Event Anisotropy

What have we learned?

Raimond Snellings

Overview

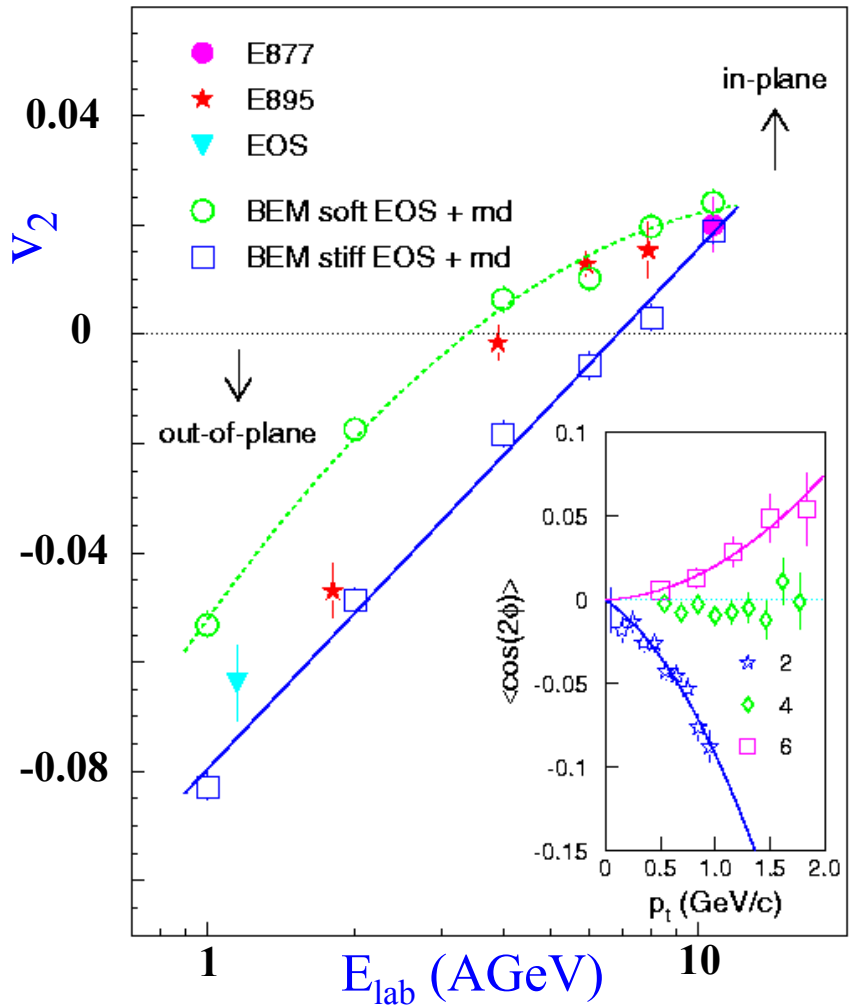
- Event anisotropy (elliptic flow) from AGS to RHIC
- How sensitive is elliptic flow? dynamics of the collision, bulk properties of the created matter, and even early pressure/thermalization?
- Using the geometry by varying size in x and y; HBT, energy loss, in the future J/Ψ, etc.

Low and High density limits

- Low density limit; physics as we “know” it from cascade models (partonic and hadronic). Ingredients which can be “obtained” experimentally are the initial geometry and dN/dy.
- High density limit; hydro approach -> local thermalization at early time, indicative of multiple (>100?) interactions in early (parton) phase.
- Initial expectation; reality in between, transition from low to high density limit while increasing beam energy (Bass *et al*., Teaney *et al*., Humanic, Danielewicz, various parton cascades with modified cross sections/densities starting interactions at early times).

Measurements at AGS; E895 and E877 (Protons)

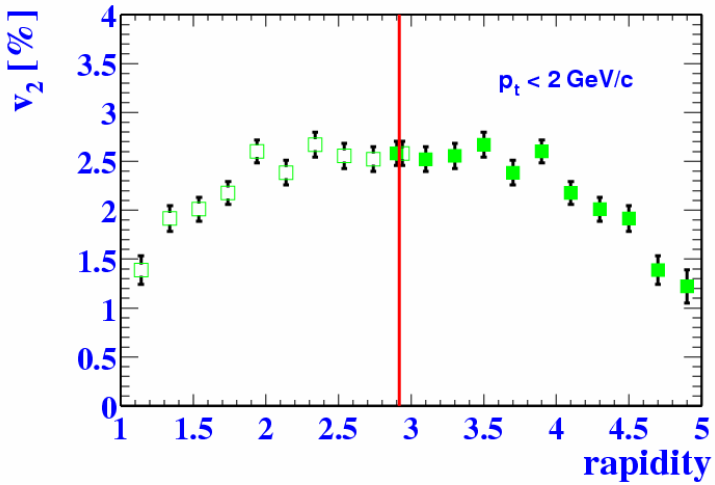
- At low beam energies negative v_2 ("squeeze-out")
- Balancing energy around 4 AGeV, sensitive to EOS

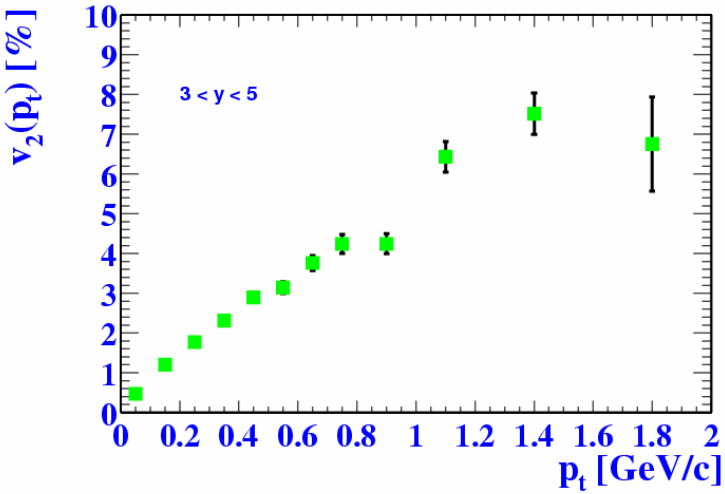


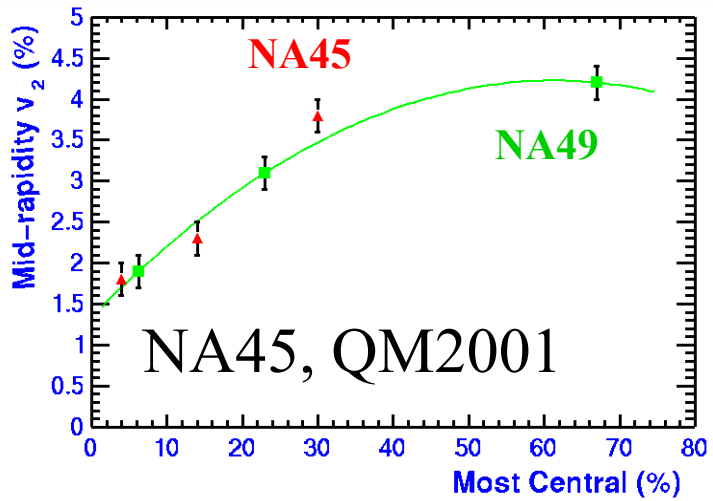
E895, Phys. Rev. Lett. 83 (1999) 1295

P. Danielewicz, Phys. Rev. Lett. 81 (1998) 2438

Measurements at SPS; NA49, CERES



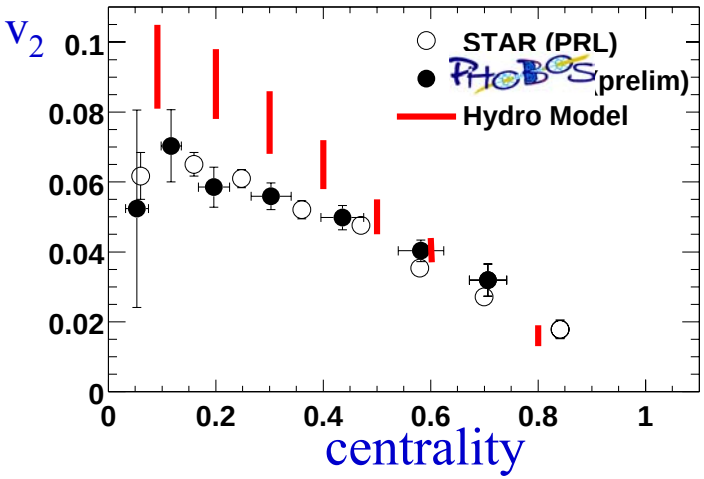


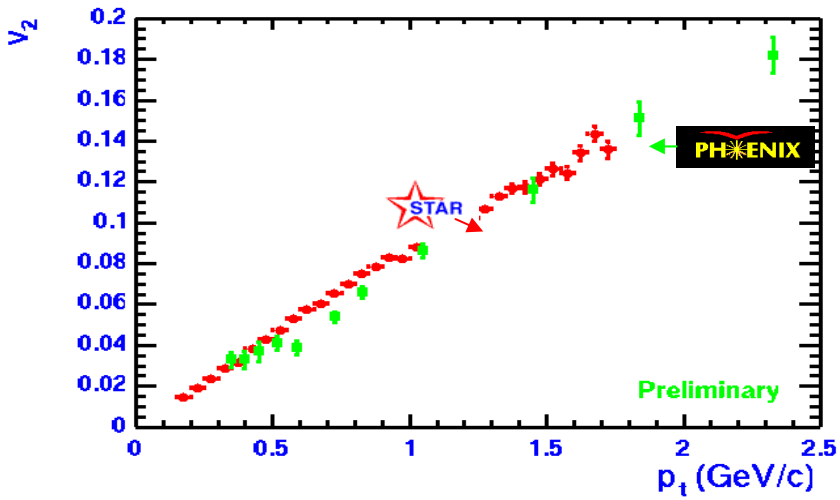


preliminary

158 GeV/A reanalyzed
Cross section weighted averages
300 k events

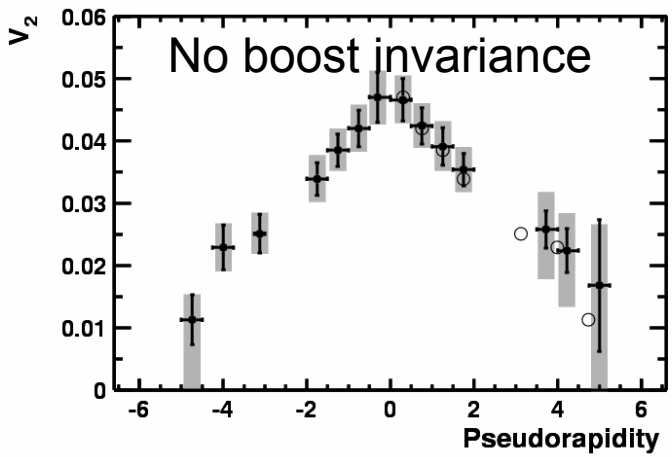
Measurements at RHIC; Phenix, Phobos and STAR





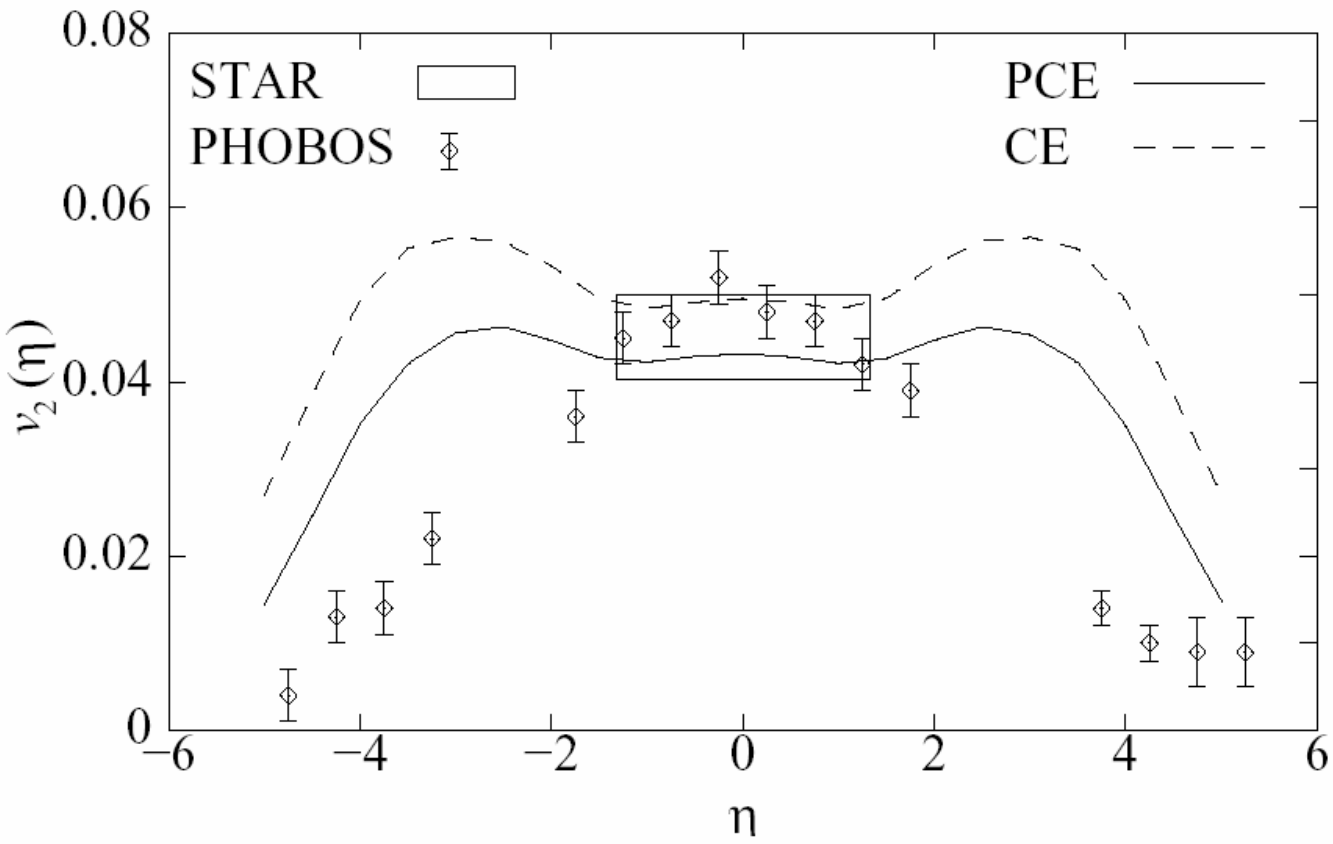
PHOBOS Collaboration, submitted to PRL

R.A. Lacey for the PHENIX Collaboration, nucl-ex/0105003 (QM2001)



The STAR Collaboration, Phys. Rev. Lett. **86** (2001) 402

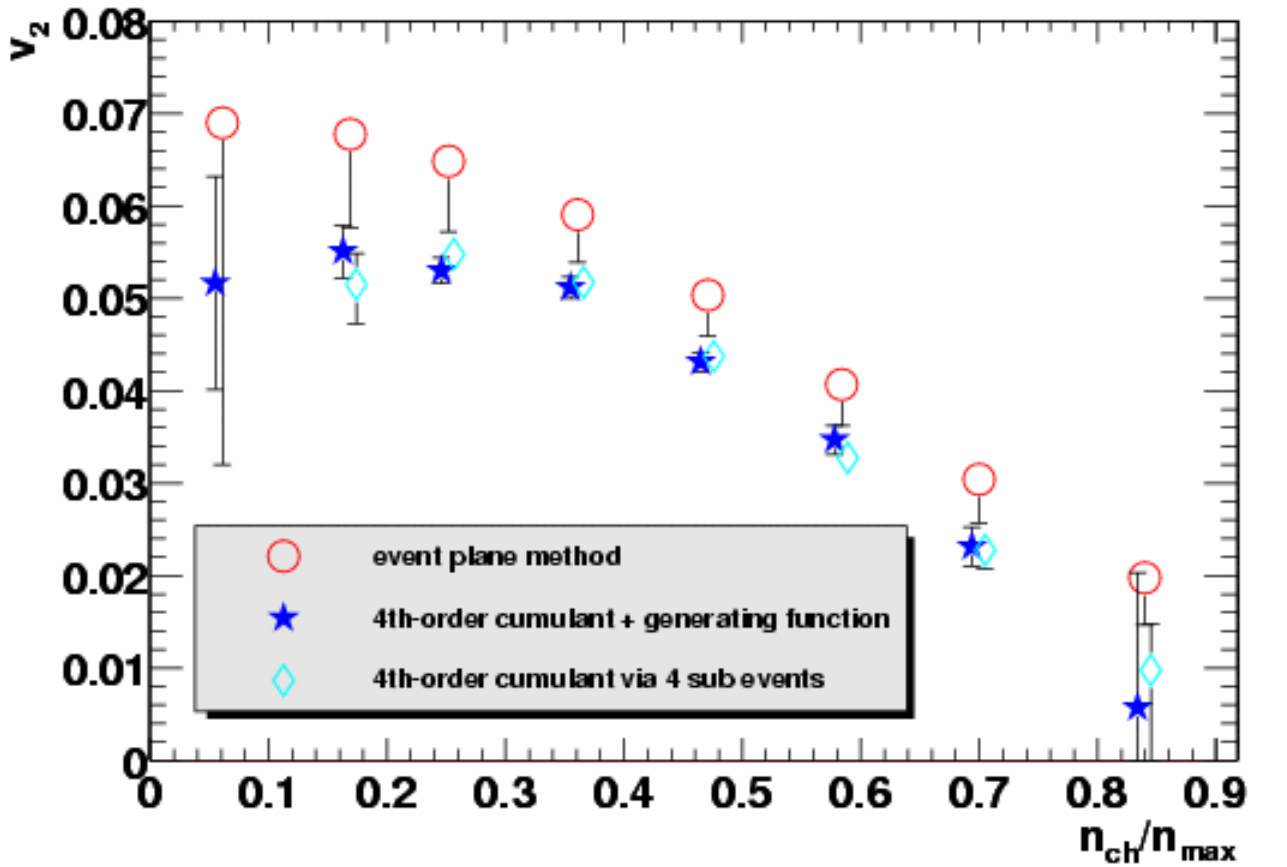
Rapidity dependence of v_2



T. Hirano and K. Tsuda, nucl-th/0205043

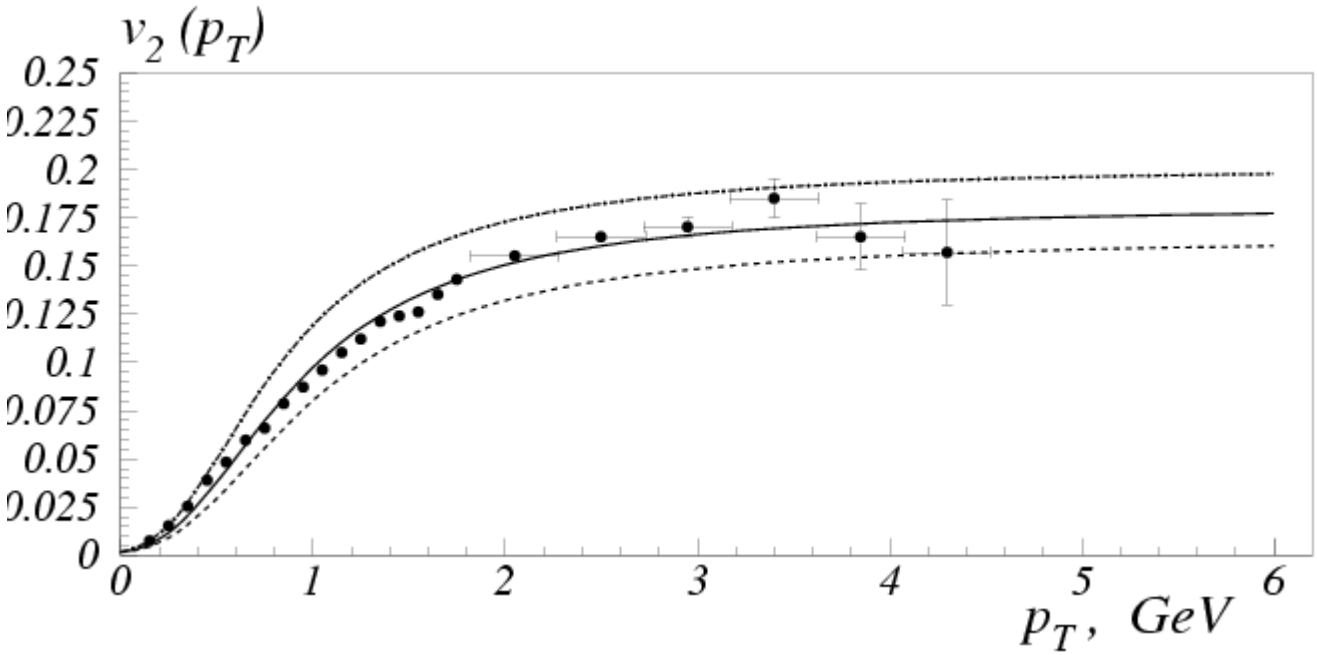
4 particle correlations

Aihong



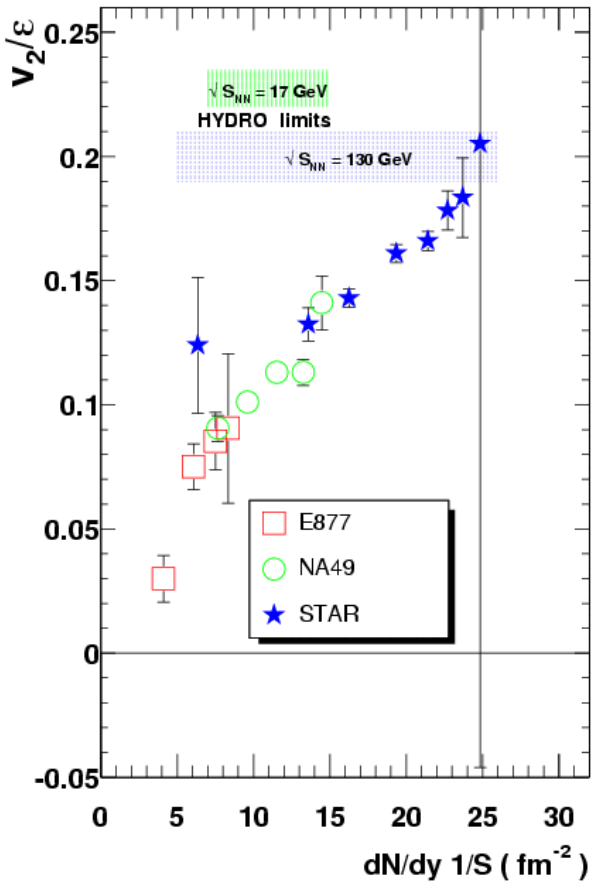
“non-flow”

Yuri V. Kovchegov and Kirill L. Tuchin hep-ph/0203213

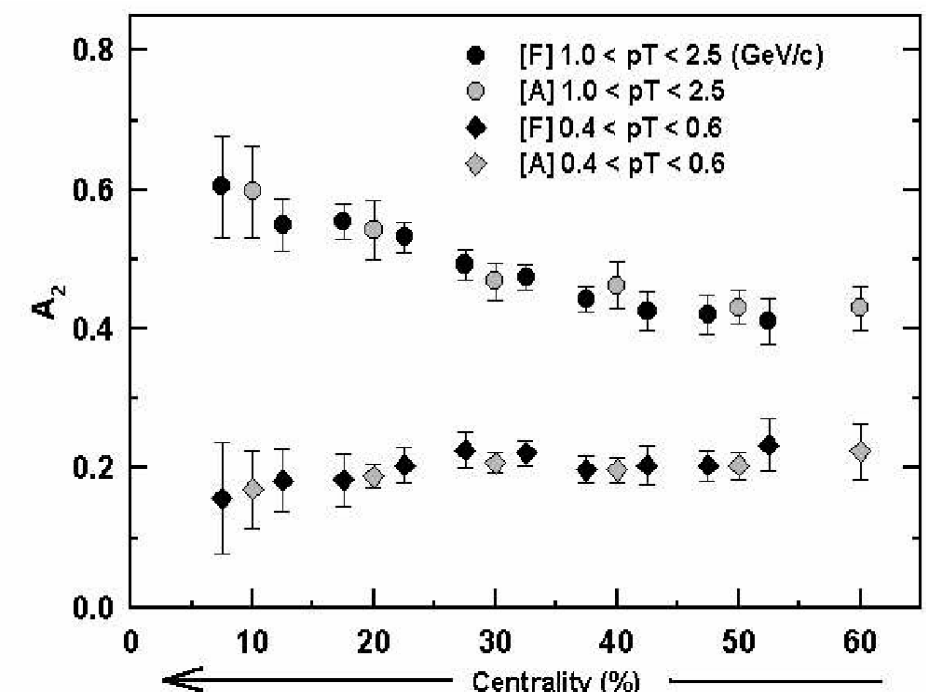


v_2 scaled with initial geometry

STAR, nucl-ex/0206001

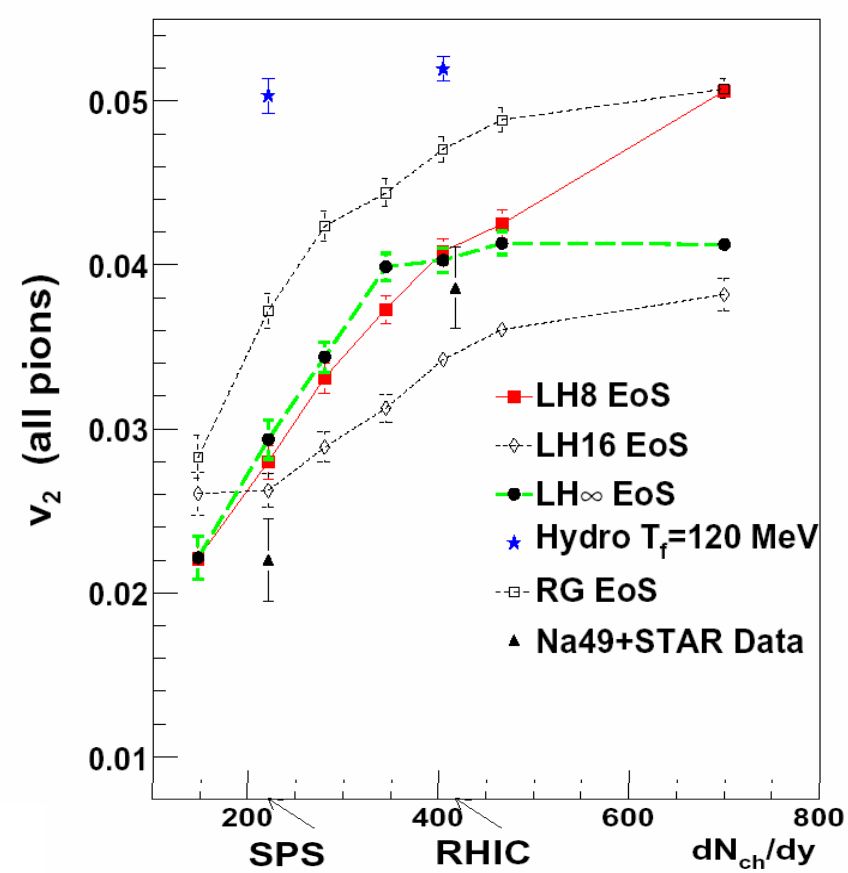


PHENIX, nucl-ex/0204005



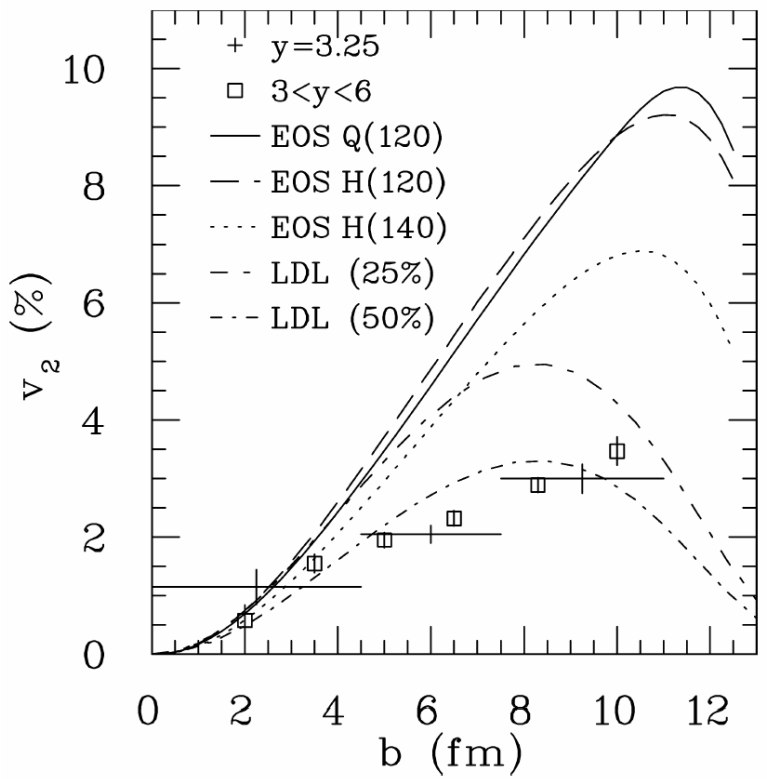
v_2 at fixed impact parameter (so ε is constant) versus dN_{ch}/dy

D. Teaney, J. Lauret and E.V. Shuryak, nucl-th/0110037

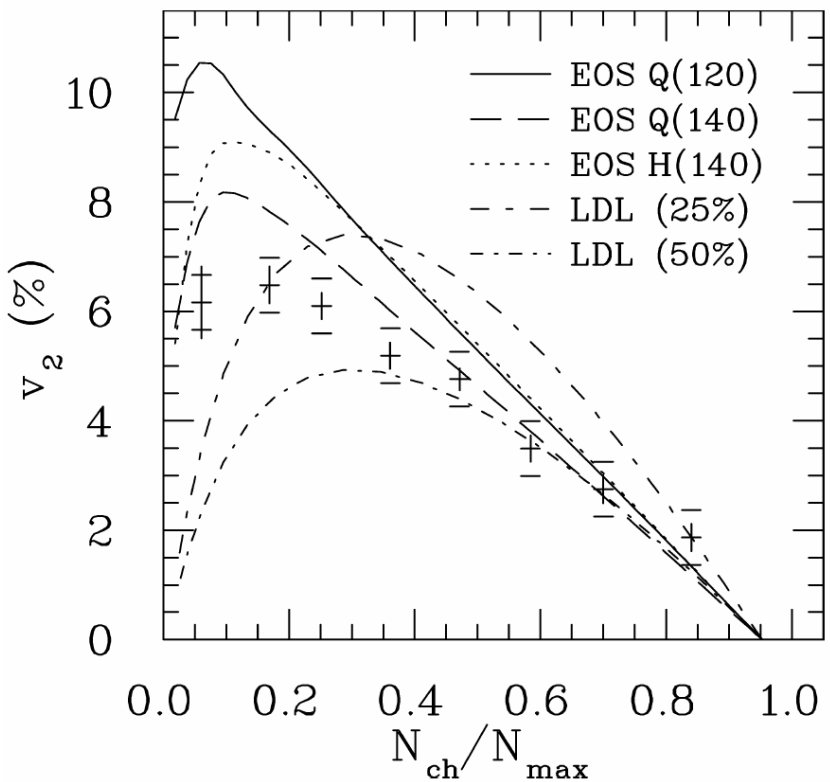


Local thermal equilibrium versus Low Density Limit

SPS; LDL describes centrality dependence



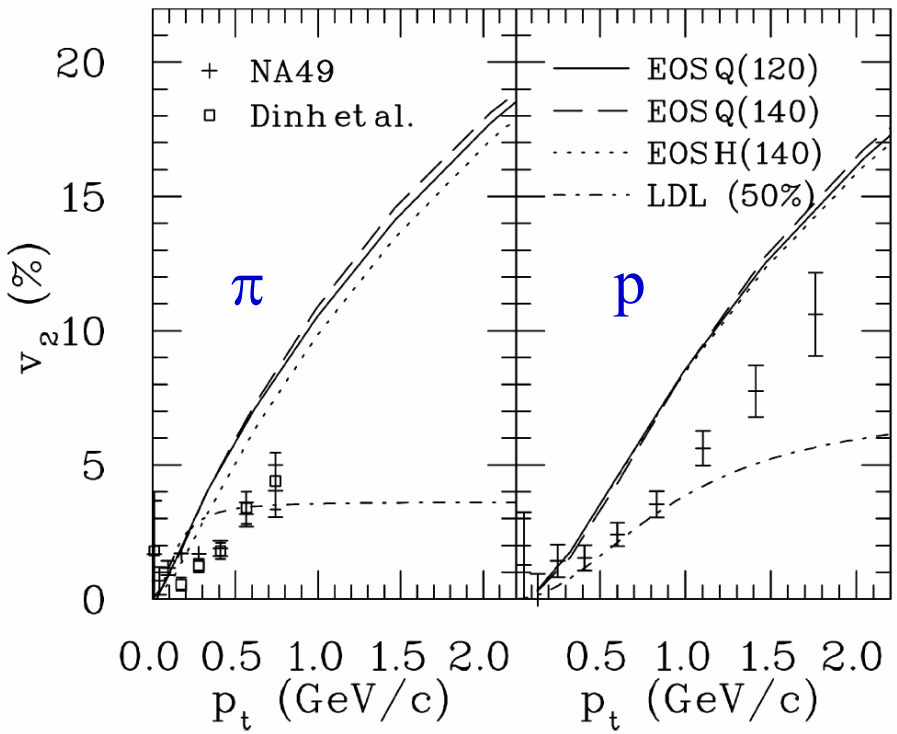
RHIC; LDL describes centrality dependence within systematic errors



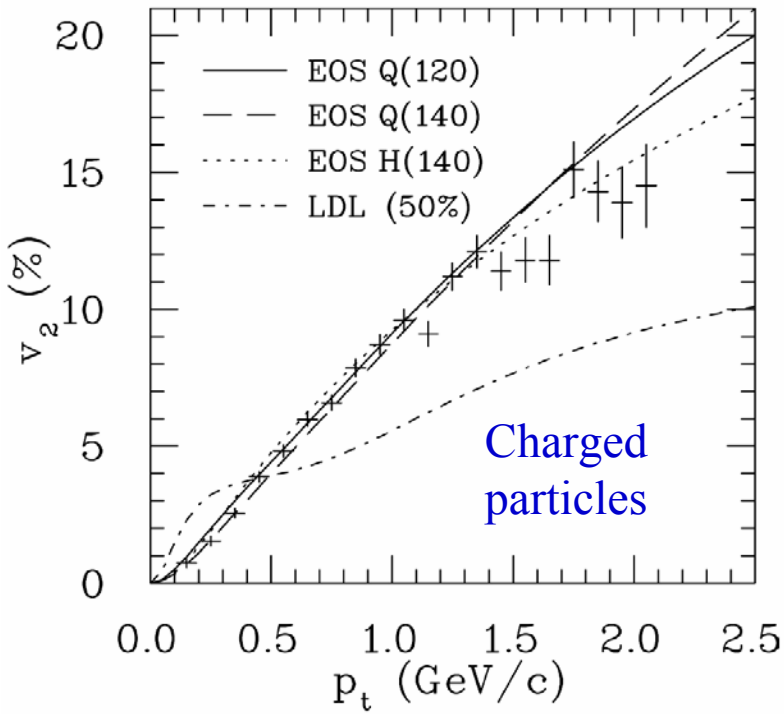
H. Heiselberg and A-M. Levy, Phys. Rev. C 59 (1999) 2716; P. Kolb et al., Phys. Lett. B 500 (2001) 232

Local thermal equilibrium versus Low Density Limit

SPS; LDL and Hydro miss p_t dependence



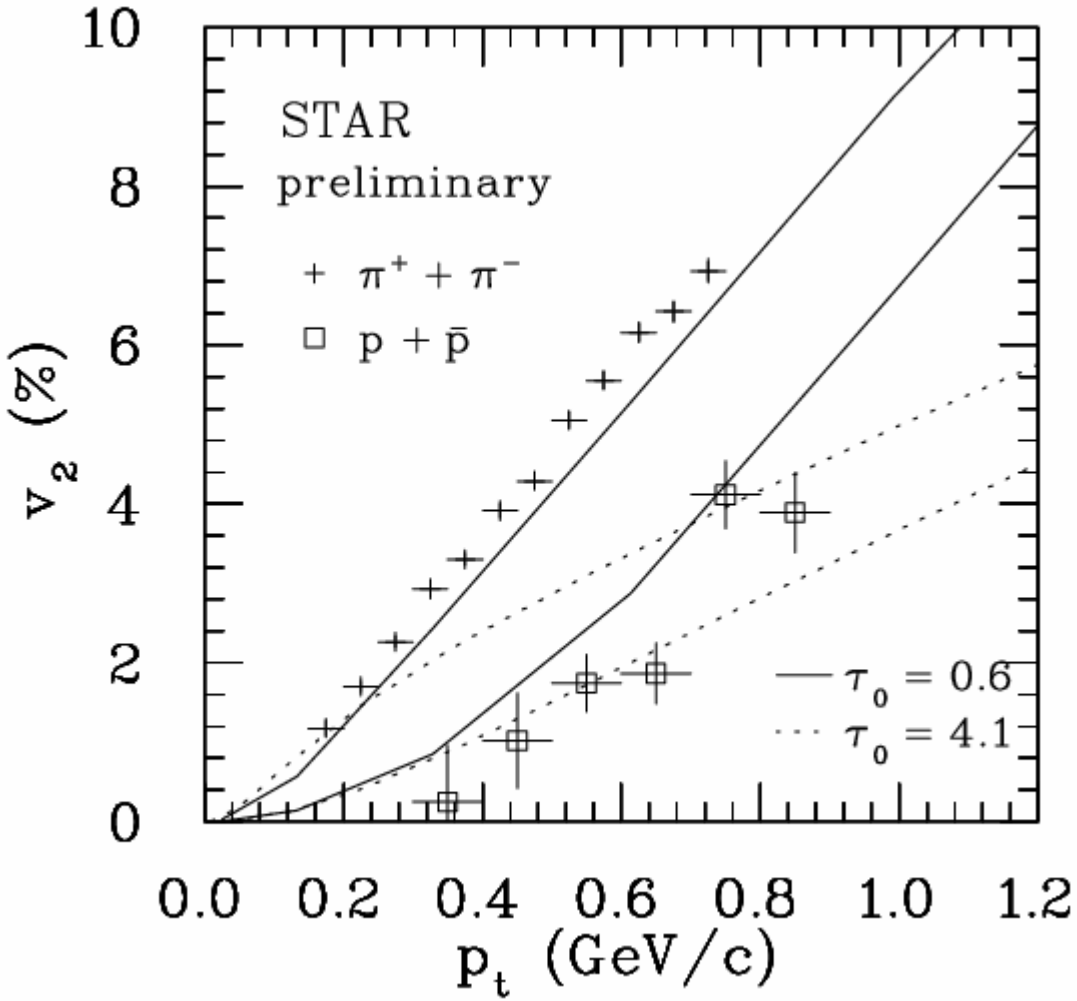
RHIC; p_t dependence described by Hydro



p_t dependence sensitive to approaching thermalization?

Local thermal equilibrium at early time?

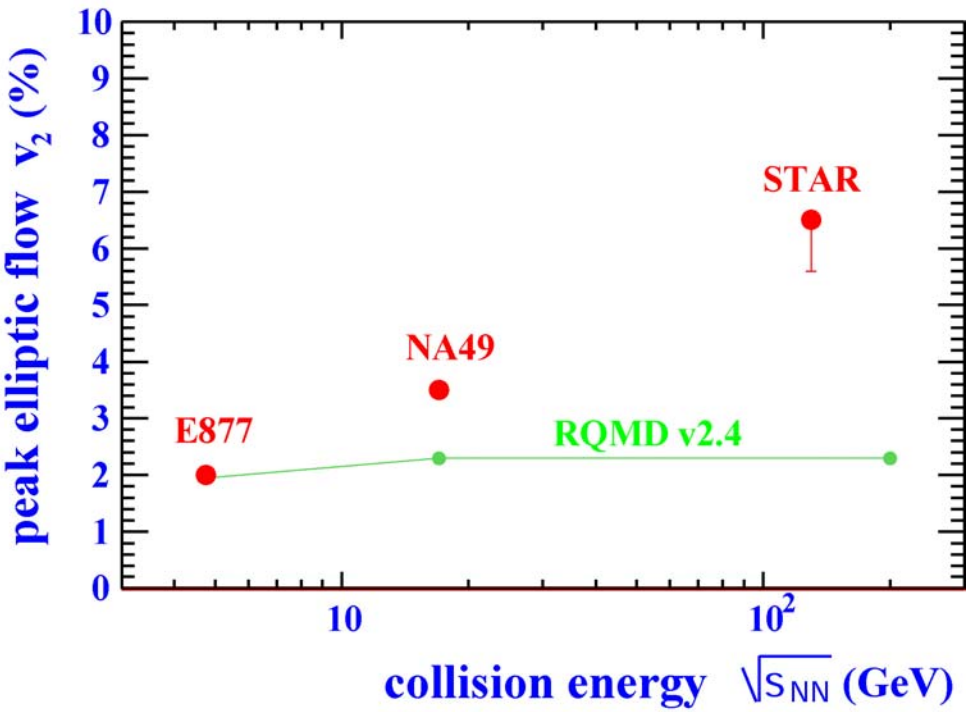
- Late thermalization (initial free streaming) suppresses $v_2(p_t)$ and does not describe the data



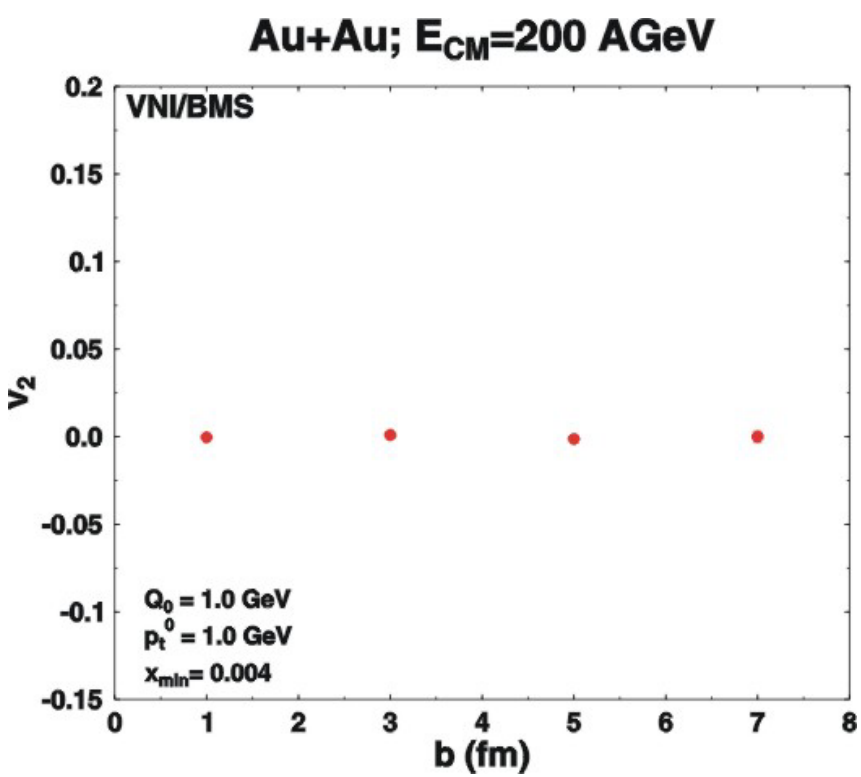
P. Huovinen, nucl-th/0108033 (INPC)

From AGS to RHIC

- AGS; magnitude described by cascade models (misses p_t dependence)
- SPS; combining Hydro + Cascade
- RHIC; Hydro description for central to mid-central collisions



VNI/BMS



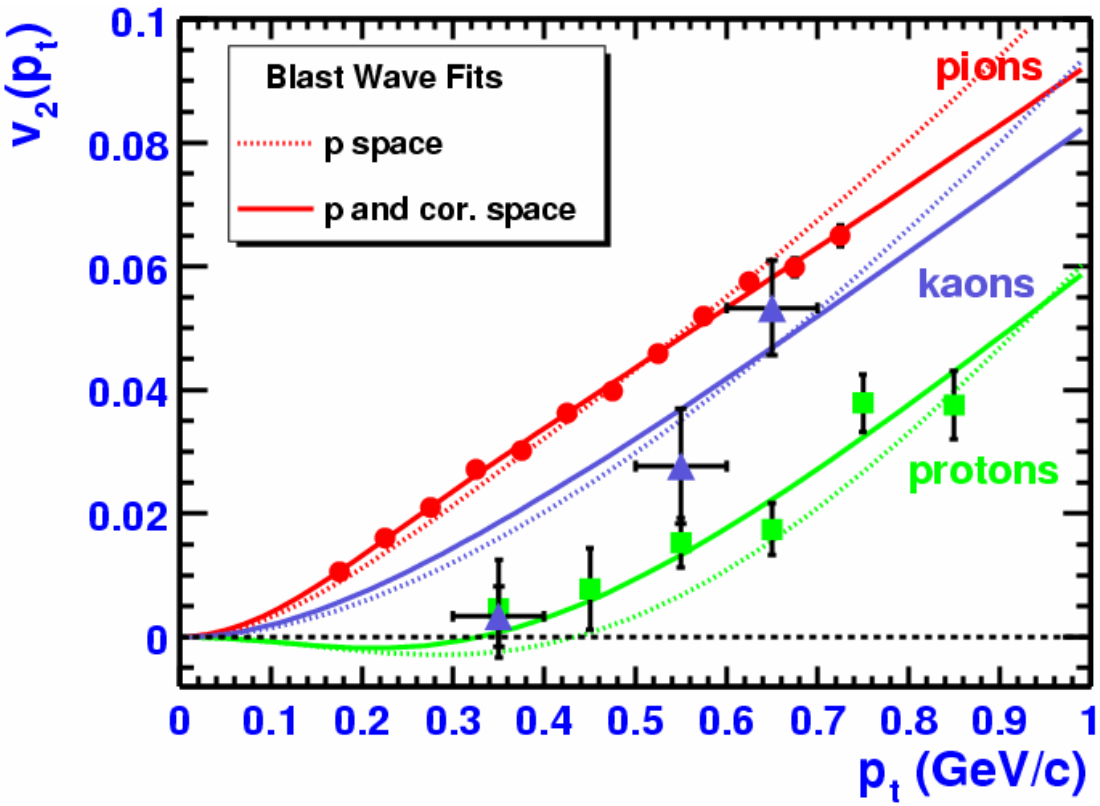
- Steffen Bass:
  - unscreened pQCD cross sections with a cut-off p_0=1 GeV are on the order of 0.4 mbarn – a factor of 10 too small for generating sizable elliptic flow
  - ➢ V_2 is soft, non-perturbative physics!

Measurements at RHIC; STAR, identified particles

At AGS; S. Voloshin for the E877 Collaboration

At SPS; Heiselberg and Levy

	dashed	solid
T (MeV)	135 ± 20	100 ± 24
$\beta_0(c)$	0.52 ± 0.02	0.54 ± 0.03
$\beta_a(c)$	0.09 ± 0.02	0.04 ± 0.01
S_2	0.0	0.04 ± 0.01

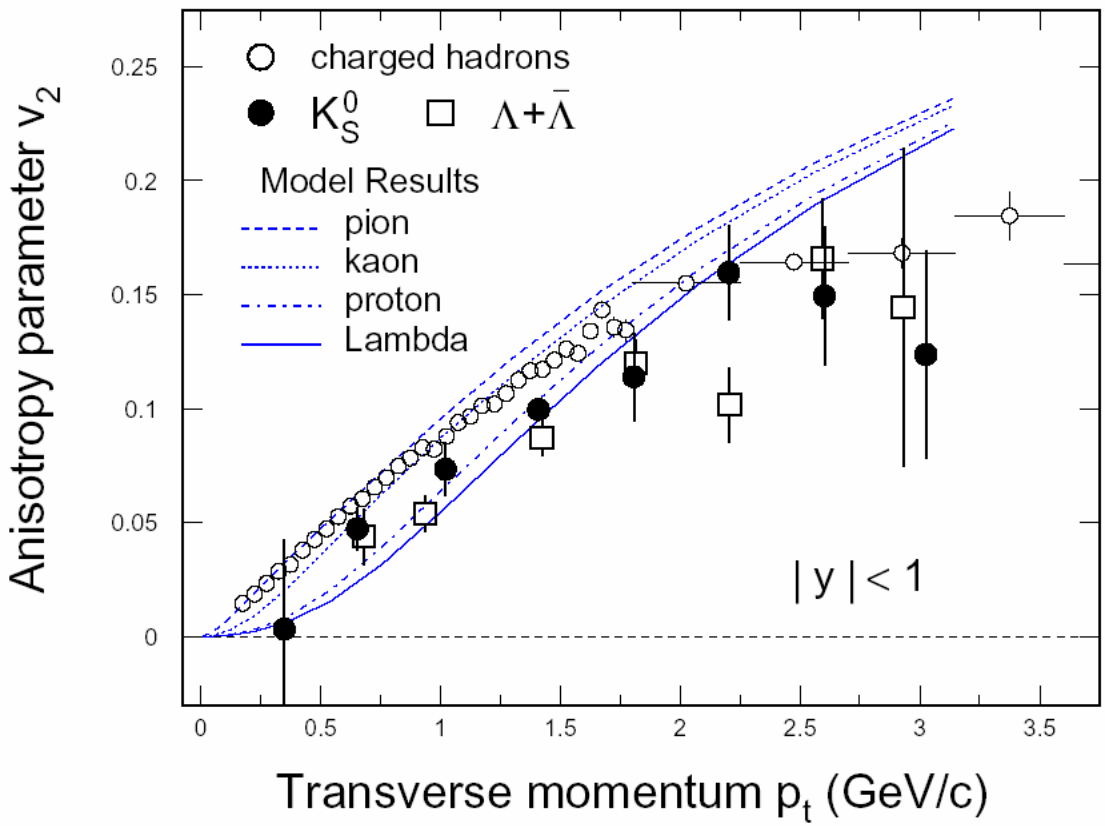


The STAR Collaboration, Phys. Rev. Lett. 87 (2001) 182301

Strangeness elliptic flow; STAR RHIC 130

How important are small hadronic interaction cross sections?

Hydro calculations:
P. Huovinen



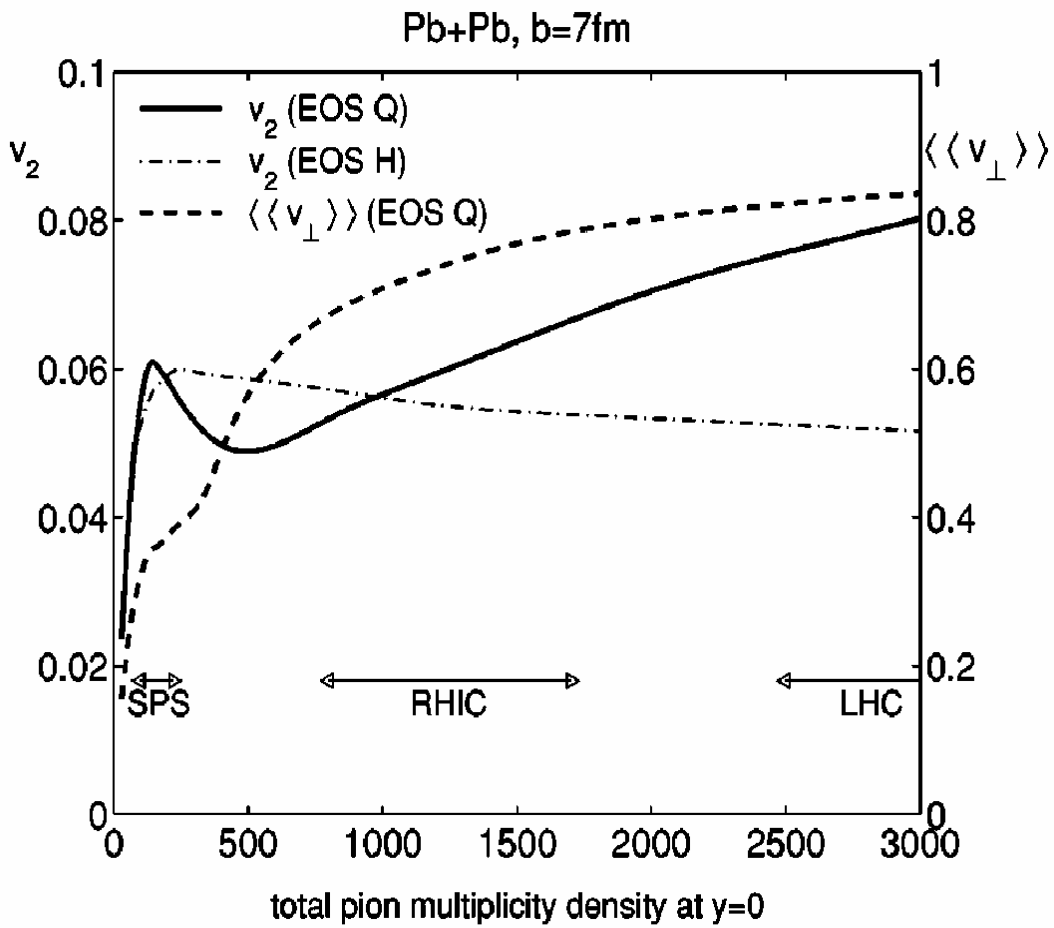
STAR, hep-ex/0205072

Approaching a system in local thermal equilibrium?

- v_2 for smaller system at same eccentricity (for mid central events) and examine scaling with A. Due to interplay of eccentricity and energy density Hydro predicts at RHIC energies larger v_2 for smaller system. This would unambiguously distinguish LDL and Hydro.
- $v_2(p_t)$ for particles with small hadronic interaction cross section, ϕ (complicated by kaon coalescence) Ω etc.
- v_2 at higher energies
- Use the combined information of single particle spectra, HBT and elliptic flow

Higher energies

P. Kolb, J. Sollfrank, and U. Heinz, Phys. Rev. C. C62 054909 (2000).

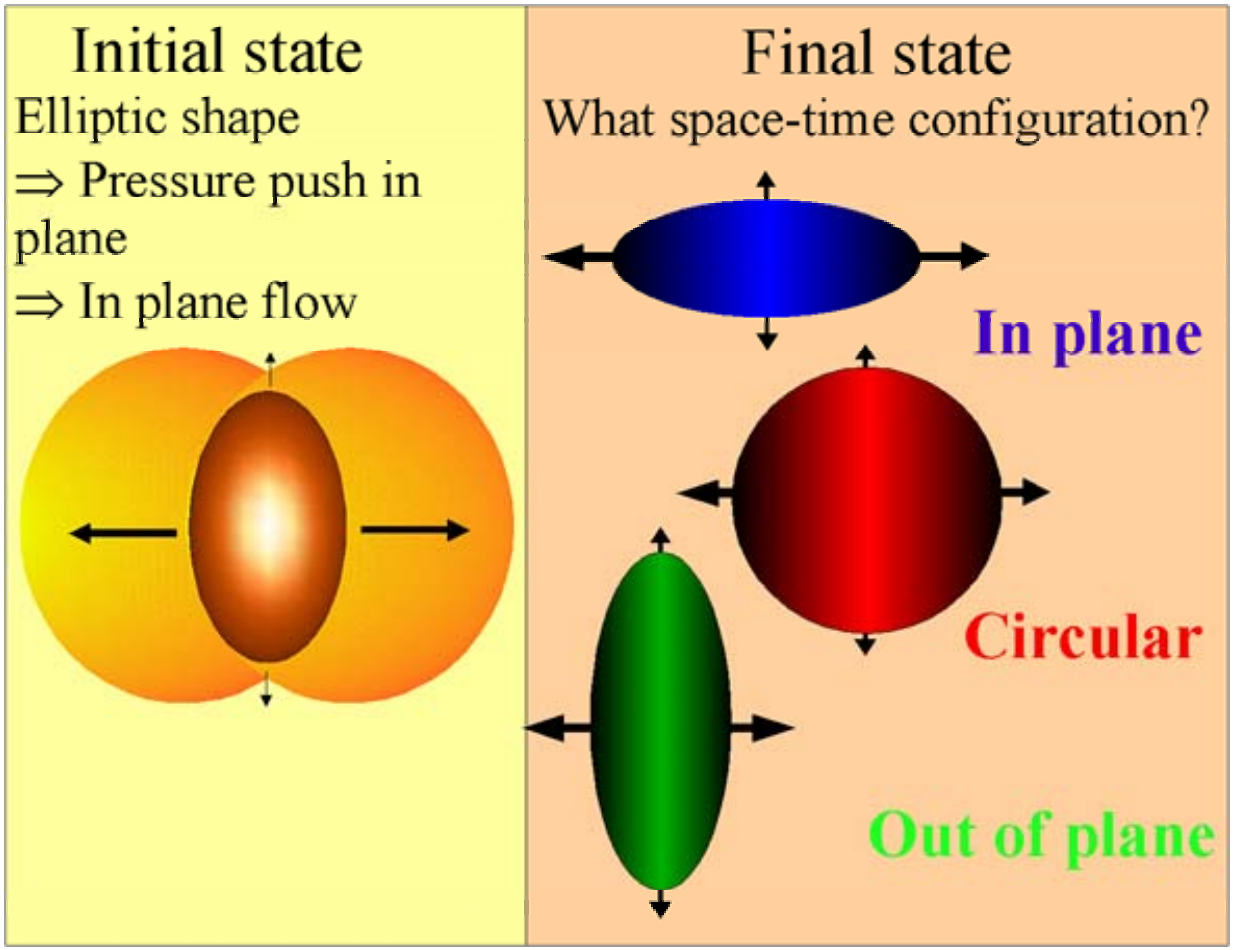


Event anisotropy, spectra and HBT

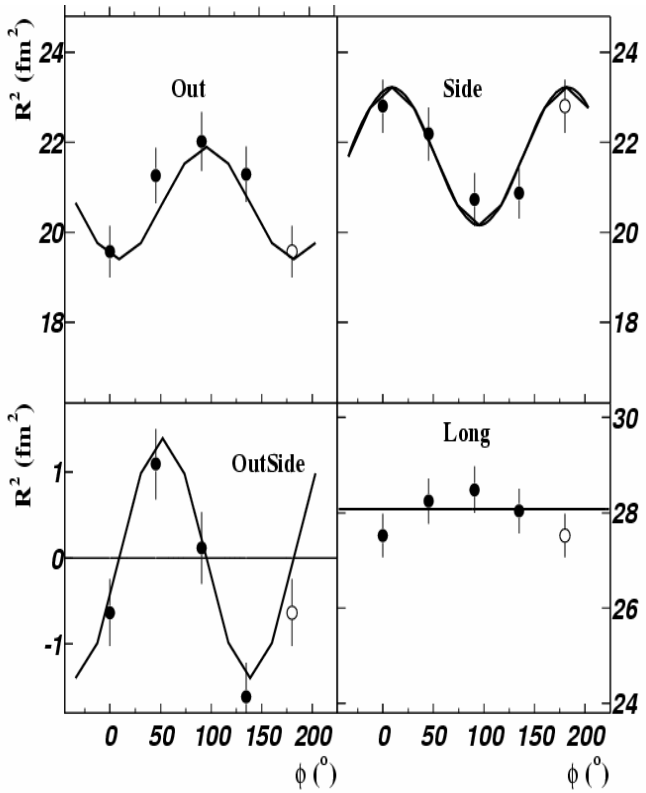
Combining observables can and should be done in the RHIC experiments

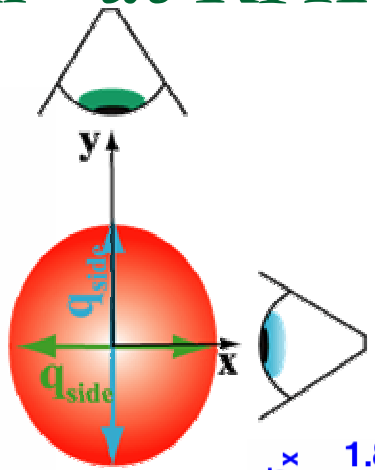
Parameter	Symbol	Spectra	Elliptic flow $v_2(p_t, m)$	HBT (p_t, ϕ)
Temperature	T	yes	yes	yes
Average transverse flow velocity	β_t or ρ_0	yes	yes	yes
Azimuthal modulation in flow velocity	β_a or ρ_a		yes	yes
Coordinate-space anisotropy	S_2		yes	yes
Radius in y-direction	R_y			yes
Duration of particle emission	τ			yes

Transverse "radii" of the system at freeze-out?



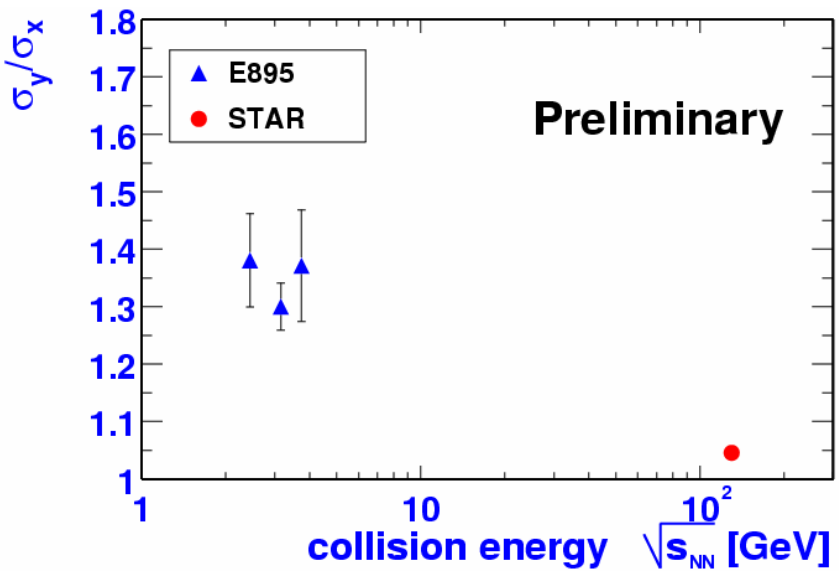
Using the (freeze-out) geometry; Transverse "radii" at RHIC





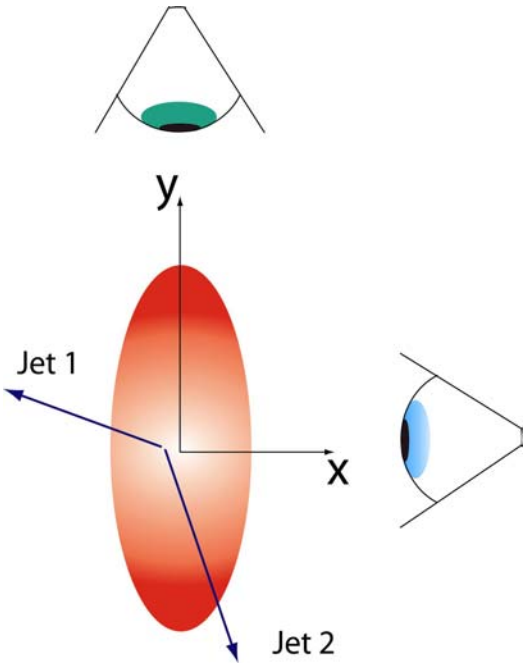
Source still extended perpendicular to the reaction plane

Smaller oscillation compared to AGS

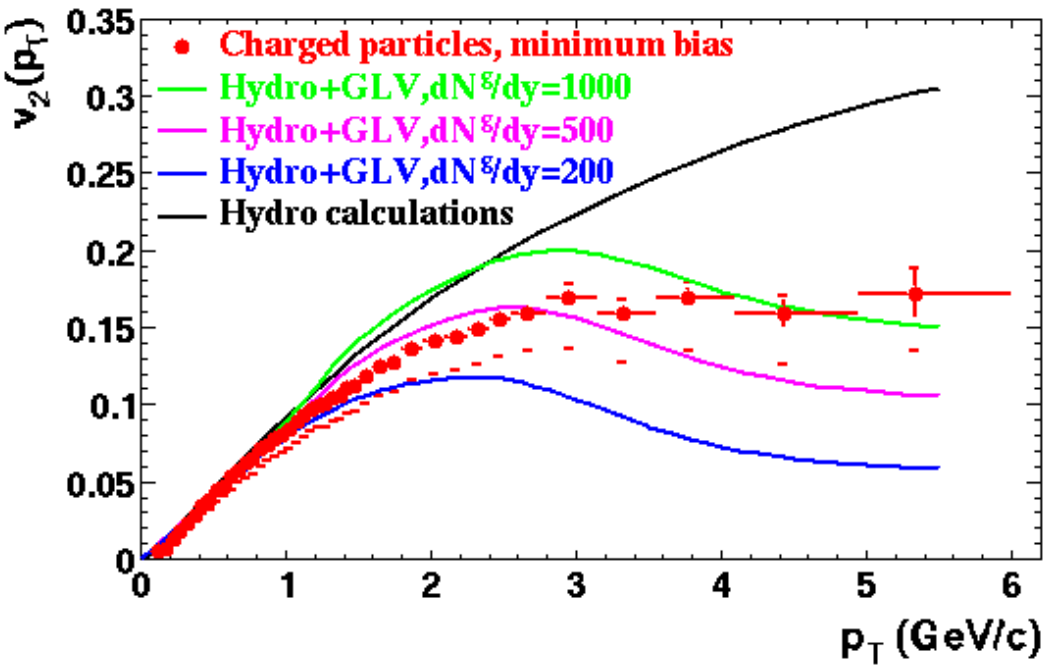


Randy Wells

Using the (initial) geometry; "high-pt" event anisotropy



STAR, nucl-ex/0206006



http://www.lbl.gov/nsd/annual/rbf/nsd1998/rnc/RNC.htm

R17. Event Anisotropy as a Probe of Jet Quenching

R.J.M. Snellings and X.-N. Wang

R.S, A.M. Poskanzer, S.A. Voloshin, STAR note, nucl-ex/9904003

Summary

- Comments on the detailed elliptic flow studies at RHIC:
  - L. McLerran: one needs very strong interactions amongst the quark and gluons at very early times in the collision (hep-ph/0202025).
  - U. Heinz: resulting in a well-developed quark-gluon plasma with almost ideal fluid-dynamical collective behavior and a lifetime of several fm/c (hep-ph/0109006).
  - E. Shuryak: probably the most direct signature of QGP plasma formation, observed at RHIC (nucl-th/0112042).
- Elliptic flow, spectra and HBT are the main tools for characterizing the dynamics of the system. Need to be understood in detail before firm conclusions from other exiting measurements at RHIC can be made.
- More model independent information can/should be gotten from multi strange particle elliptic flow + spectra