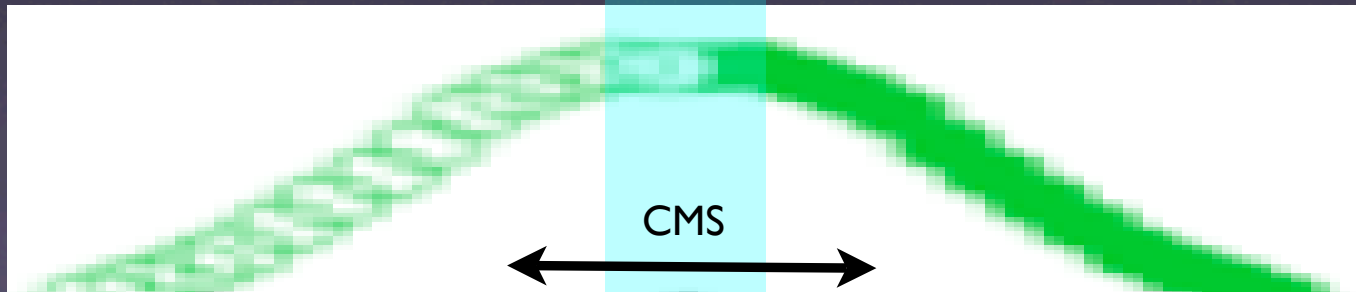
Acc. \approx Clustersize \approx Rapidity gap

RHIC



Acc. \approx Clustersize $<$ Rapidity gap

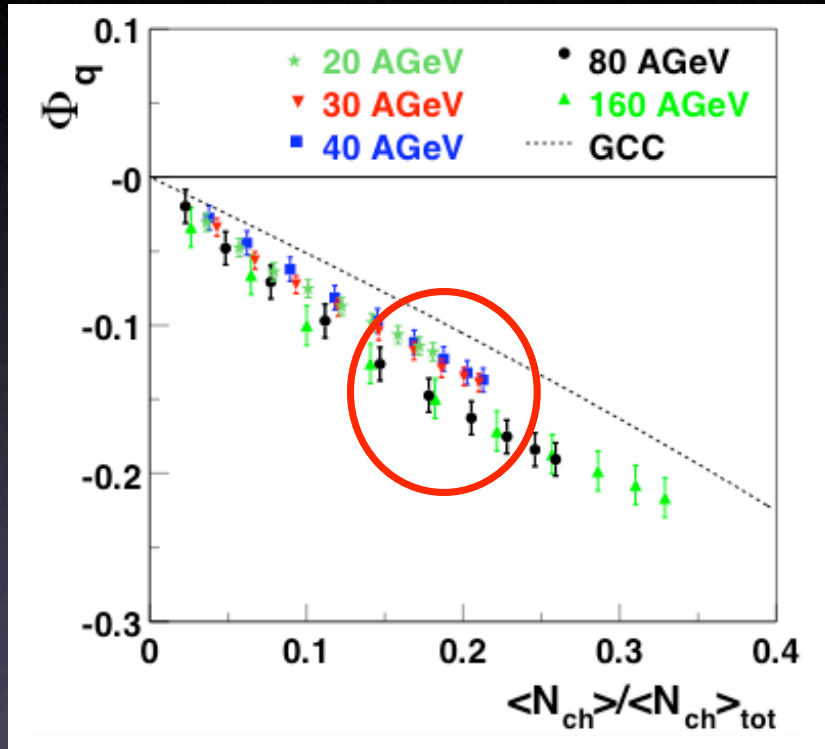
LHC



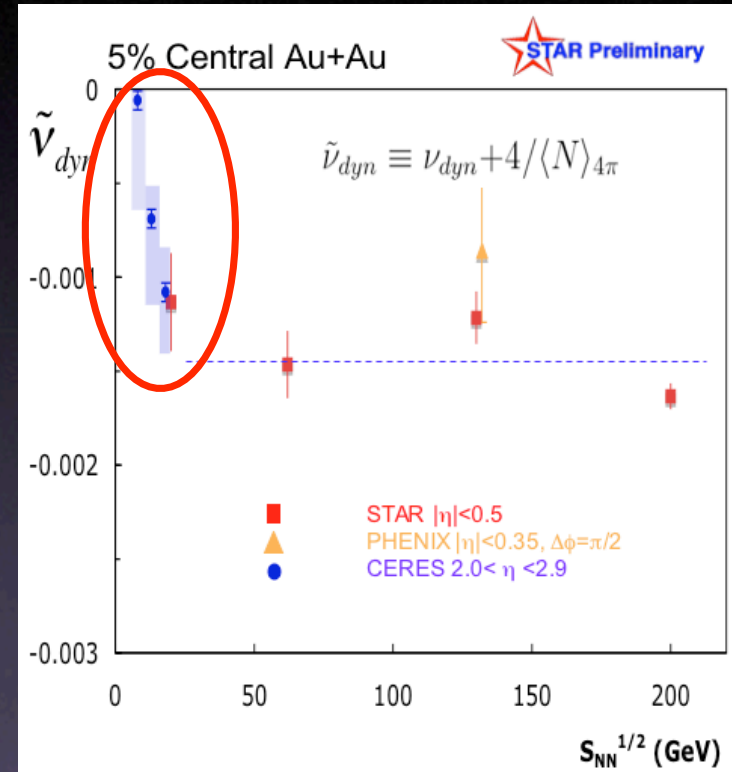
Acc. $>$ Clustersize \ll Rapidity gap

Excitation Function: Charge Fluctuations

NA49, PRC 70 064903 (2004)



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

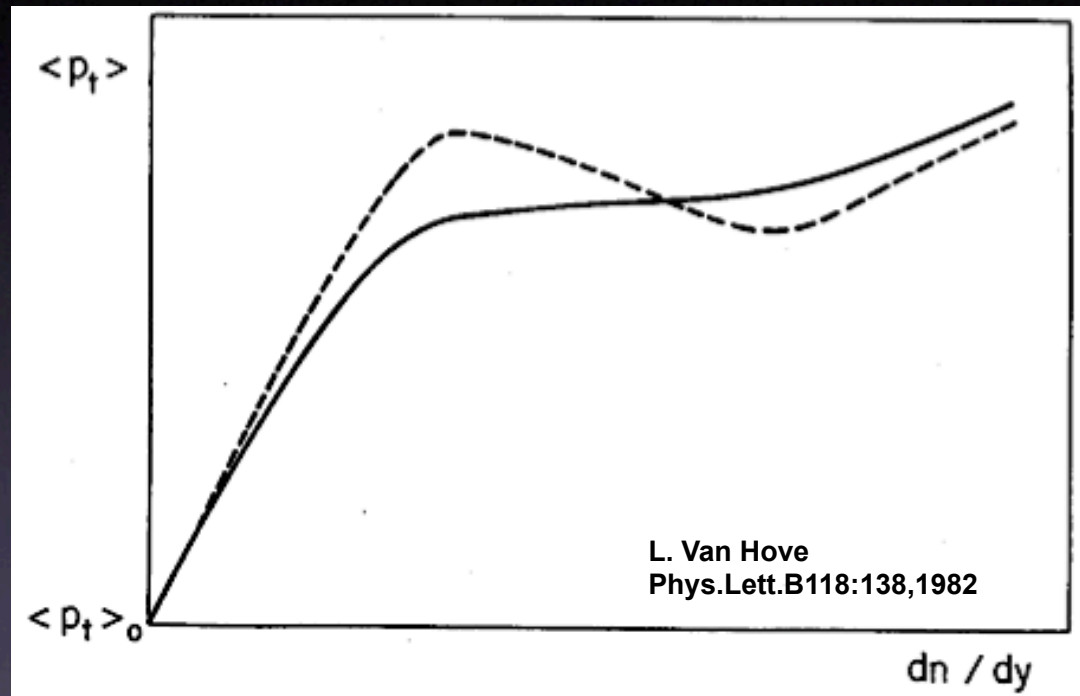


QGP
 ↓

Small \sqrt{s} dependence of charge fluctuations?

Excitation Function: Transverse Momentum

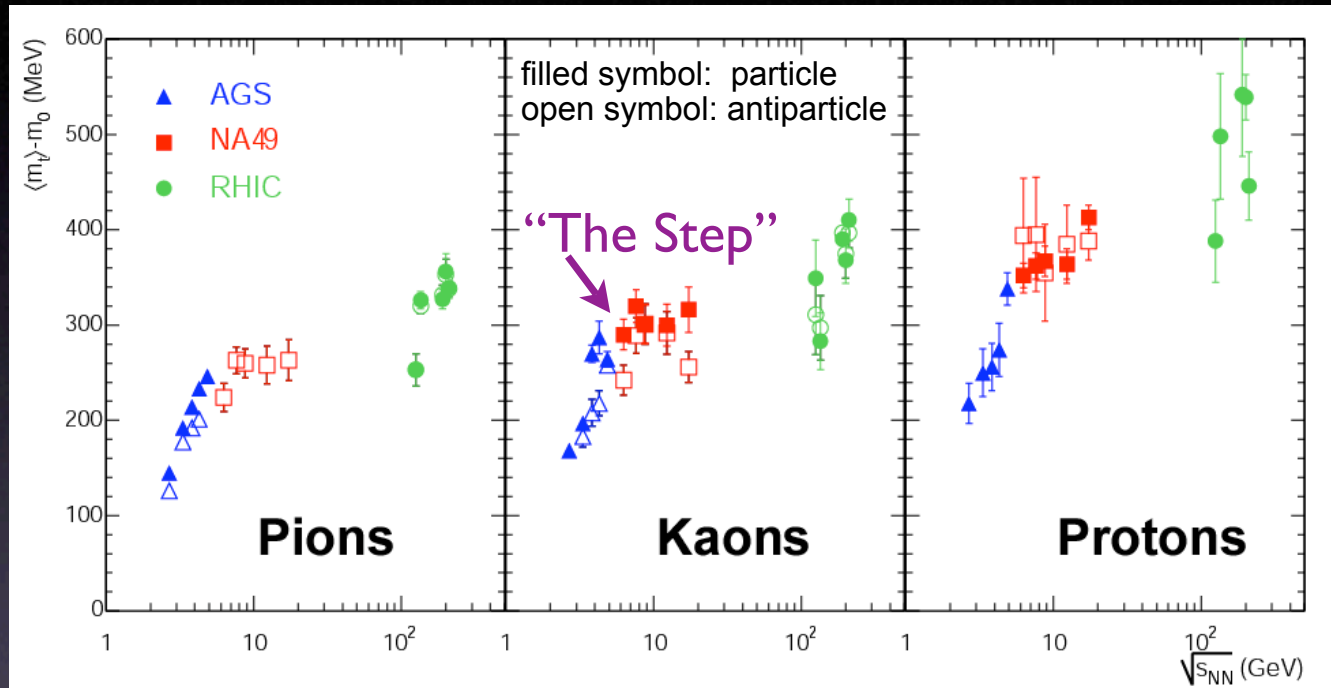
≈ “Temperature”



≈ “Entropy Density”

Excitation Function: Momentum Spectra

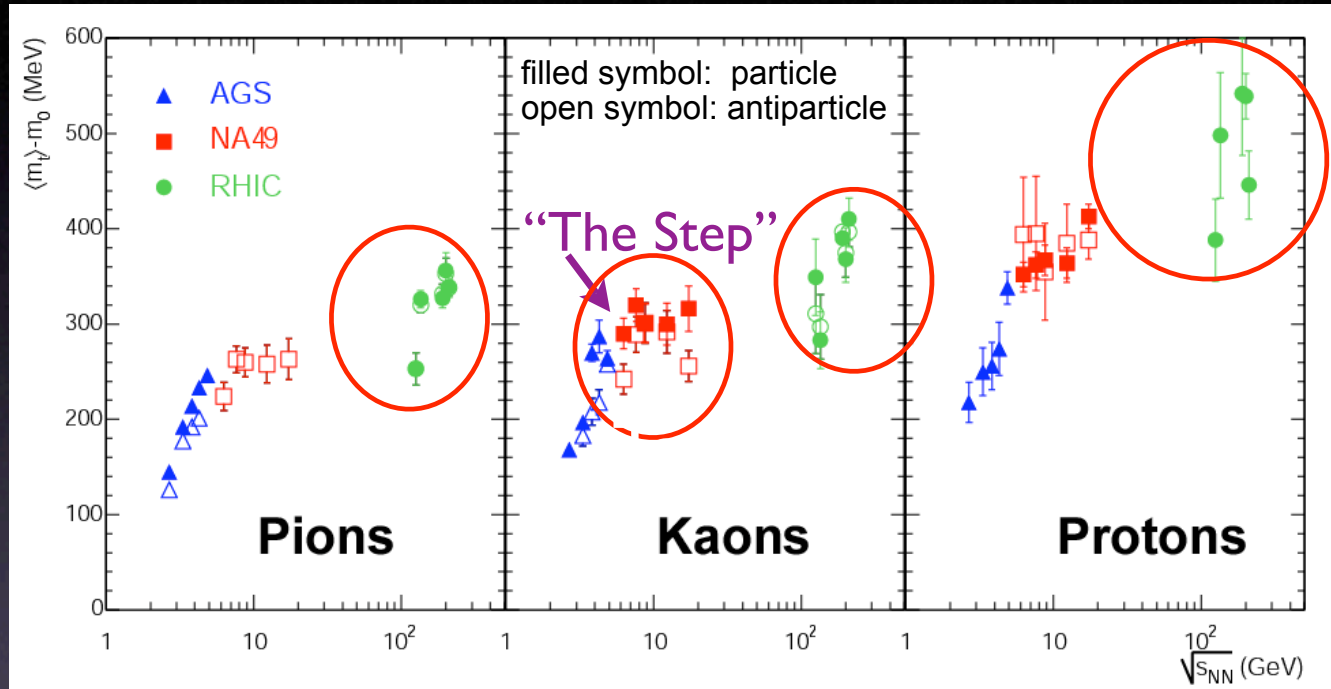
Compilation by NA49
Plot from Claudia Hoehne, QM'05



- Structure in energy dependence of $\langle m_T \rangle$
- Reminiscent of Van Hove's T vs σ prediction
- Surprisingly difficult measurement
 - Decay corrections, PID acceptance

5th Challenge: Experimental Systematics

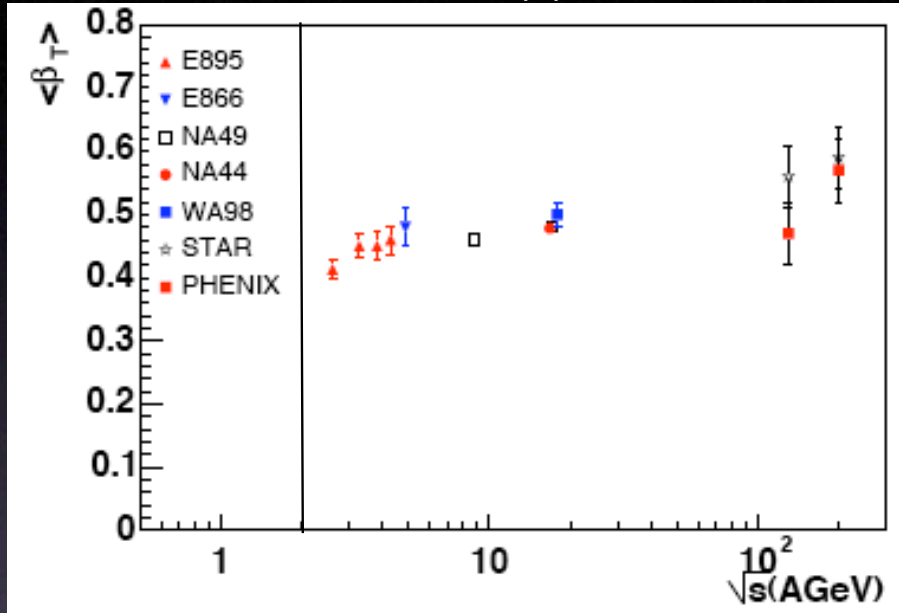
Compilation by NA49
Plot from Claudia Hoehne, QM'05



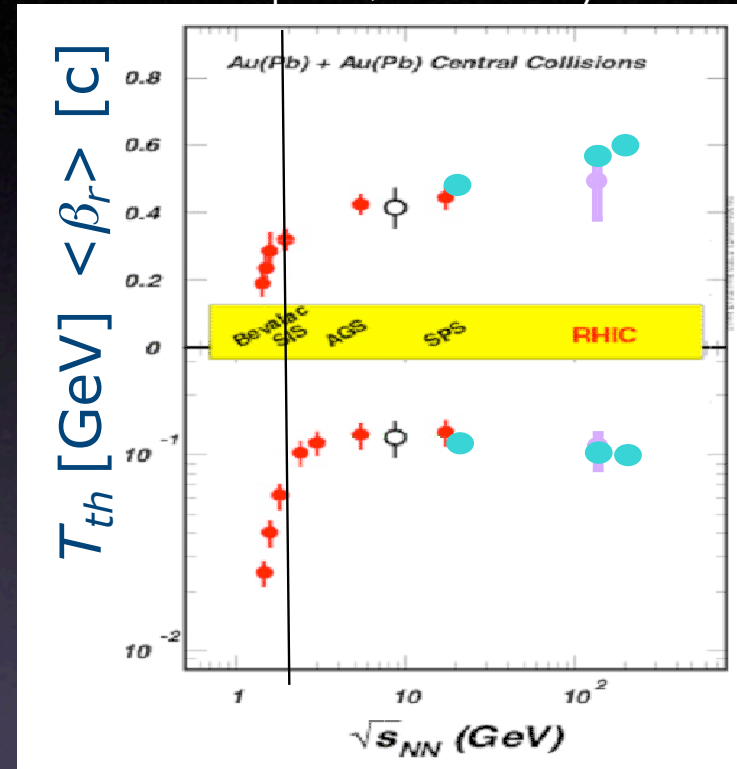
Experimental systematic errors underestimated
Structure at AGS/SPS boundary

Excitation Function: $\langle \beta_T \rangle$

PHENIX Whitepaper



STAR compilation, Plot from T. Nayak



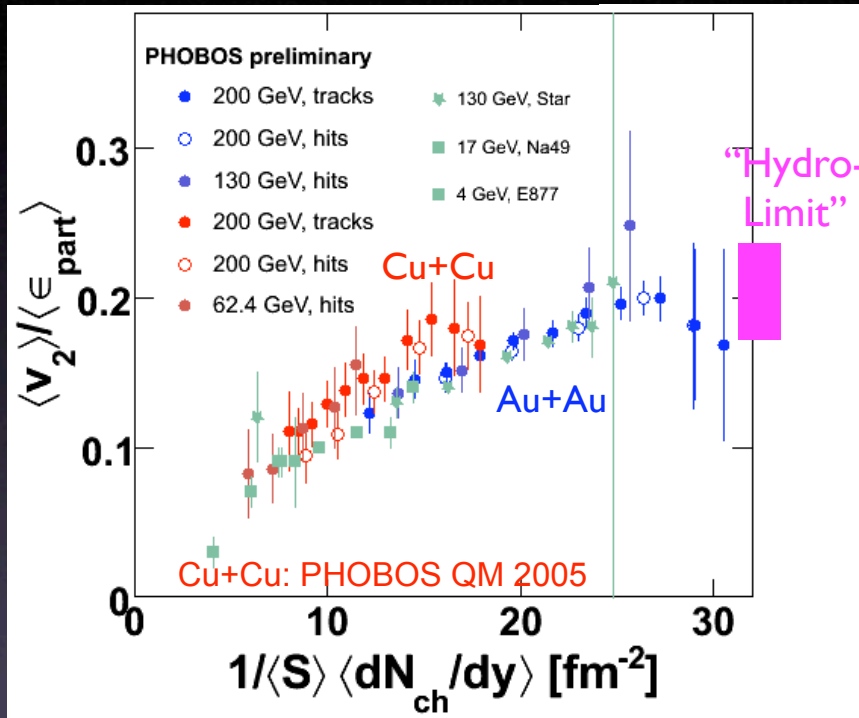
$\langle m_T \rangle$ decomposed in T_{th} and $\langle \beta_T \rangle$ at freeze-out

Connection to initial temperature?

Excitation Function: Elliptic flow

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

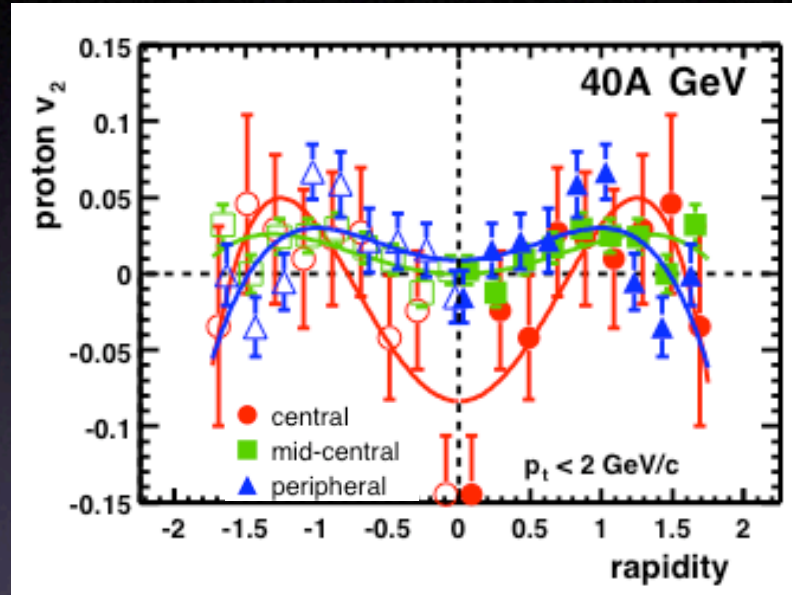
c.f. R. Snellings, R. Lacey



“Participant Eccentricity”
 provides universal scaling

Approach to equilibrium or
 sampling different regions of EOS?

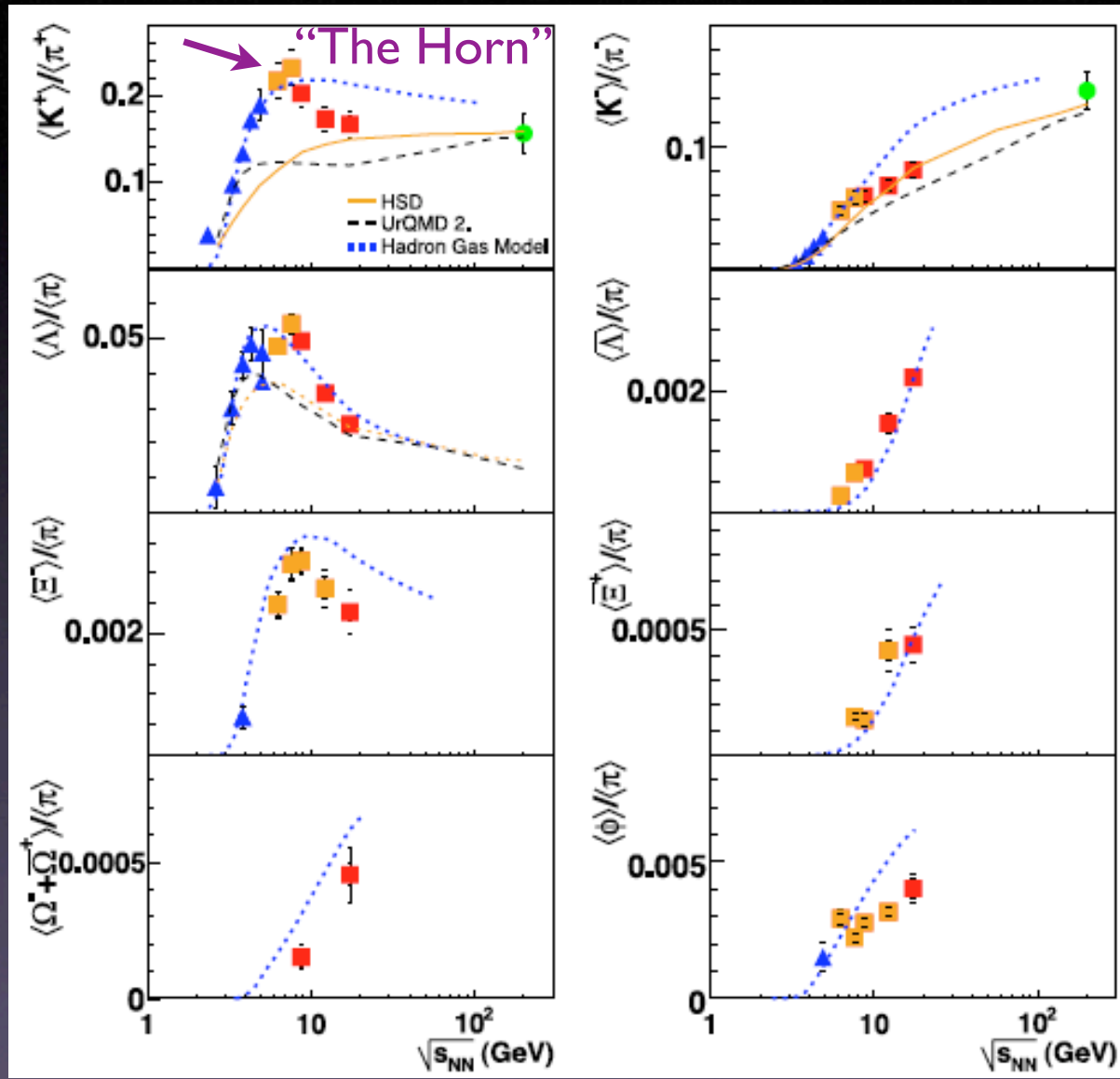
NA49 PRC C68 034903 (2003)



Collapse of proton flow at 40A GeV?

c.f. H. Stoecker

Excitation Function: Strangeness production vs \sqrt{s}

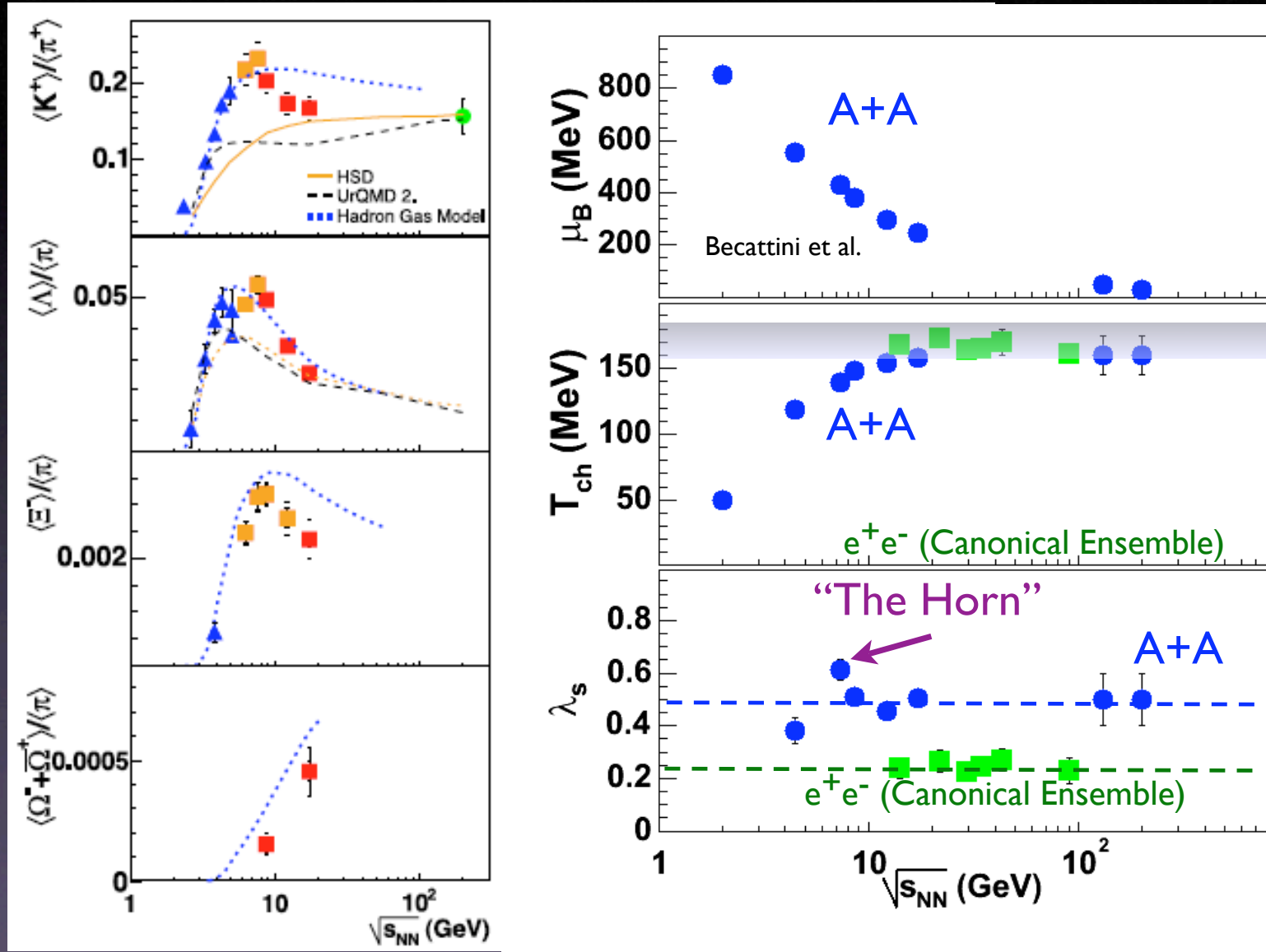


NA49 Phys.Rev.C66:054902,2002

Plot from M. Mitrowski, SQM'06

Gunther Roland Florence July 2006

Strangeness production vs \sqrt{s}

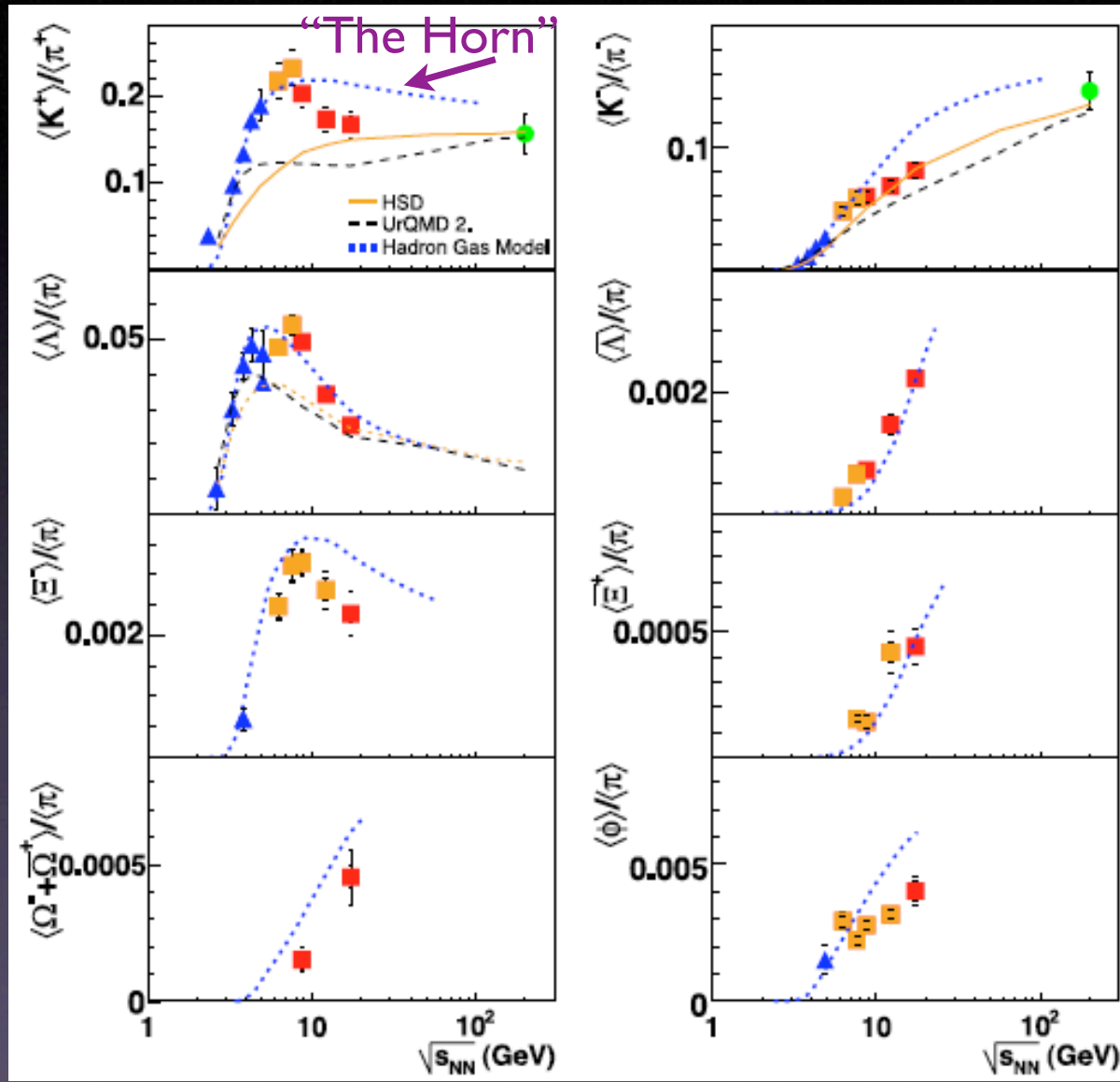


NA49 Phys.Rev.C66:054902,2002

Plot from M. Mitrowski, SQM'06

Gunther Roland Florence July 2006

Excitation Function: Strangeness production vs \sqrt{s}



Challenges:

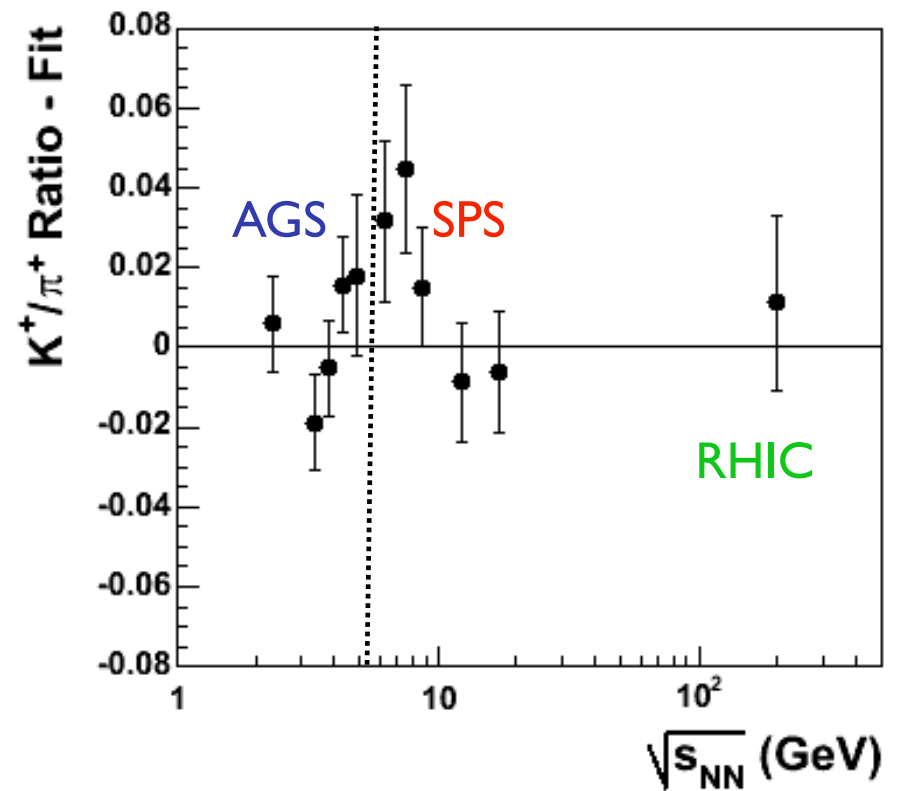
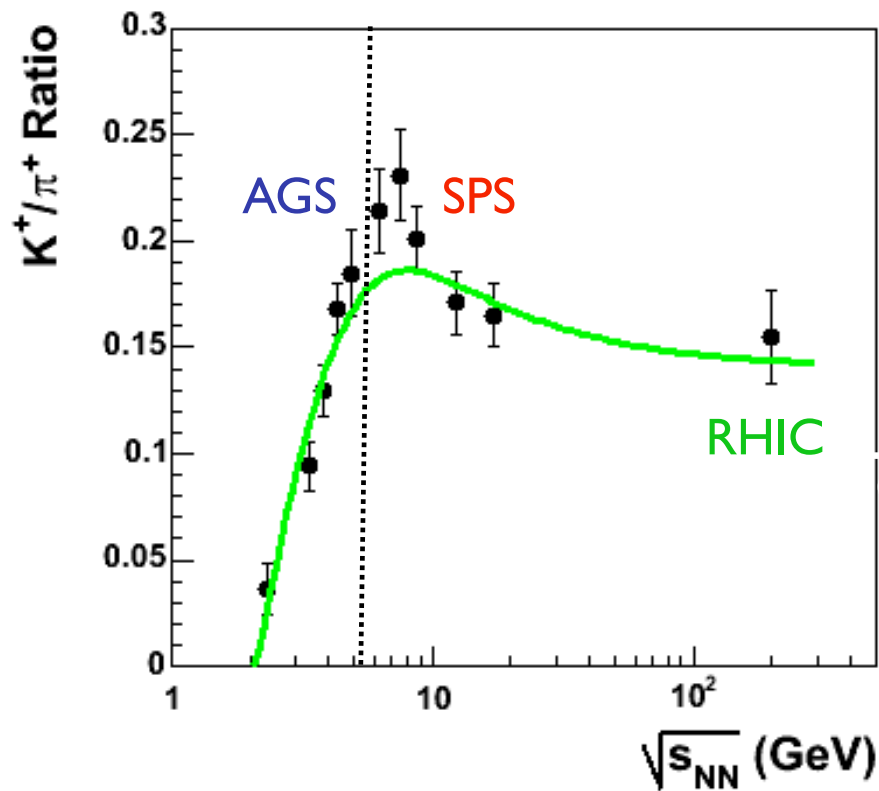
Net-Baryon/meson balance?

Rapidity scales (mid-y vs 4π)?

Sharp structures in finite systems?

Experimental confirmation?

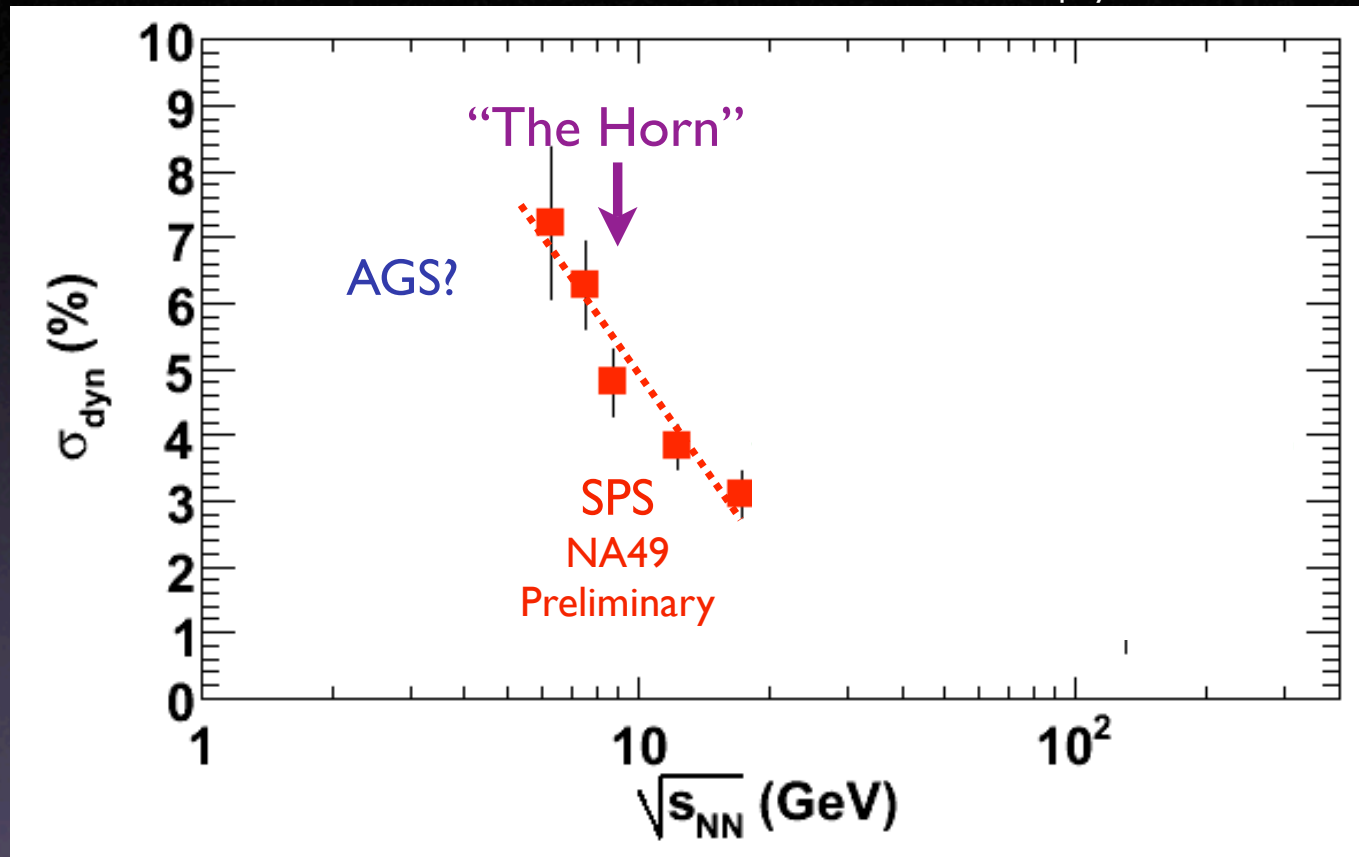
Strangeness excitation function



Excitation Function: K/ π Fluctuations

NA49, Christof Roland, QM'04

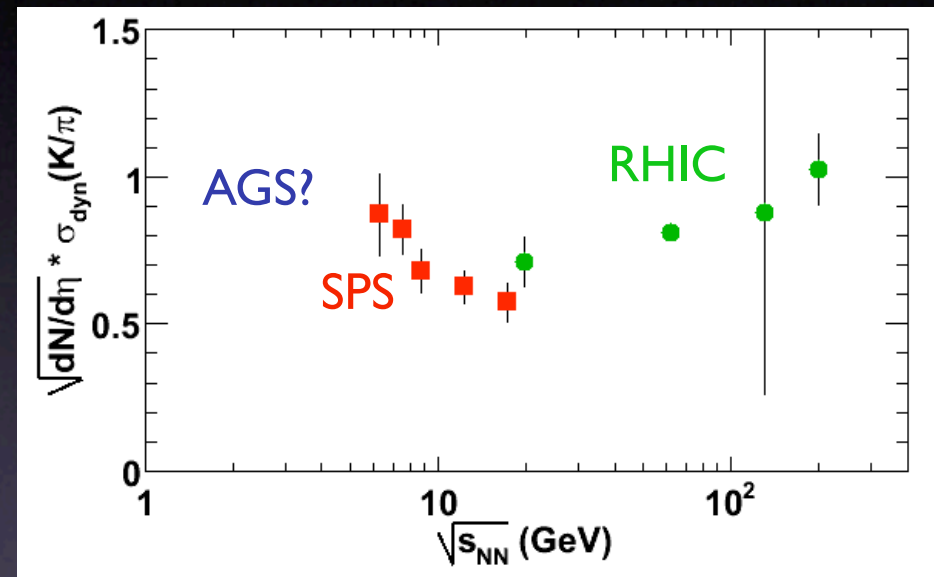
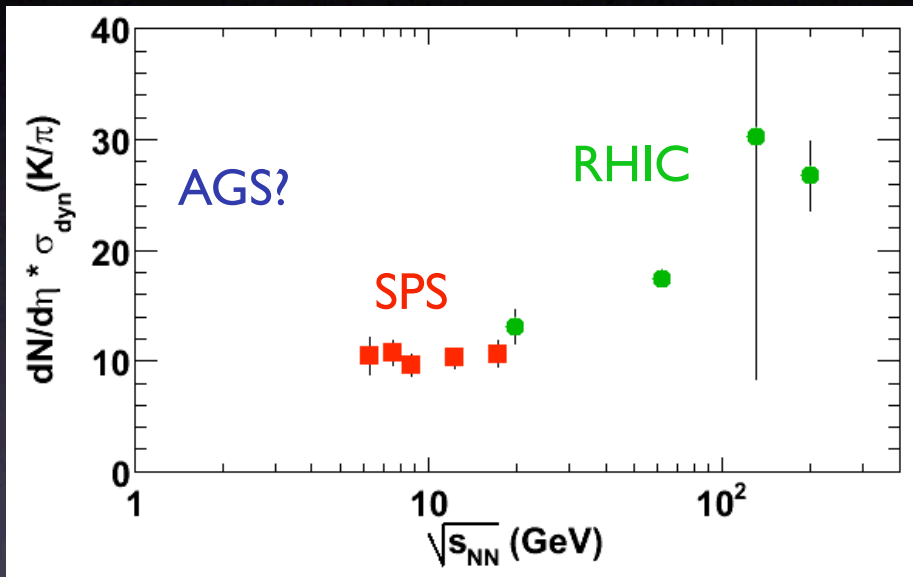
STAR, Supriya Das, SQM'06



Connection to initial temperature?

Excitation Function: K/ π Fluctuations

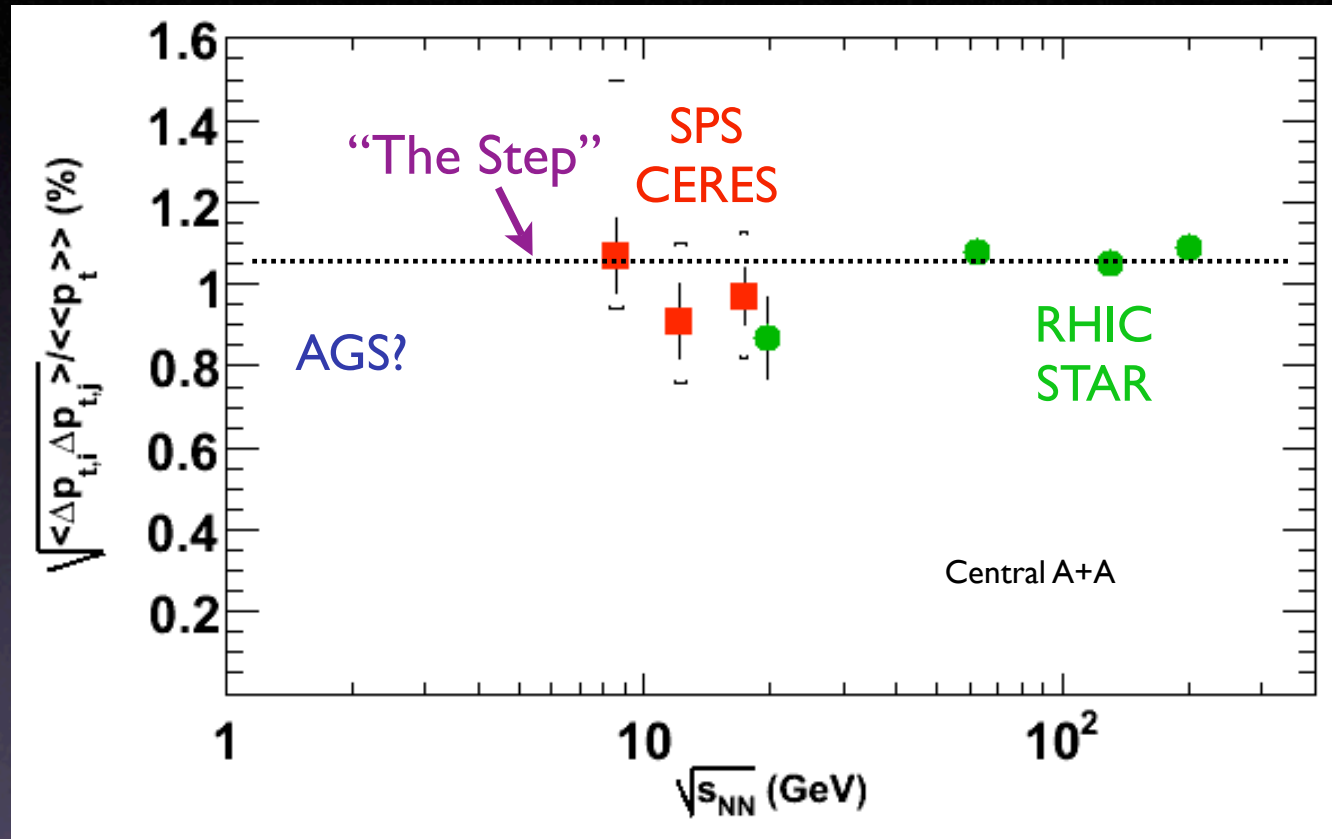
Normalized by dN/dy or $(dN/dy)^{1/2}$



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

Excitation Function: Momentum Fluctuations

Compilation by STAR
STAR PRC 72 044902 (2005)

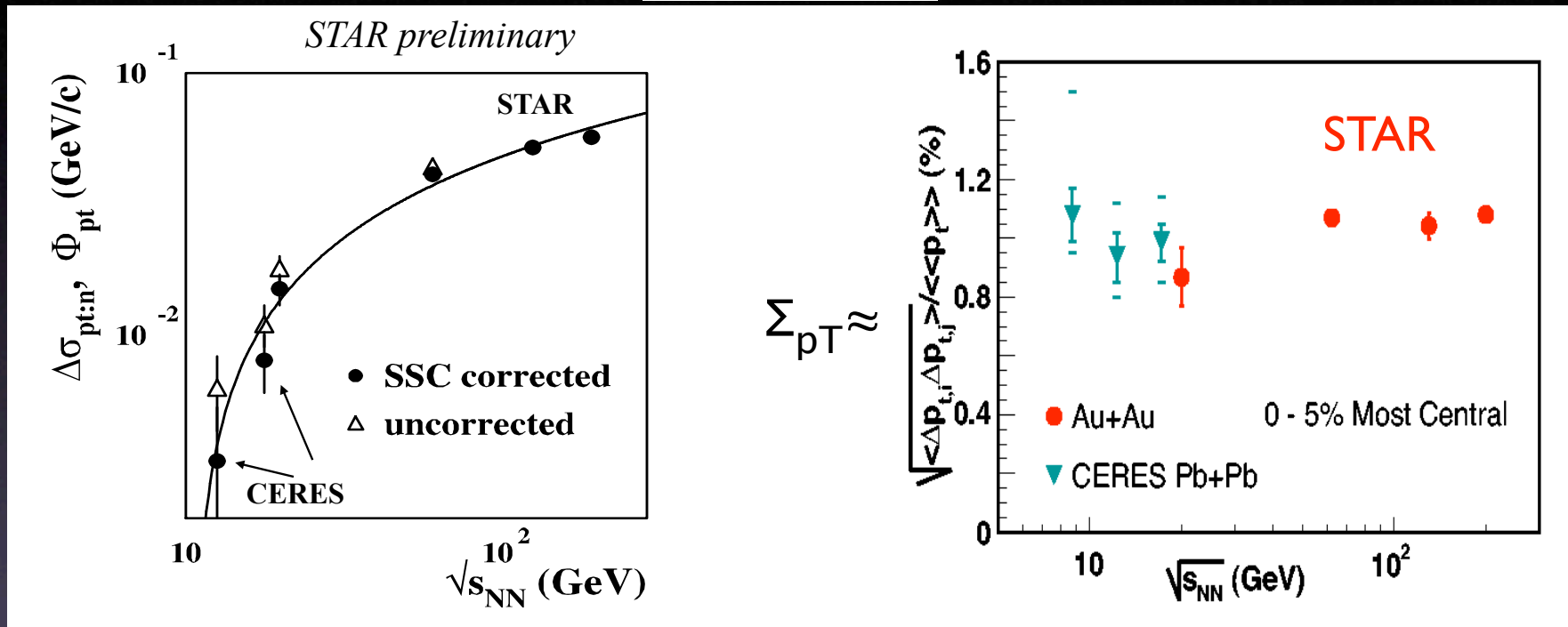


Monotonic energy dependence over measured range
No results near “kink” region

Excitation Function: Momentum Fluctuations

$$\Sigma_{pT} \simeq \sqrt{\frac{2\Phi_{pT} \sqrt{\sigma_{pT}^2}}{N \bar{p}_T^2}}$$

Scaling: Connection between $\langle p_T \rangle$, N , fluctuations?



Connection to 2-particle correlations

Interpretation connected to choice of variables

Summary

- Structure in hadronic observables vs \sqrt{s} ?
 - Yes - in AGS/SPS Energy range
 - K/π
 - K/π fluctuations
 - $\langle m_T \rangle$
 - N_{ch}
 - Charge Fluctuations

Summary cntd.

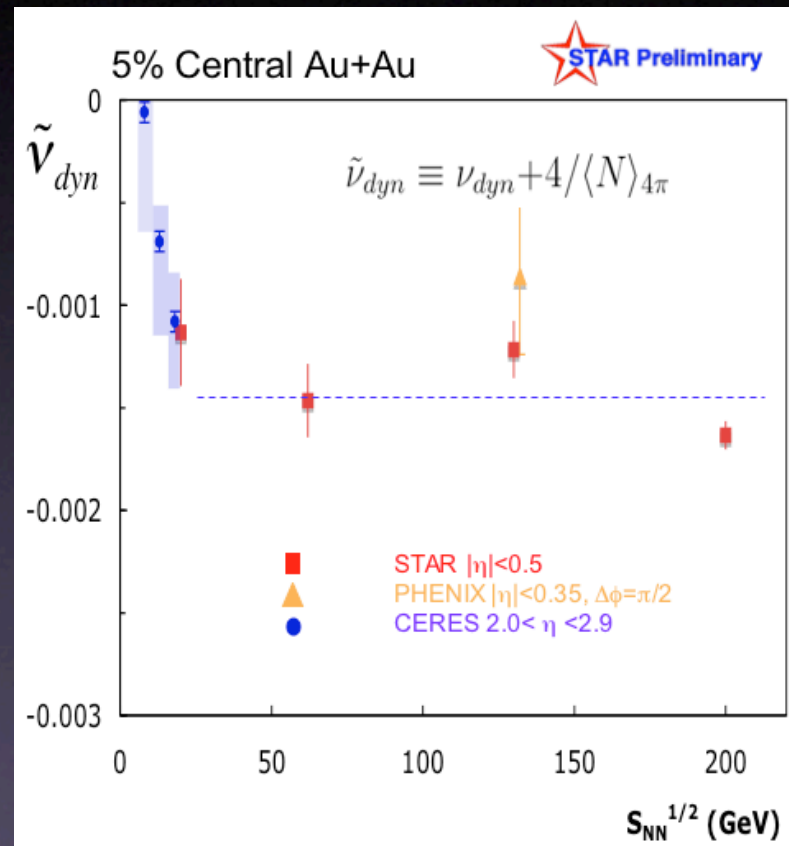
- Challenges
 - Moving across phase diagram
 - Rapidly changing baryon/meson ratio
 - Location of structure vs context
 - Fixed vs varying rapidity scales
 - Cluster width, rapidity width vs mass
 - Finite size system, fluctuations: Sharp structures possible?
 - Experimental verification → **FAIR, RHIC**

c.f. P. Senger, H.G. Ritter,
P. Sorensen, J. Mitchell, M.G.

Excitation Function: Charge Fluctuations

NA49, PRC 70 064903 (2004)

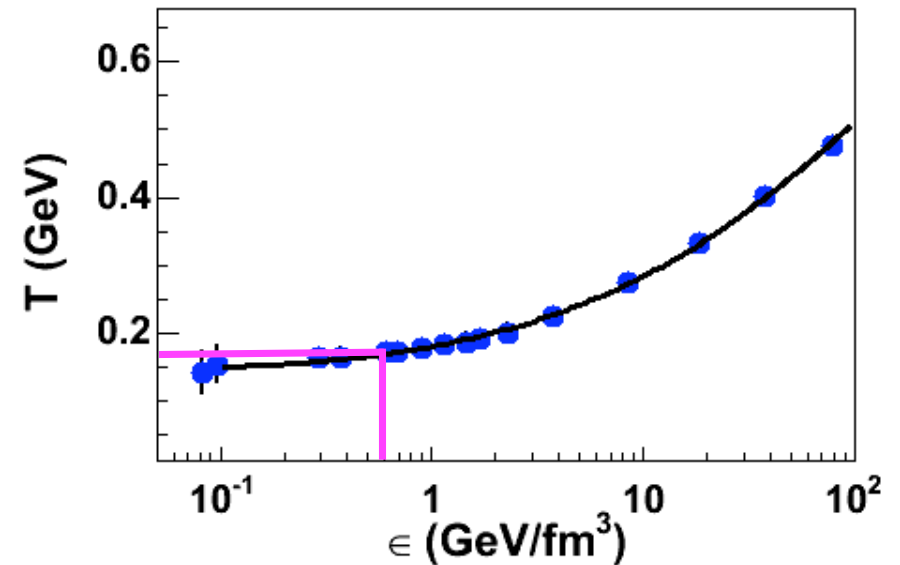
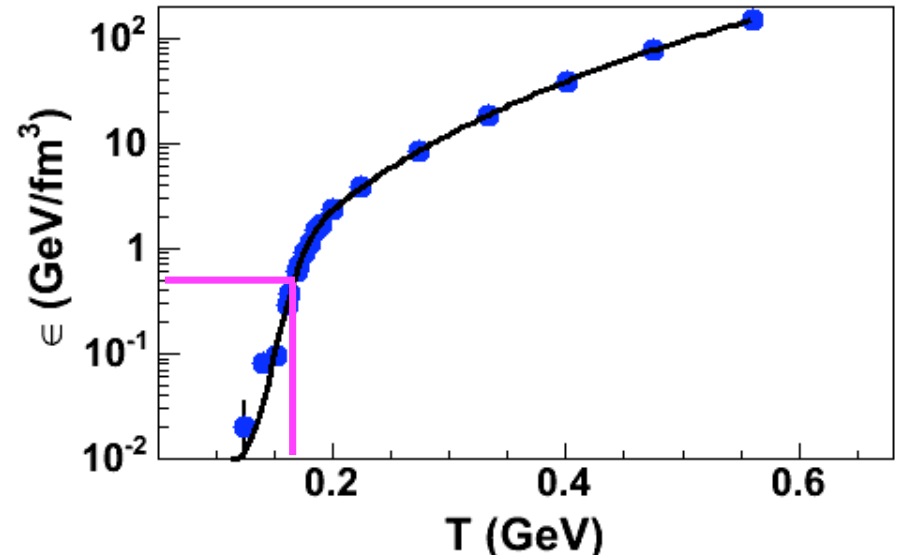
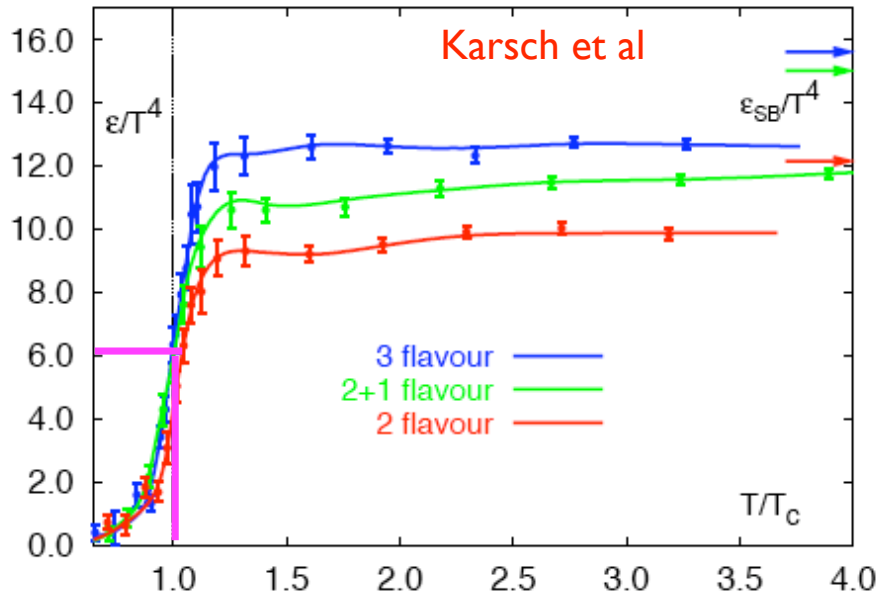
Plot from Claude Pruneau
RHIC Users meeting workshop '04
PHENIX: PRL 89 082301 (2002)



QGP
↓

Little (no) \sqrt{s} dependence of charge fluctuations

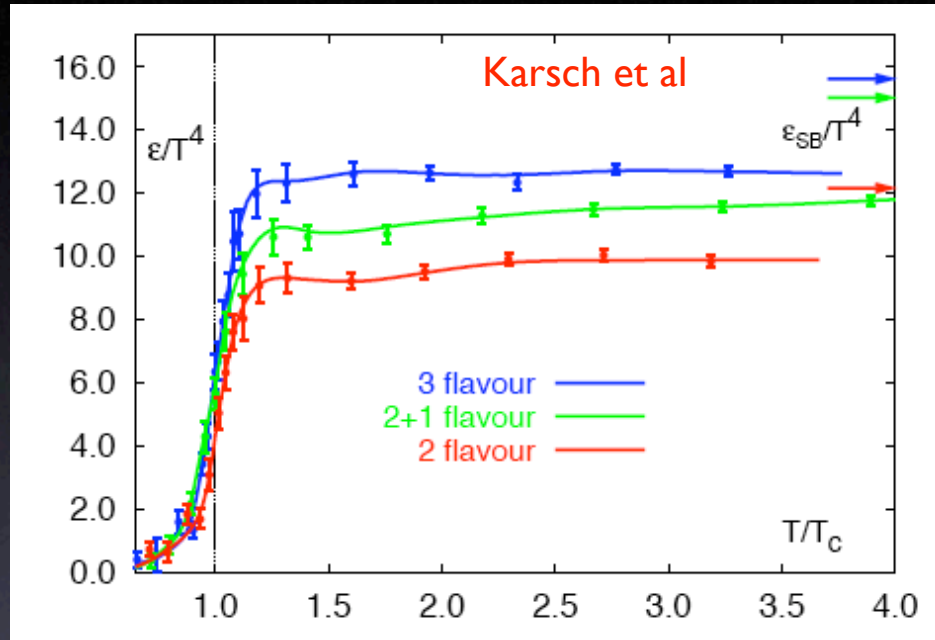
Temperature vs Energy Density



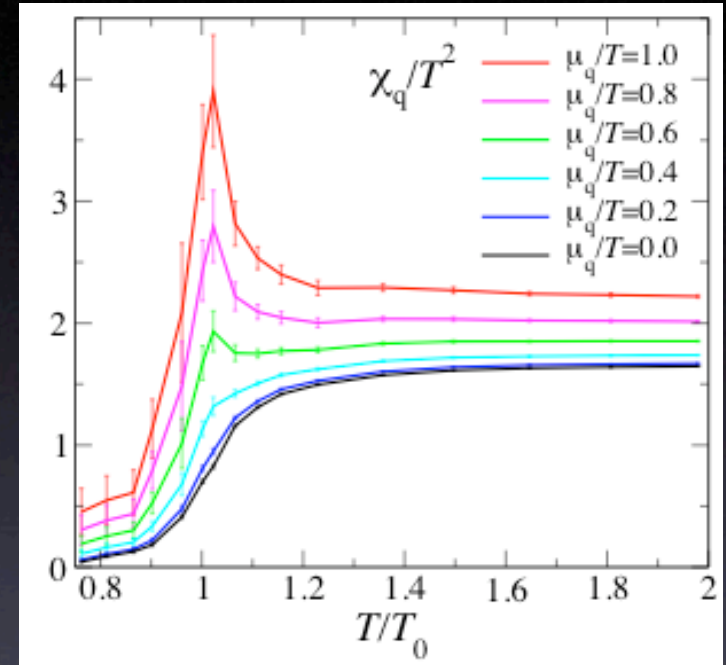
Starting from ϵ (experiment),
expectations not that dramatic

Onset of Deconfinement

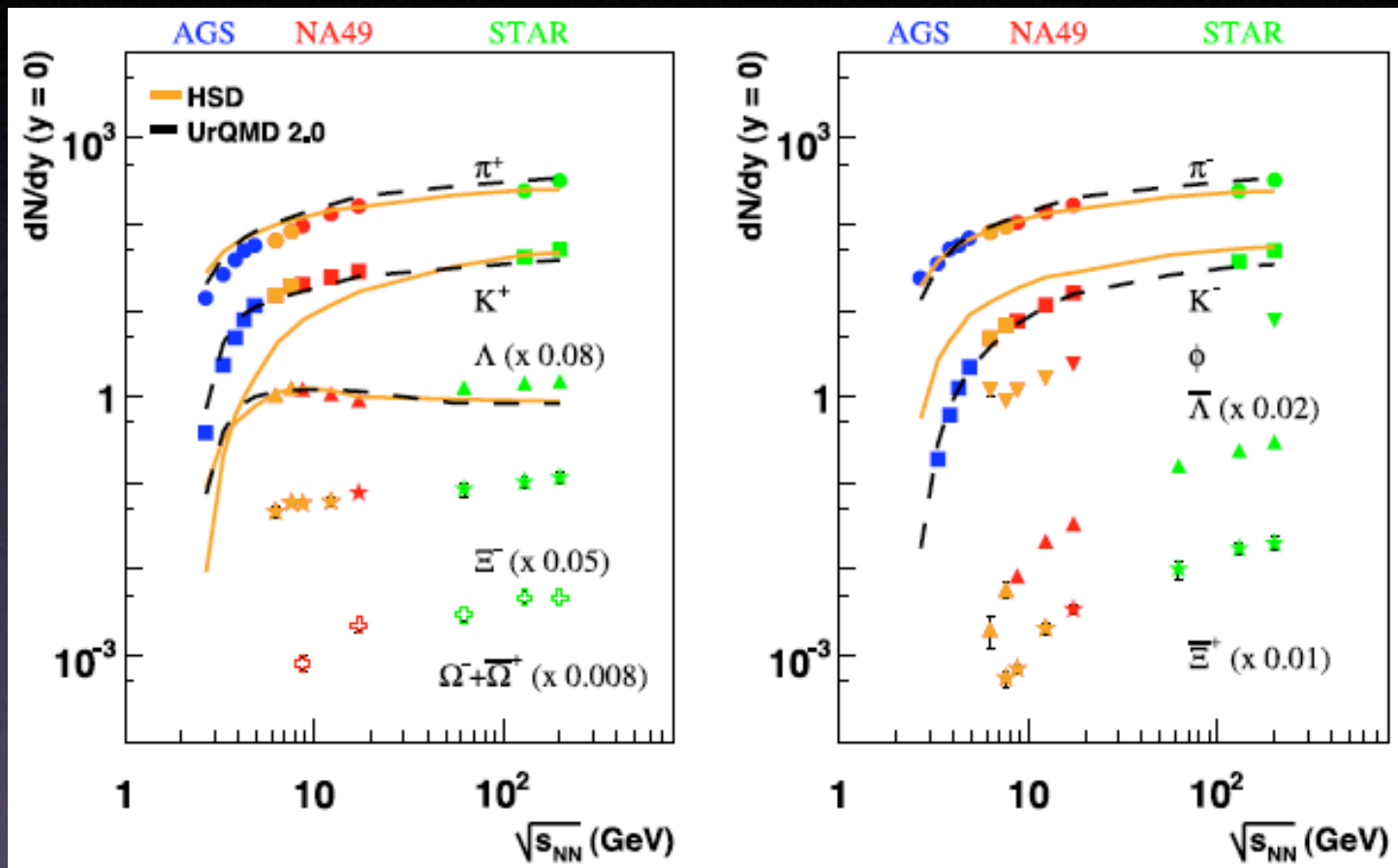
vary T at $\mu_B = 0$



vary T and μ_B (\rightarrow CP)

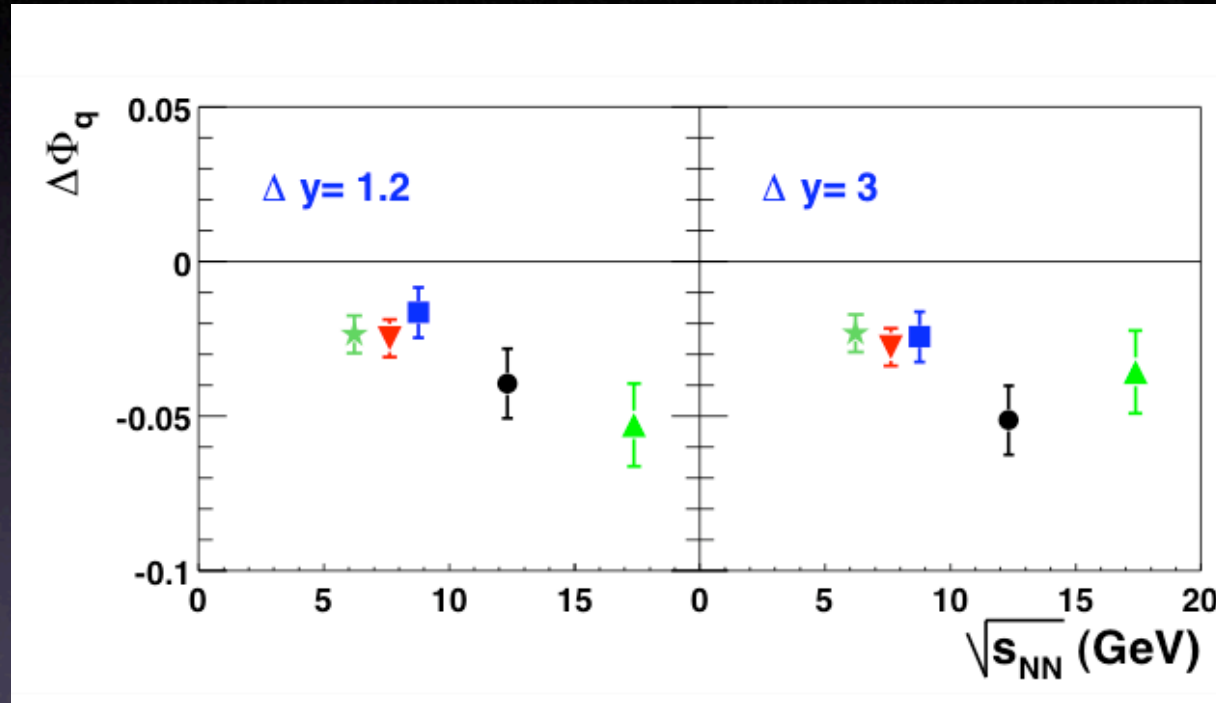


Can we trace this behavior in experiment?



Energy-Dependence at lower energies

NA49, PRC 70 064903 (2004)



Some energy dependence at low energies?

