Elliptic flow of multi-strange baryons Ξ and Ω in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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- Introduction
- Results from radial transverse flow
- Ξ and Ω v_2 analysis
- Results and Discussion

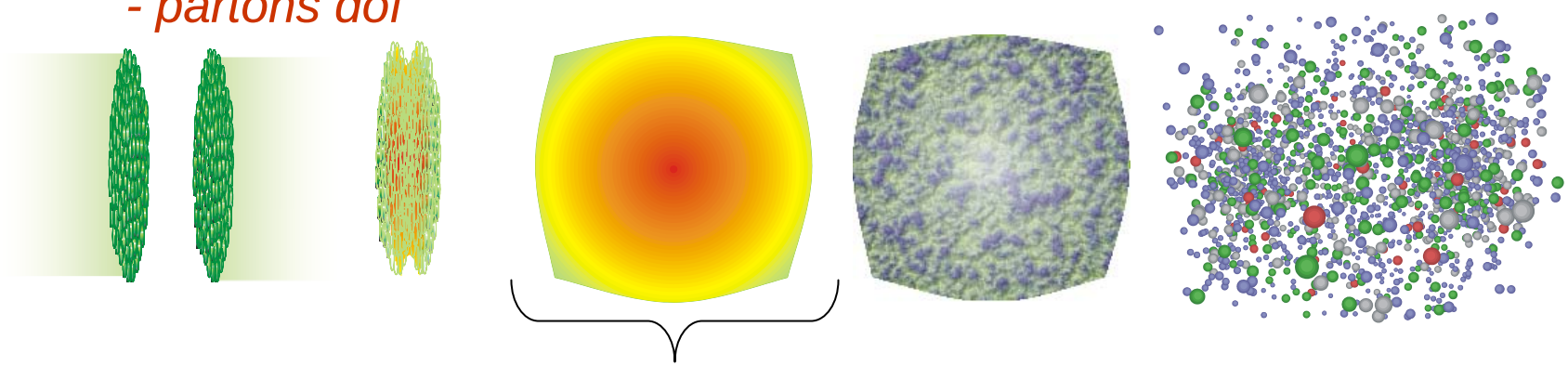
Introduction

Time

1) Initial Condition
- baryon transfer
- E_T production
- partons dof

2) System Evolves
- parton/hadron expansion

3) Bulk Freeze-out
- hadrons dof
- interactions stop



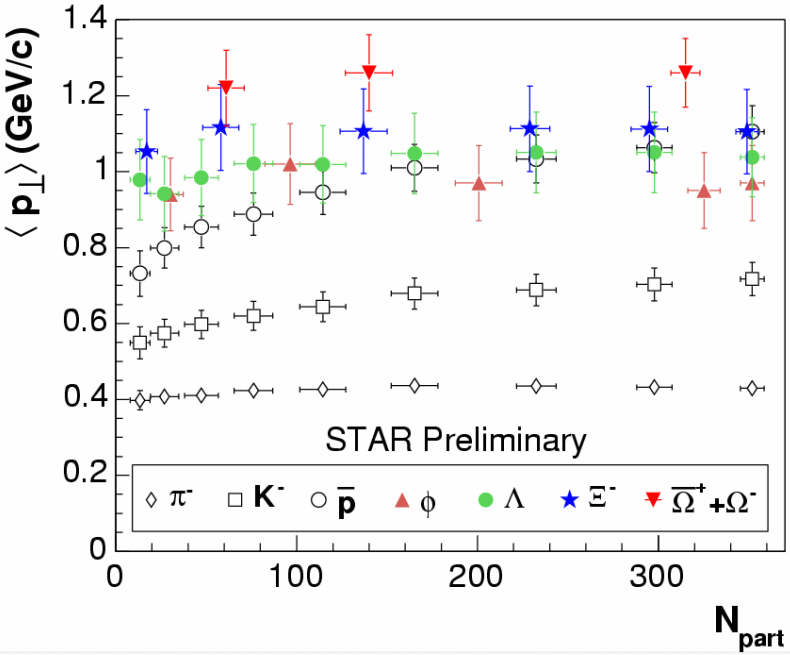
Q. Collectivity?

Tools:
- Transverse Flow
- Elliptic Flow

Problem:
- Flow is additive

Approach:
- Probes "insensitive" to hadronic stage (ϕ,Ξ,Ω,D,J/Ψ)

Radial transverse flow



- π, K, p : $\langle p_\perp \rangle$ increases with collision centrality
- π, K, p : $\langle p_\perp \rangle$ centrality dependence is stronger for heavier particles

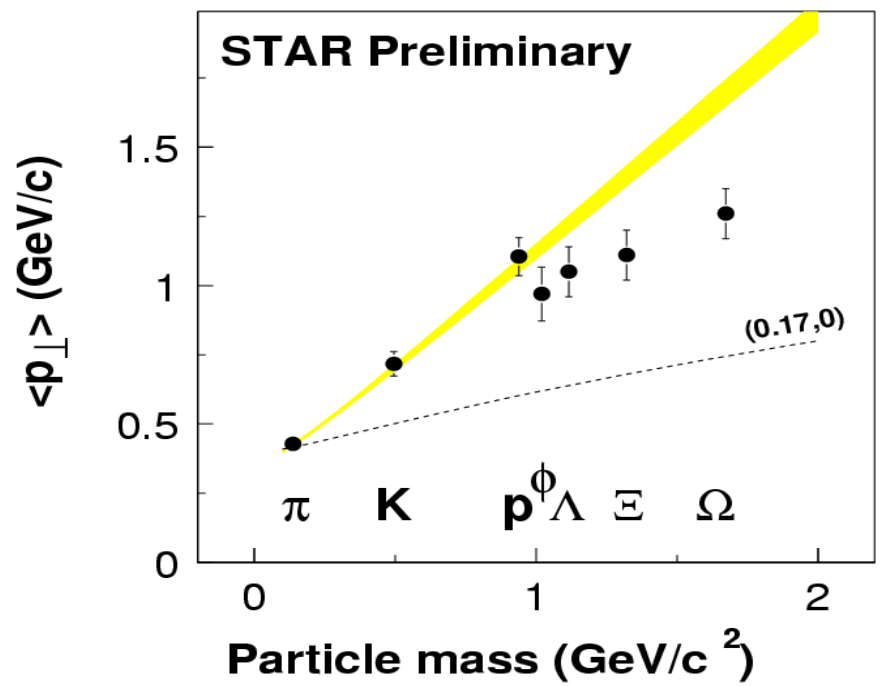
→ Consistent with collective flow picture.

- Ξ, Ω : $\langle p_\perp \rangle$ shows no dependence with N_{part}

→ Different flow behavior!

- π, K, p : $\langle p_\perp \rangle$ increases with particle mass as described by thermal models

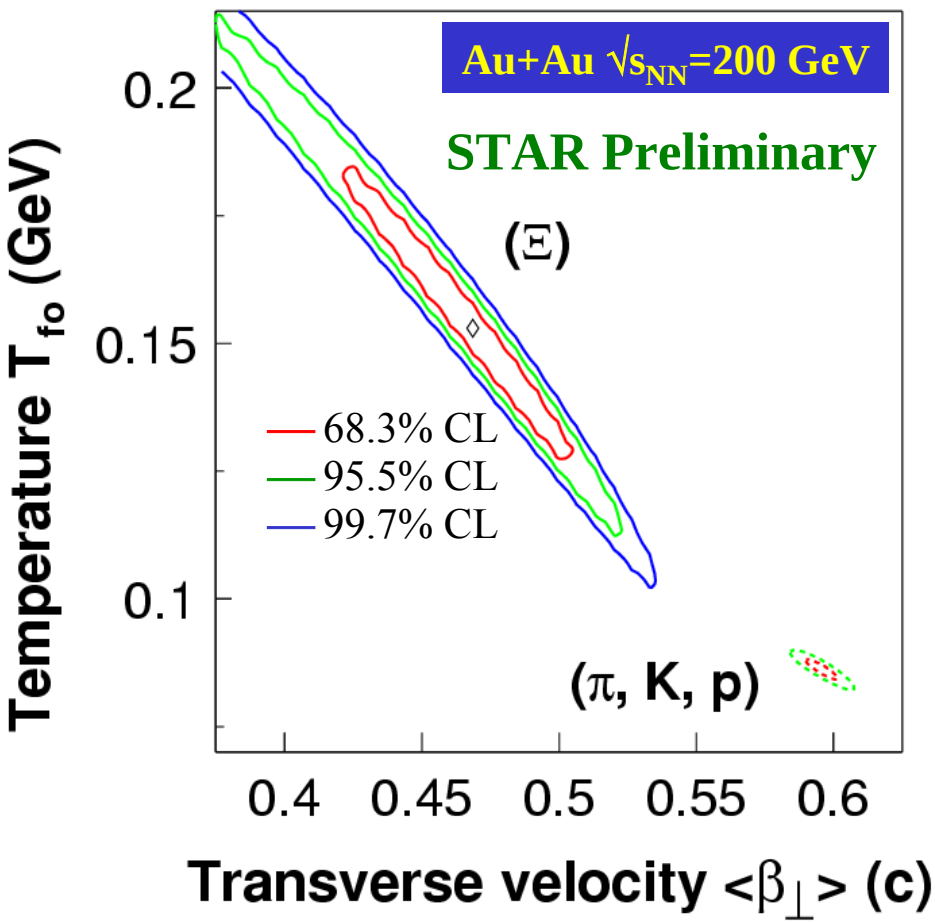
- Ξ, Ω : $\langle p_\perp \rangle$ deviates from common thermal freeze-out picture!
  - Early thermal freeze-out ?
  - Early collectivity ?



BlastWave fits

Source is assumed to be:

- In local thermal equilibrium
- Strongly boosted

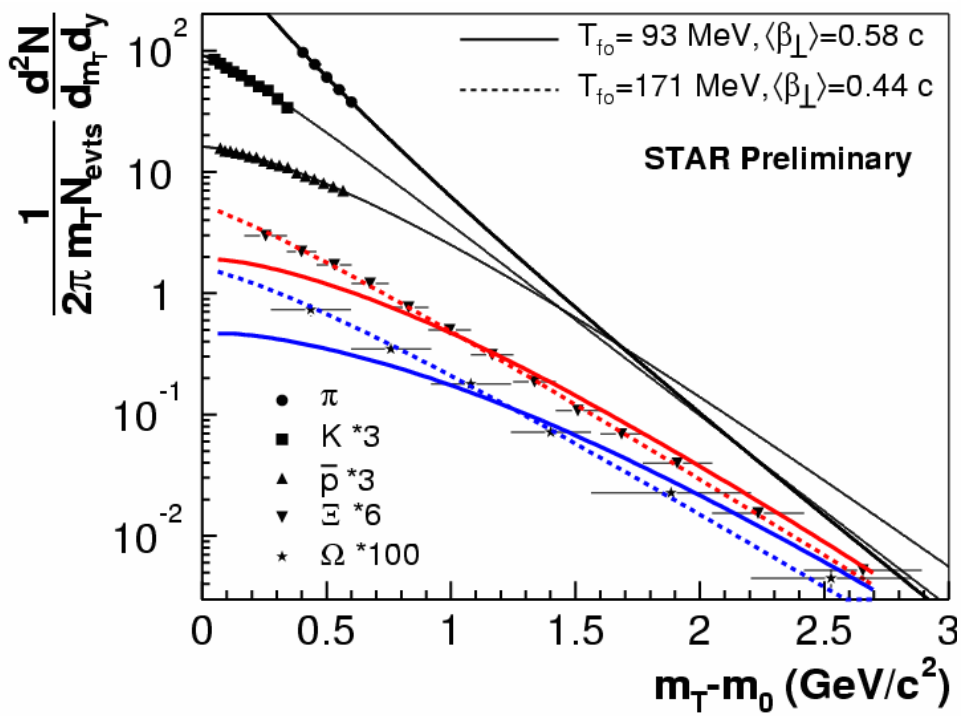


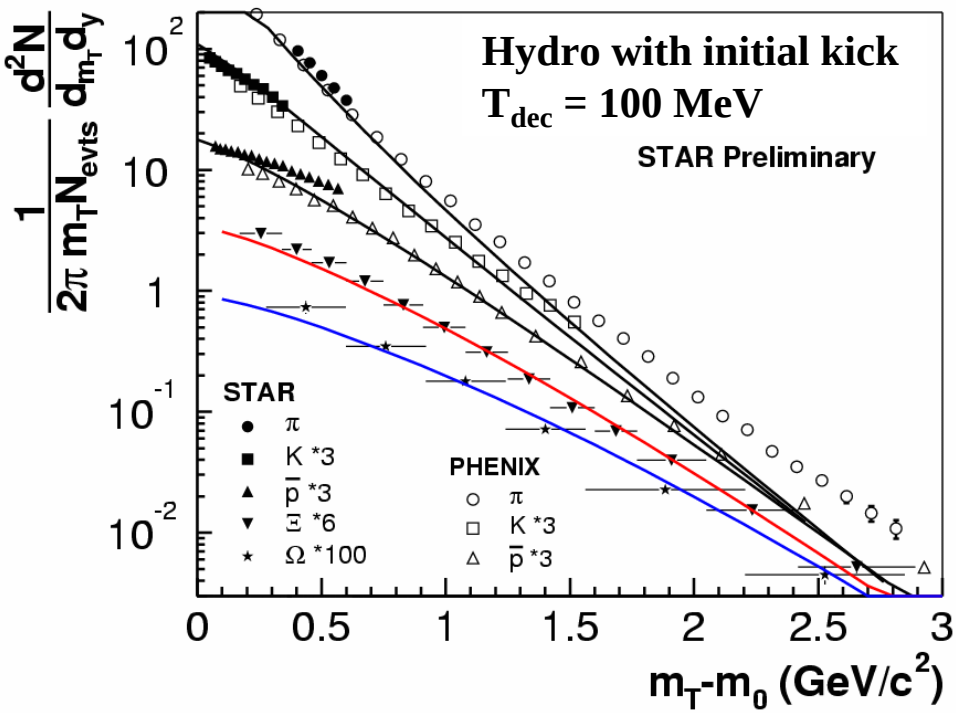
- π, K, p: Common thermal freeze-out at T~90 MeV and $<\beta_\perp>$~0.60 c
- Ξ: Shows different thermal freeze-out behavior:
  - **Higher temperature**
  - **Lower transverse flow**

⇒ Probe earlier stage of the collision, one at which transverse flow has already developed

⇒ If created at an early partonic stage it must show significant elliptic flow (v_2)

Hydrodynamic calculation



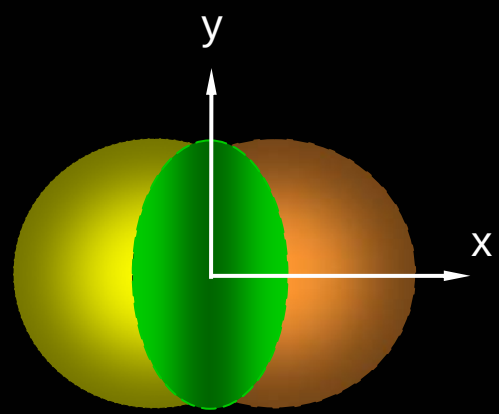


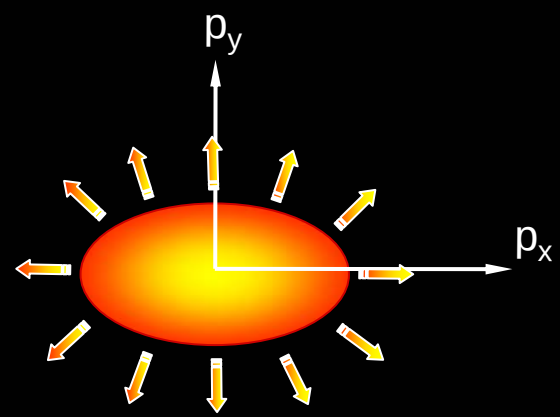
Hydrodynamic calculation with an E.O.S. containing a partonic and a hadronic phase:

- **P.F.Kolb and R.Rapp, Phys. Rev. C 67 (2003) 044903**
- **P.F.Kolb, J.Sollfrank, and U.Heinz, Phys. Rev. C 62 (2000) 054909**

Anisotropy parameter v_2

coordinate-space-anisotropy ⇔ momentum-space-anisotropy





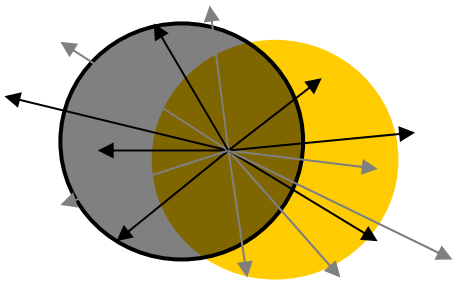
Initial/final conditions, dof, EOS

$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Multi-strange baryons elliptic flow analysis

Strategy: Extract v_2 from the distribution of the particle raw yields as a function of the azimuthal angle with respect to the reaction-plane

The reaction-plane is estimated using the event-plane defined by the anisotropy in the azimuthal distribution of tracks.

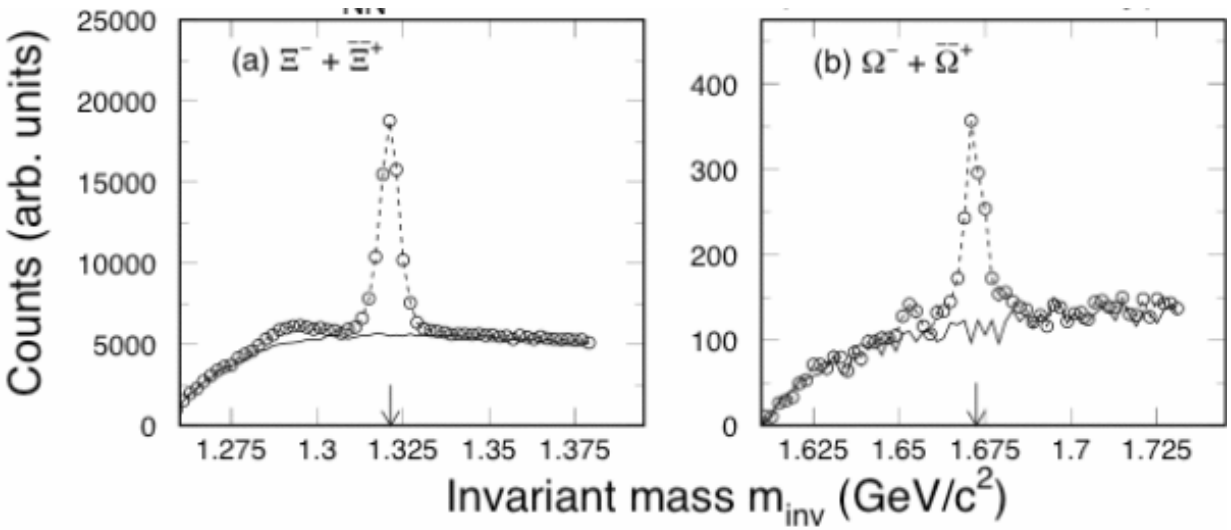


v_2 must be corrected for the event-plane resolution that is estimated from a sub-events analysis.

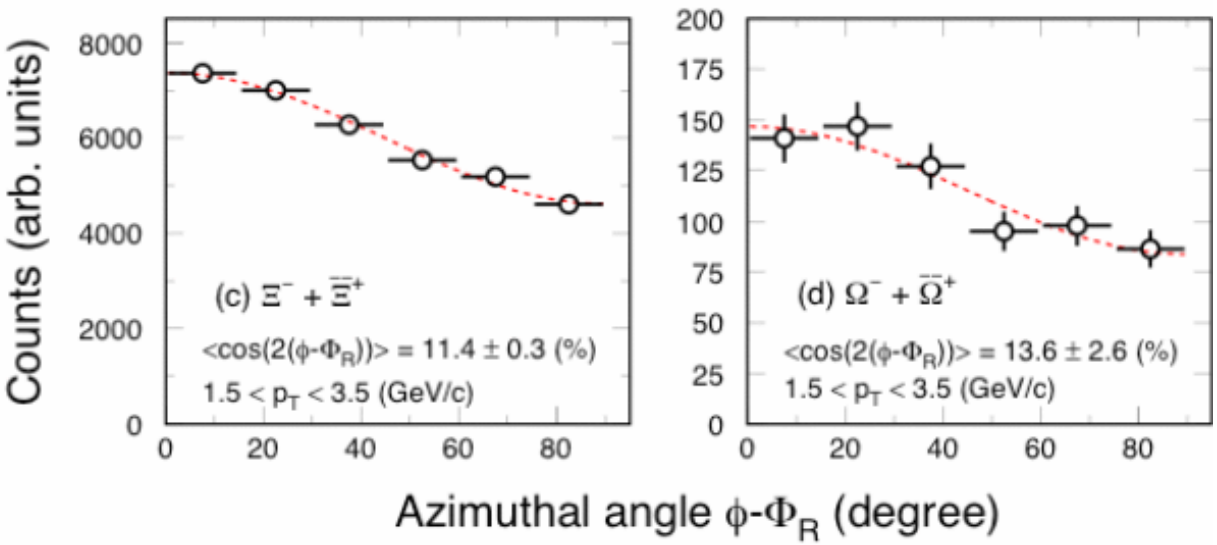
Used data: ($\sqrt{s_{NN}}$=200 GeV)
MinBias 0-80% : ~ 1.6 M Good Evts
~ 75k Ξ + $\bar{\Xi}$
~ 1.6k Ω + $\bar{\Omega}$
Central 0-10% : ~ 2M Good Evts
~ 160k Ξ + $\bar{\Xi}$

Event-plane resolution:
MinBias : 0.693 +/- 0.001
Central : 0.678 +/- 0.002

Multi-strange baryons elliptic flow analysis



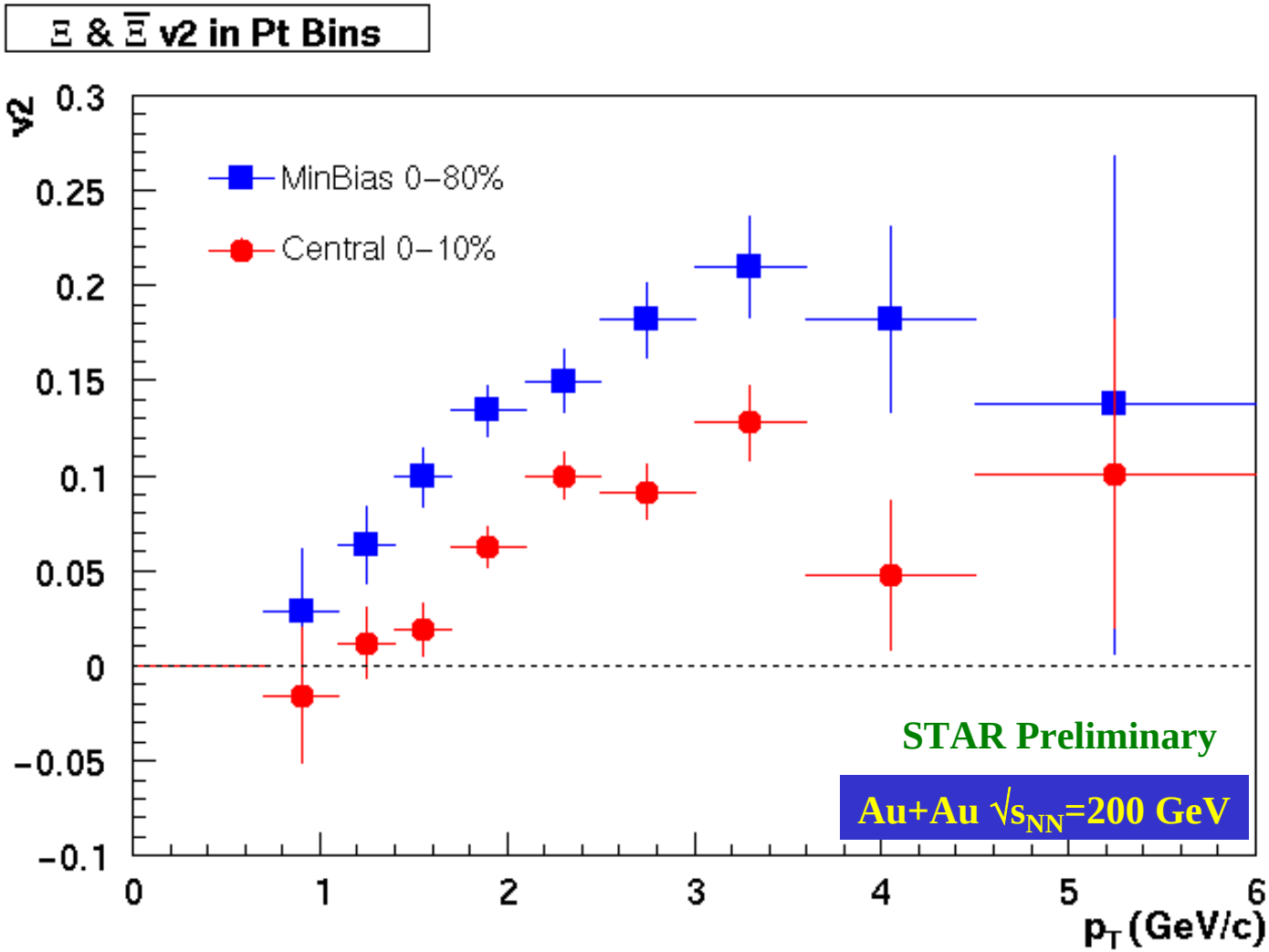
Extract the raw yields from the invariant mass distribution in each Φ-Φ_R (and $p_\perp$) bin



Clear $\cos(2(\Phi-\Phi_R))$ oscillations:

- **Significant elliptic flow**
- **Similar for Ξ and Ω**

$\Xi + \bar{\Xi}$ Elliptic flow measurements

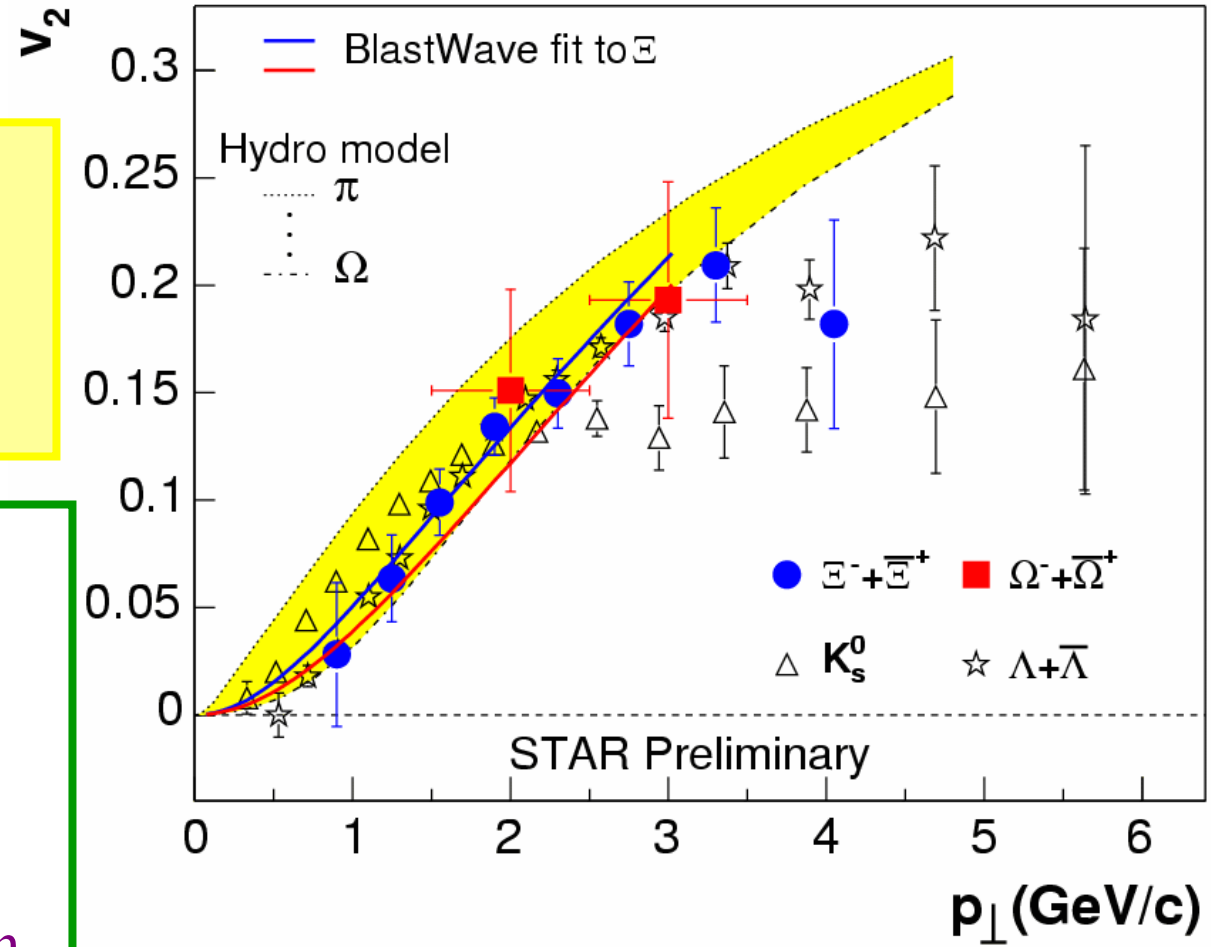


- **Lower v_2 for central collisions (smaller initial spatial anisotropy)**
- **Behaviors are similar**

Multi-strange baryons v_2 from minimum-bias data

- $\Xi + \bar{\Xi}$ shows <u>sizeable</u> elliptic flow!
- $\Omega + \bar{\Omega}$ shows <u>sizeable</u> elliptic flow!

- Seems to saturate at v_2~20% around $p_\perp$~3.0 GeV/c …
- Ξ $v_2(p_\perp)$ follows Λ evolution
- Ω $v_2(p_\perp)$ consistent with Ξ and Λ $v_2(p_\perp)$

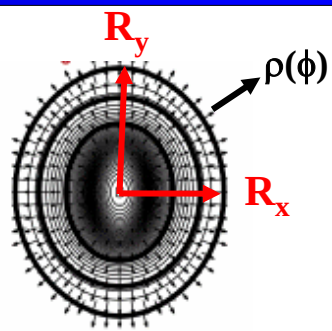


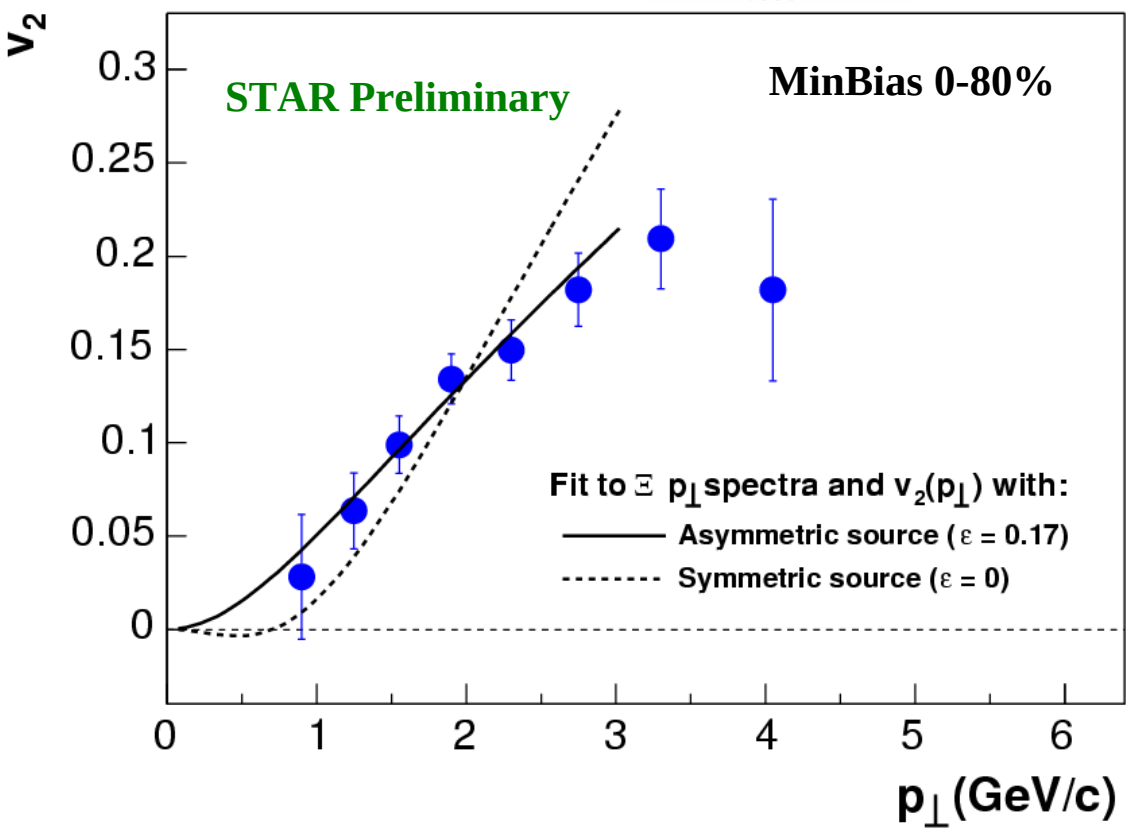
Hydro: P. Huovinen et al.

$\Xi + \bar{\Xi}$ v_2 – BlastWave Fits

Source at freeze-out:

- $\rho(\phi) = \rho_0 + \rho_a \cos(2\phi)$
- $\varepsilon = (R_y^2 - R_x^2)/(R_y^2 + R_x^2)$





Common fit to Ξ and $\bar{\Xi}$ $p_\perp$ spectra and $v_2(p_\perp)$:

T_{fo} = 142 +- 11 MeV

ρ_0 = 0.801 +- 0.030

ρ_a = 0.047 +- 0.011

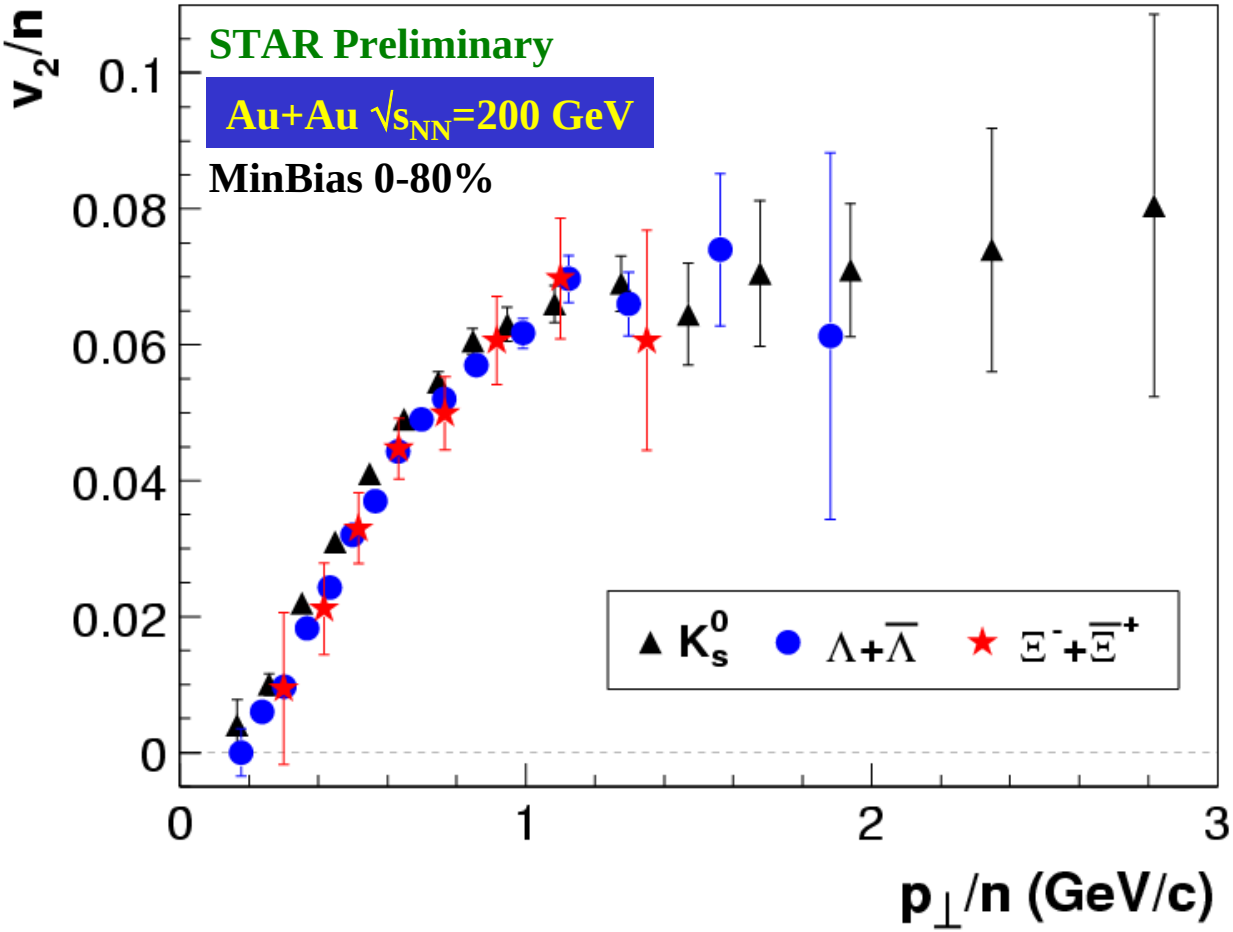
ε = 0.17 +- 0.04

χ^2/dof = 7.2/17

- Initial ε from glauber calculation: **ε = 0.30**
- From azimuthally sensitive π HBT: **ε = 0.01 → 0.13**
- From BlastWave fit to PHENIX π,K,p v_2: **ε = 0.121±0.004**

Ξ data requires strong spatial asymmetry of the source at freeze-out

Quark coalescence picture



Hadronization via quark coalescence:

v_2 of a hadron at a given $p_\perp$ is the partonic v_2 at $p_\perp/n$ scaled by the # of quarks (n).

- Shown to work for K^0_s & Λ (nucl-ex/0306007)
- Works also for Ξ

$\Rightarrow v_2^s \sim v_2^{u,d} \sim 7\%$

D. Molnar, S.A. Voloshin Phys. Rev. Lett. 91, 092301 (2003)
V. Greco, C.M. Ko, P. Levai Phys. Rev. C68, 034904 (2003)
R.J. Fries, B. Muller, C. Nonaka, S.A. Bass Phys. Rev. C68, 044902 (2003)
Z. Lin, C.M. Ko Phys. Rev. Lett. 89, 202302 (2002)

Summary

From radial transverse flow ($p_\perp$ spectra):

- Within our BlastWave calculation, multi-strange baryons seem to show earlier freeze-out

From elliptic flow:

- <u>Ξ shows elliptic flow!</u> As strong as for other particle species
- <u>Ω shows elliptic flow!</u> As strong as for other particle species

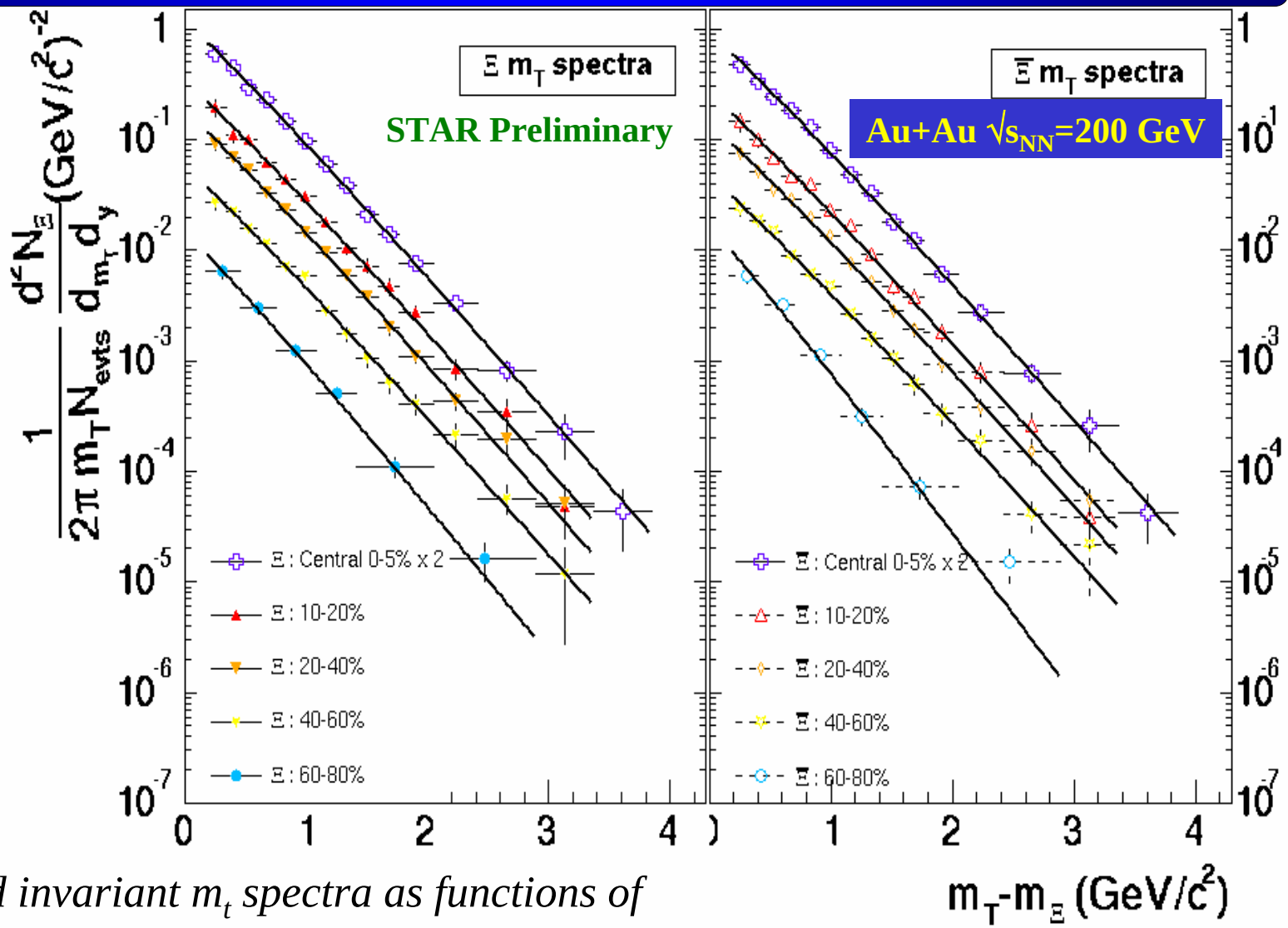
Quark coalescence picture seems to work above $p_\perp \sim 2$ GeV :

(K^0_s(ds), Λ(uds), Ξ(dss))

⇒ Indication of early collectivity with partonic degrees of freedom

Extra slides

Corrected mt spectra



Statistical errors only

Corrected invariant m_t spectra as functions of centrality for Ξ^- (left) and Ξ^+ (right)