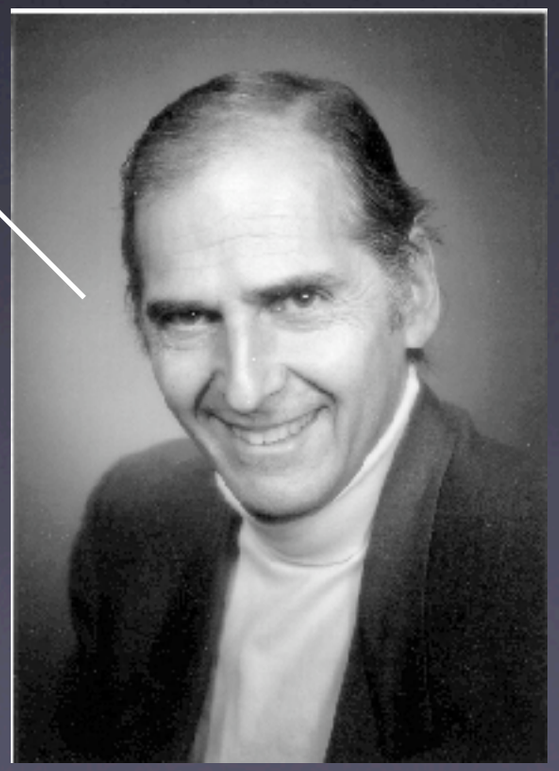
The Short Version

"I could do this talk in 5 minutes.
If we knew where the critical point is,
we could make the measurement
in a day..."



PHENIX Capabilities for the Low-Energy RHIC Run

Peter Steinberg
Chemistry Department, BNL

Workshop on the Critical Point @ RHIC, 3/9/2006

What am I doing here?

Formation of dense partonic matter in relativistic nucleus-nucleus collisions at RHIC: Experimental evaluation by the PHENIX collaboration

arXiv:nucl-ex/0410003 v3 25 Mar 2005

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and all of PHENIX for the White Paper

Phase Diagram

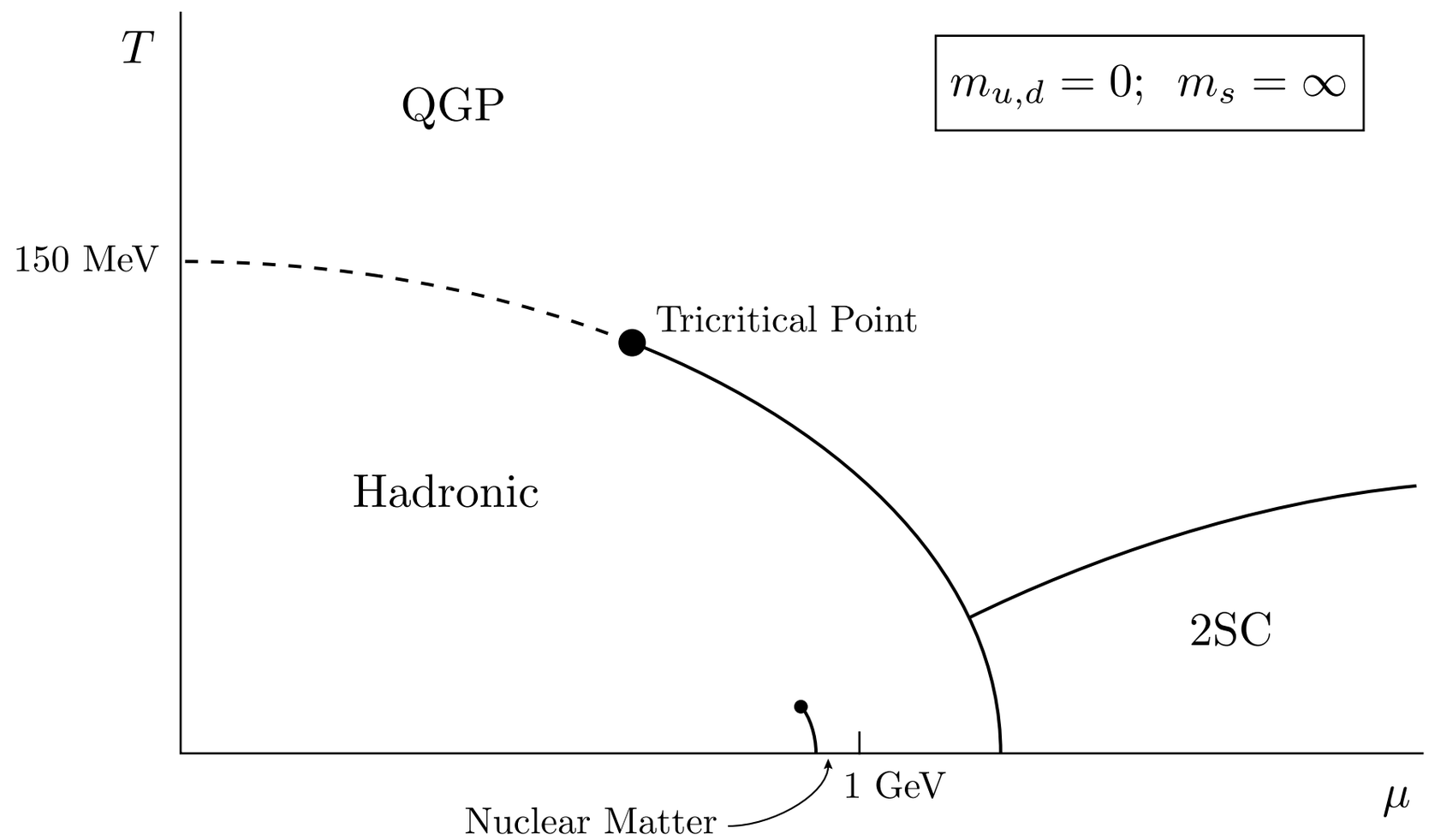


Fig. 2. Theoretical phase diagram of nuclear matter for two massless quarks as a function of temperature T and baryon chemical potential μ [12].

Why we are here today...

Baryon Density & Dynamics

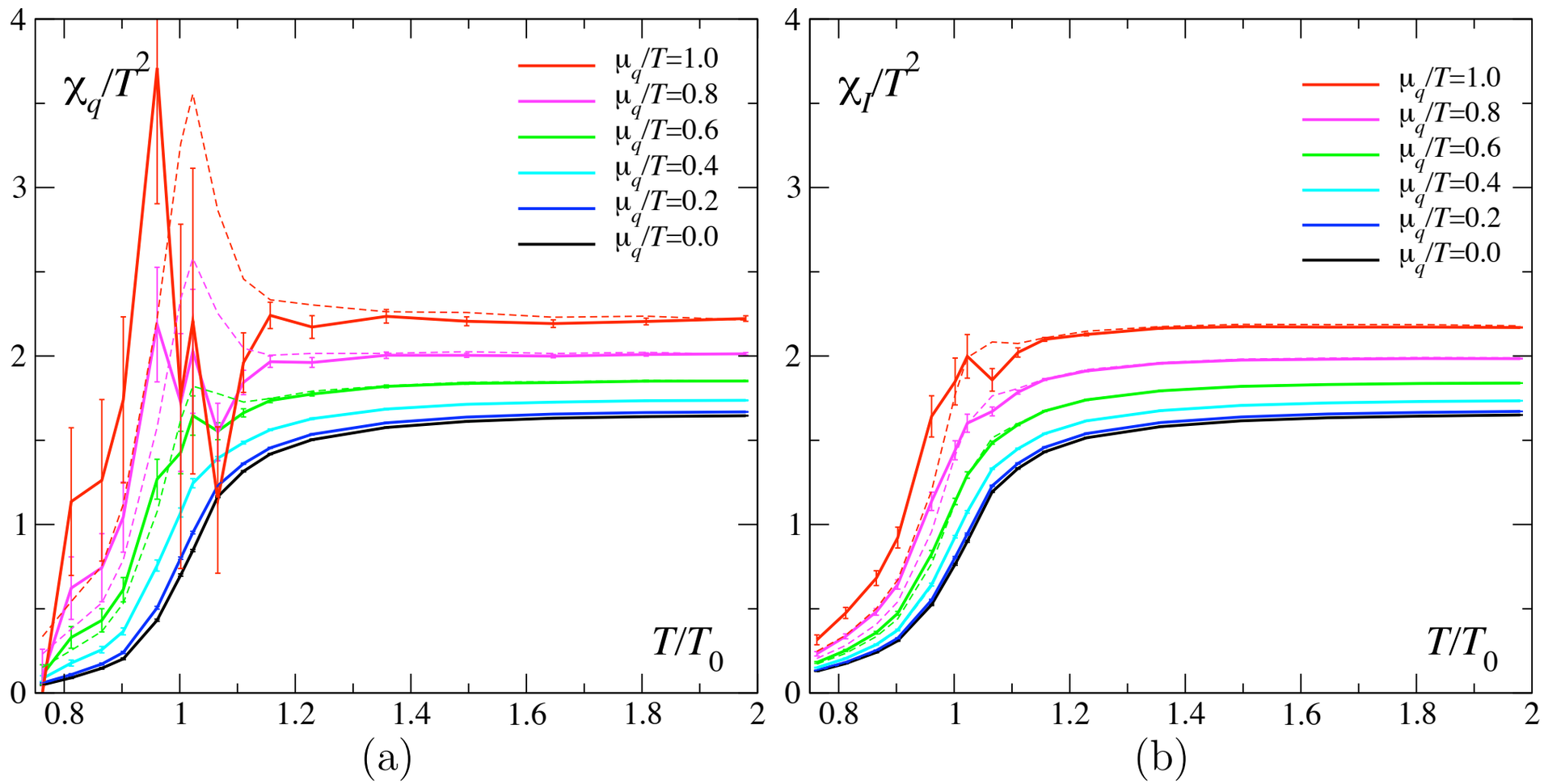
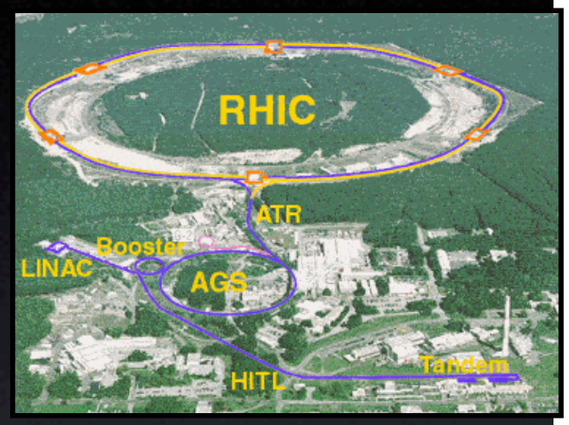
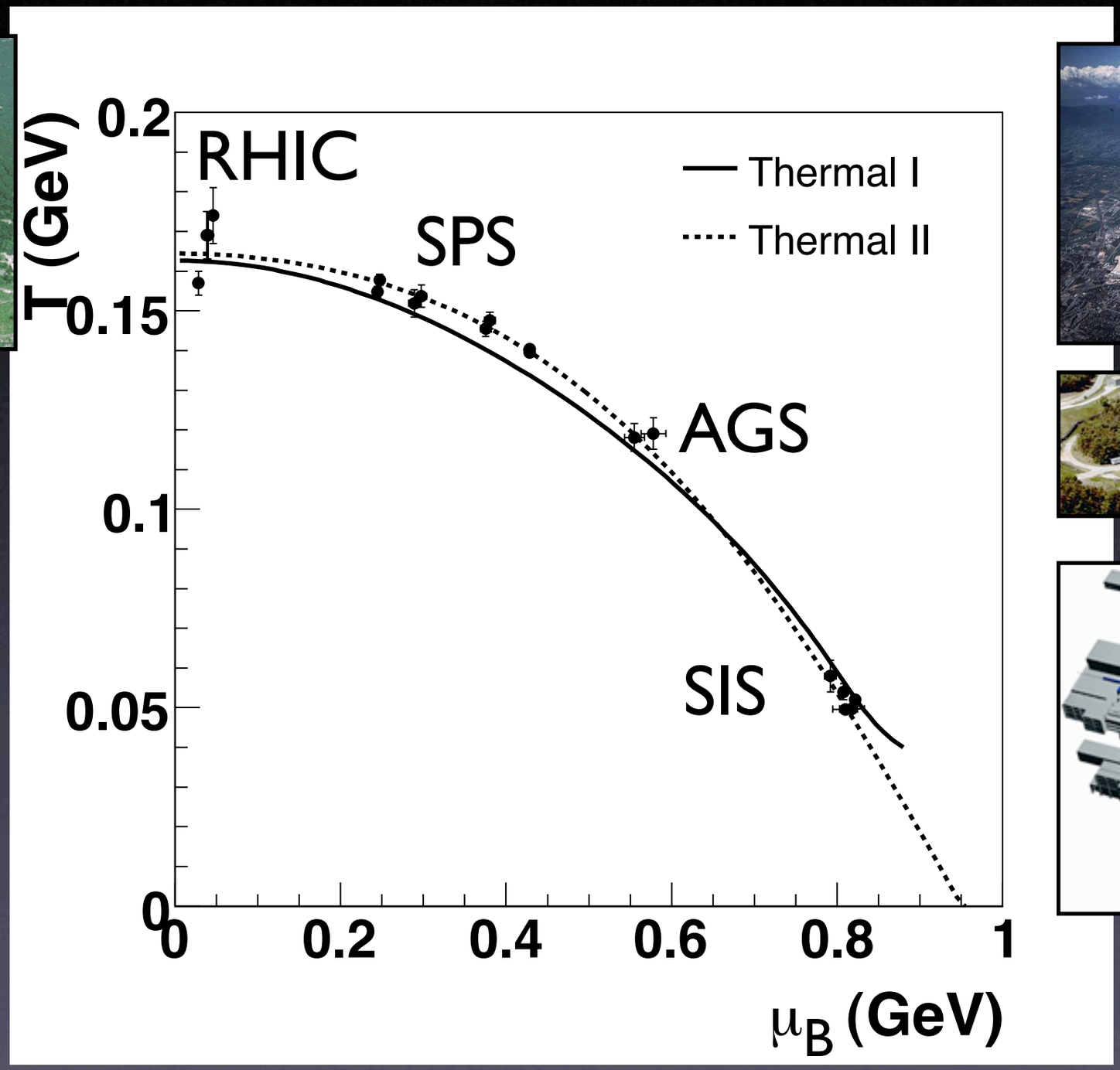


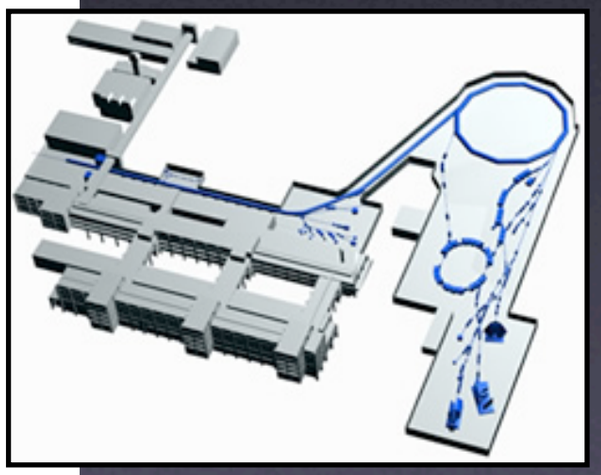
Figure 3.3: The quark number susceptibility χ_q/T^2 (left) and isovector susceptibility χ_I/T^2 (right) as functions of T/T_0 for various μ_q/T ranging from $\mu_q/T = 0$ (lowest curve) rising in steps of 0.2 to $\mu_q/T = 1$, calculated from a Taylor series in 6th order. Also shown as dashed lines are results from a 4th order expansion in μ_q/T.

Ejiri et al (2003)

“Phase Diagram”



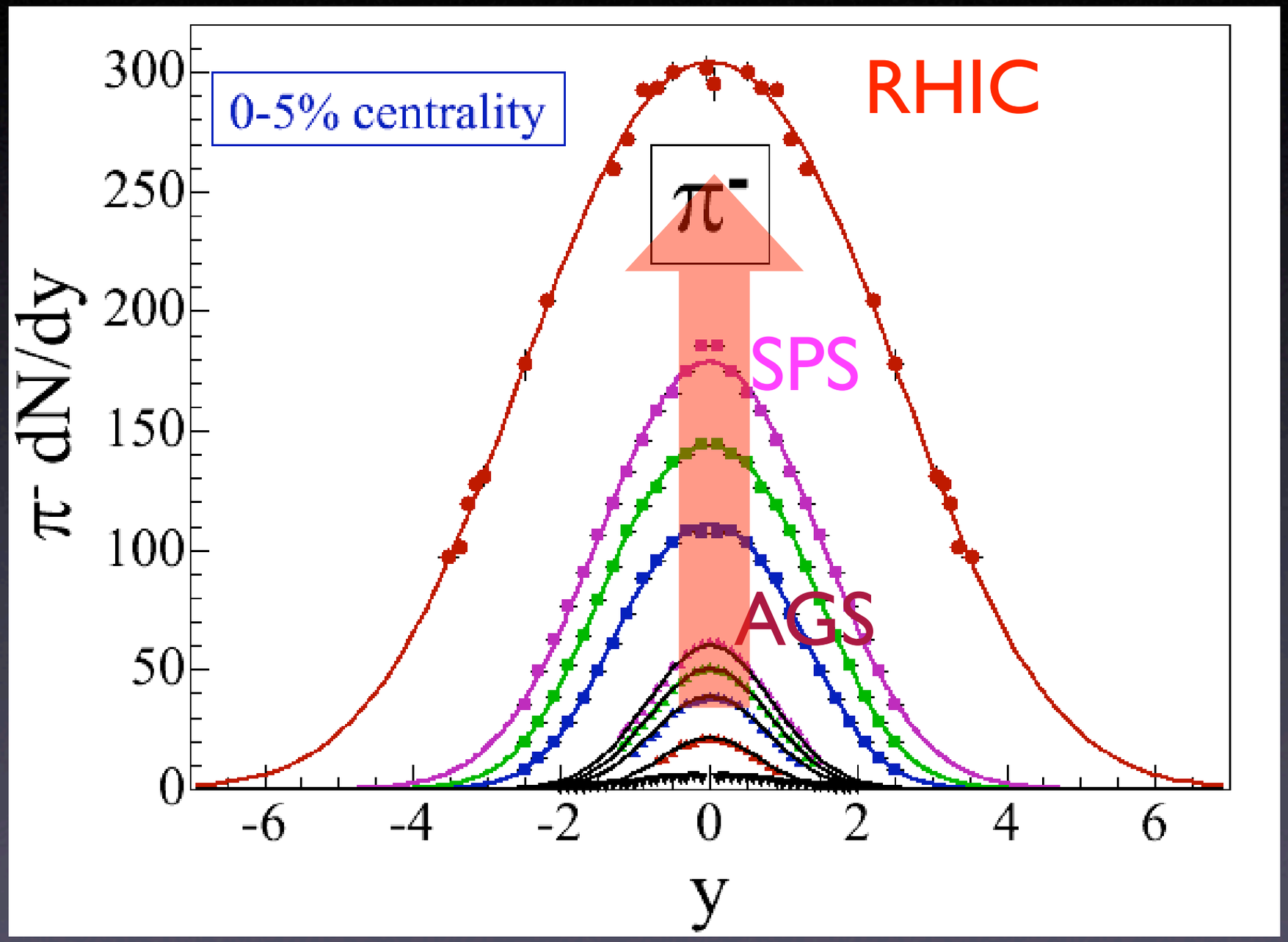




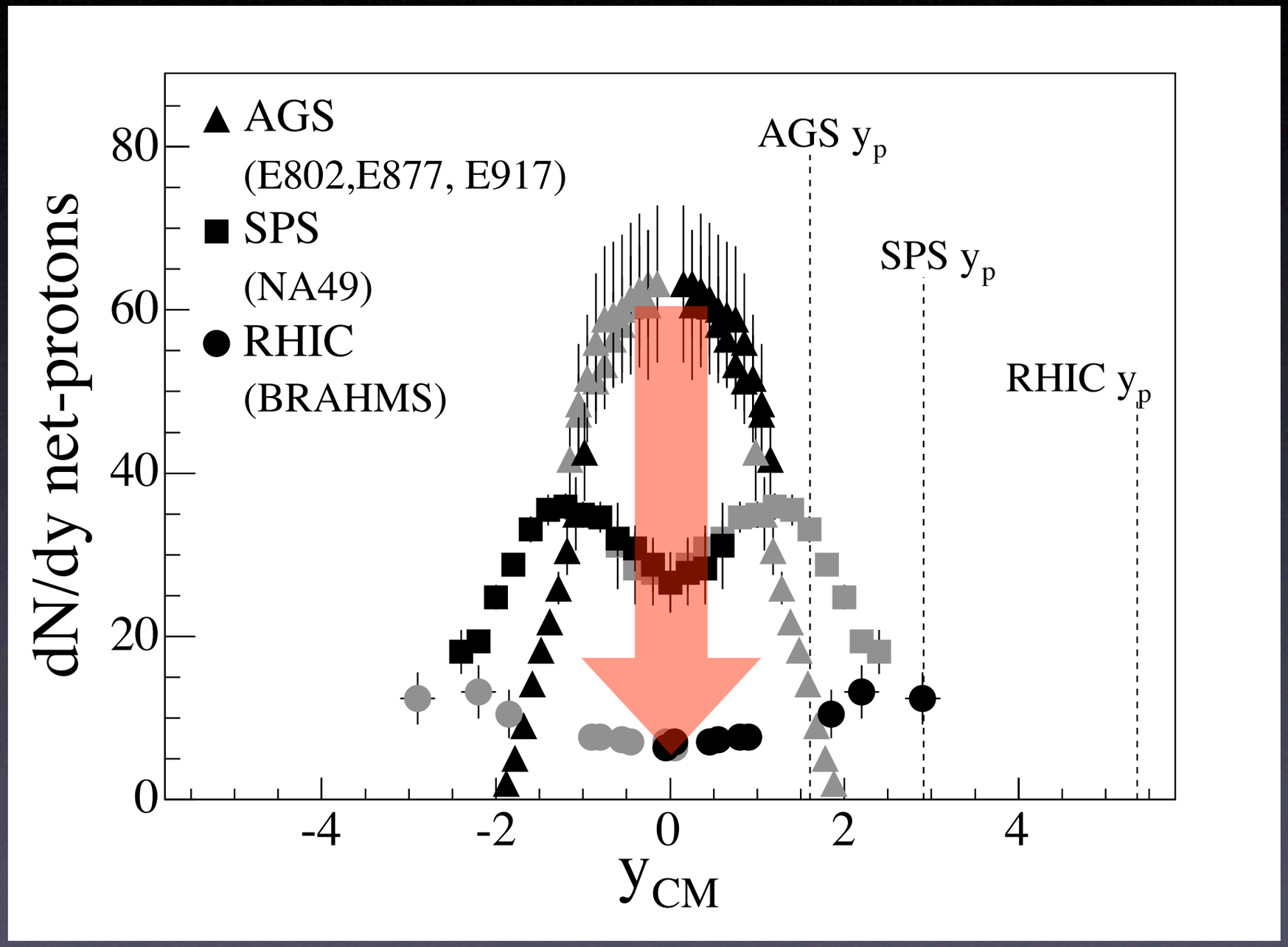
As beam energy decreases, increases baryon density

“Radiation”

D. Ouerdane, BRAHMS



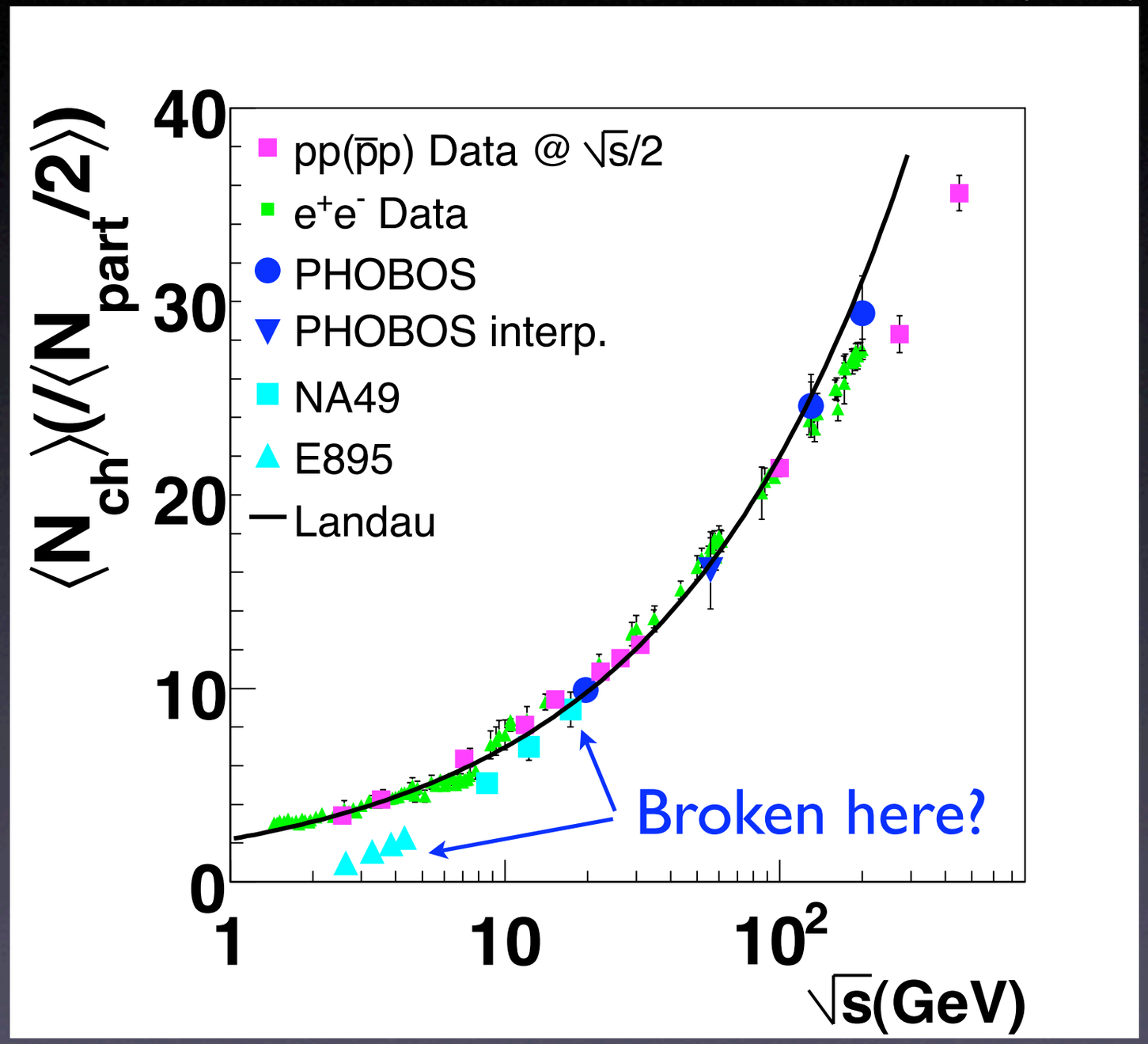
“Matter”



Large variation in baryon density near y=0 below RHIC energies

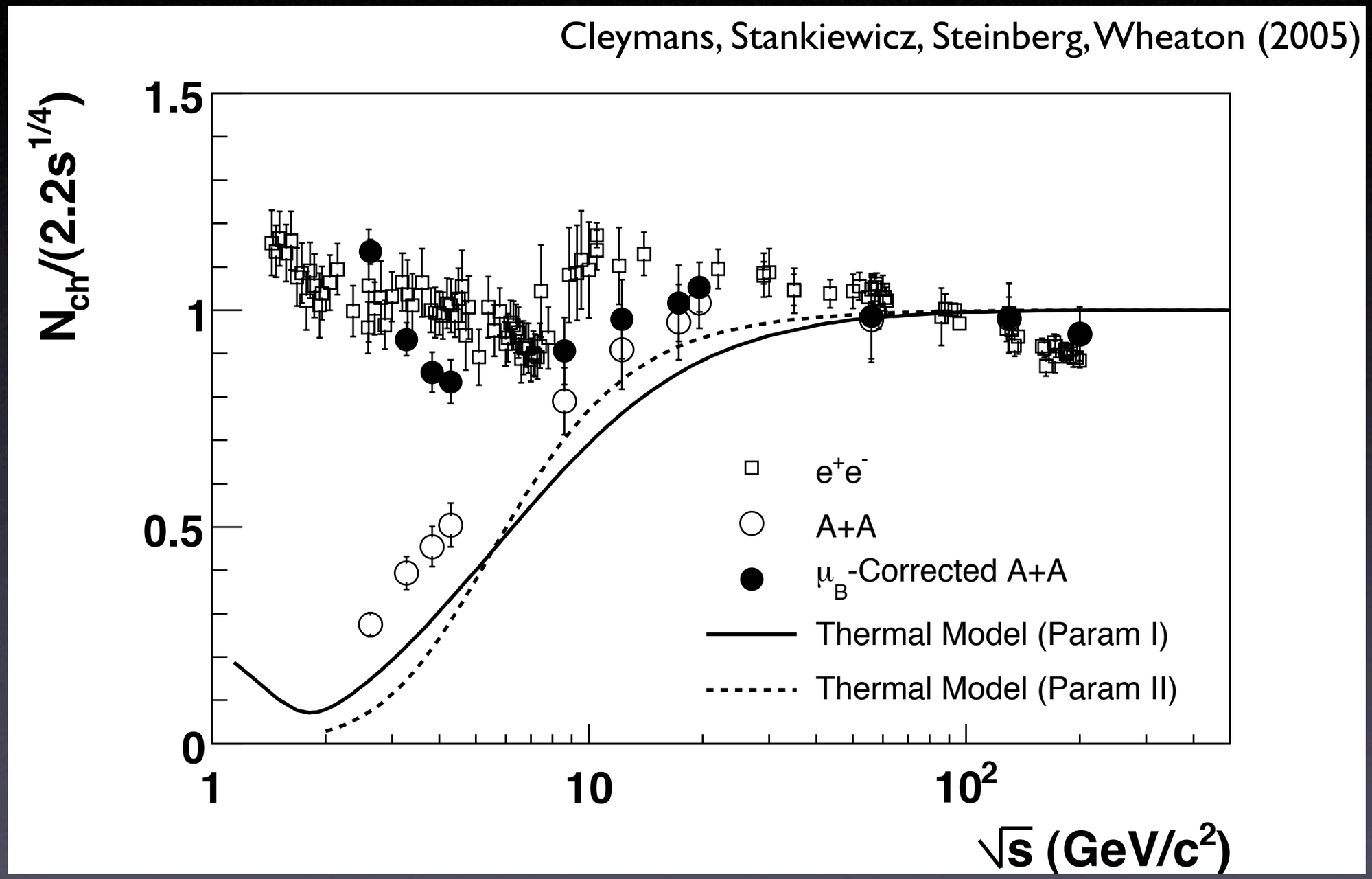
Total Entropy

PHOBOS (2003)



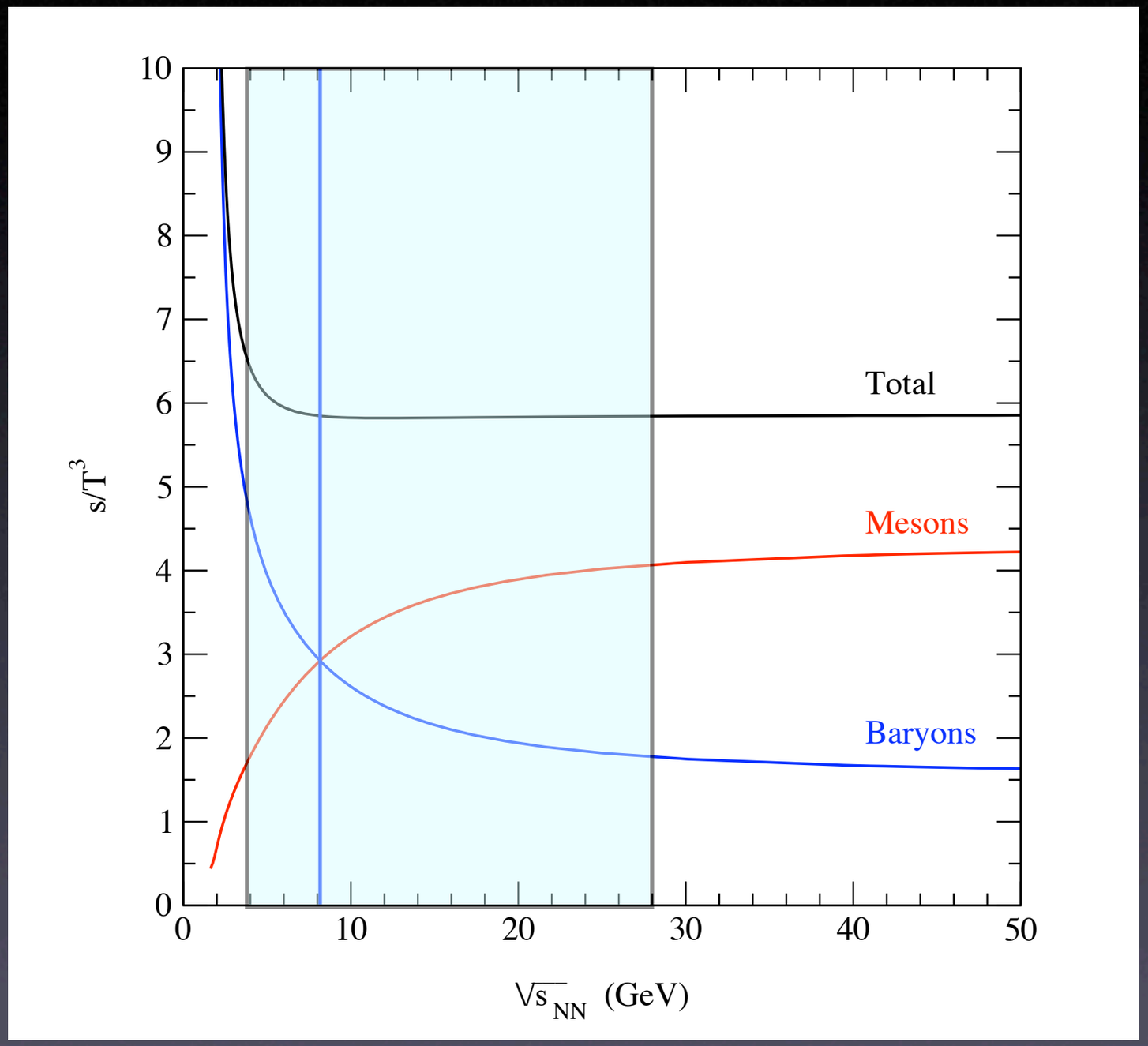
Simple relationship between available energy and entropy, apparently valid for many systems

Baryons suppress entropy...



$$S = \frac{E + PV}{T} - \frac{\mu_B N_B}{T} \Rightarrow \Delta \frac{N_{ch}}{N_{part}/2} \propto \frac{\mu_B}{T}$$

...but not degrees of freedom



Cleymans, Oeschler, Redlich, Wheaton (2005)

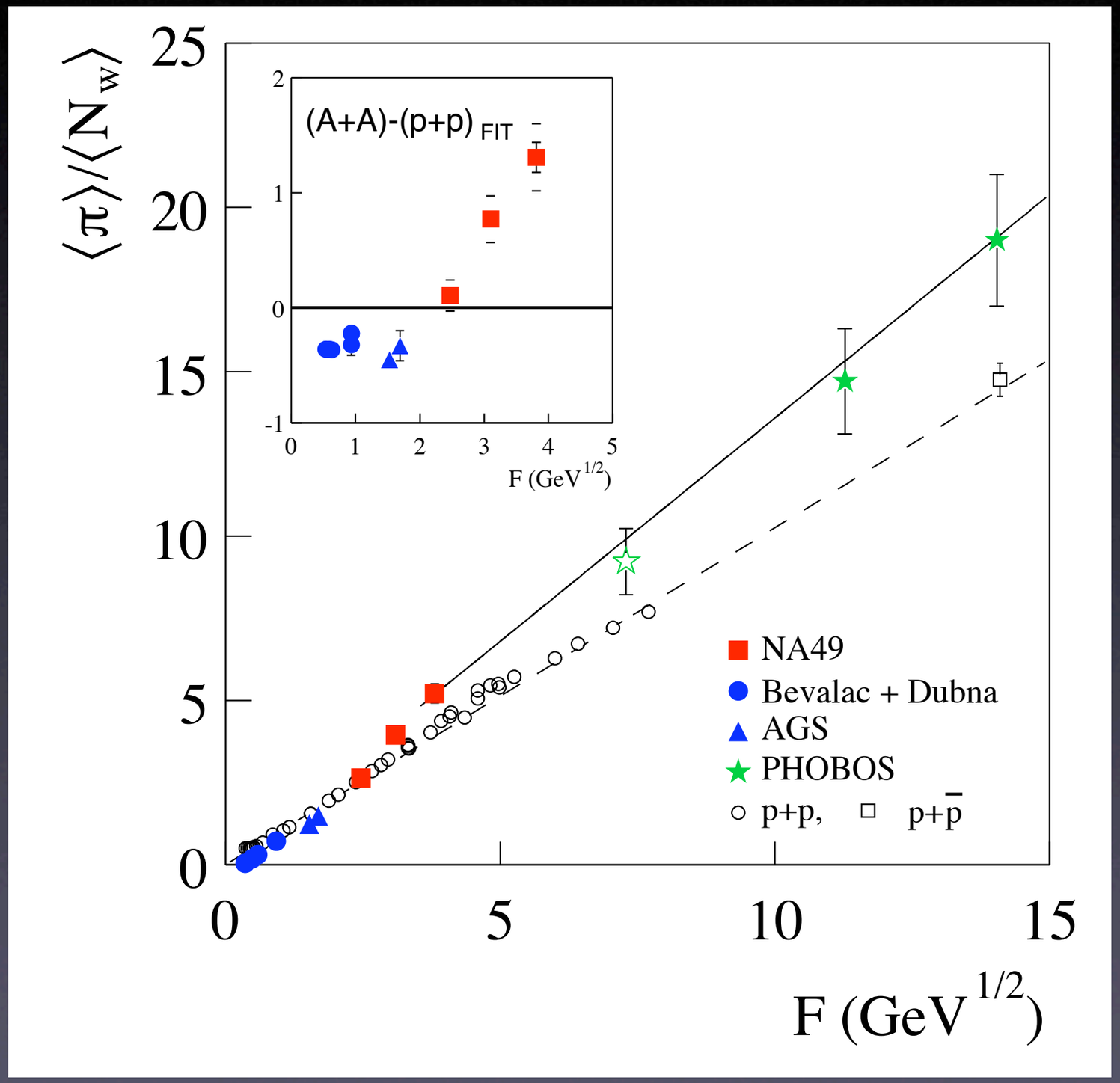
Despite strongly-varying baryon/meson ratio, total degrees of freedom (s/T^3) seems to be <u>constant</u>

Relation to "Kink"

A change in the number of degrees of freedom?...

Or just leaving out the non-pion contributions to the total?

Rapidly-changing baryon density leads to interesting physics!



The Low-E Scan

- The critical point is a clear, compelling reason to perform a low-E scan at RHIC
  - But still need to understand effect of baryon density on dynamics

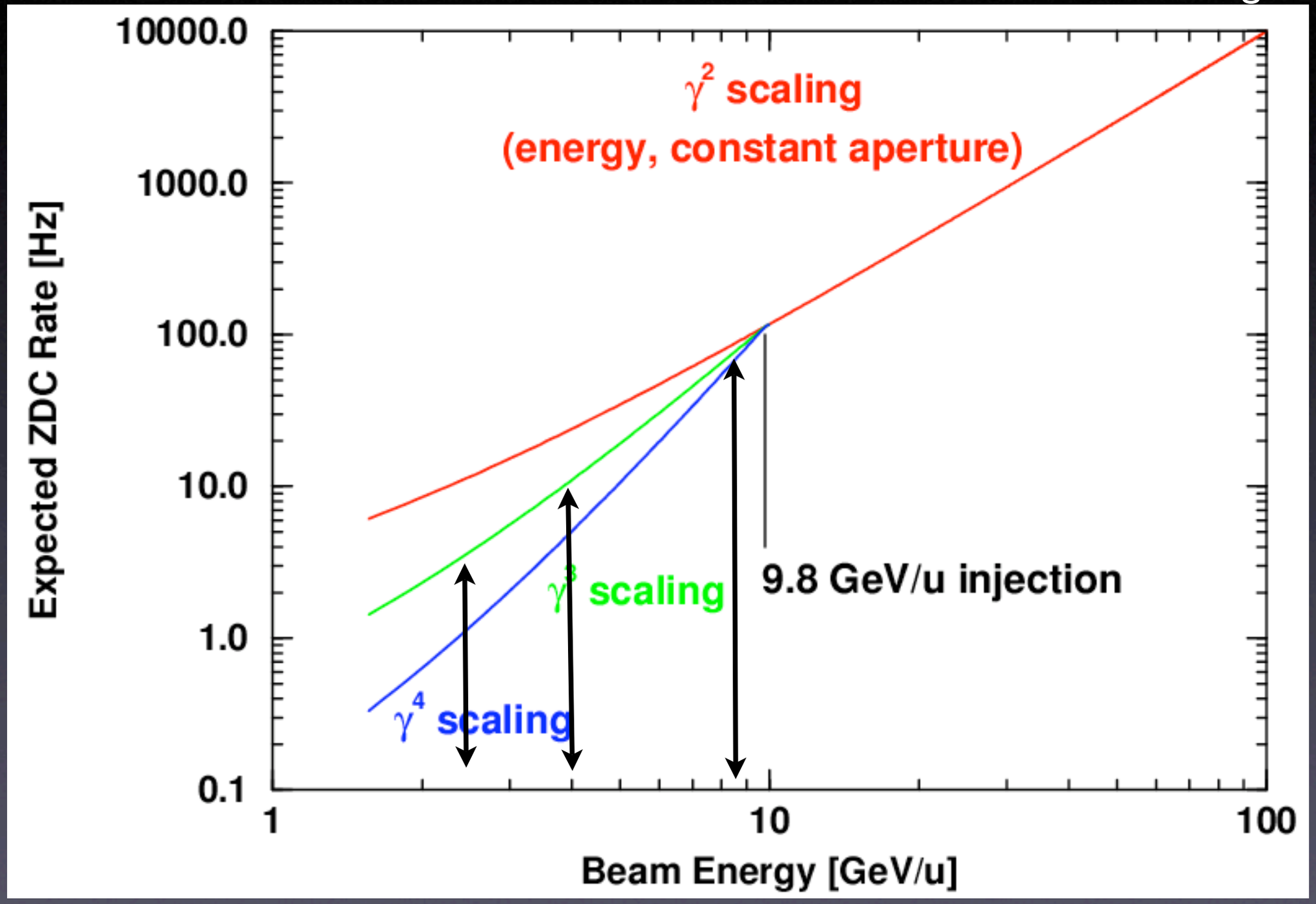
- Unprecedented opportunity to scan <u>two</u> orders of magnitude in CM energy with
  - A single machine
  - A single detector (x2: STAR & PHENIX) with constant kinematic acceptance

- We should always keep our eyes open!
  - Need <u>data</u> to figure out "how things work"

Experiments at Low-Energy RHIC (RHIC½?)

Expected RHIC Rates

T. Satogata

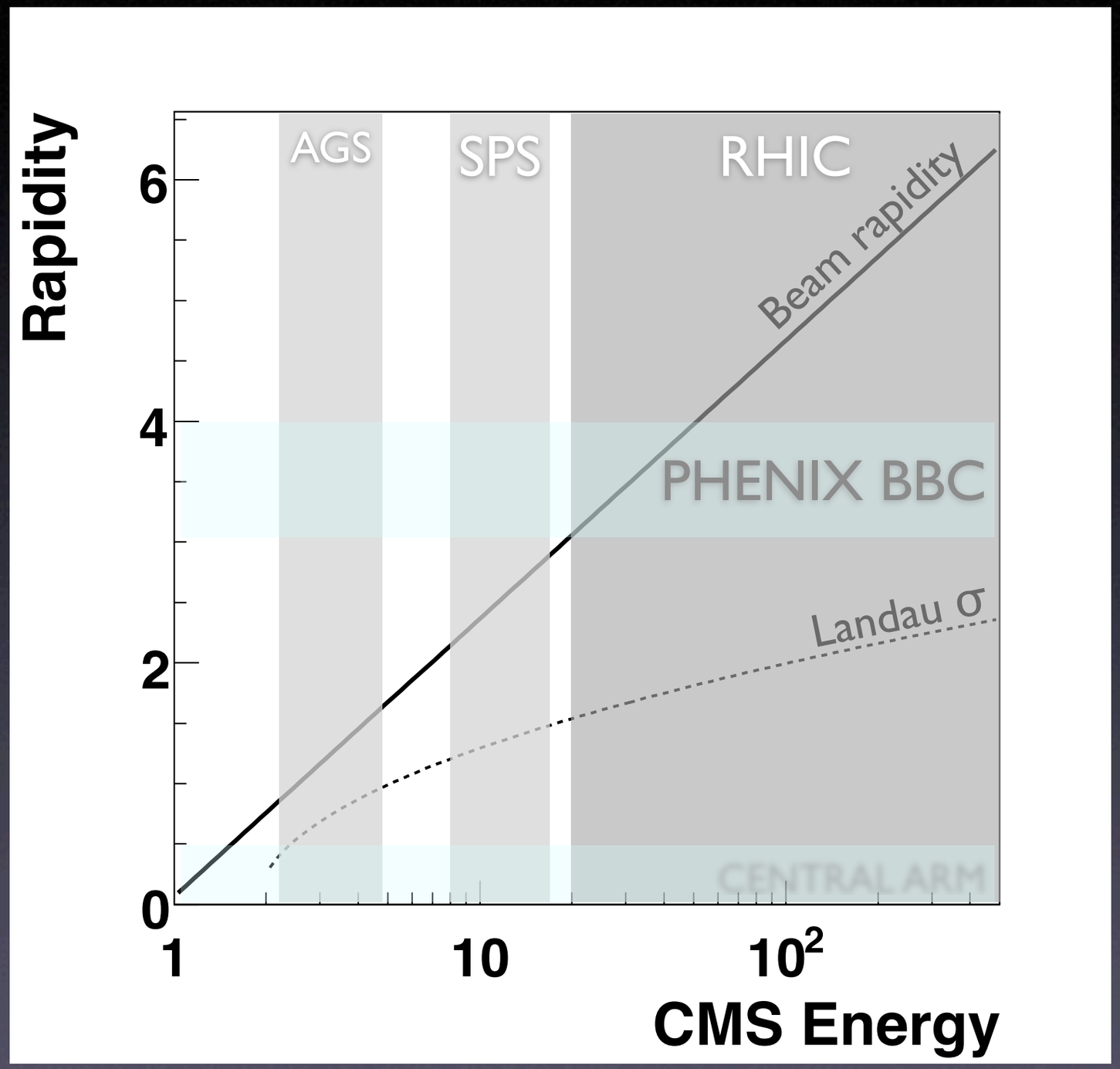


Event Counts

CM Energy	Rate	Events/day
5 GeV	~3 Hz	$120k \cdot \epsilon_{vtx}$
8 GeV	~10 Hz	$400k \cdot \epsilon_{vtx}$
17 GeV	~70 Hz	$2.8M \cdot \epsilon_{vtx}$

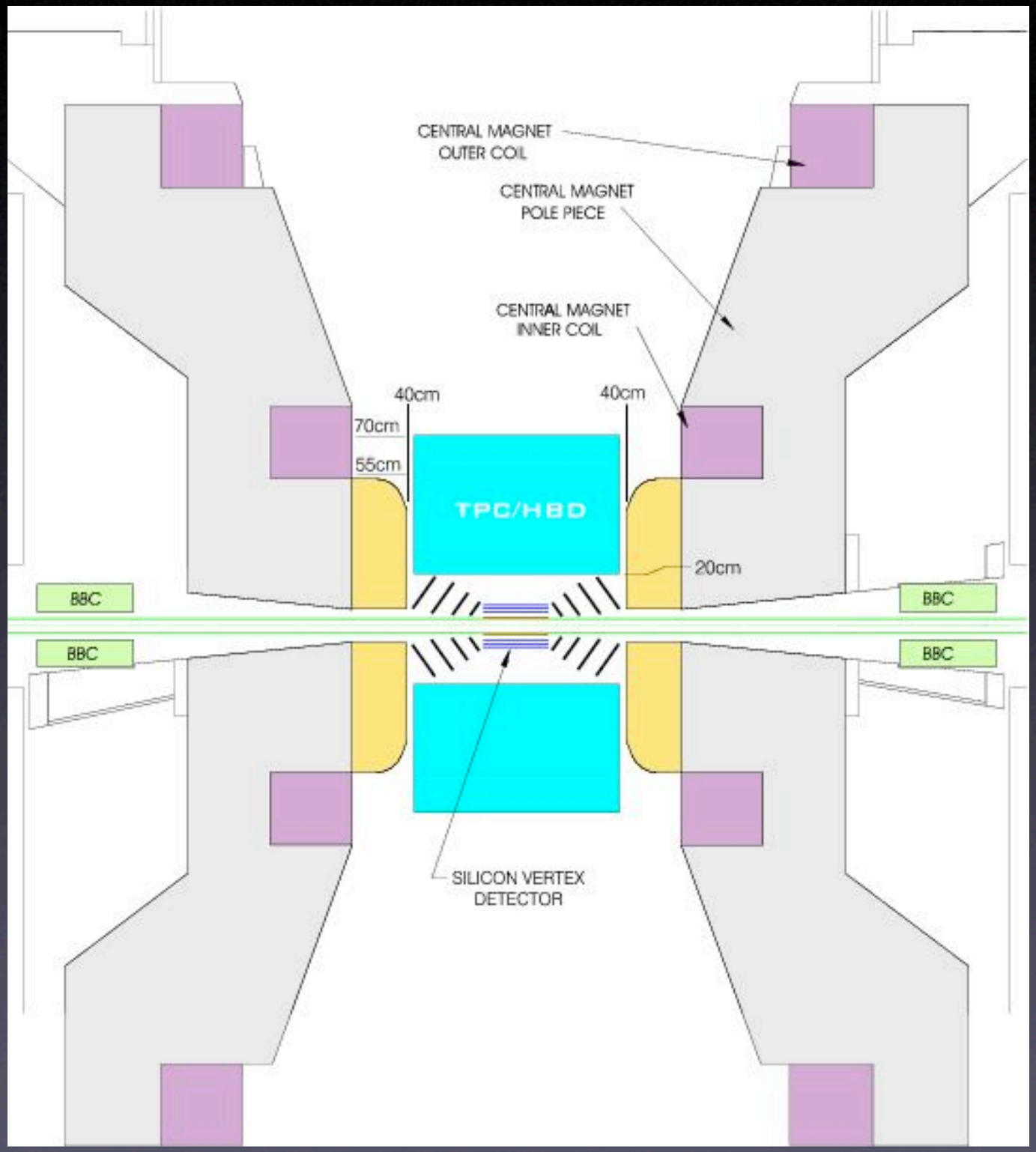
Assume 4×10^4 beam seconds/day

Energy vs. Rapidity vs. PHENIX

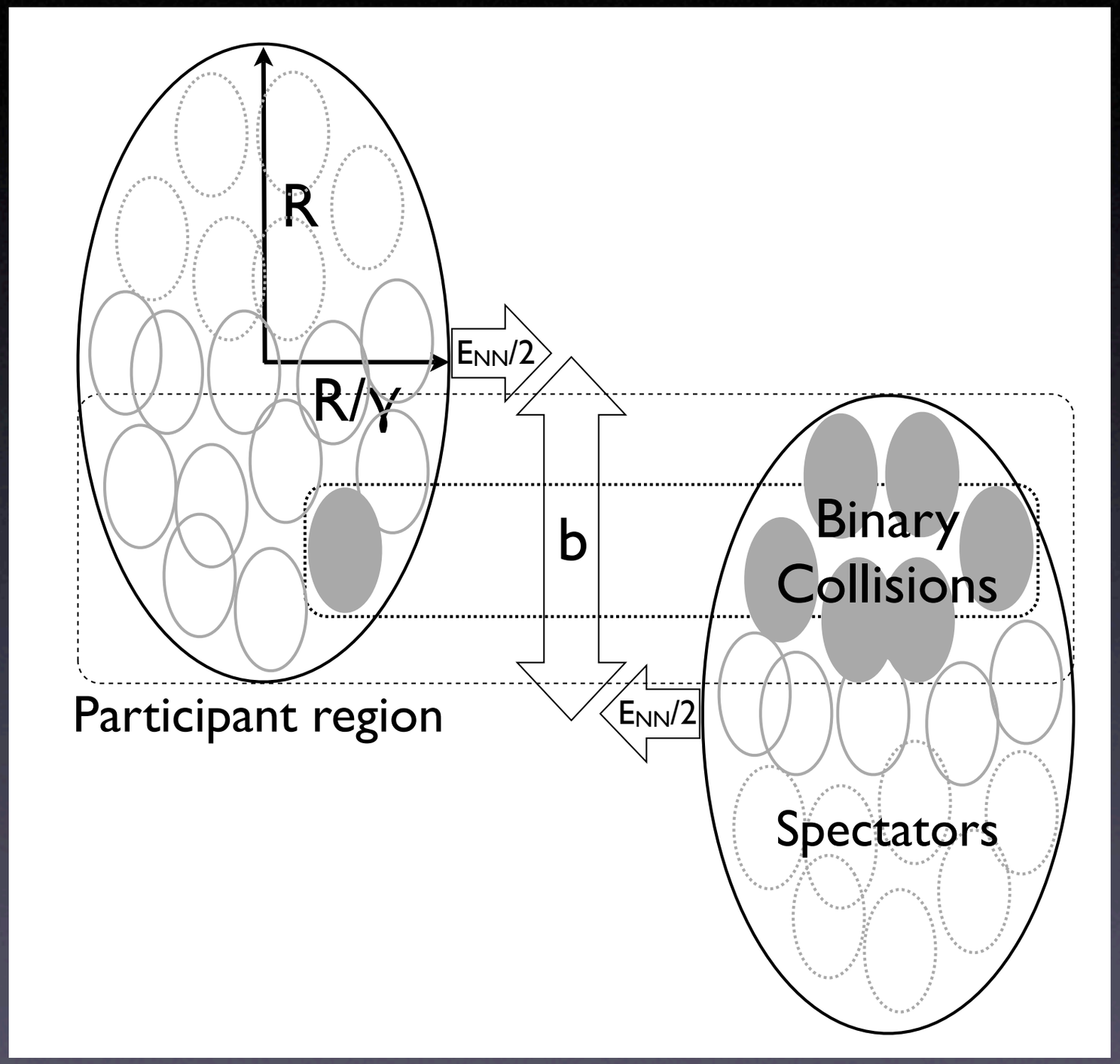


Triggering & Acceptance

- ZDC - at low energy?
- BBC - 3<|η|<4
  - Will be of limited use for low energy running
- Need a high-efficiency trigger scheme
- Central arm has |η|<0.35
- BUT lots of forward capability and <u>upgrades</u>
  - Muon arms 1<|η|<2
  - VTX |η|<2
  - NCC
  - MPC
  - Other low-E specific detectors

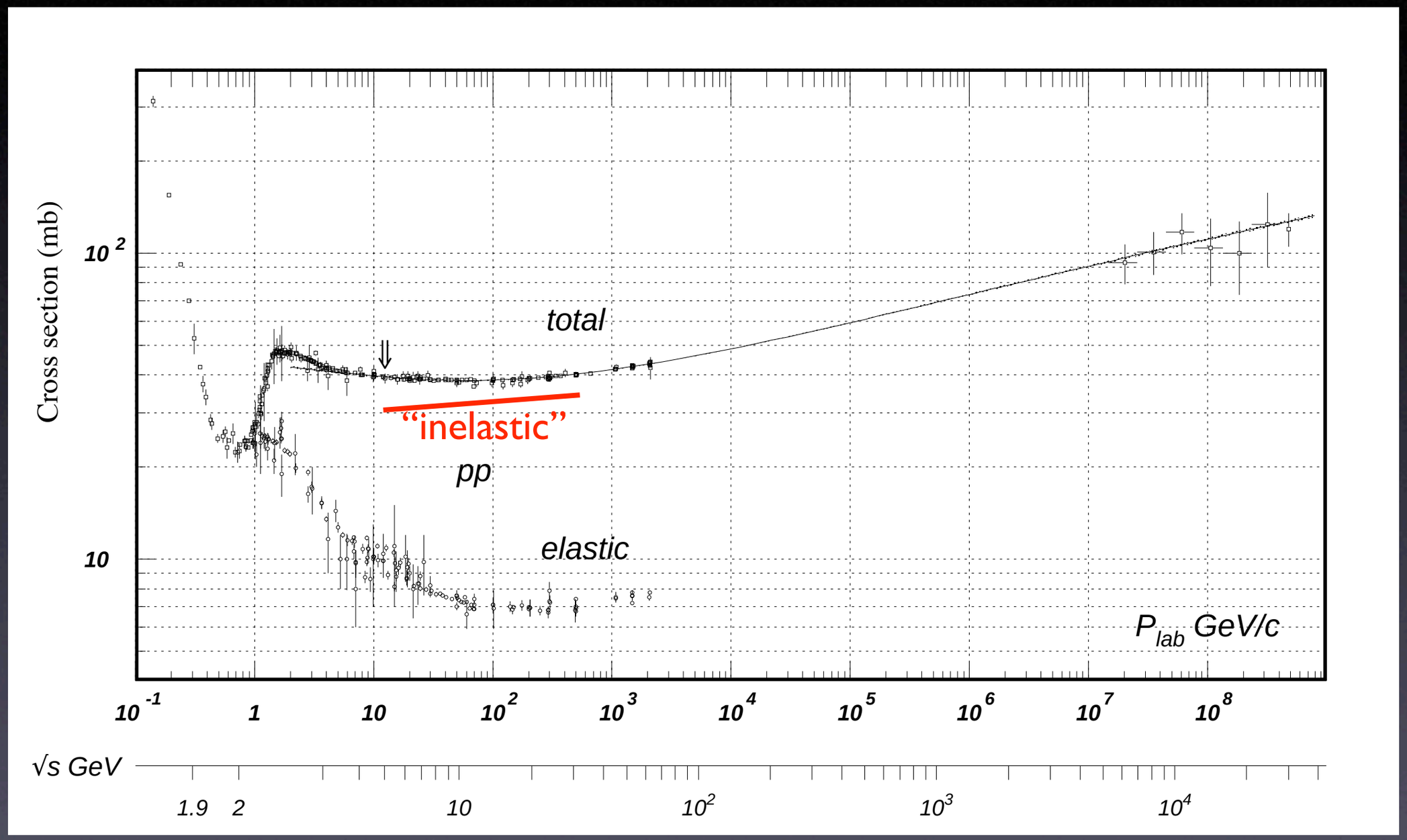


Collision Geometry



Collisions/Participant depends on NN cross section

p+p Cross Section

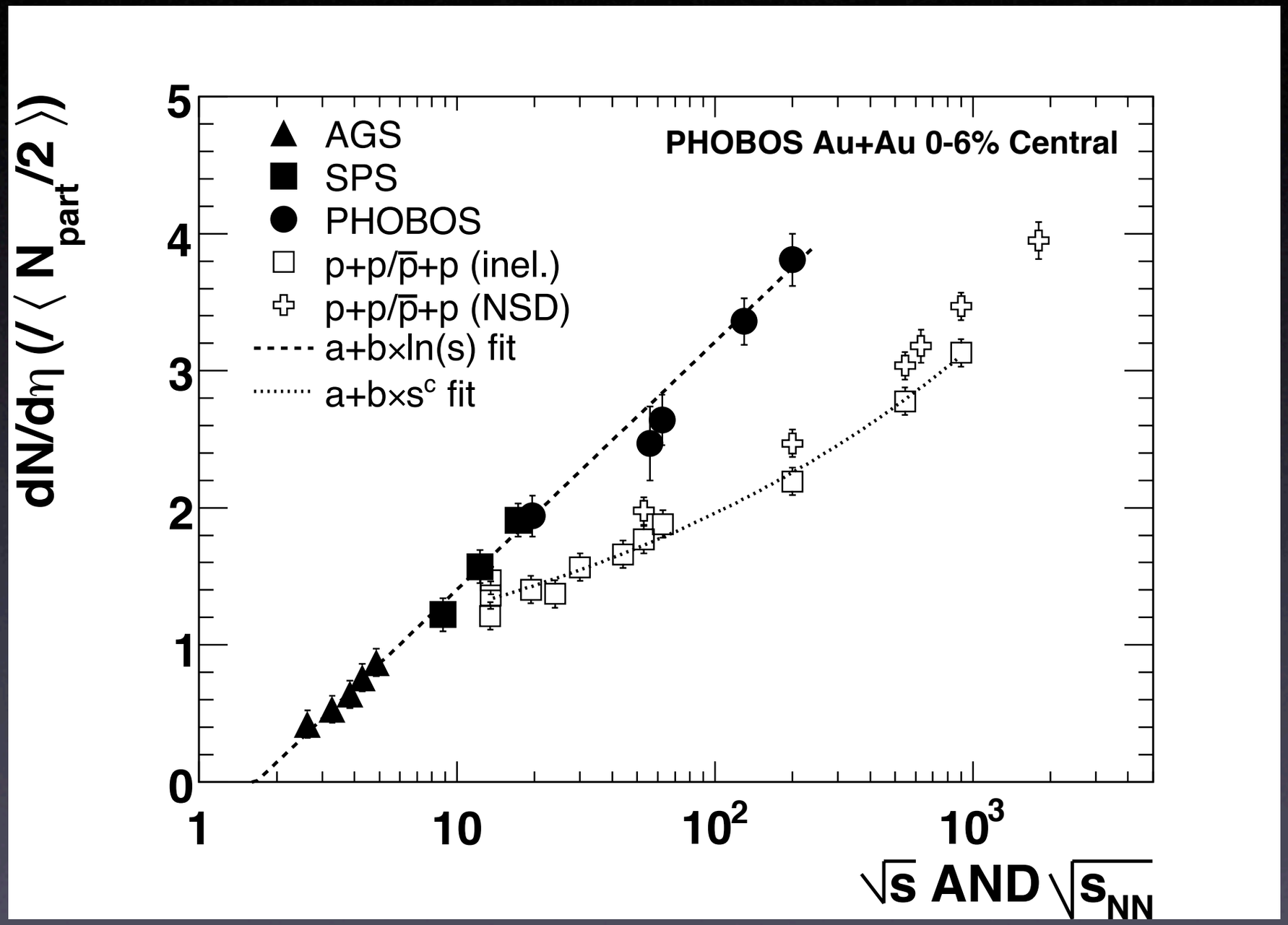


...which turns out to be ~constant in region of interest!

Bulk Observables

Multiplicity, Spectra, Strangeness

Particle Density @ η=0



Two major deficiencies: not dN/dy, no PID.
PHENIX can remedy both of these.

Transverse Dynamics

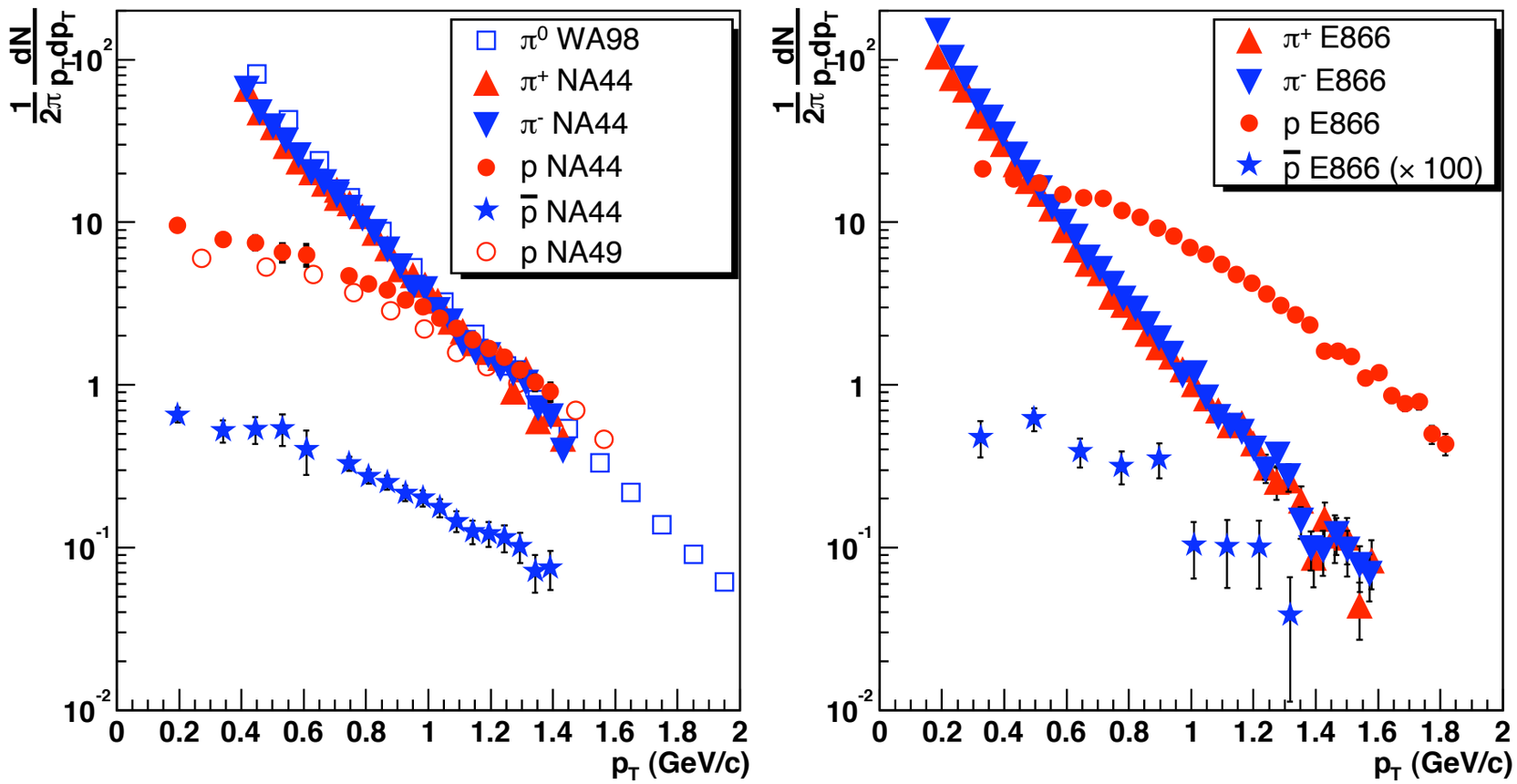


Fig. 47. Invariant yields of p, $\bar{p}$, and π as function of p_T in central Pb+Pb collisions at the SPS ($\sqrt{s_{NN}} = 17$ GeV) (left panel) and in central Au+Au collisions at the AGS ($\sqrt{s_{NN}} = 5$ GeV) (right panel). The $\bar{p}$ spectrum from the AGS is scaled up by a factor 100. All data are at mid-rapidity ($y - y_{cm} \approx 0$) and are from W98 [163], NA44 [226], NA49 [227], and E866 [228,229].

Explored by different detectors at different machines

Transverse Dynamics

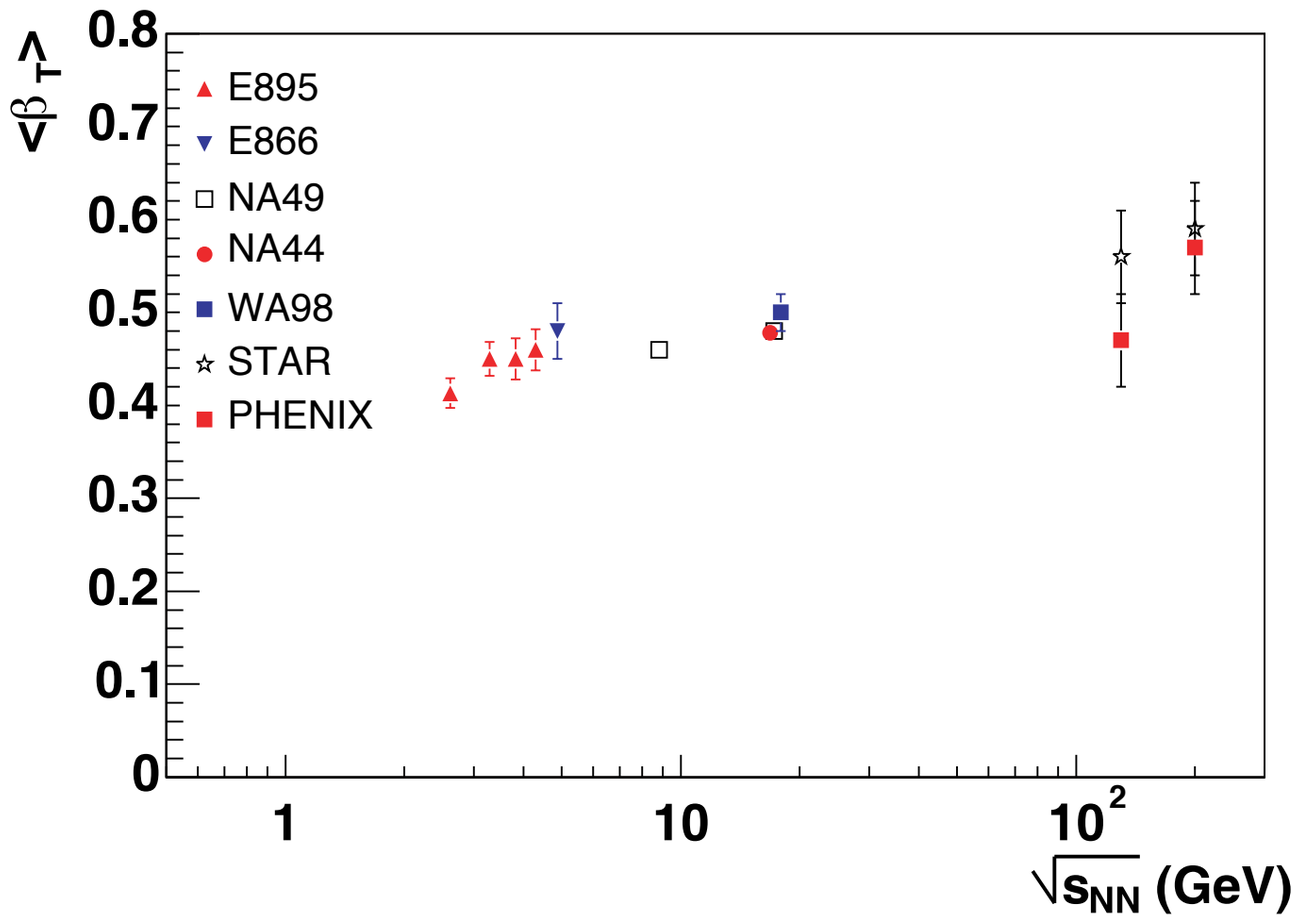
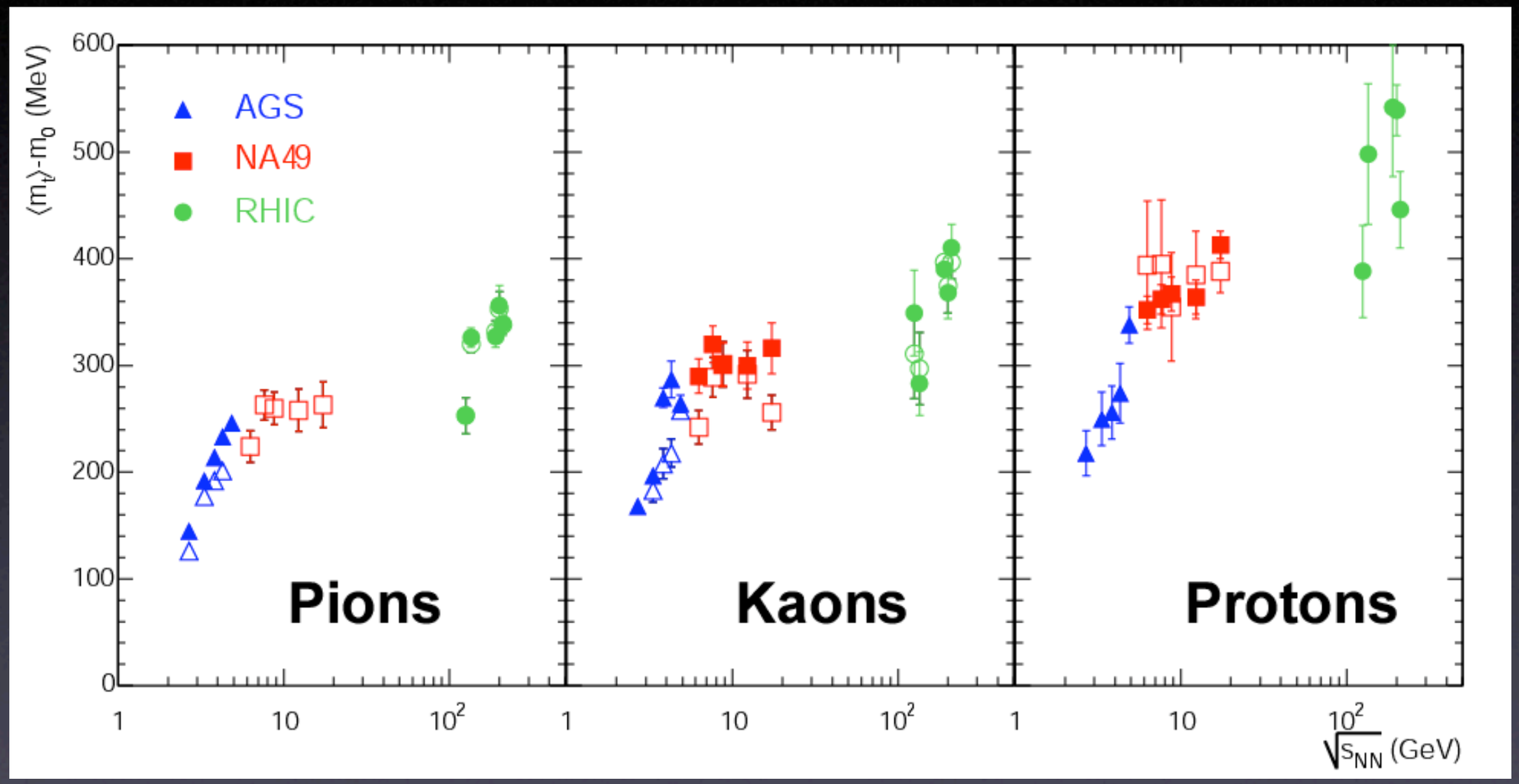


Fig. 13. Beam-energy dependence of the extracted mean transverse expansion velocity as a function of beam energy from simultaneous fits to spectra of different mass [97,98,99,100,101,48,102].

Just energy dependence of radial expansion?

Transverse Dynamics

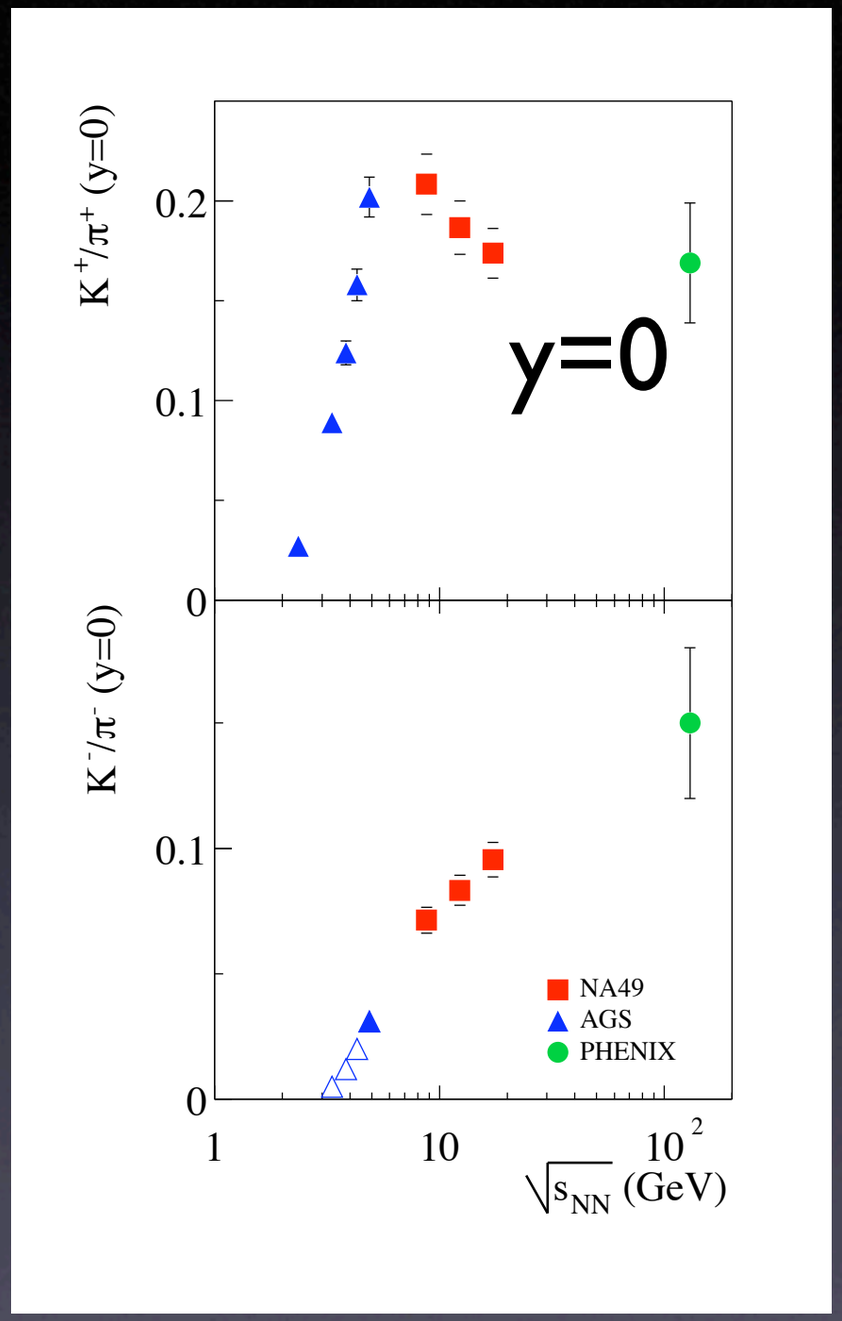
NA49, Hoehne QM2005

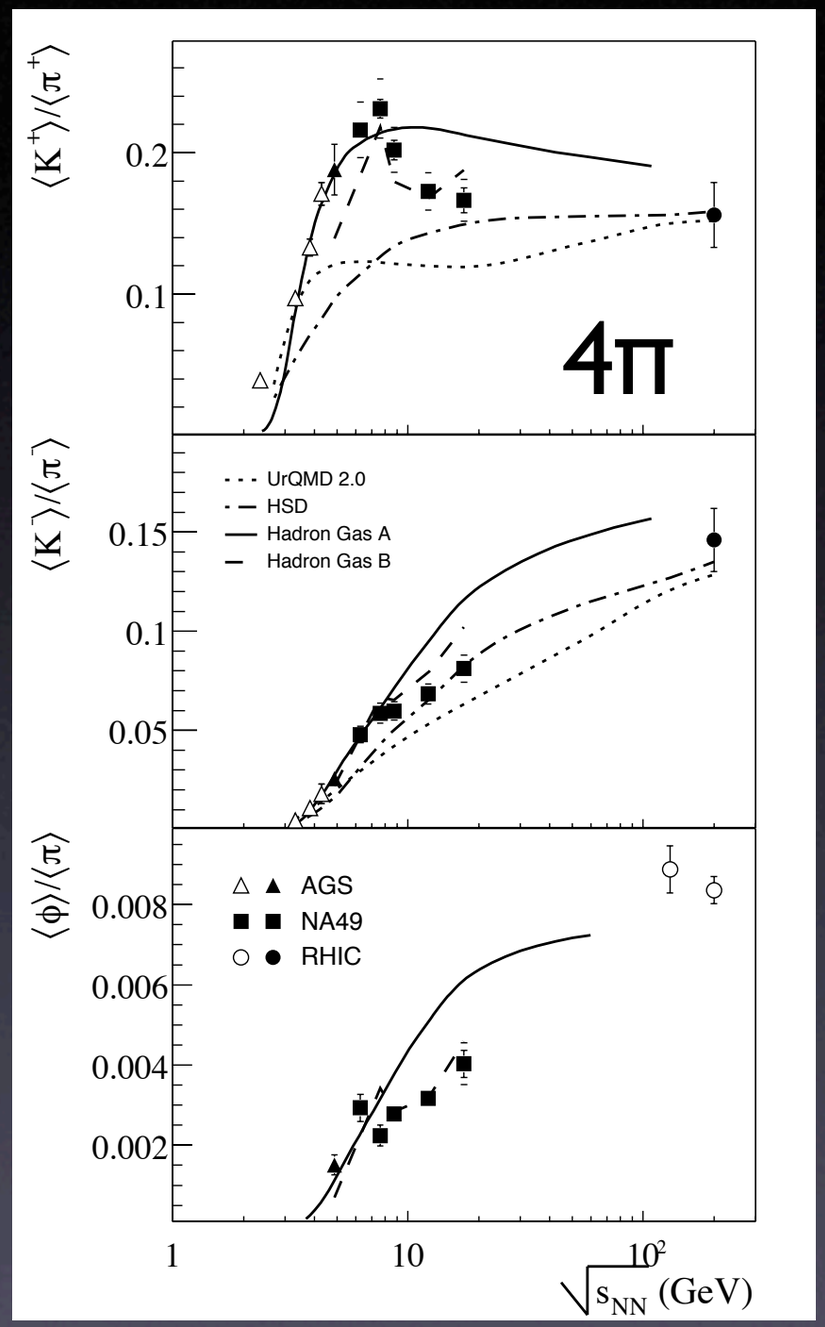


Dramatic change in $\langle m_T \rangle$ right where baryon density is changing!

How does baryon density affect transverse activity?

K/π Horns

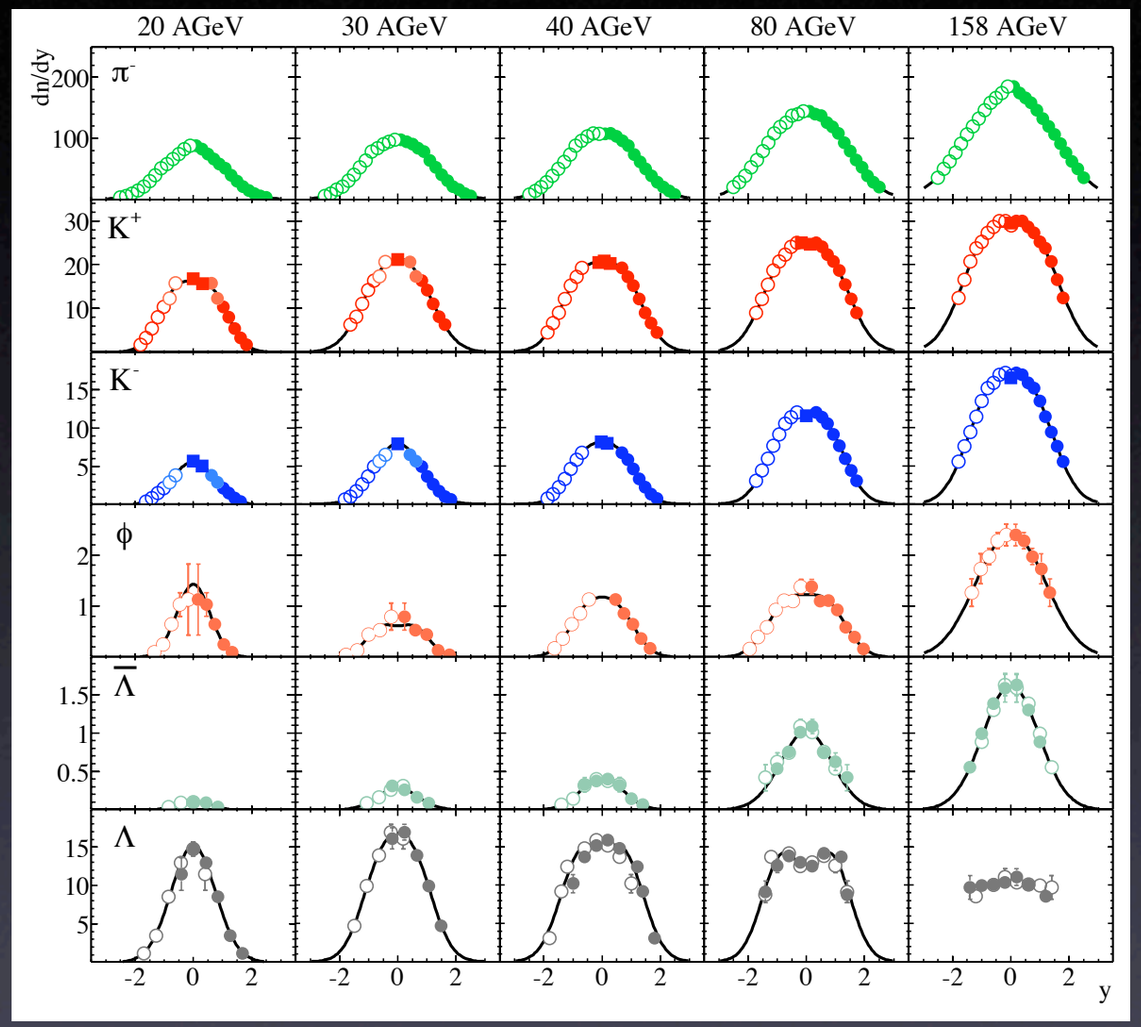


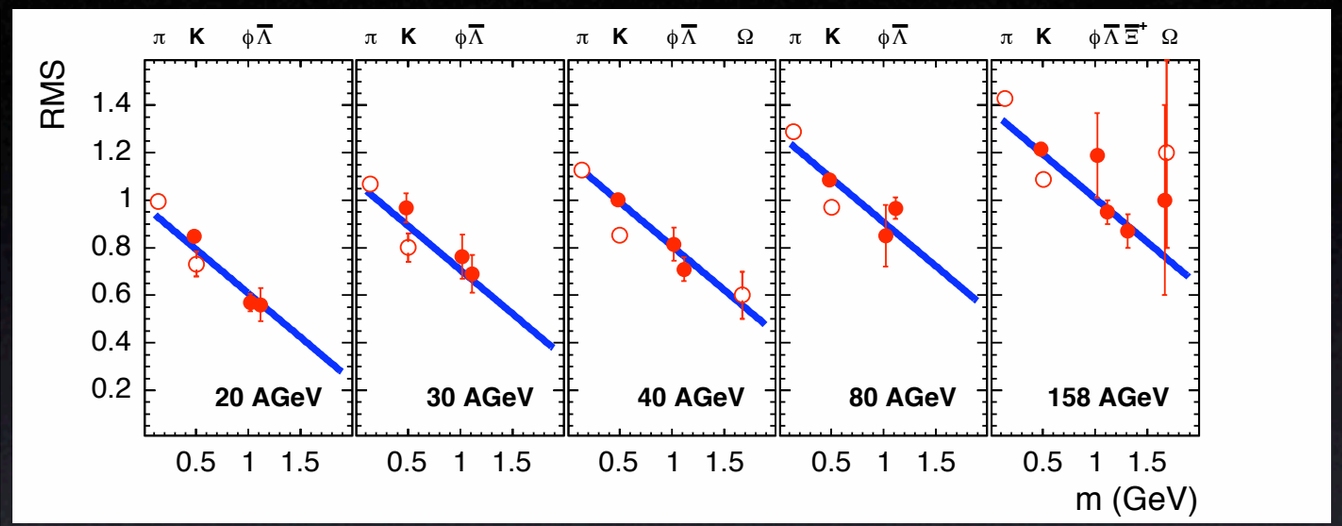


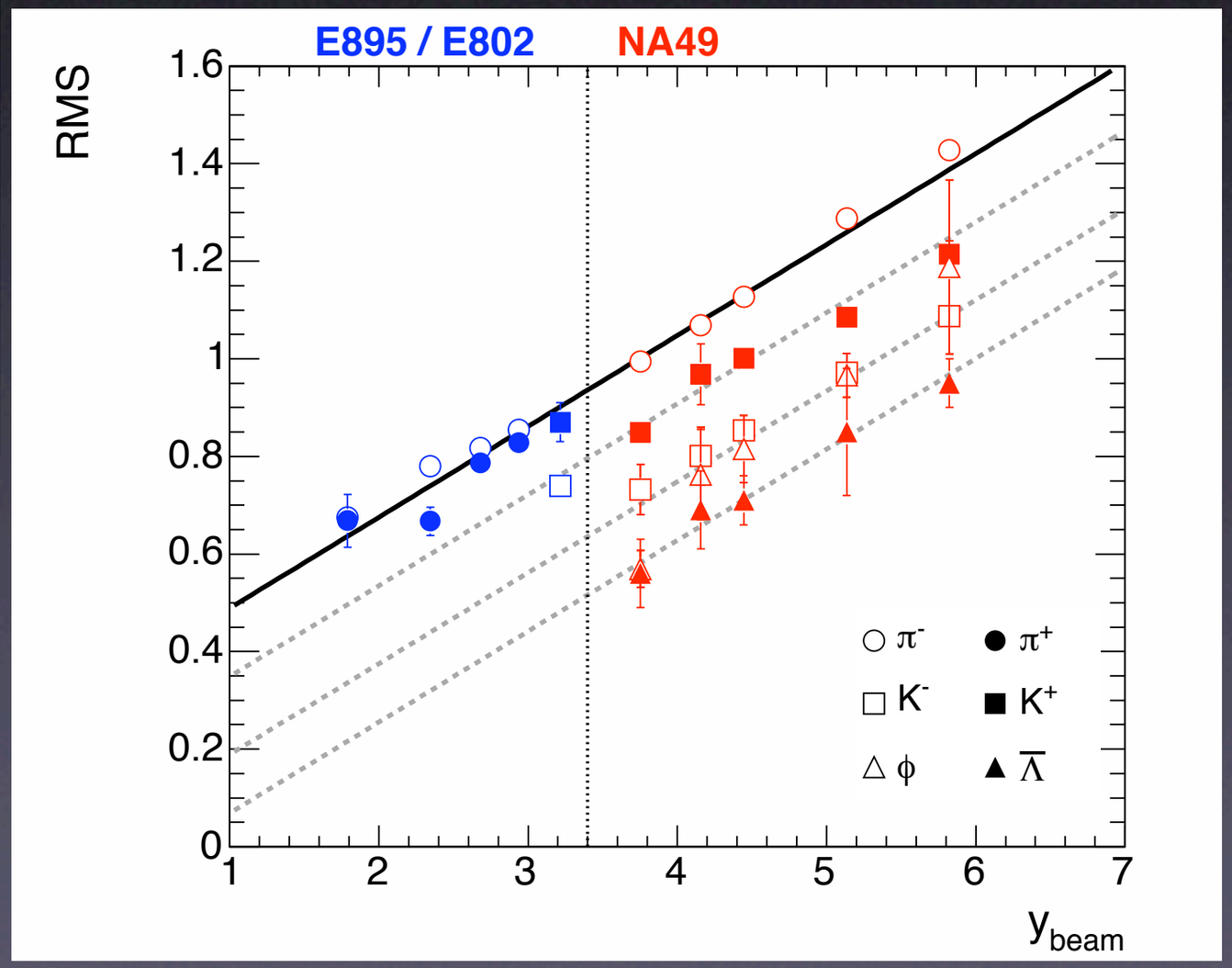
Shows up at mid-rapidity and in 4π results: comparison of PHENIX & STAR will be important

NA49 Hadron Spectra

C. Blume, SQM2004







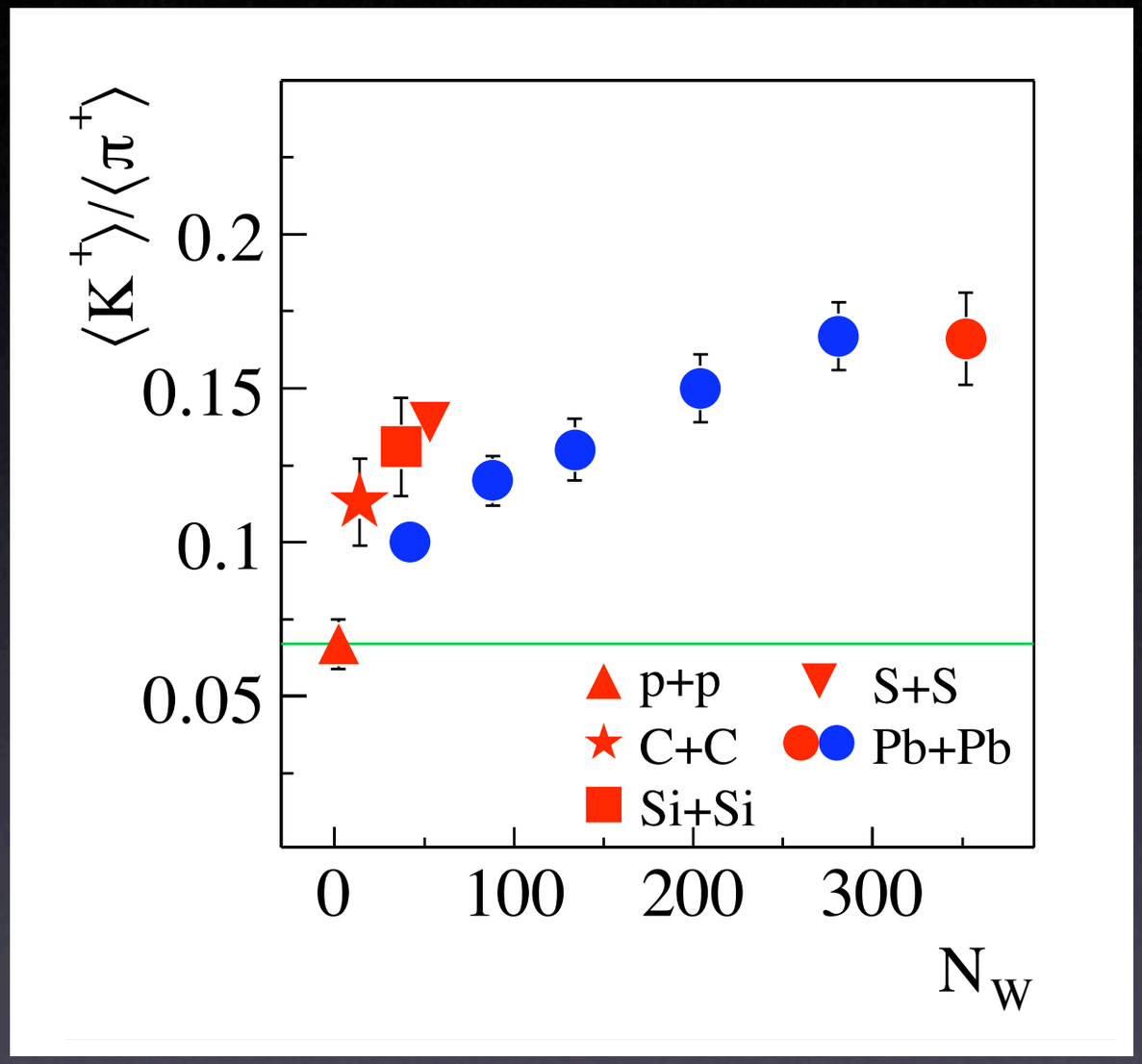
Rich data set, 5 energies!

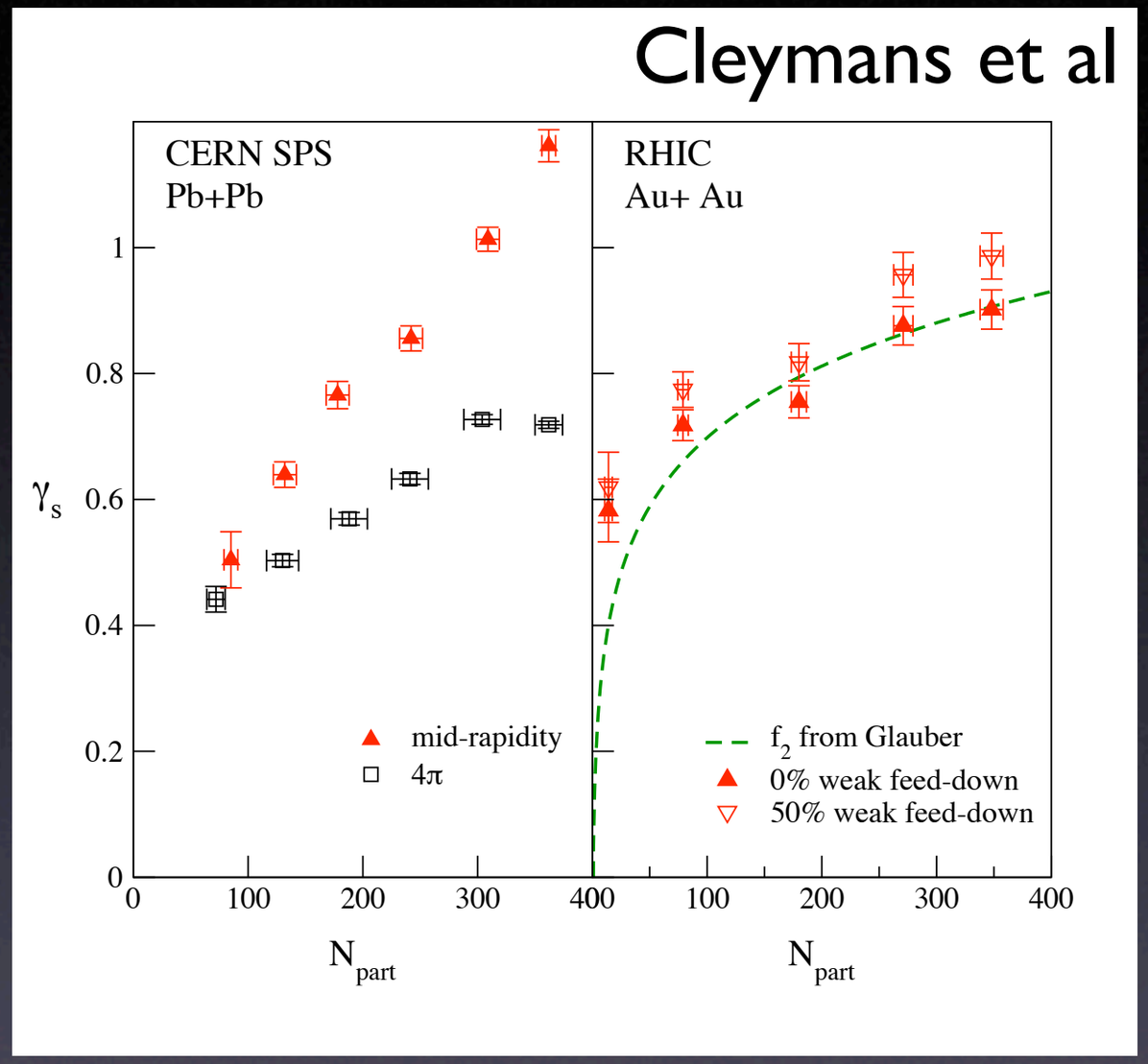
Widths <u>increase</u> log(s)

Widths <u>decrease</u> ~m

Energy scans are crucial!

Strangeness vs. Centrality





How does geometry (which controls baryon stopping) affect strangeness enhancement?

PHENIX can untangle this with energy vs. centrality dependence of strangeness production

Correlations & Fluctuations

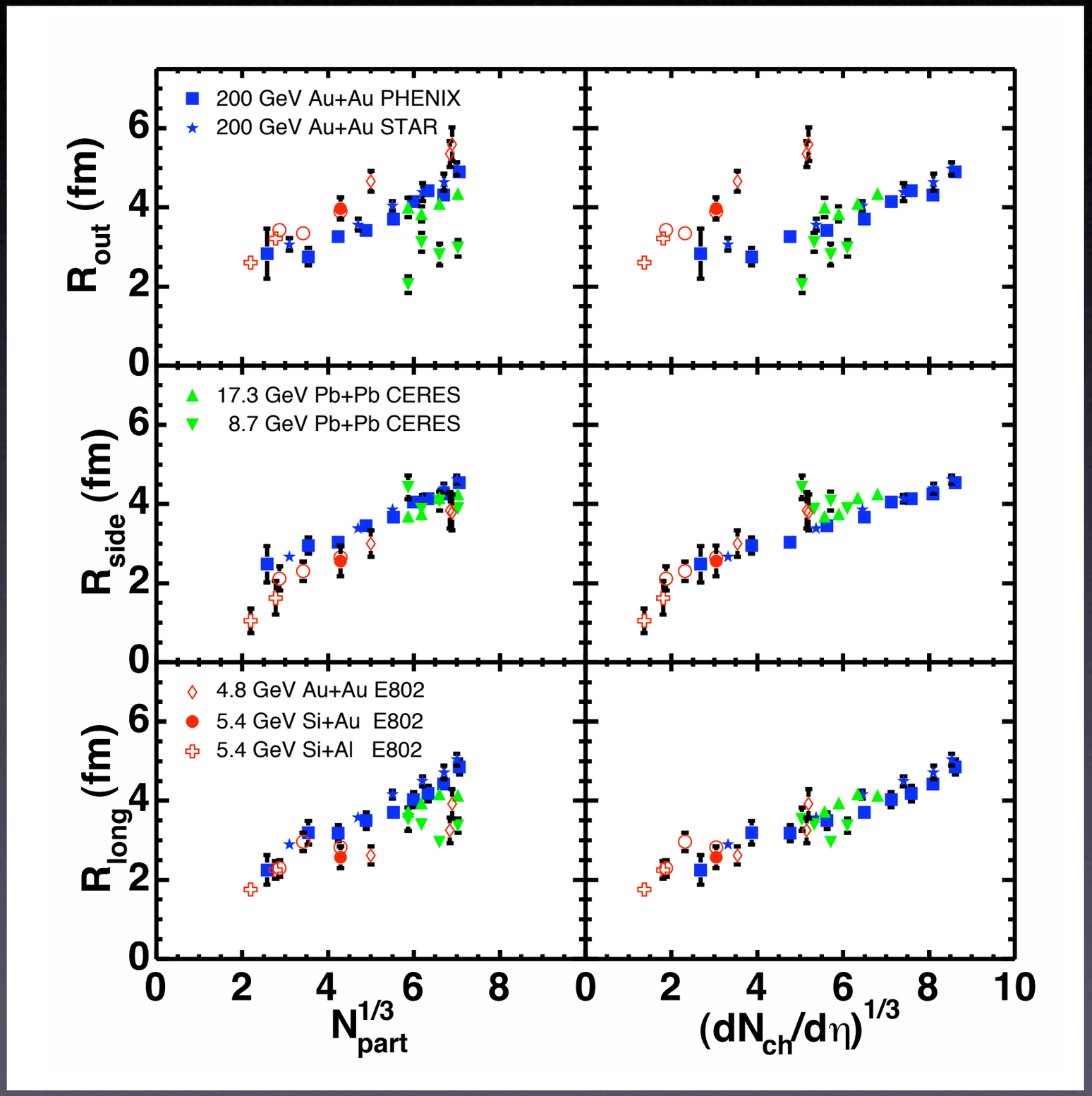
HBT, Elliptic Flow, Fluctuations

HBT Systematics

Excellent diagnostic
of space-time dynamics
and
freezeout properties!

PHENIX will take
opportunity
to measure full
range of energies
in same detector

meson vs. baryon
correlations?



Elliptic Flow vs. Energy

GSI Report (2003)

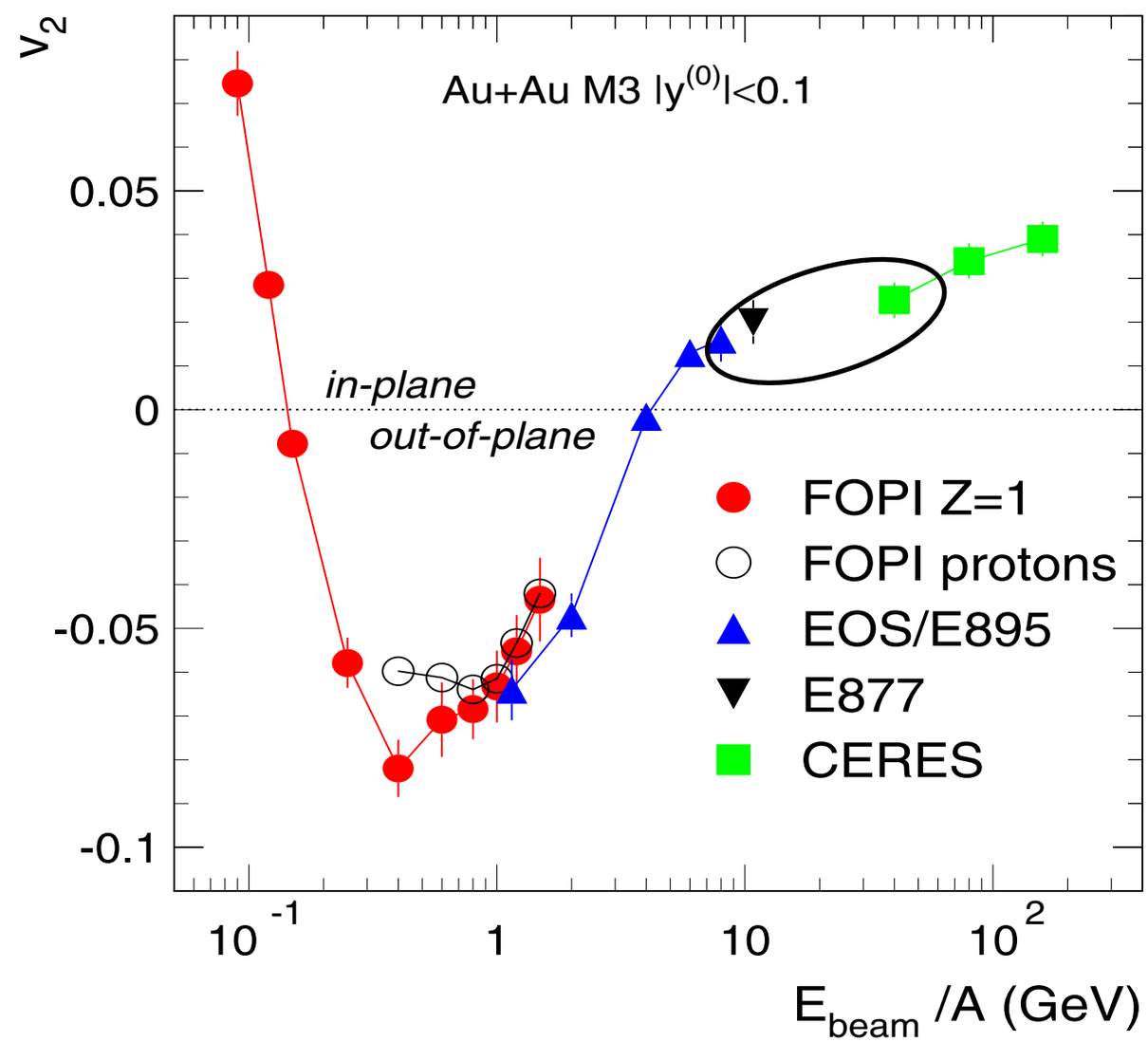


Figure 2: Excitation function of the elliptic flow for the M3 centrality bin. The FOPI data are compared to all existing measurements at fixed target experiments (protons).

Proton v_2

Opportunity between AGS & SPS

Elliptic Flow vs. Energy

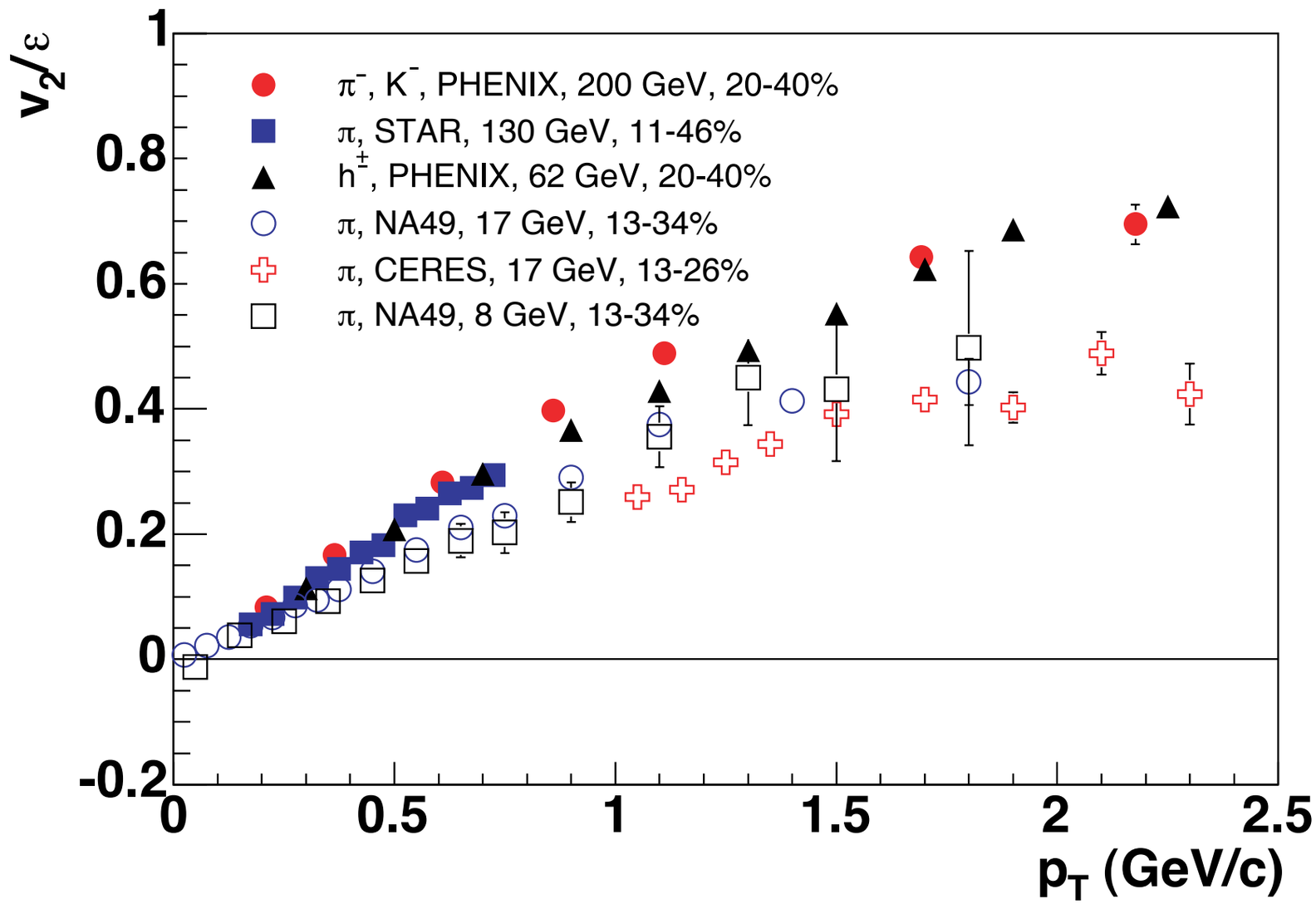


Fig. 16. $v_2(p_T)/\varepsilon$ vs. p_T for mid-central collisions at RHIC (filled symbols) and SPS (open symbols). Dividing by eccentricity removes to first order the effect of different centrality selections across the experiments [50,103,70,104,105].

Elliptic Flow vs. Energy

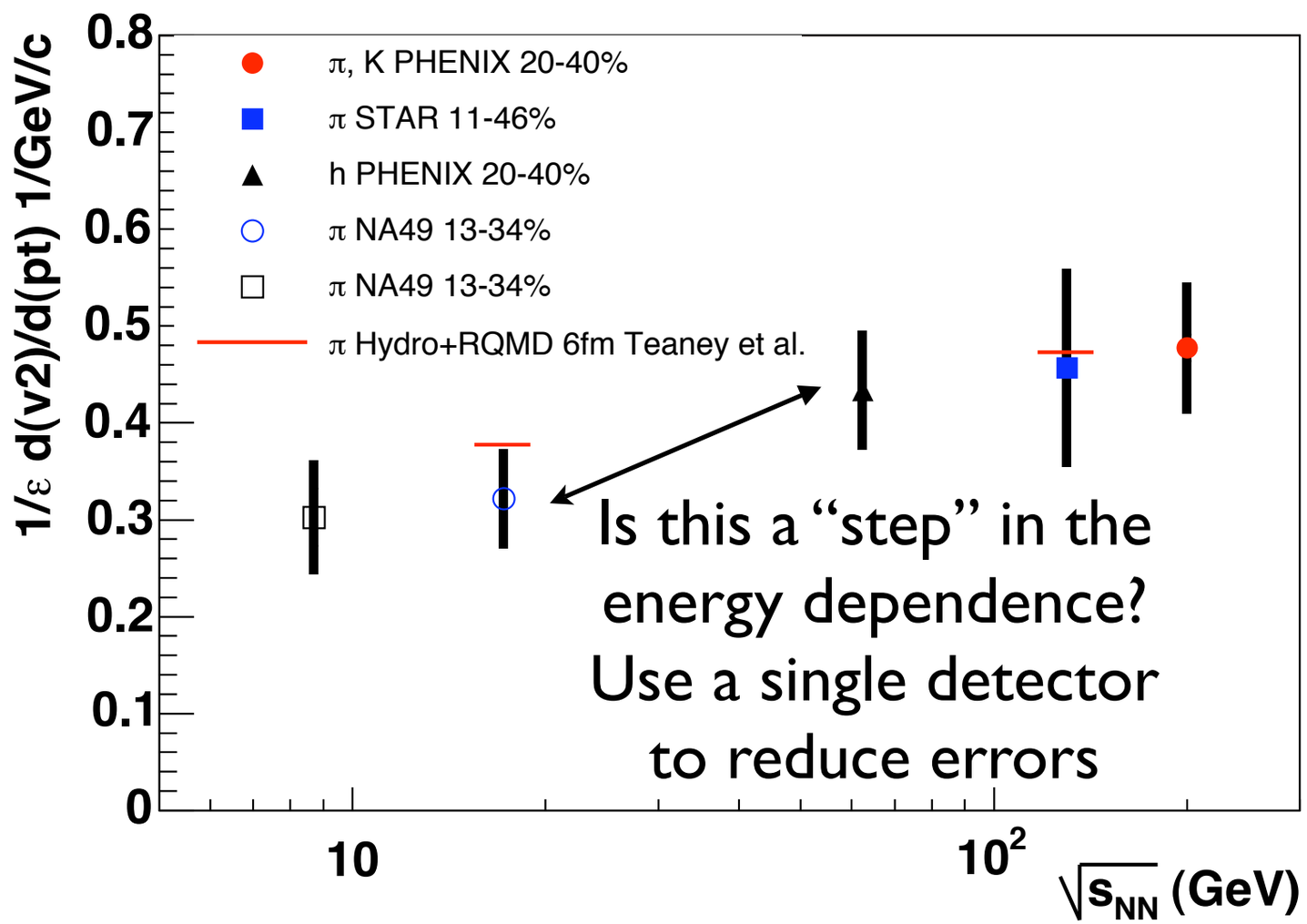
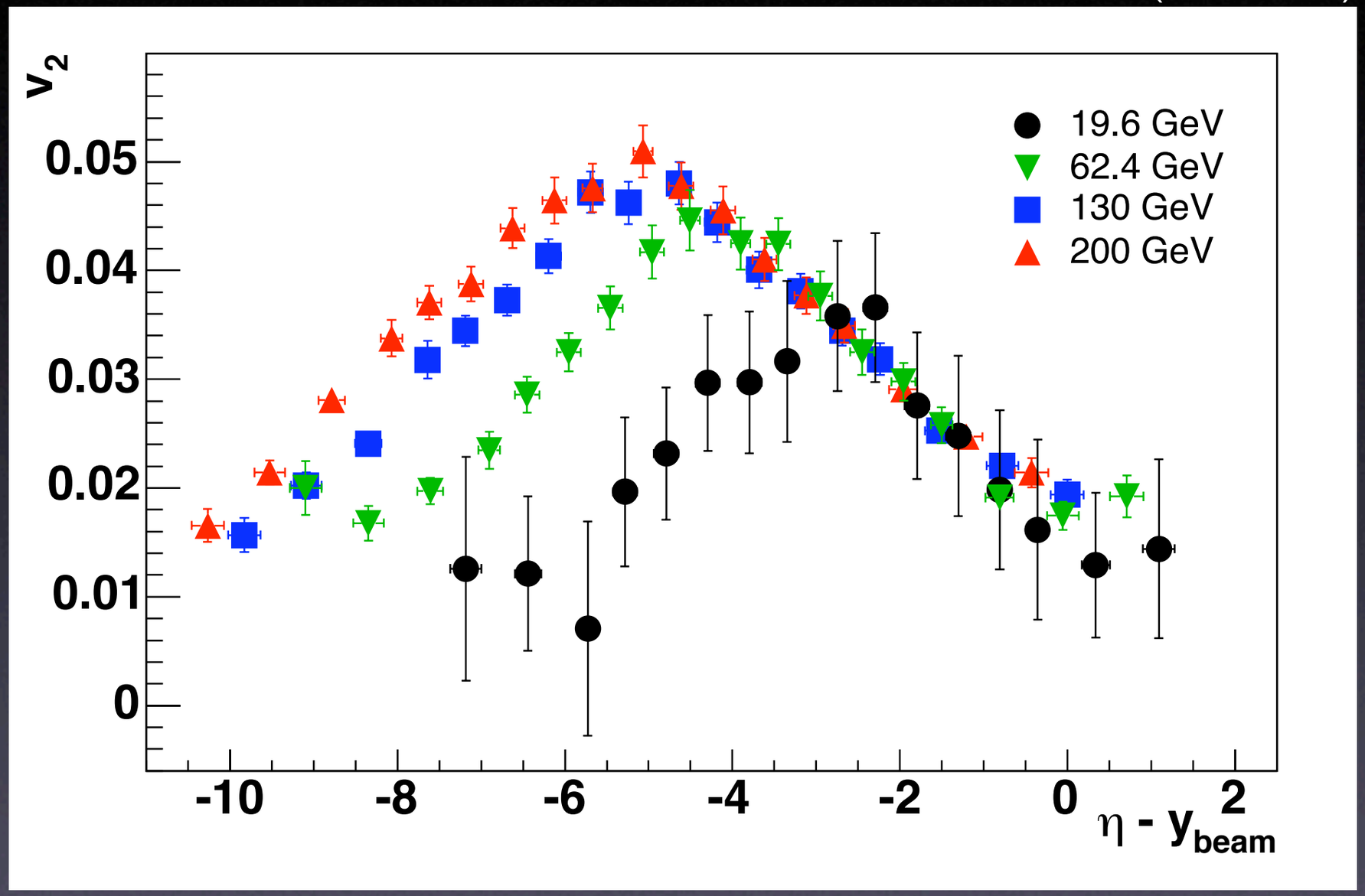


Fig. 17. The slope of the scaled elliptic flow, $(dv_2/dp_T)/\varepsilon$, for mid-central collisions at RHIC (filled symbols) and the SPS (open symbols). The slope is calculated from the data in Fig. 16 for the data $p_T < 1$ GeV/c. The solid error bars represent the total systematic error including the systematic error on v_2 and ε [50,103,70,104].

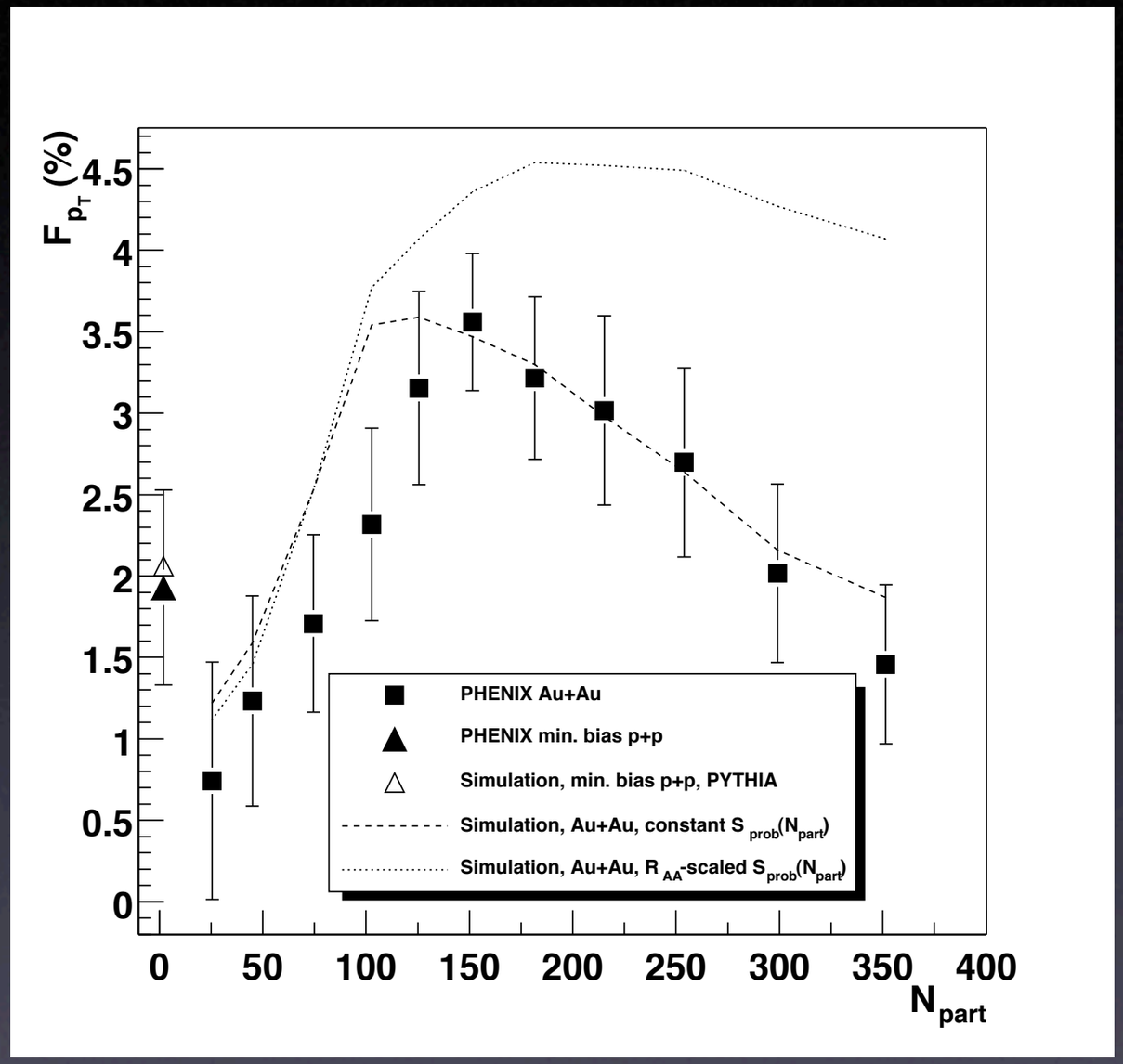
Longitudinal Scaling of v_2

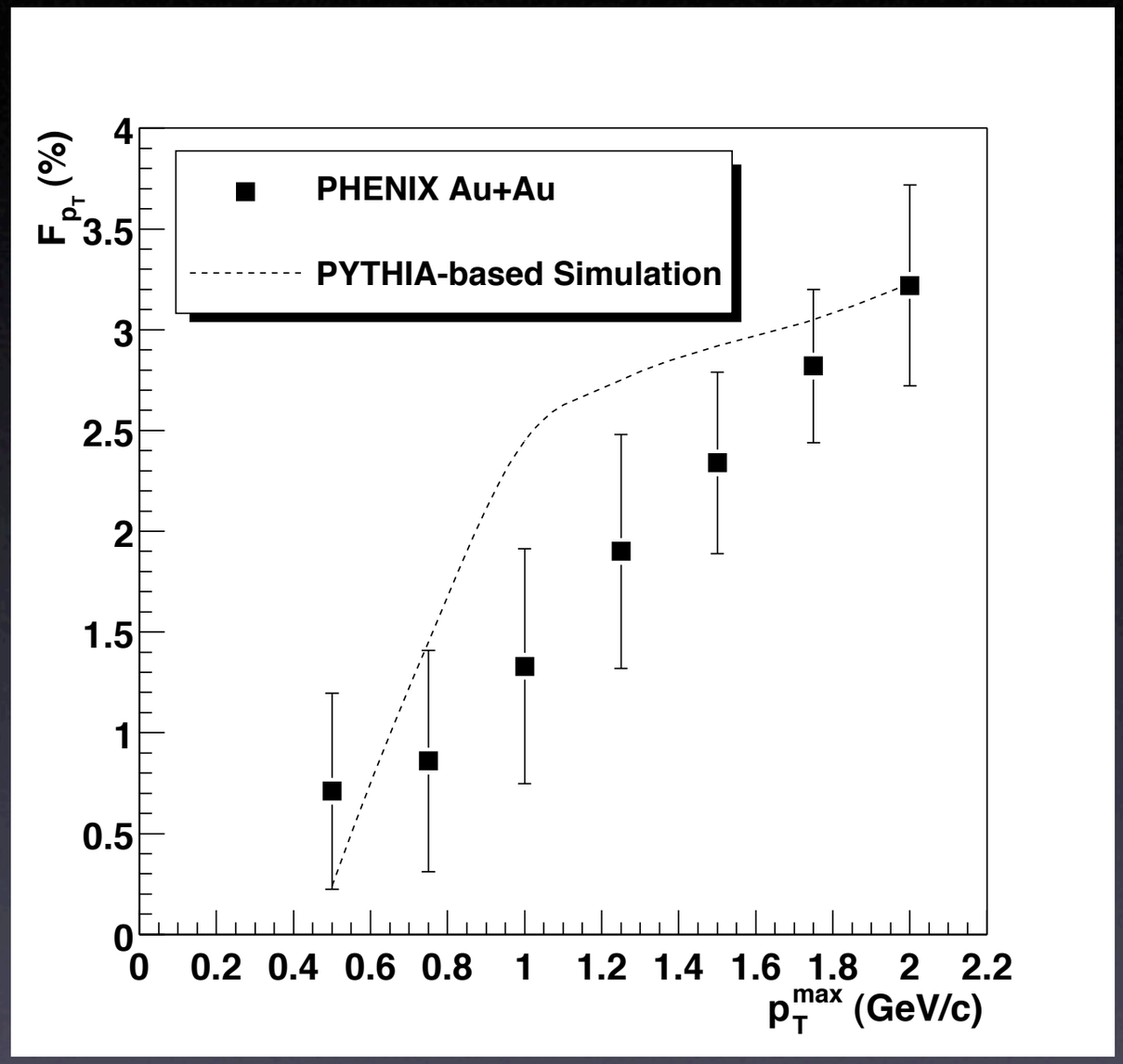
PHOBOS (PRL 2005)



Does particle density control elliptic flow? Baryon density?
How will this plot be modified <u>below</u> top SPS energy?

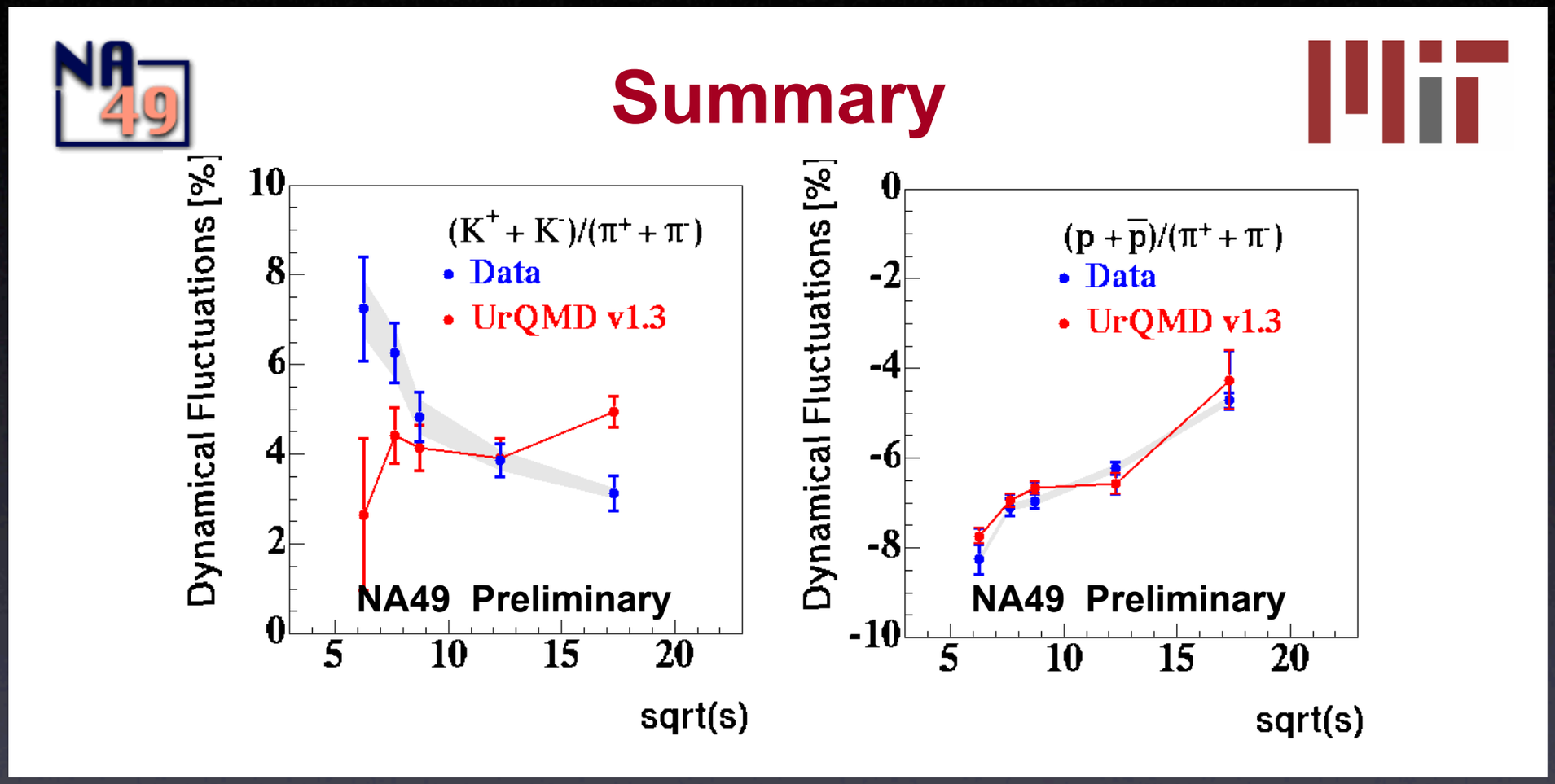
<p_T> Fluctuations





Established technique - but dominated by moderate p_T at top RHIC energies

Flavor Fluctuations

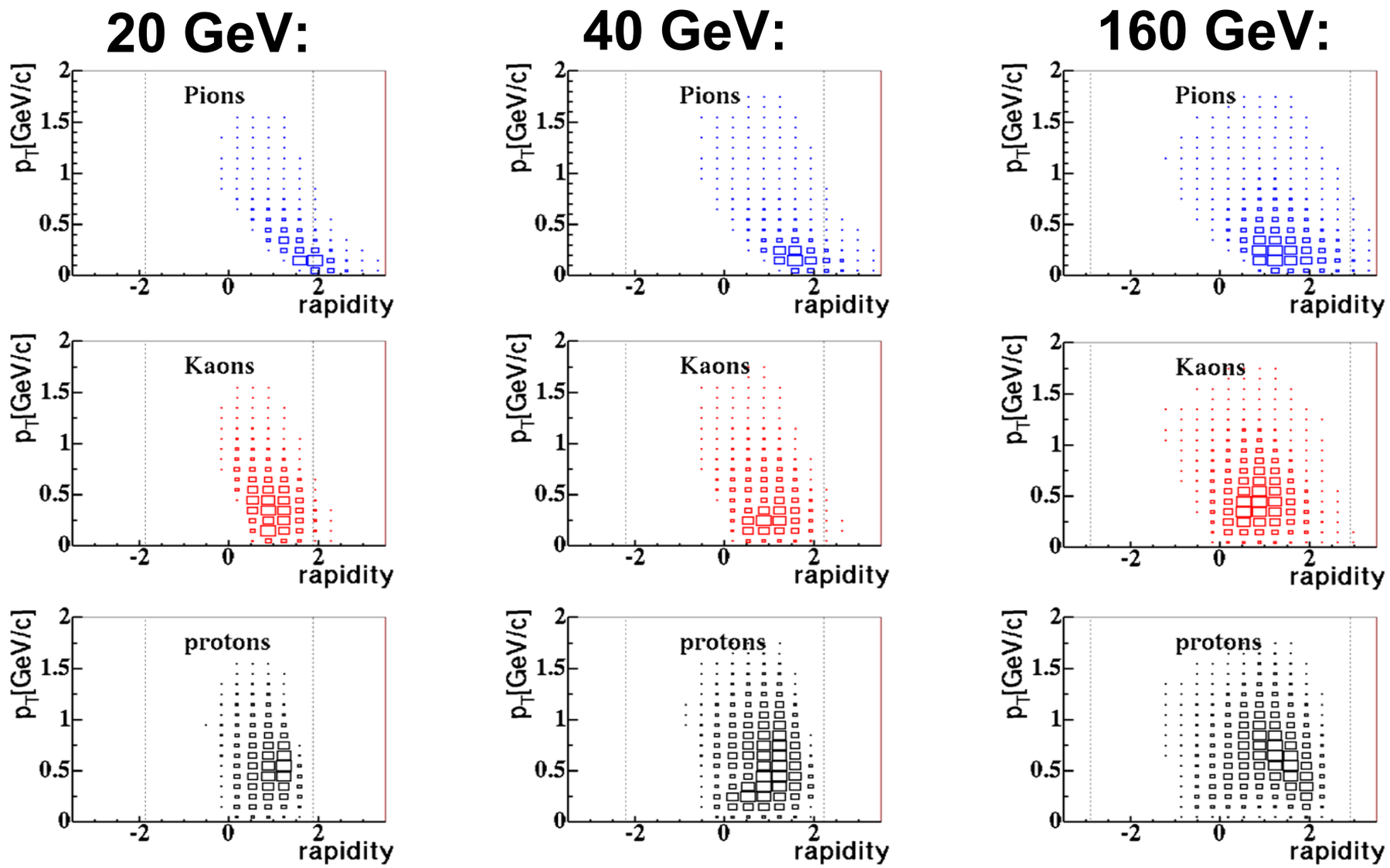


PHENIX is current working on an analysis of K/π fluctuations in top energy Au+Au

Stay tuned...

Flavor Fluctuations

Acceptance



Quark Matter 2004 Christof Roland / MIT January 2004

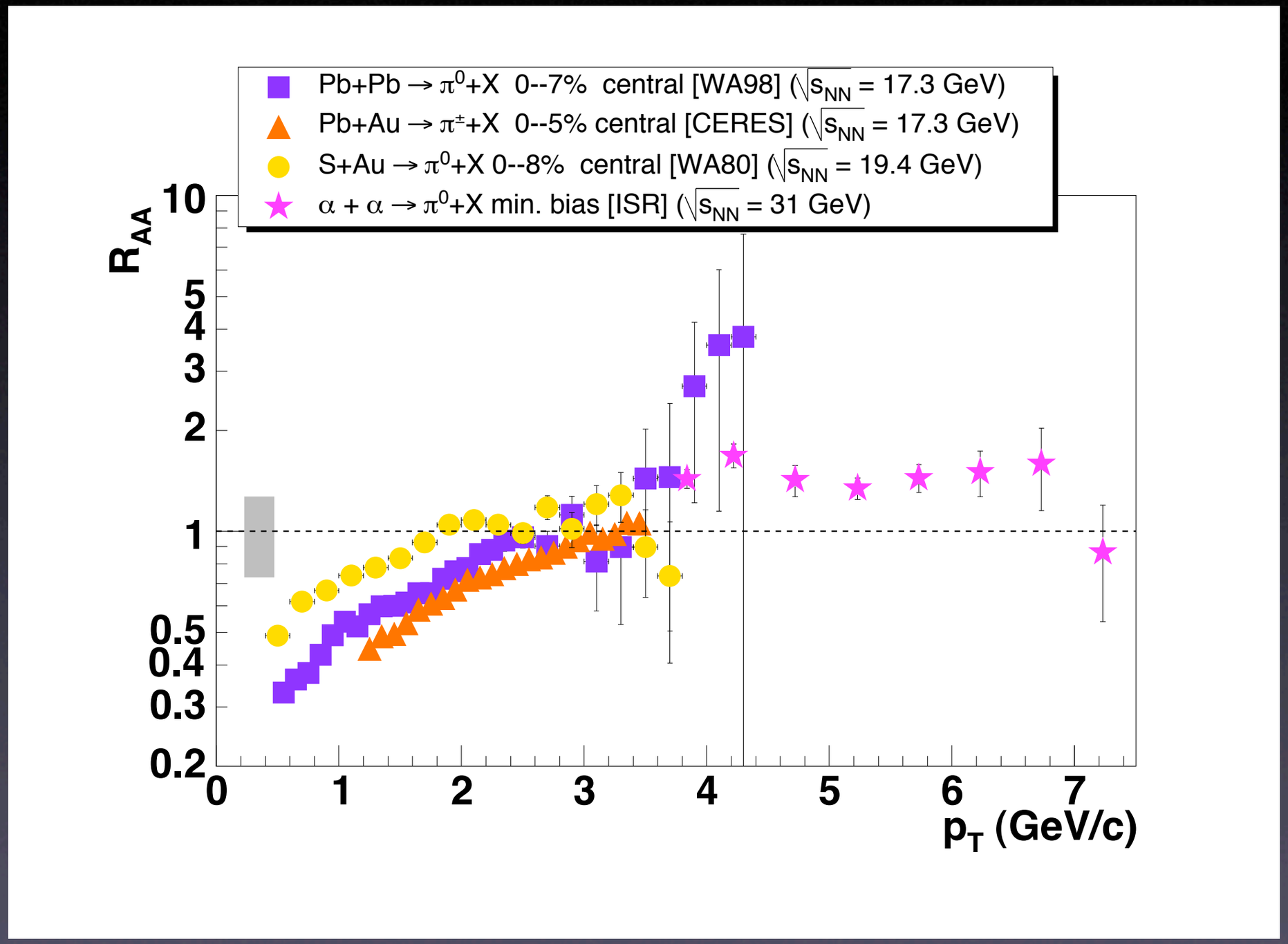
50-500 Tracks/event

Rare Probes

Jet quenching, Dileptons, Open Charm

life is hard...

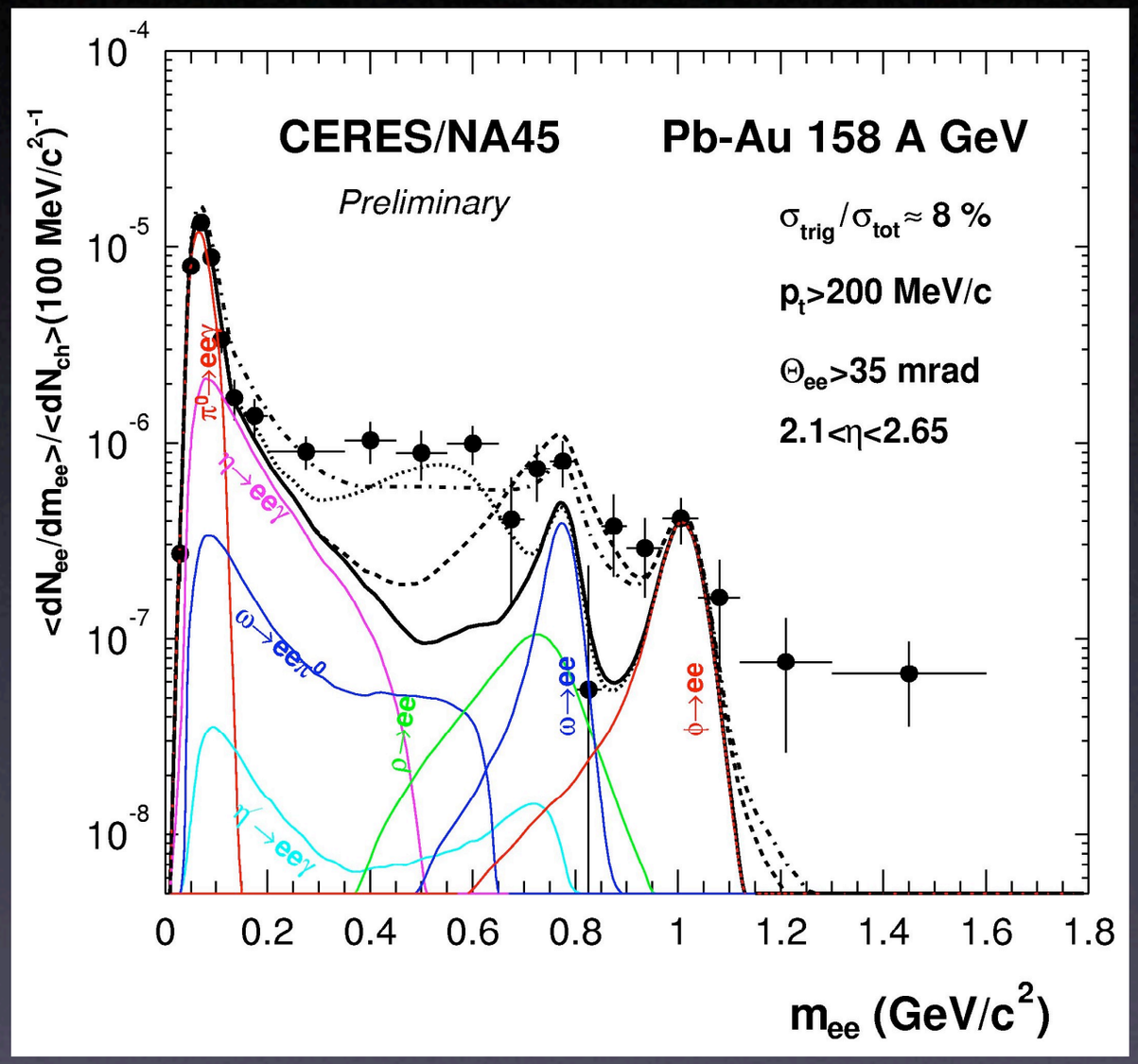
Onset of Jet Quenching?

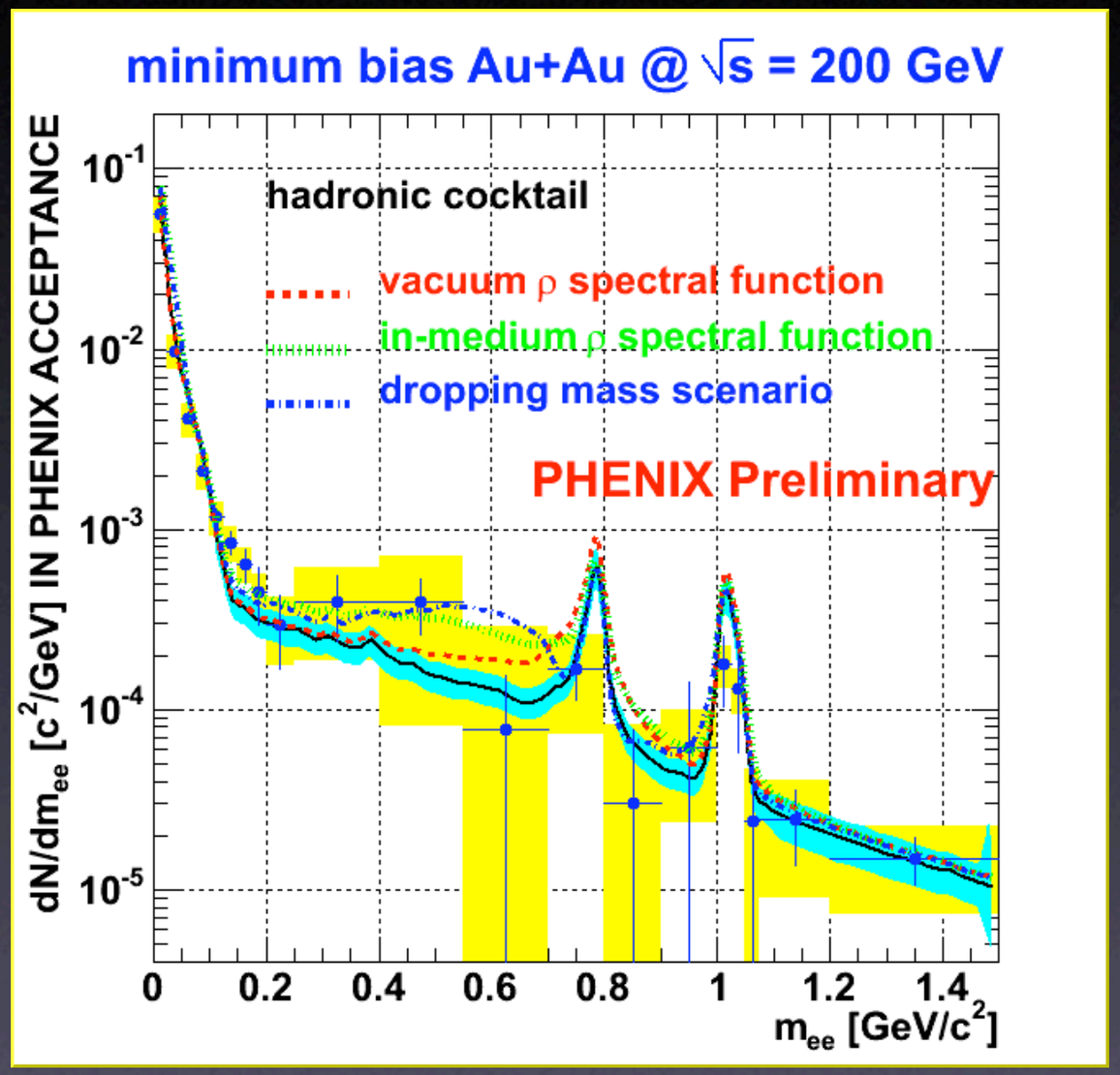


Can we finally trace the emergence of jets in A+A?
Will need consistent p+p and A+A

Di-electron Physics

765M events





Low mass dielectrons may be sensitive to vector meson modifications. PHENIX will improve this using HBD.

e+e- Rates in PHENIX

C. Woody, RHIC II Workshop

Rates for Vector Meson Production

Consider Run 8 (200 GeV Au x Au, 4x Design Luminosity) :

- $L_{peak} = 30 \times 10^{26}\ cm^{-2}\ s^{-1}$
- $L_{ave\ store} = 8 \times 10^{26}\ cm^{-2}\ s^{-1}$
- 20 KHz peak min. bias rate
- 5.4 KHz avg min. bias rate
- 10 week dedicated HBD run (central field in ± configuration)
- $\blacksquare_{RHIC} \times \blacksquare_{PHENIX} = 0.5 \times 0.5 = 0.25$

8.2×10^9 min. bias events produced

$N_{\blacksquare \to e^+e^-} = 1.5 \times 10^{-5}$ / min.bias event

- $\blacksquare$'s produced in $|\blacksquare| < 0.5$
- e^+, e^- into PHENIX central arm acceptance
- $p_{T,e} > 200$ MeV/c

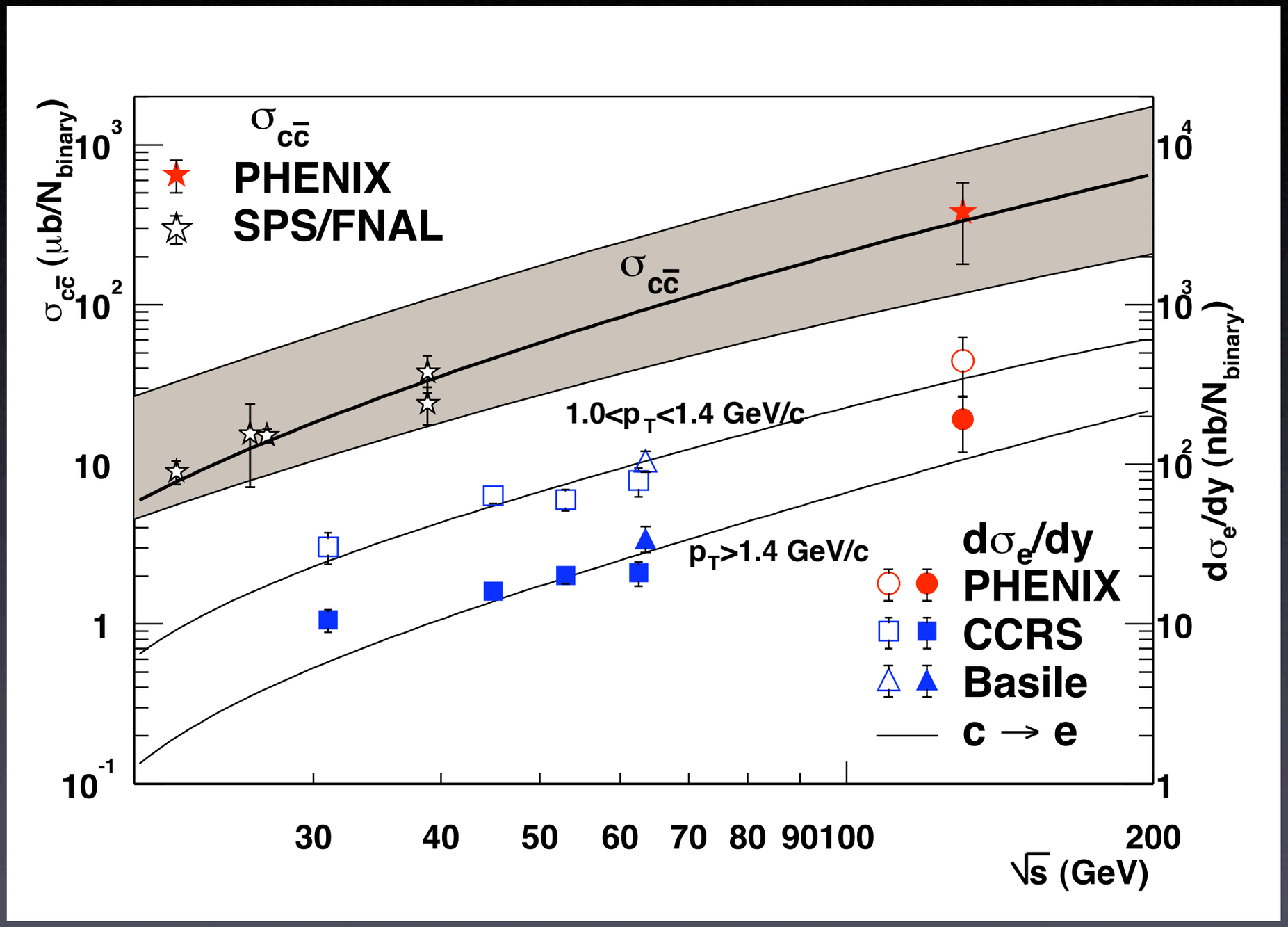
$e^+e^- \to$ PHENIX) = 1 : 0.9 : 0.7

$N_{\blacksquare \to e^+e^-} = 1.2 \times 10^5$ produced in PHENIX acceptance

CERES & PHENIX need 10-100's millions of events.
Will be extremely challenging in low-E RHIC

Charm Production

x500



Charm would also be nice, but rates become negligible at low energies (need FAIR@GSI)

Conclusions

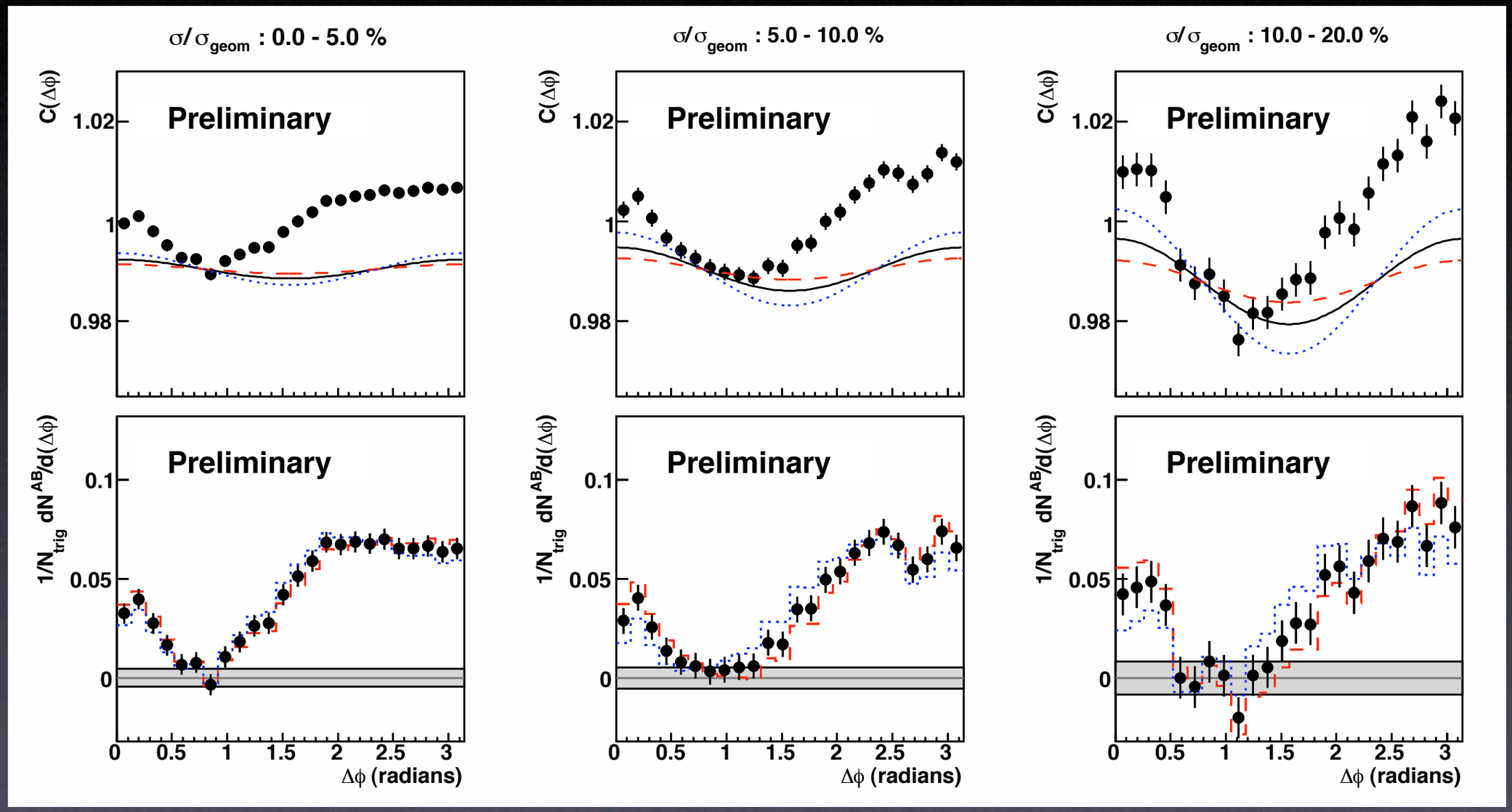
- Unprecedented opportunity to study strongly-interacting matter over 2 orders of magnitude in excitation energy!

- How does net baryon density affect dynamics?

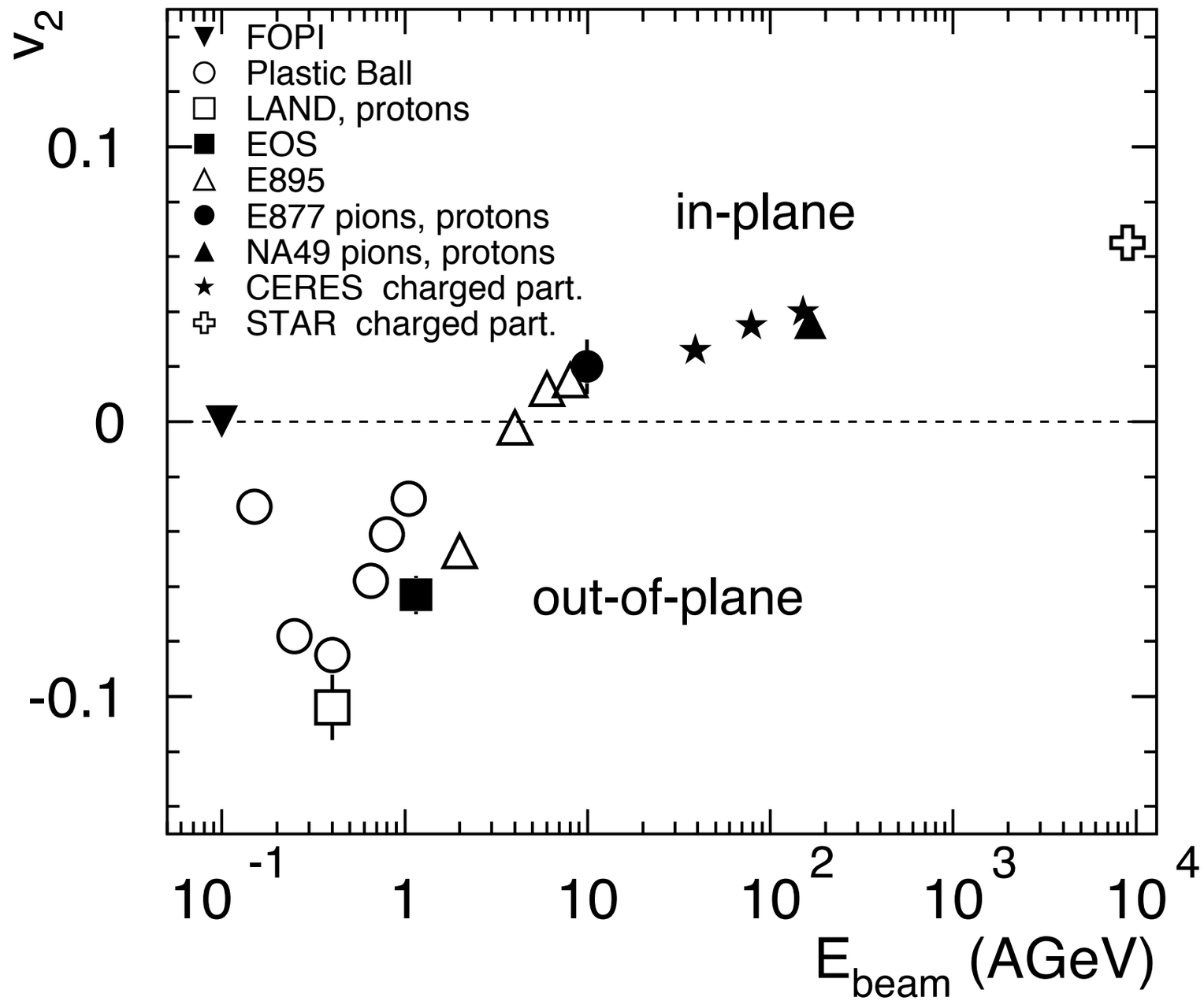
- PHENIX will provide a broad and deep menu of observables
  - Bulk observables (entropy, flavor, dynamics)
  - Correlations & Fluctuations
  - Rare probes (iff a long, dedicated run)

- High return to modest investment

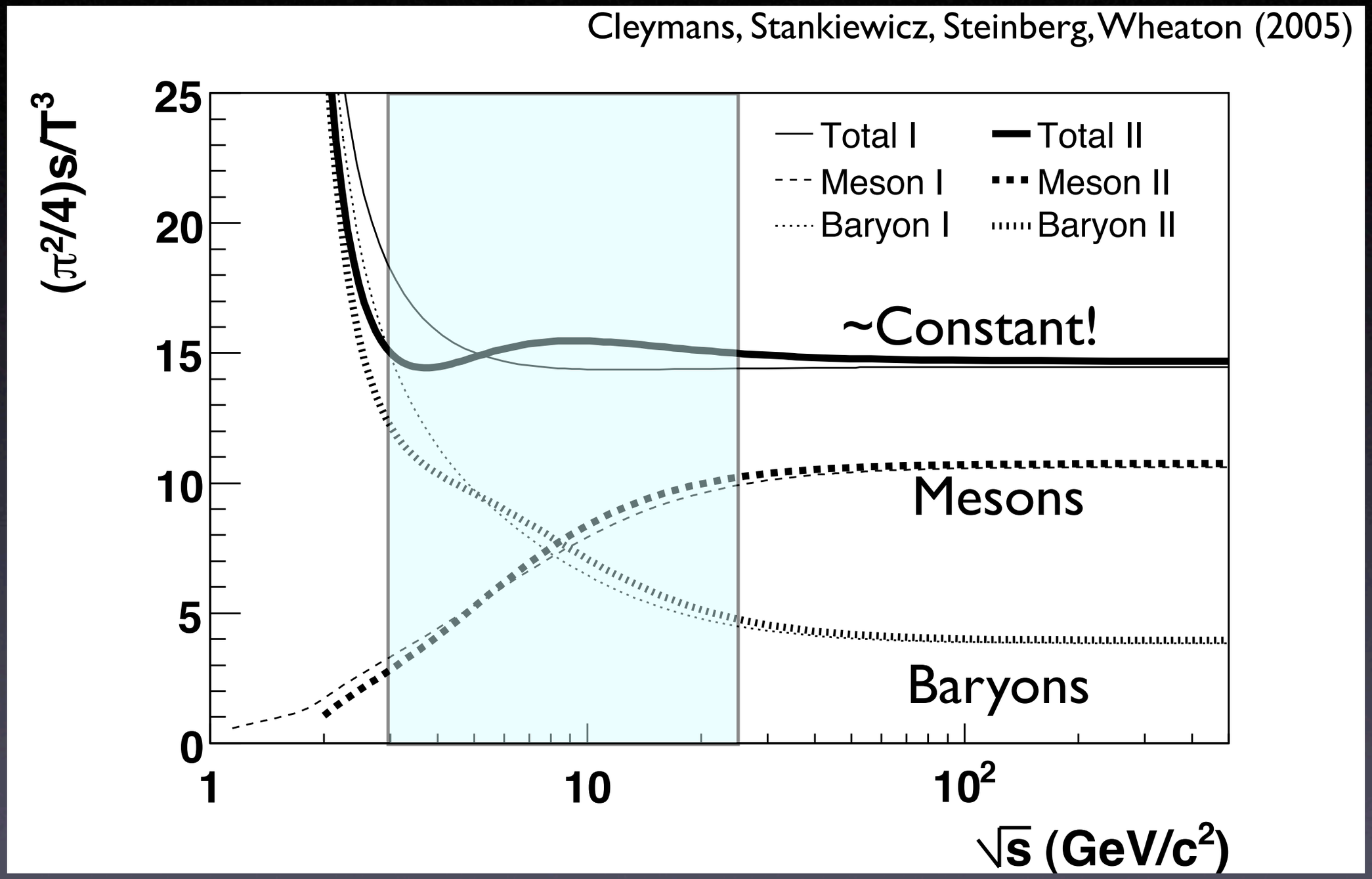
CERES di-hadrons



Elliptic Flow vs. Energy



...but not degrees of freedom



Despite changing baryon/meson ratio,
total degrees of freedom (s/T^3) seems to be <u>constant</u>