UNIVERSITY OF BIRMINGHAM

"Soft physics in STAR"

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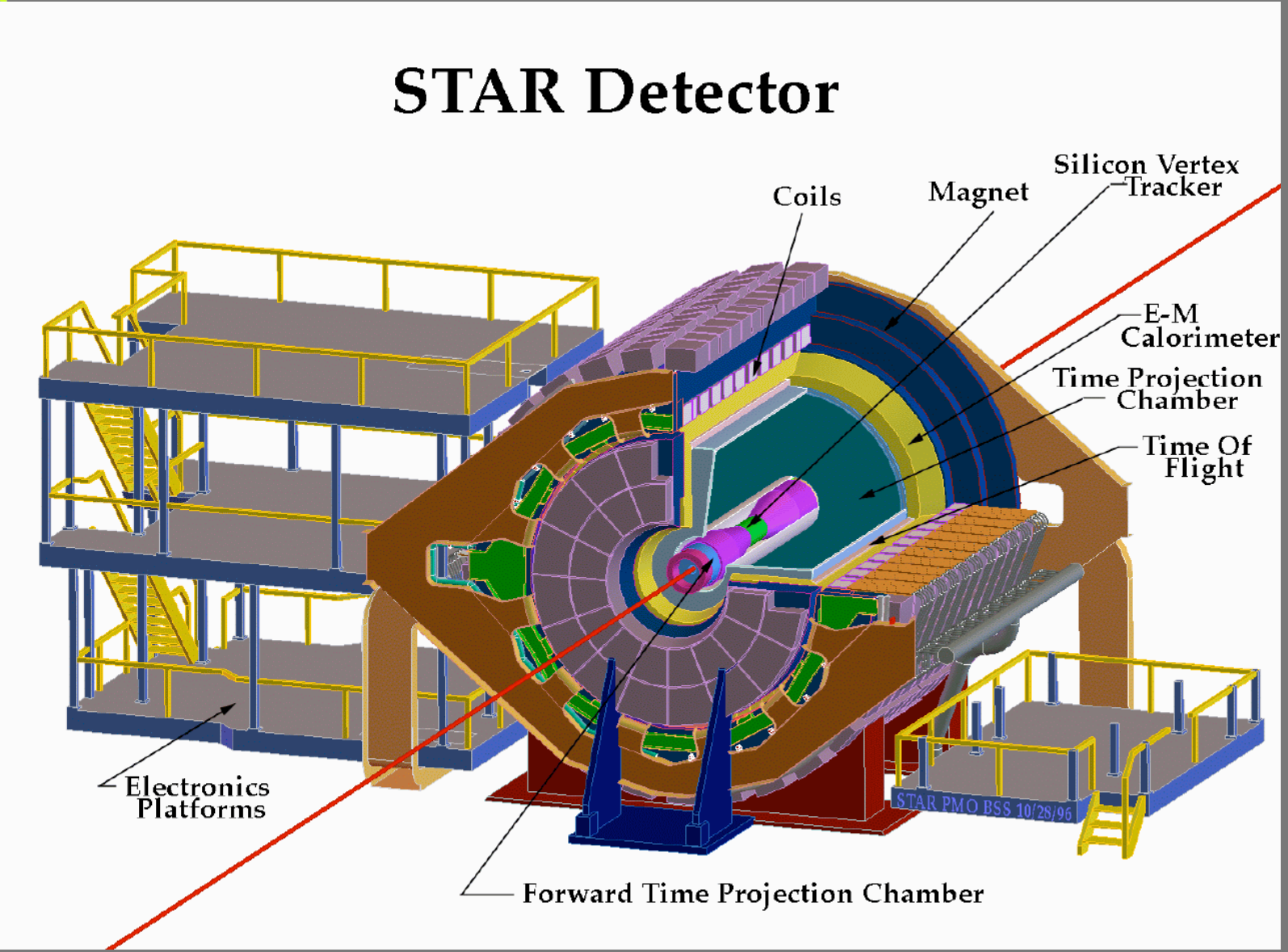
Overview

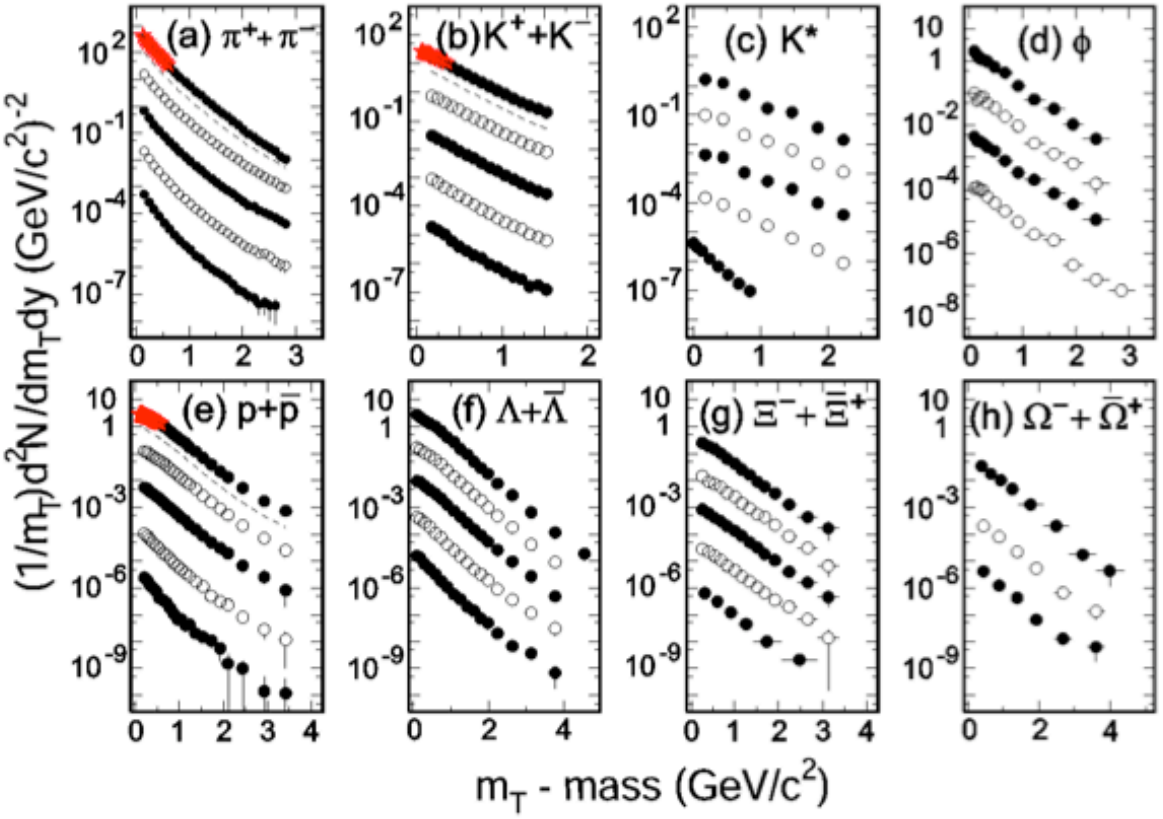
- Bulk particle production
  - Spectra, chemistry - thermal fits, dynamics - blast-wave
  - Elliptic flow
- Probing the medium
  - Fluctuations
  - *Auto*correlations
- Final state
  - HBT
  - Resonances

STAR Experiment



Particle spectra measurements

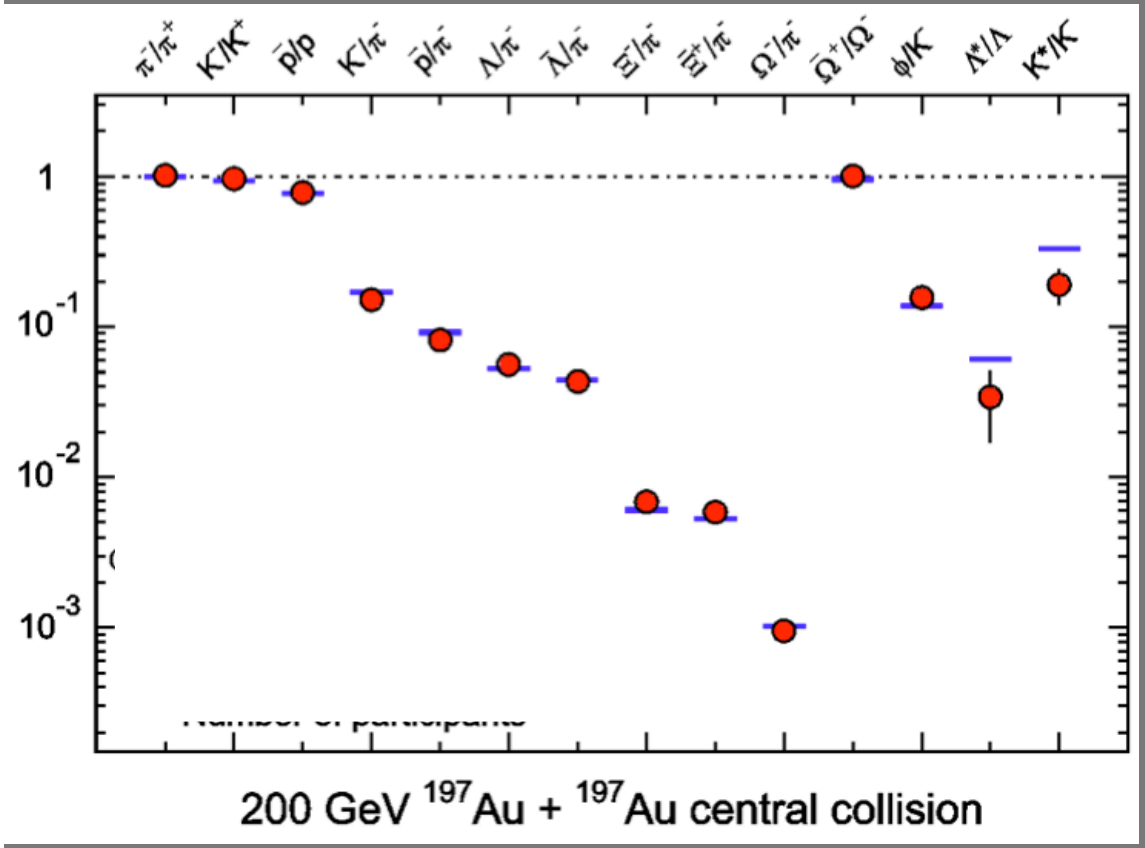
Nucl. Phys. A 757 (2005) 102. Fig. 13 & refs. therein



- Most comprehensive identified particle species dataset.
- Integrate (extrapolated) spectra to get yields.
- Look at shape of transverse momentum spectrum to learn about dynamics.

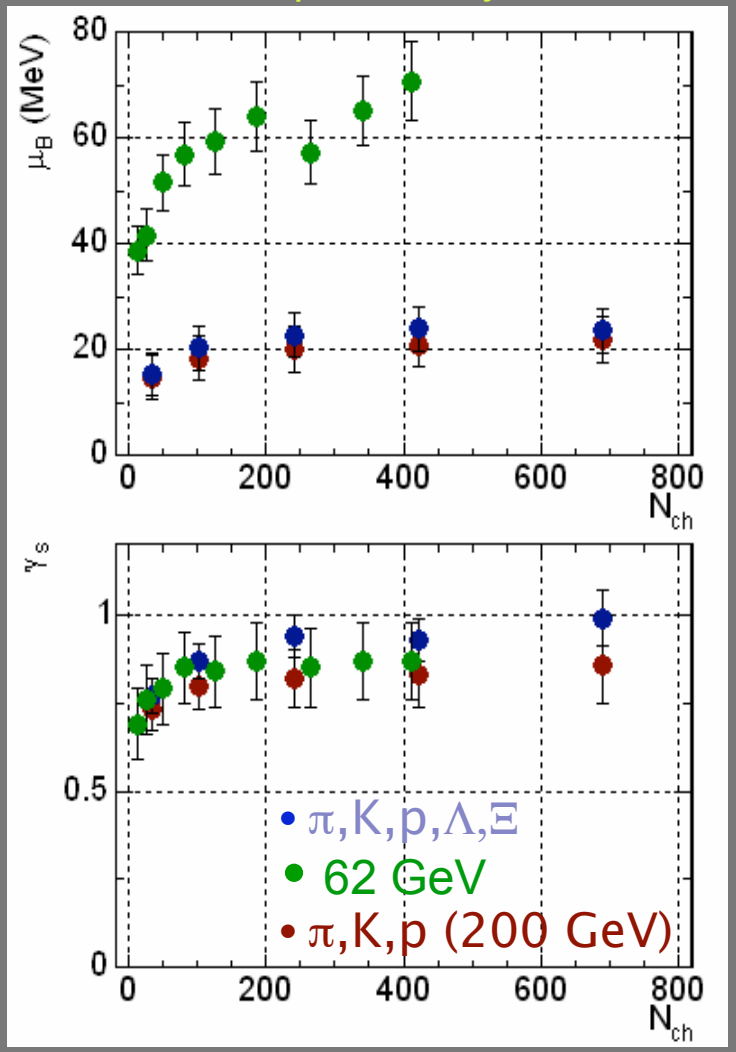
Yields: thermal model

Nucl. Phys. A 757 (2005) 102. Fig. 12 & refs. therein



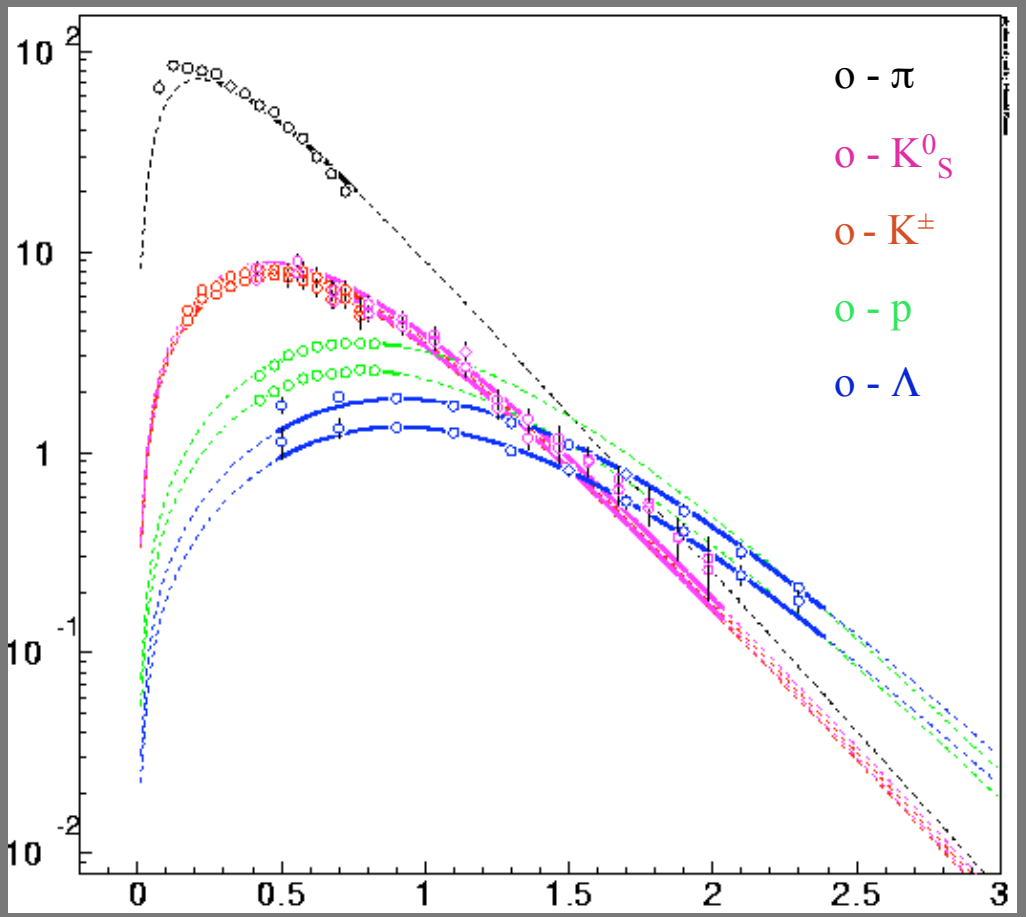
- Ratios of many particle yields successfully reproduced
- Is there true thermalization or is this statistical filling of phase space?

Thermal Model Chemical fits



- 4 parameters T_{ch}, μ_b, μ_s & γ_s
- T_{ch} ~ 160 GeV (not shown)
  - constant with centrality
  - same for 200 & 62 GeV
- μ_B changes with energy due to stopping
  - shows dependence on N_{ch} at small values of N_{ch}
- γ_s factor shows some centrality dependence
  - fully saturated in most central collisions

Spectra Shapes:Radial Flow

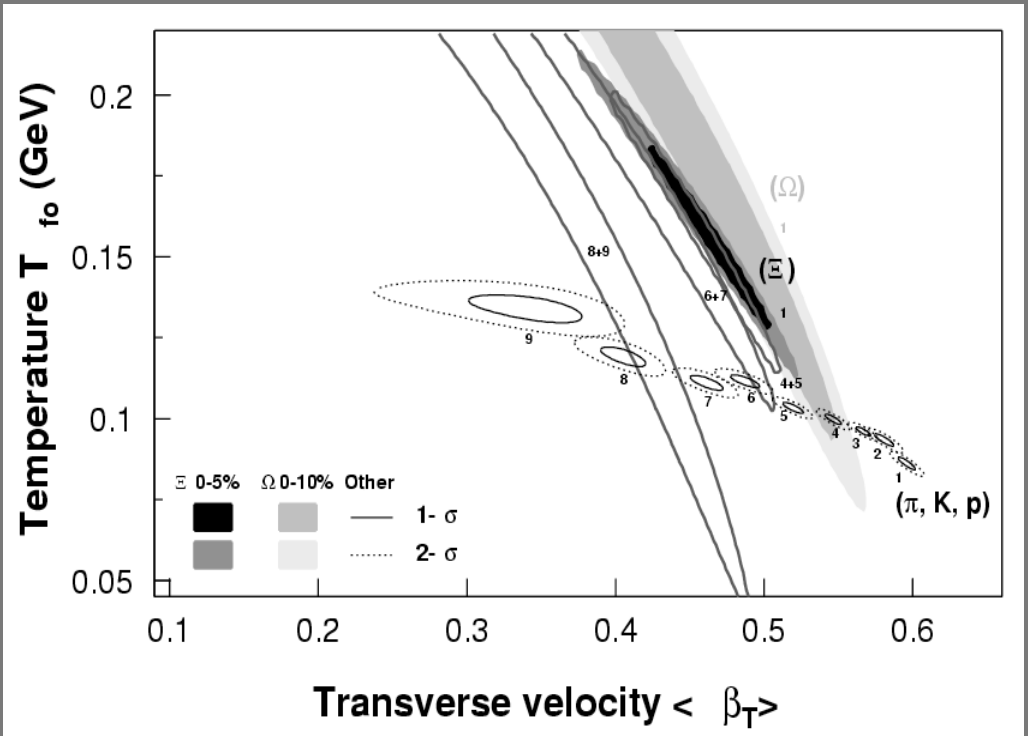


- Blast wave fit to π, K, p, Λ (and anti-particle) spectra.
- Able to model changing shape with mass

$$\frac{dN}{m_T dm_T} \propto \int_0^R r dr m_T K_1\{\frac{m_T \cosh\rho}{T_{fo}}\} I_0\{\frac{p_T \sinh\rho}{T_{fo}}\}$$

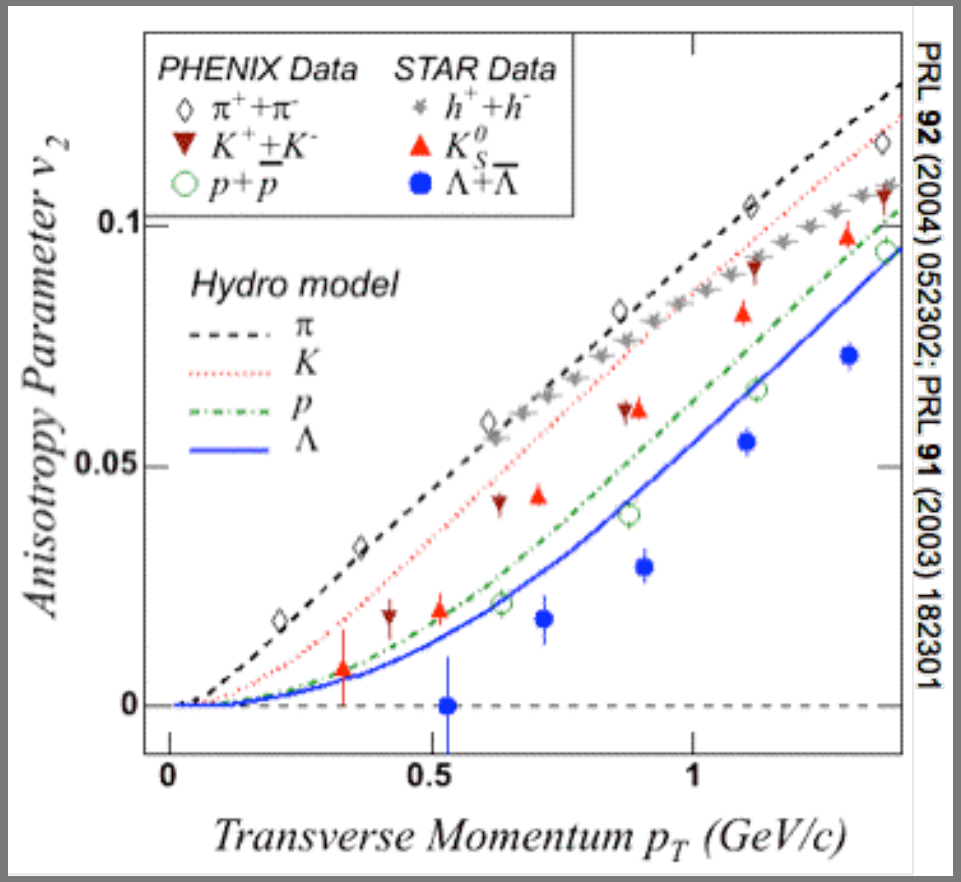
$$\rho = \tanh^{-1}\beta_r$$
$$\beta_r = \beta_s (r/R)^{\alpha}$$

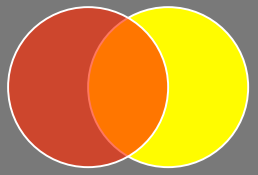
Kinetic Freezeout: Blast-wave



- Bulk particles show lower T_{fo} with more central collisions.
- ϕ, Ω, Ξ with (assumed) lower hadronic cross-sections have higher T_{fo} *but* still show strong flow.

Elliptic Flow: low p_T

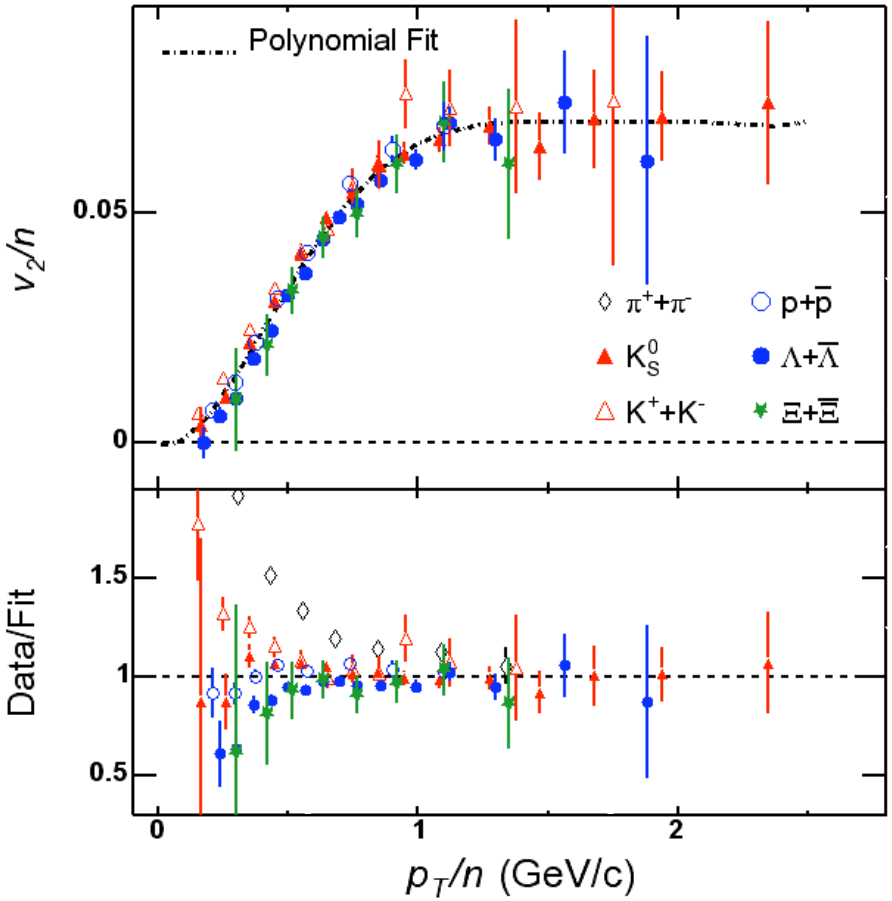




$$v_2 = \langle \cos[2(\phi - \psi_r)] \rangle$$

- Mass ordering described by hydro model
- Indicates collective motion
  - What are relevant degrees of freedom
  - Hadrons or quarks and gluons
- Detailed agreement depends on equation of state

Elliptic Flow: moderate p_T

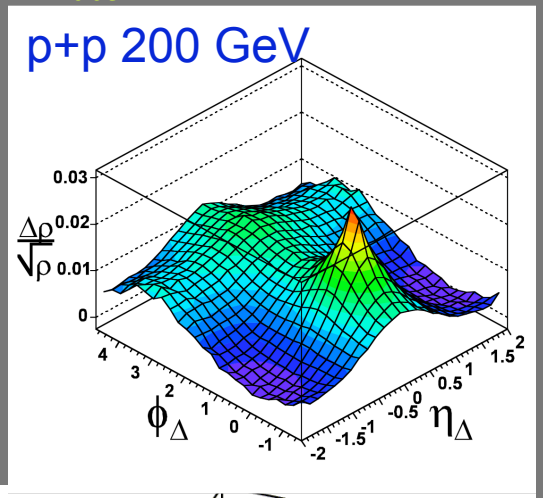


- v_2 re-plotted per constituent quark i.e.
  - Divide v_2 by n
  - Divide p_T by n
  - n=2 for mesons, n=3 for baryons
- This quark number scaling *may* indicate that constituent quarks are the relevant degrees of freedom

Spectra summary

- Thermal models used to fit yields at chemical freezeout.
- Blast-wave used to fit spectra and extract thermal freezeout parameters.
- Azimuthal anisotropies following hydrodynamic behaviour.

η,φ autocorrelations



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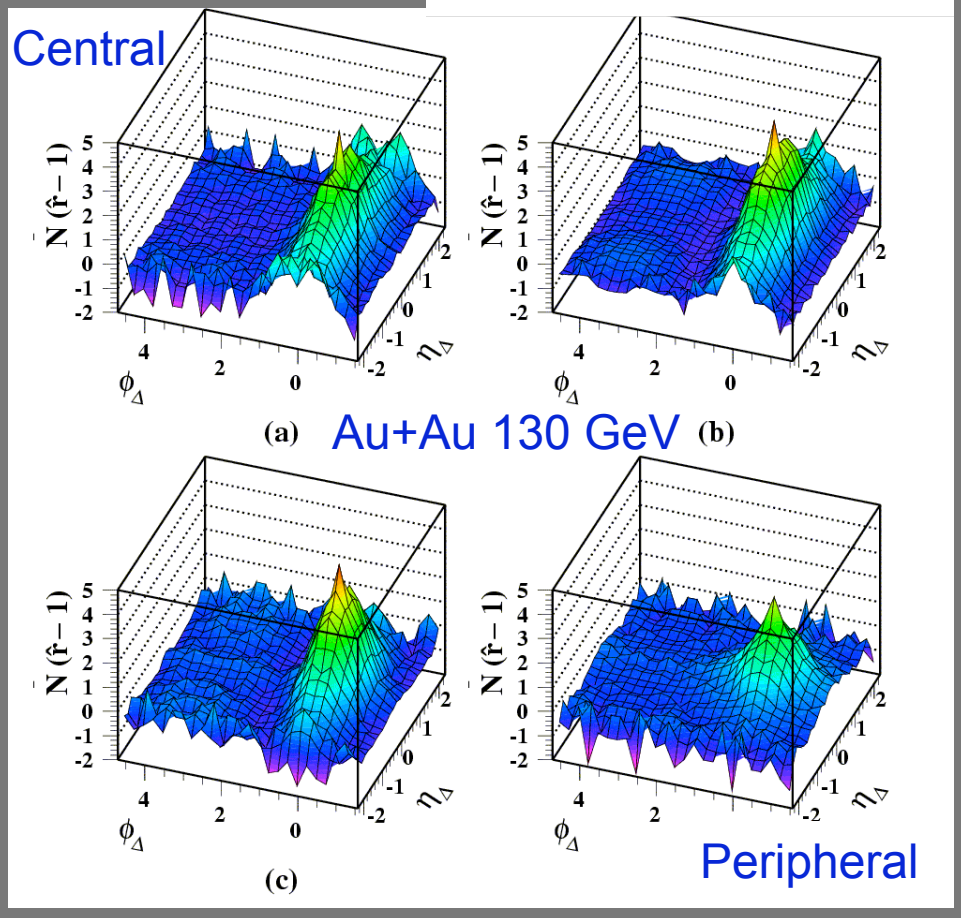
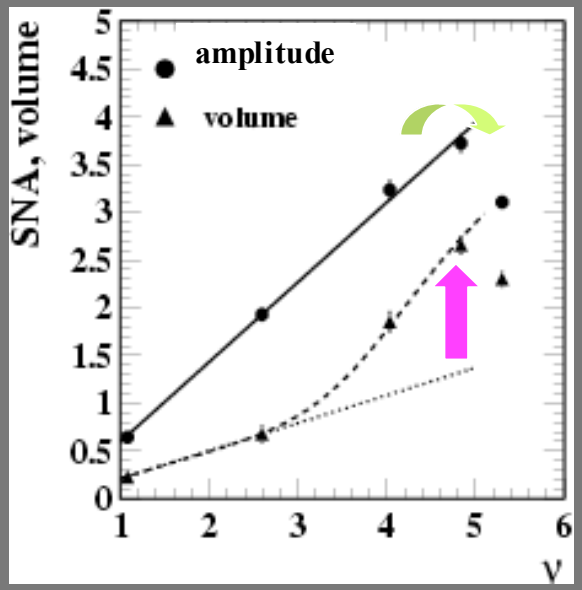


- Correlate all particle pairs
  - No (or all) triggers
  - Construct η_Δ, ϕ_Δ
- Subtract $\cos(\phi_\Delta)$ and $\cos(2\phi_\Delta)$ terms.
- Away side excess disappears even in peripheral bin
- Peaks become elongated in η_Δ and narrower in ϕ_Δ with increasing centrality.

Centrality dependence of correlation structure

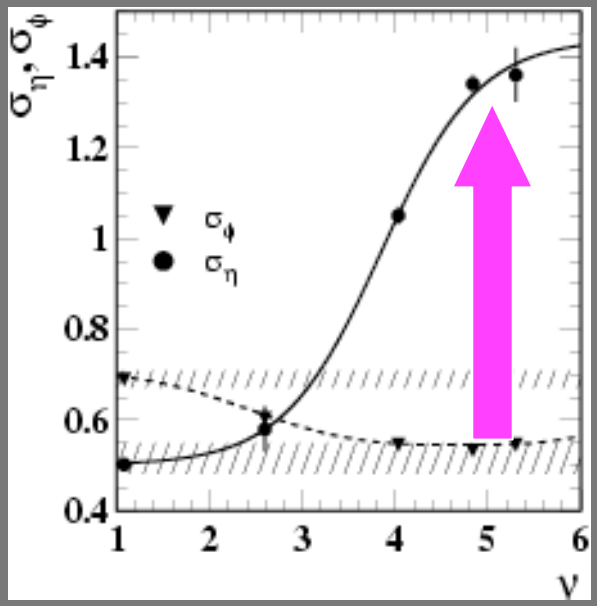
Correlation amplitude and volume per final state particle.

amplitude & volume



Linear amp. increase

widths



Factor 2.3 width increase

Alternative centrality measure:

$$\nu \equiv 2N_{bin}/N_{part} \approx (N_{part}/2)^{1/3}$$

$\langle p_t \rangle$ Fluctuations and p_t Correlations – 200 GeV Au-Au

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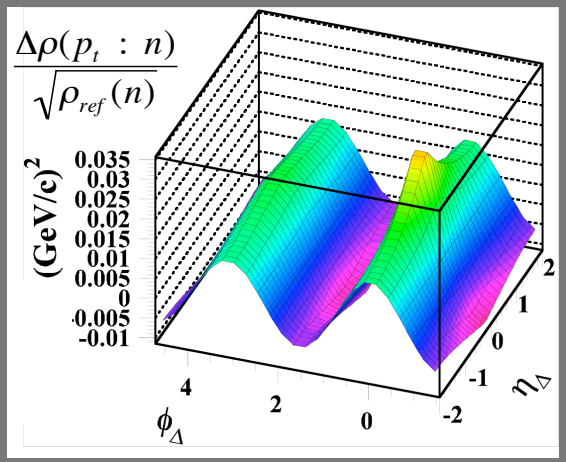
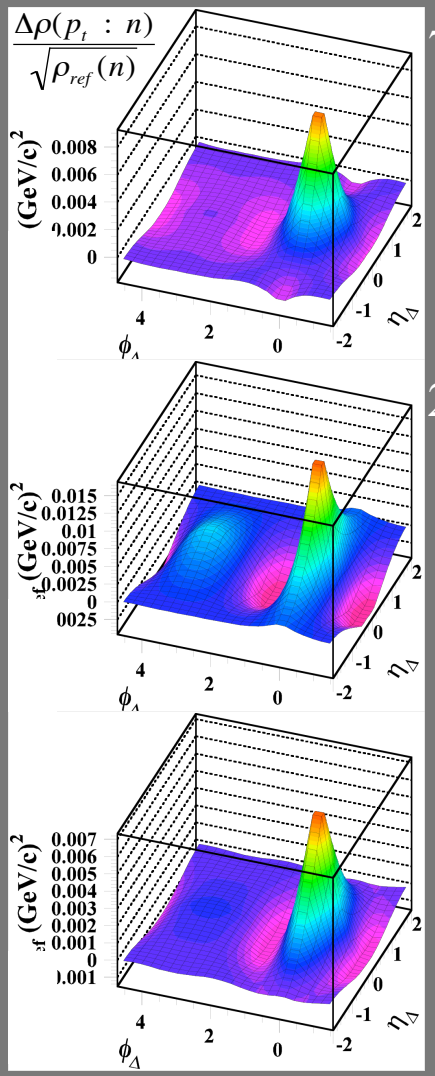
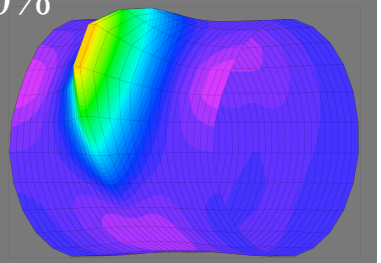


subtract multipoles

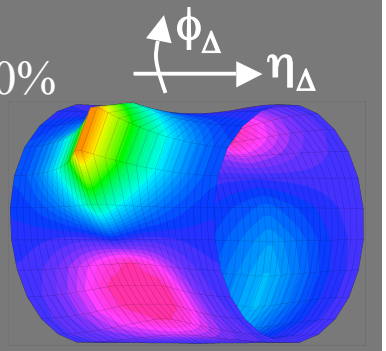
partons and velocity correlations



70-80%

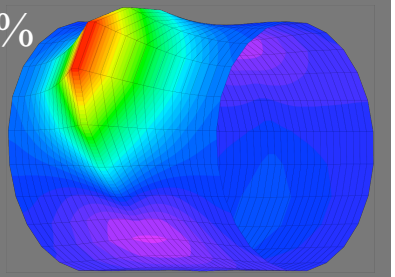


20-30%



centrality

0-5%



- Minijets: *velocity/temperature* correlation structures on (η,ϕ)
- Strong elongation on η and new *negative* same-side structure

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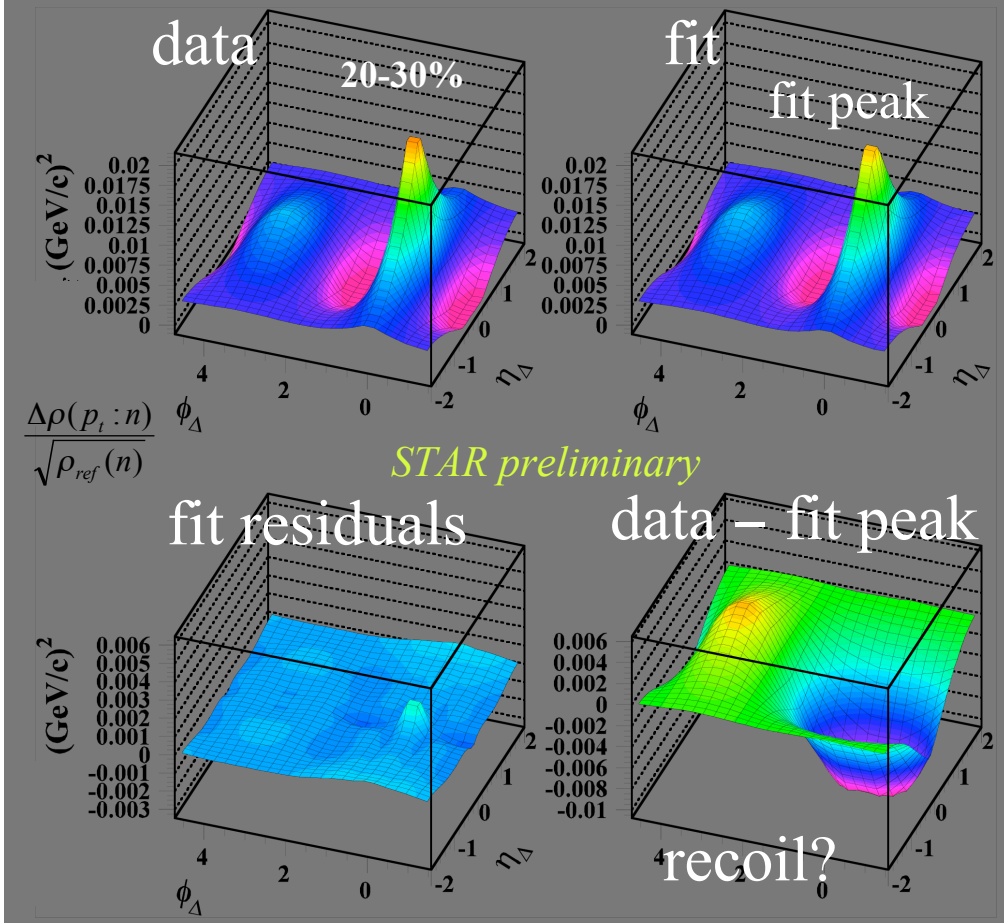
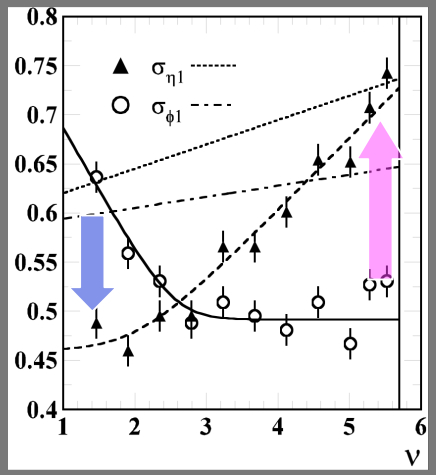
Model Fits, Hijing and a New Feature



widths

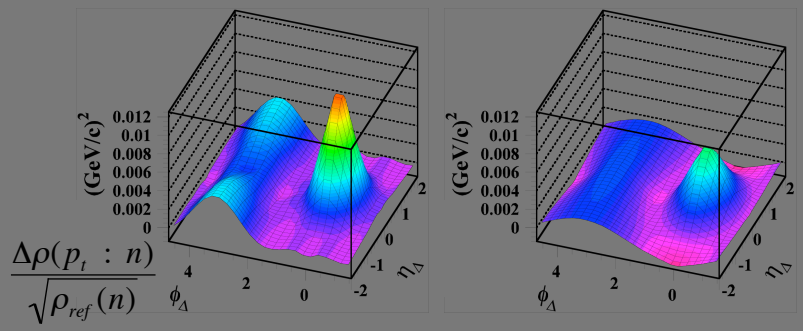


$\sigma_{\eta 1}$

$\sigma_{\phi 1}$

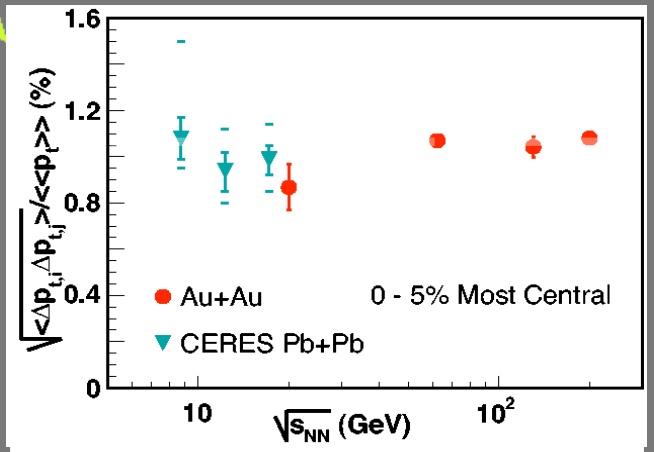
collision centrality ν

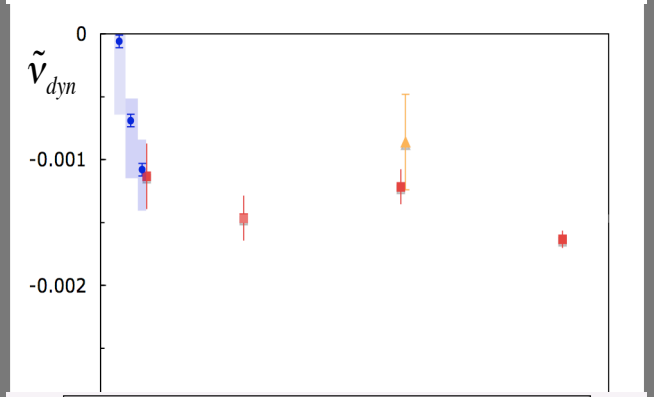
HIJING Au-Au 200 GeV
0-10% centrality

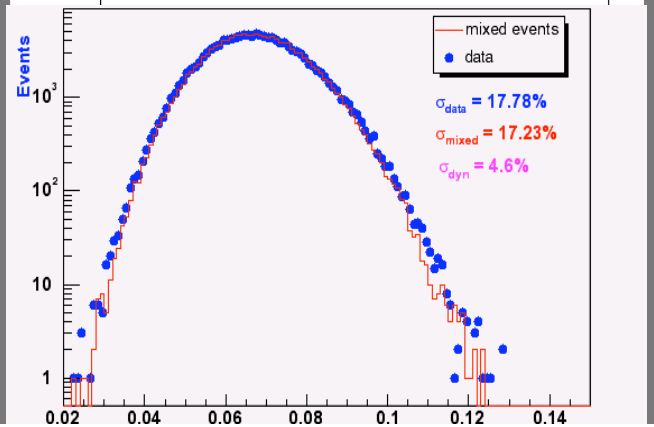


Quench off & on

Event-by-event fluctuations







- Looking for “excess” fluctuations
- No large fluctuation: chemical & kinetic equilibrium in every event?
- √s dependence looks smooth
- Net Charge reflects hadronic d.o.f, no Koch *et al*. QGP.
- Cross-over? Are we way above the transition?

K/π

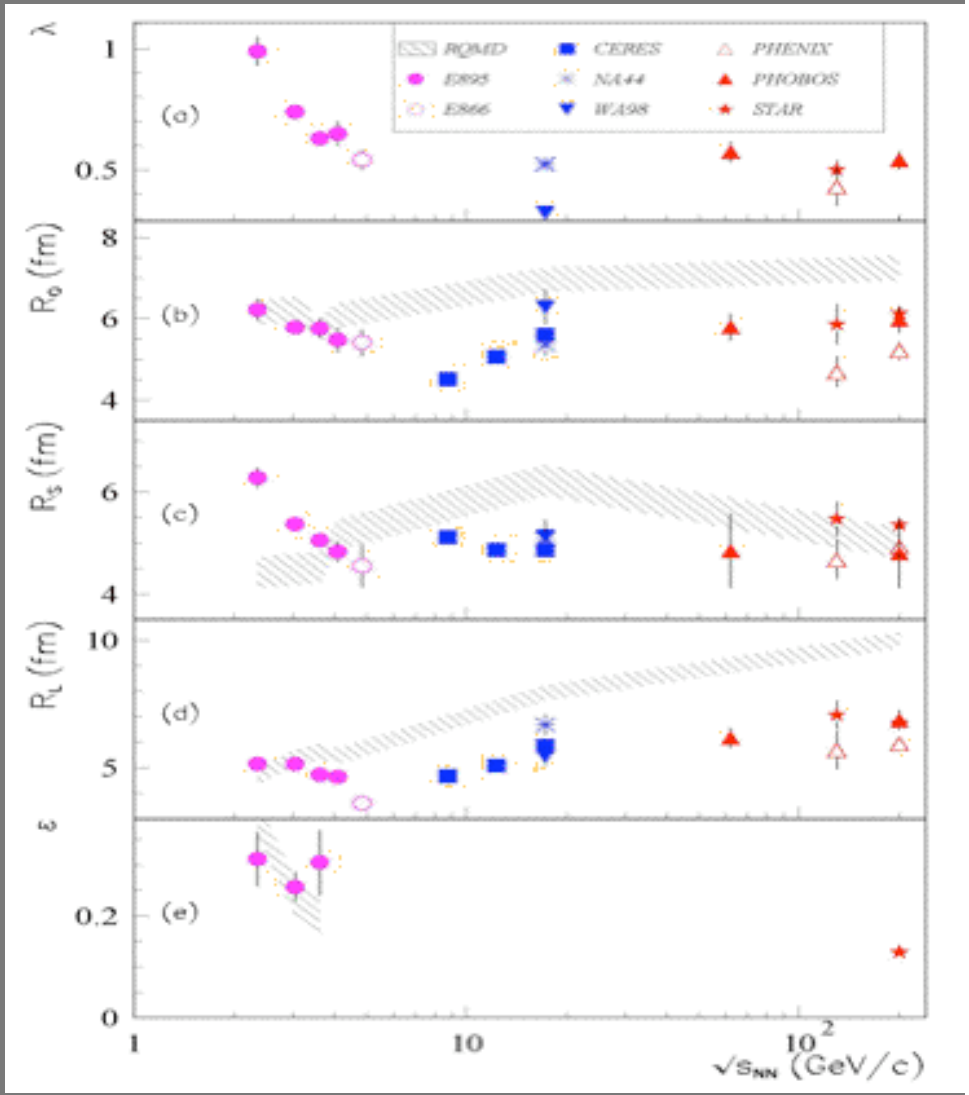
Correlations and Fluctuations Summary

- No unusual energy dependence in integral fluctuation measurements
- Correlations in η-ϕ show interesting structures which change with centrality indicating interaction with medium.

Femtoscopy (HBT)

$$C(q) = 1 + \lambda \cdot e^{-(q_o^2 R_o^2 + q_s^2 R_s^2 + q_l^2 R_l^2)}$$

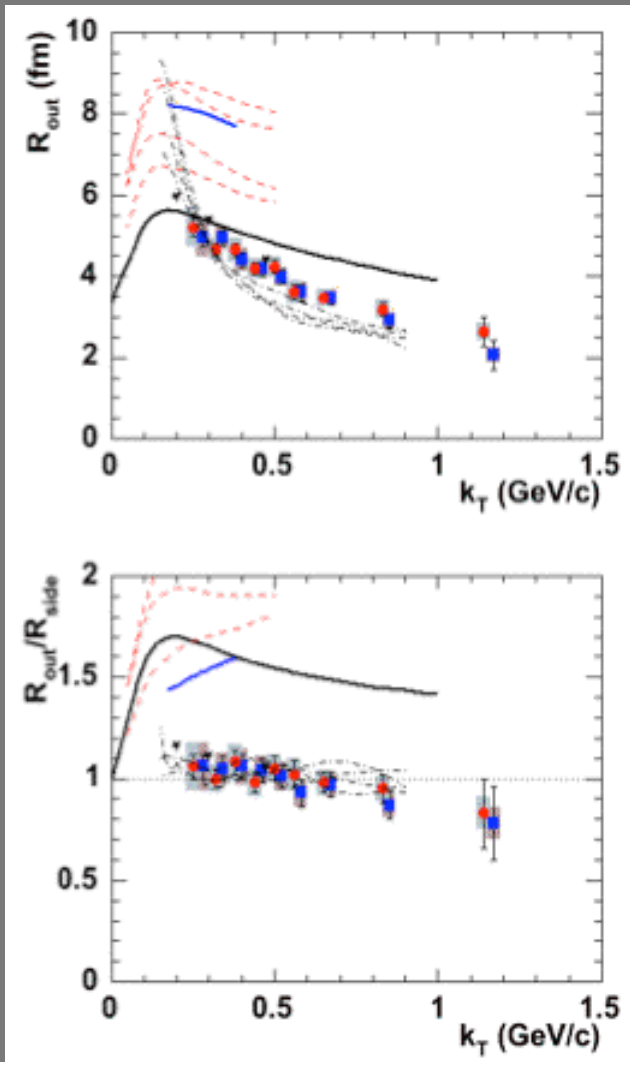
- q decomposed:
  - q_{long} - beam direction
  - q_{out} - pair k_T direction
  - q_{side} - perp. to above
- Radii relations to source:
  - R_o - emission time
  - R_s - transverse extent
  - R_l - longitudinal extent
- Radii as a fn. of energy shown
  - Surprising lack of s dependence given sensitivity to EoS & soft point

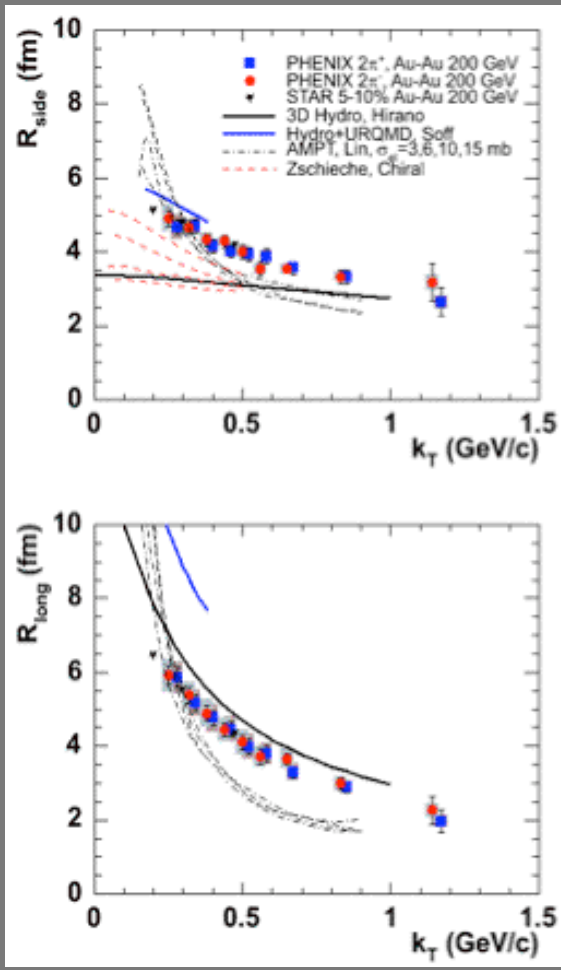


Radii and models

- Experimental data agree!
- Model comparisons shown

- Hydro models are not successful at reproducing radii as a function of k_T
  - Especially R_{out}/R_{side} ratio
  - Although they are good for p_T and v_2.

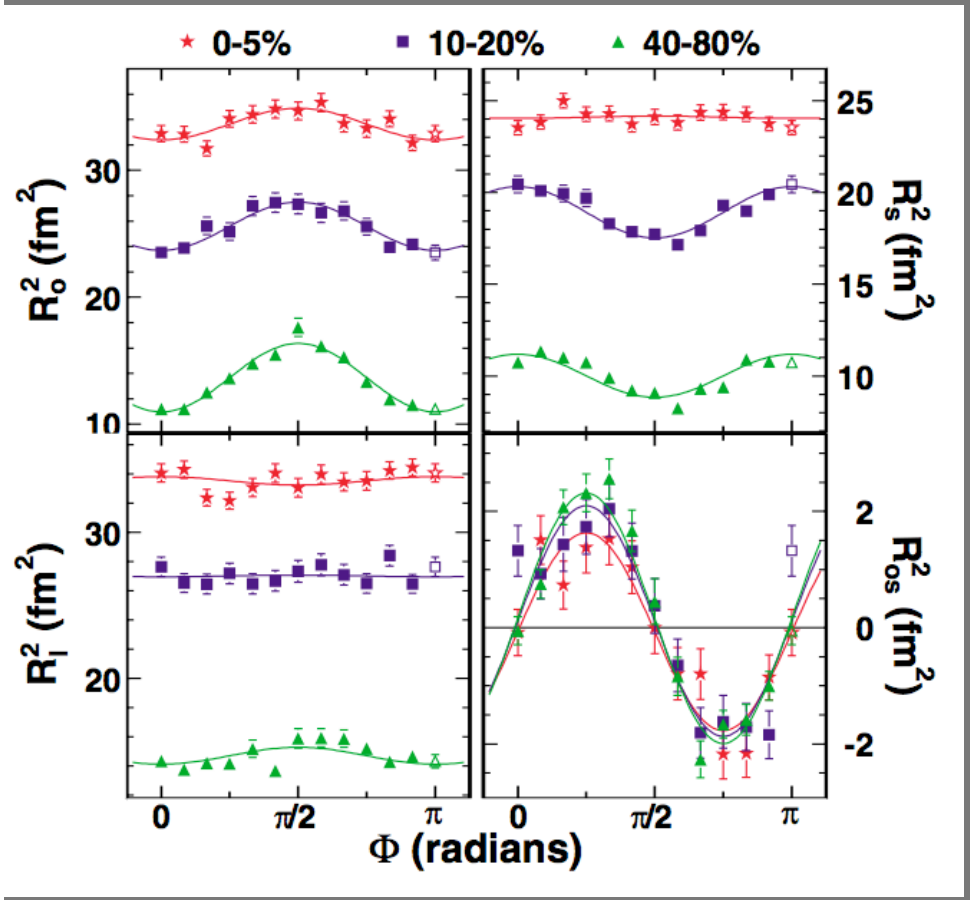


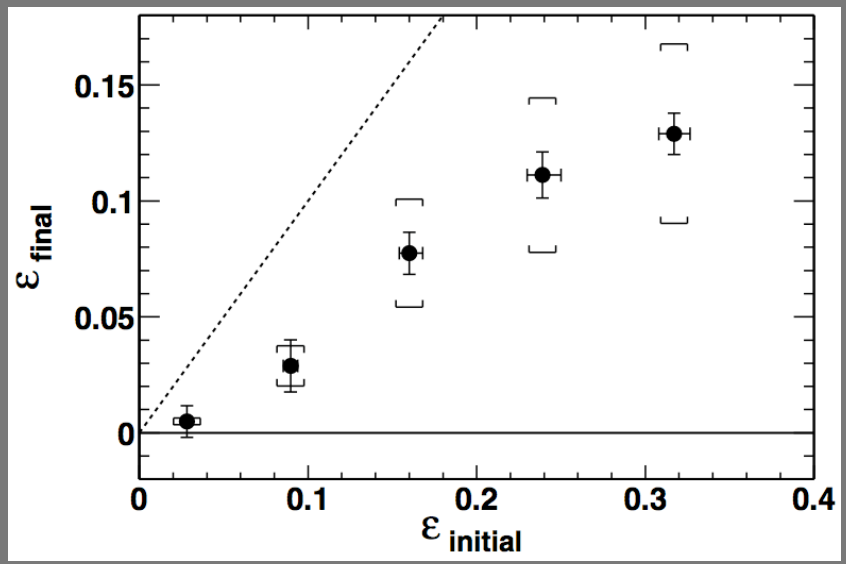


HBT w.r.t reaction plane

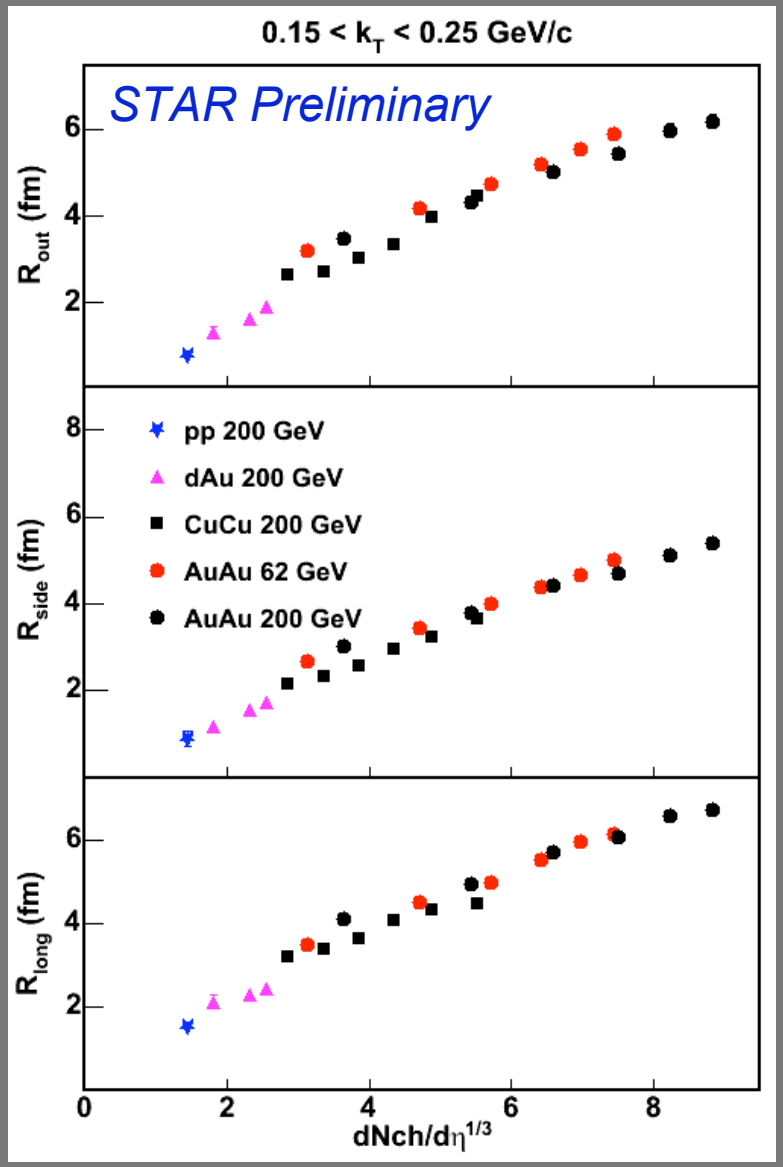
- Change of source shape - due to expansion
- Still out of plane extended though - another indication of short time scale?

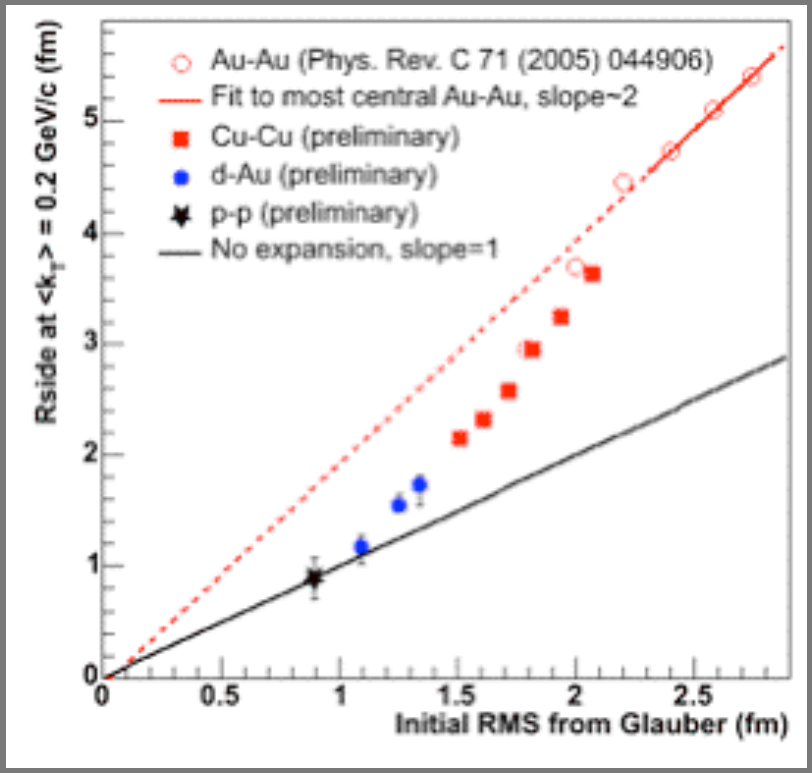
$$\varepsilon = \frac{R_x - R_y}{R_x + R_y}$$





System size & Expansion





- Smooth growth of radii
- Factor 2 expansion for central Au+Au

Resonance studies

- Resonance decay products re-scattered
  - prevents reconstruction
- Sensitive to lifetime of system
- However additional effects of regeneration to consider

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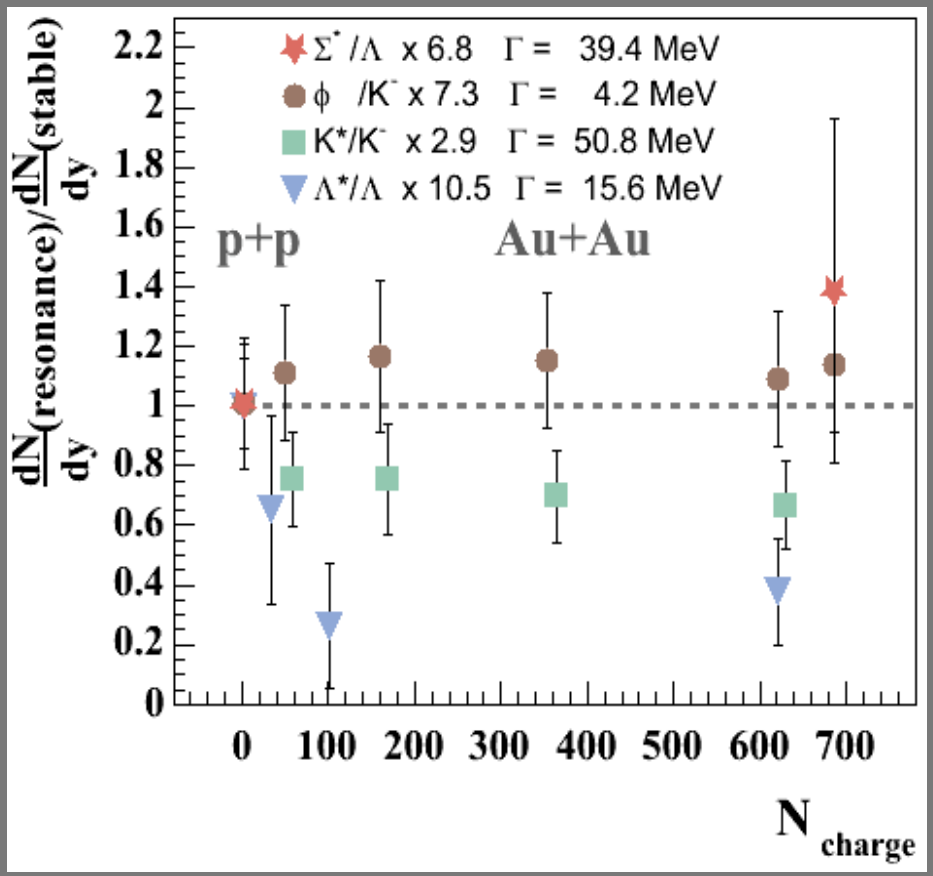

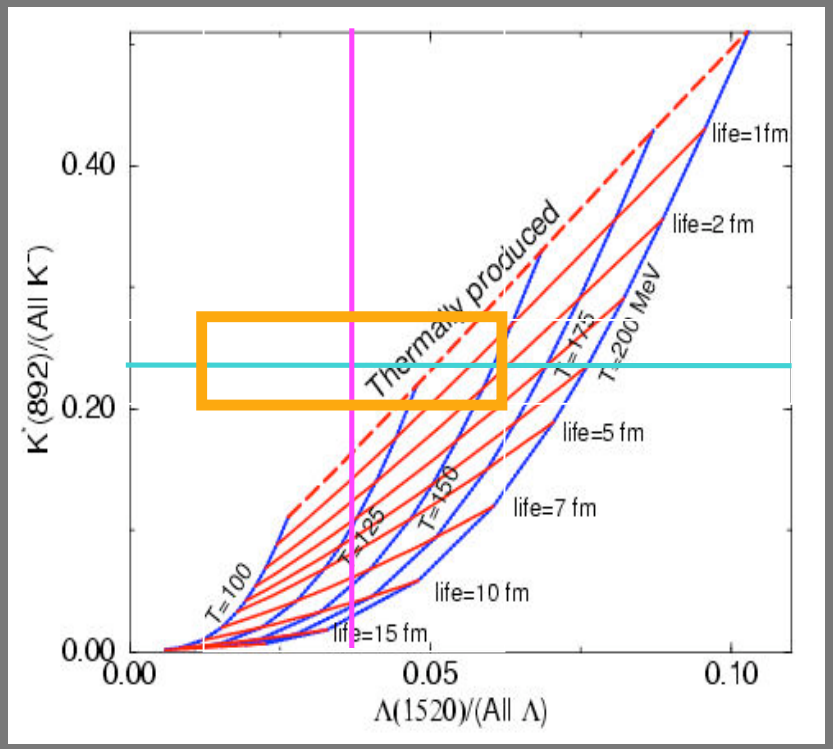

Conclusions

- Bulk phenomena successfully described by collective behaviour
  - Particle yields fit well by thermal model
  - Changing shape of transverse spectra modelled by blast-wave
  - Elliptic flow follows hydro-like behaviour
  - Number of constituent quarks relevant d.o.f?
- Medium can be probed via correlation structures
  - Reveals mini-jet like effects, coupled to bulk and possible evidence of recoil.
- Femtoscopic investigations are currently throwing up some interesting puzzles.

Acknowledgements

STAR Collaboration Institutions

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