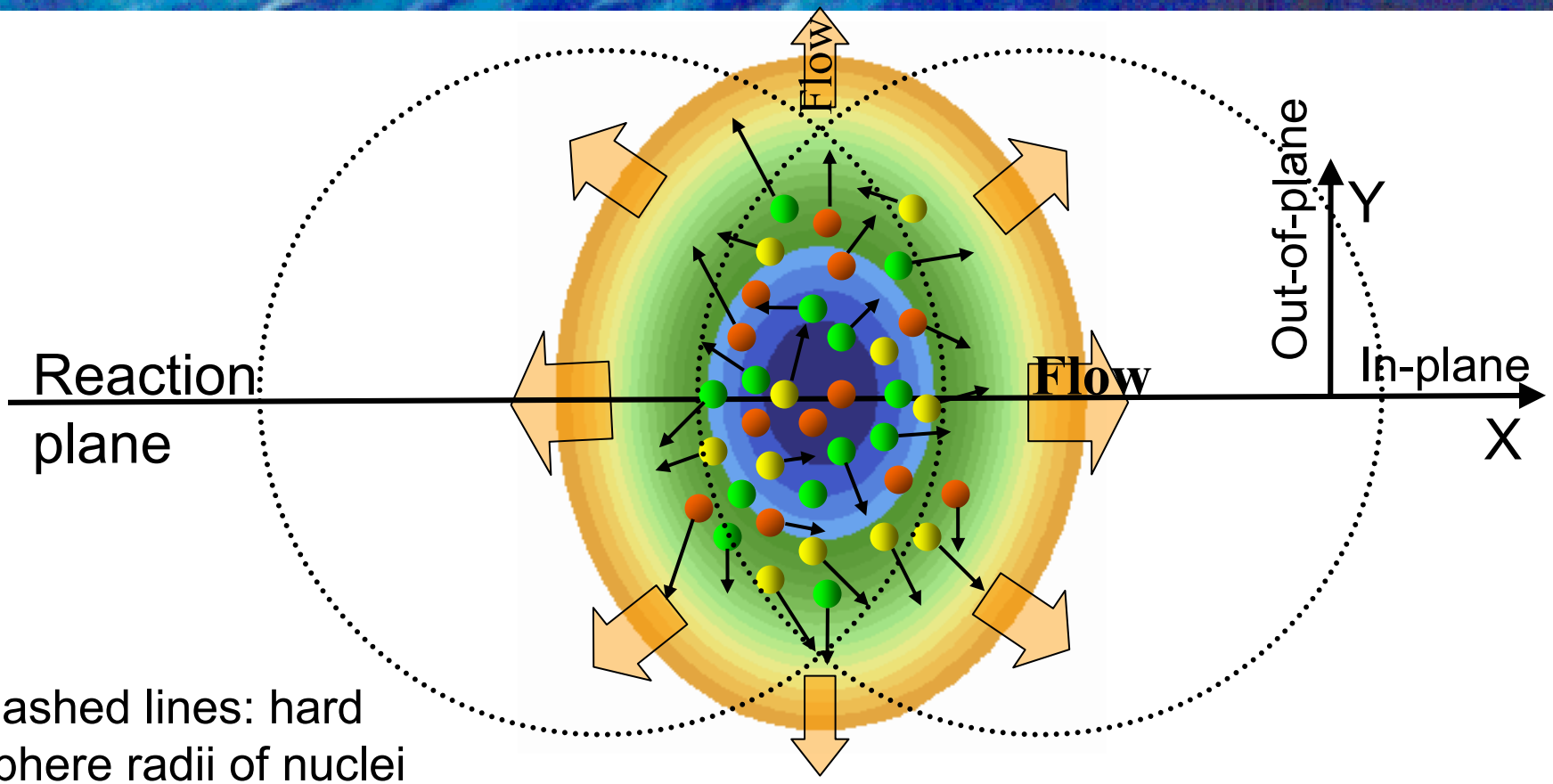
Collective flow

Fabrice Retière

Lawrence Berkeley National Laboratory

Flow (in the transverse plane)

A mid-peripheral collision



Dashed lines: hard sphere radii of nuclei

Re-interactions ⇒ **FLOW**

Re-interactions among what? **Hadrons, partons or both?**

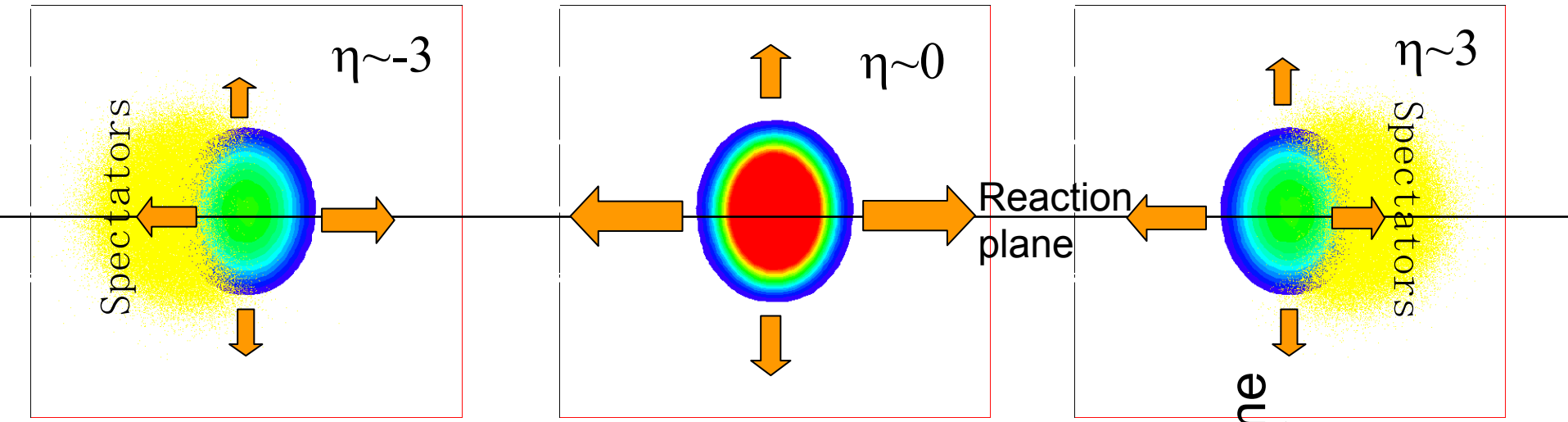
In other words, what equation of state?

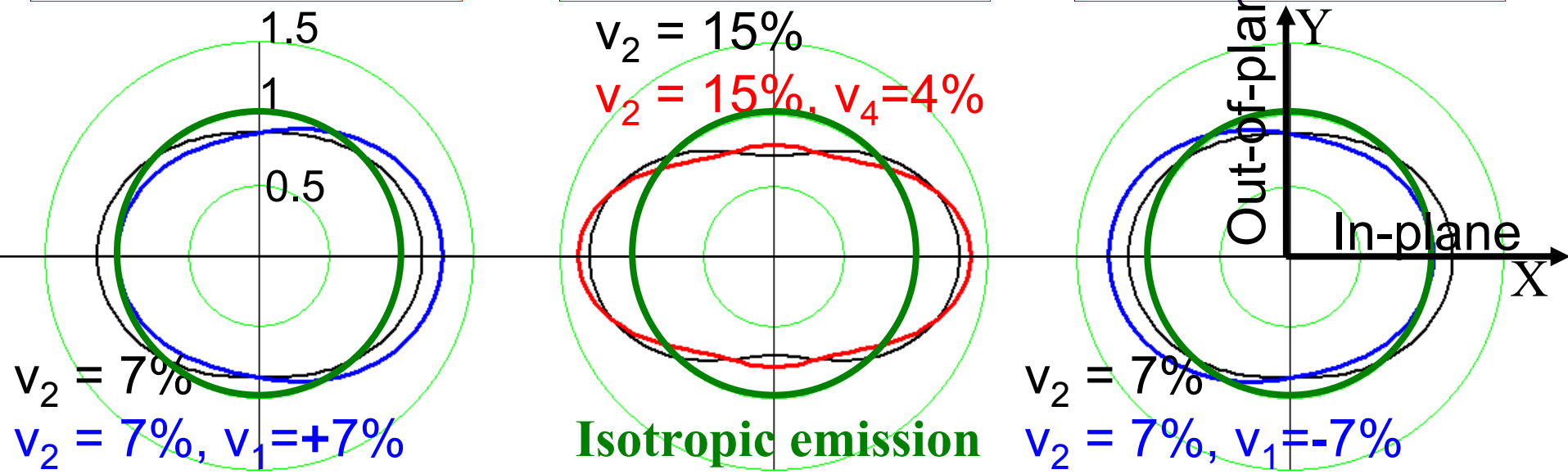
Outline

- Recent data on anisotropic flow
  - v_1, v_2, v_4 and non-flow issues
- Coping with a wealth of data self-consistently and quantitatively
- What flow? partonic or hadronic, or both?
- Summary

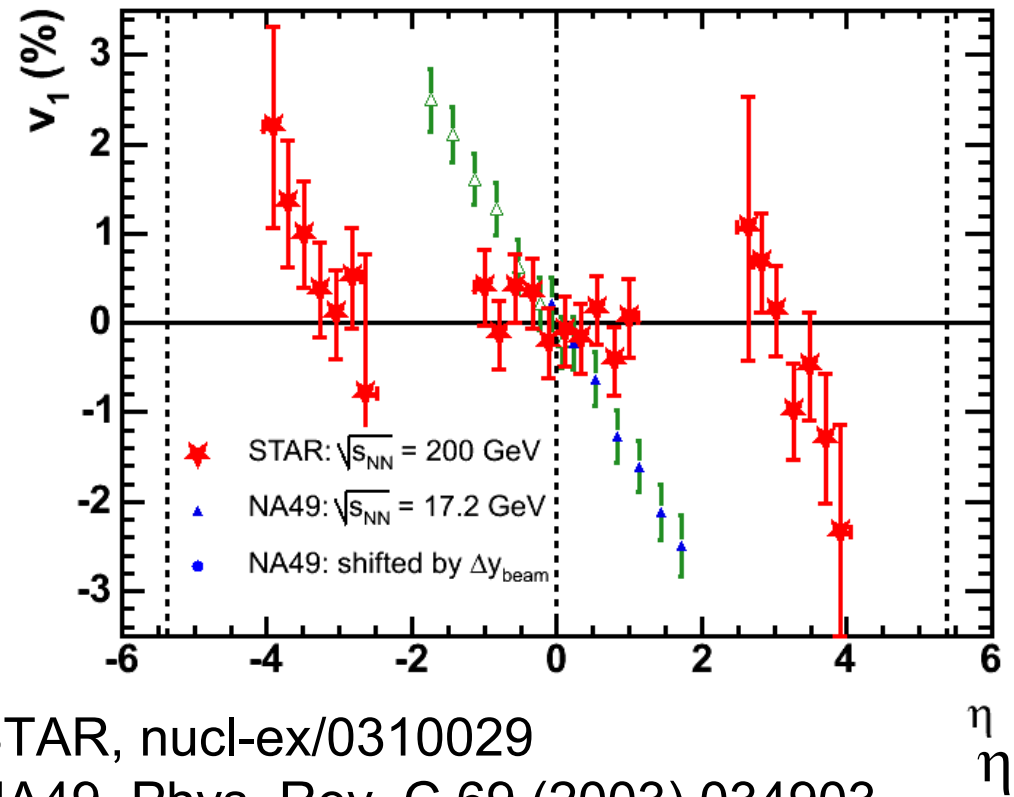
Anisotropic flow, v_1, v_2, v_4, …

$$\frac{dN}{dYp_T dp_T d\varphi} = \frac{dN}{dYp_T dp_T}\frac{1}{2\pi}\left(1 + 2v_1\cos(\varphi) + 2v_2\cos(2\varphi) + 2v_4\cos(4\varphi) + \ldots\right)$$





Directed flow v_1



STAR, nucl-ex/0310029
NA49, Phys. Rev. C 69 (2003) 034903
Talks by M. Belt-Tonjes (PHOBOS),
A.Tang (STAR)
Posters by H. Masui (PHENIX), M. Oldenburg (STAR)

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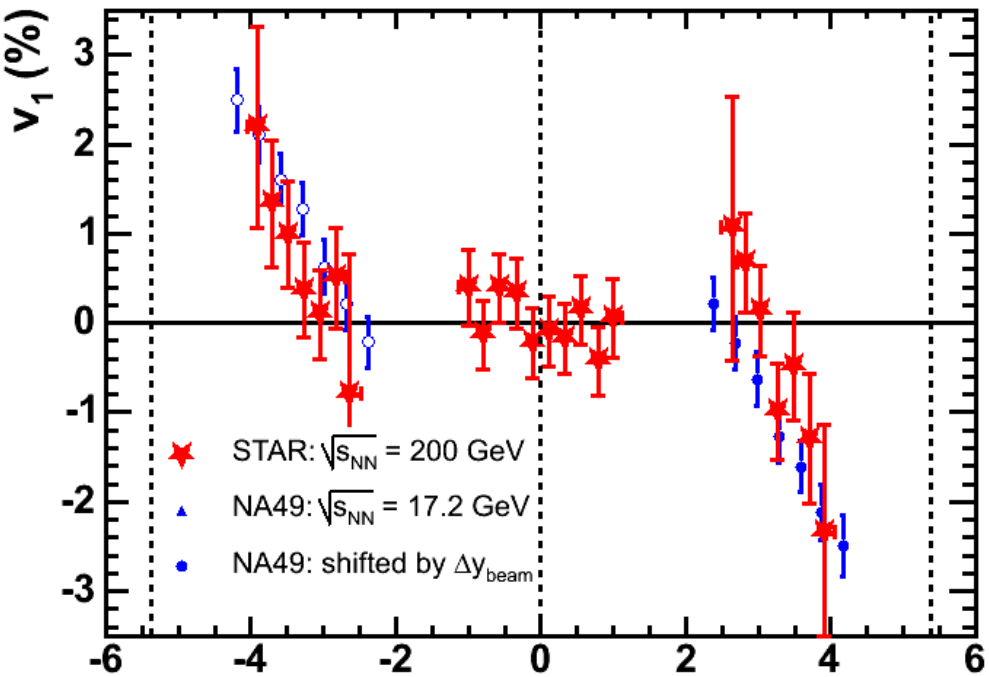

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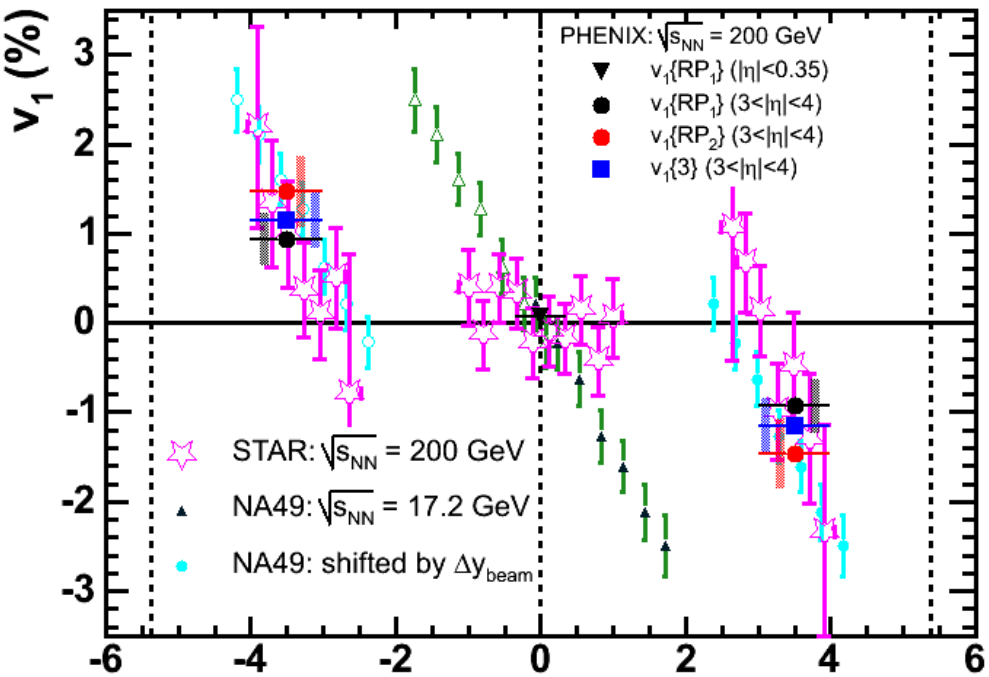

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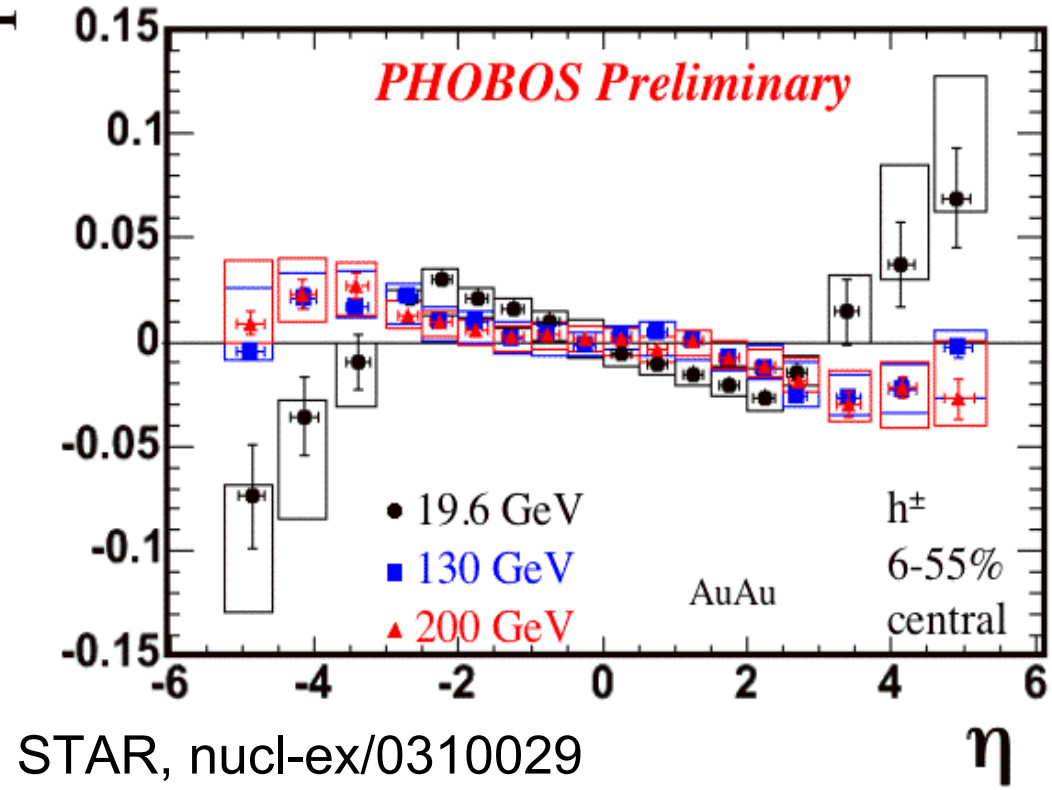

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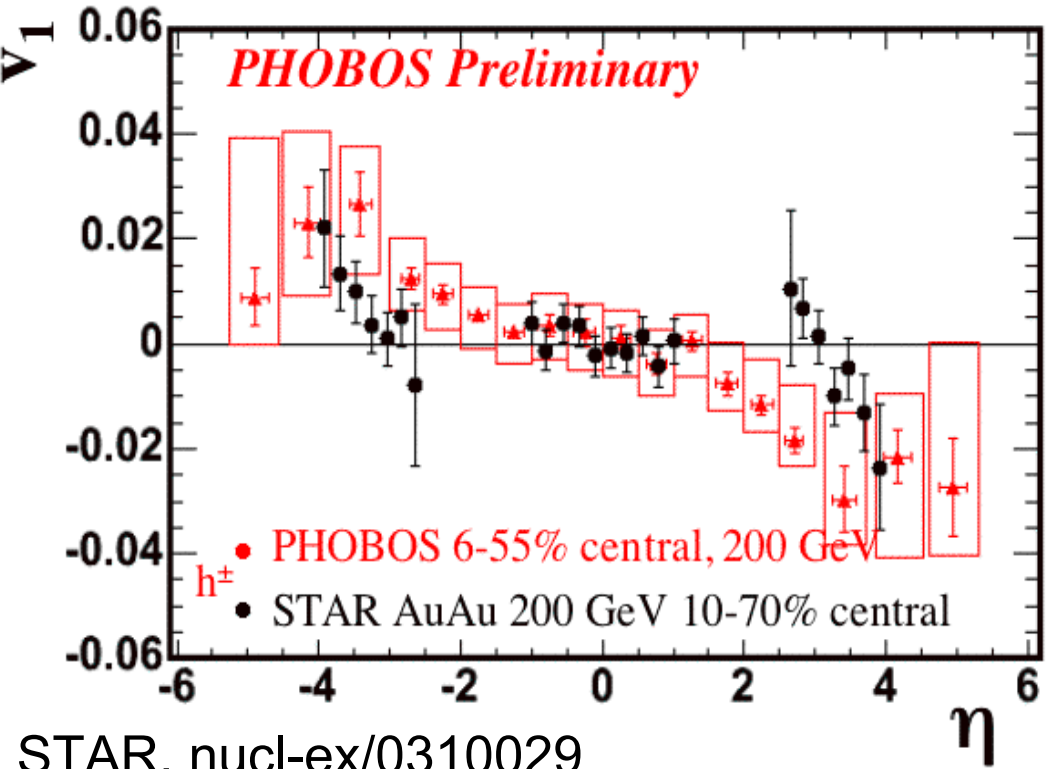

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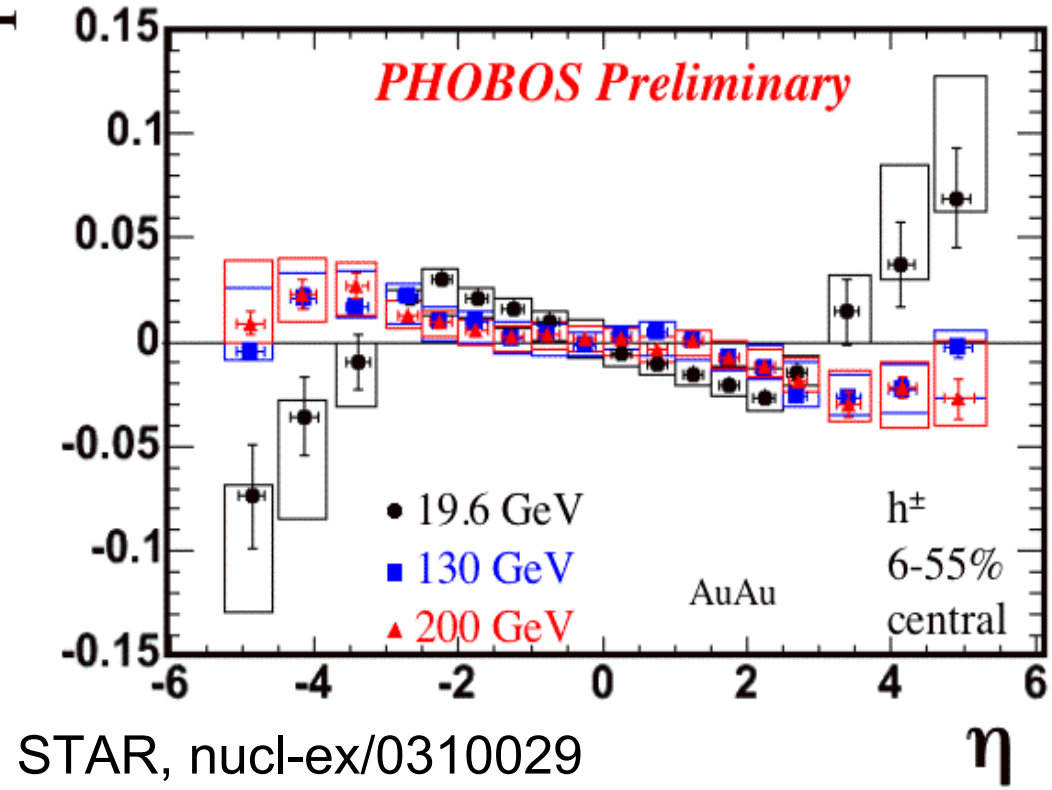
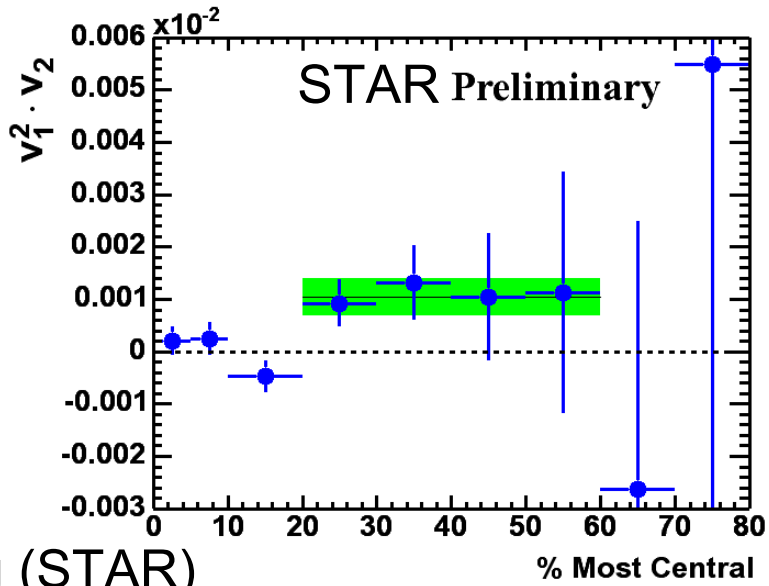


v_2 is positive, i.e. v_1 and v_2 are in the same plane



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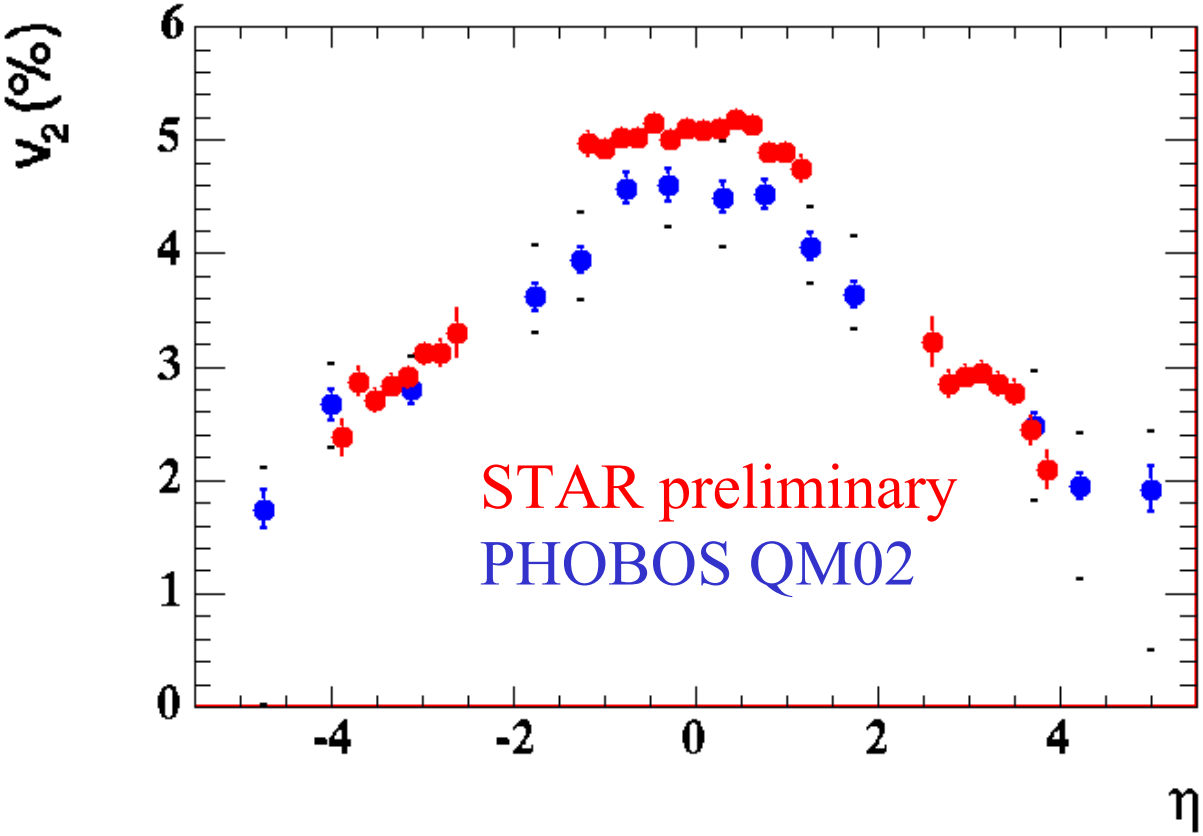
v_2 vs rapidity at RHIC



This afternoon's talk by M.B. Tonjes's (PHOBOS) and U.Heinz (theory)
M.Oldenburg's poster (STAR)

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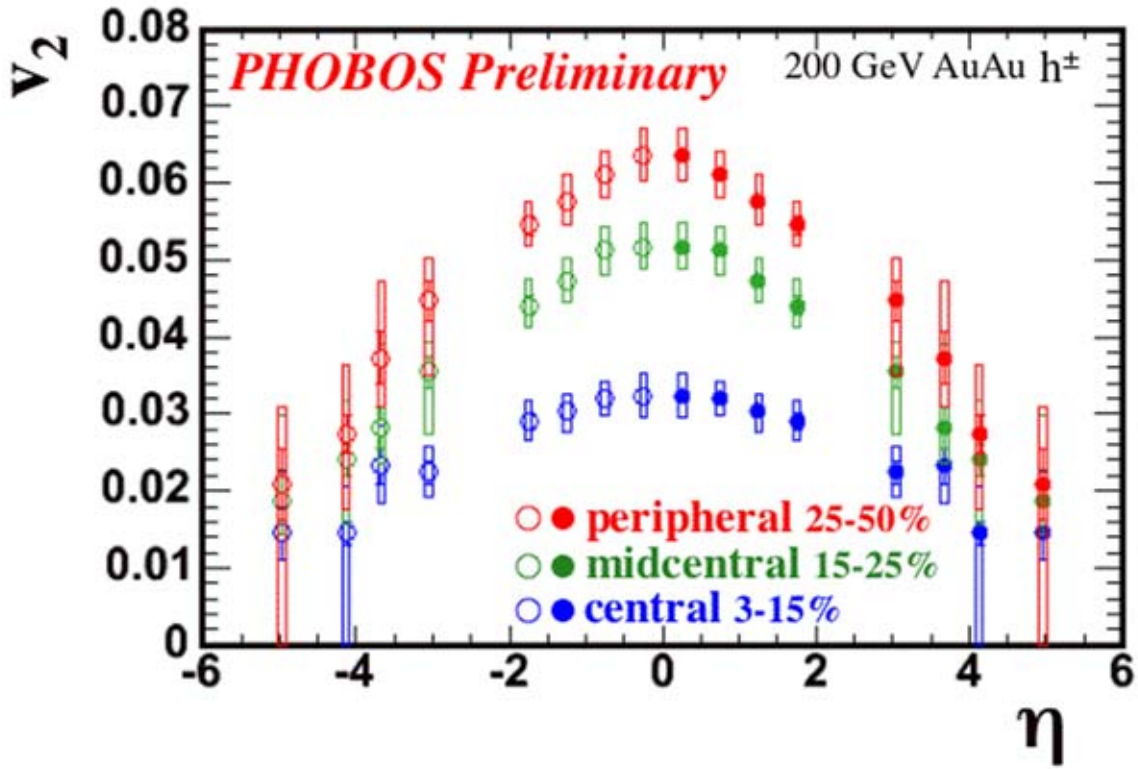

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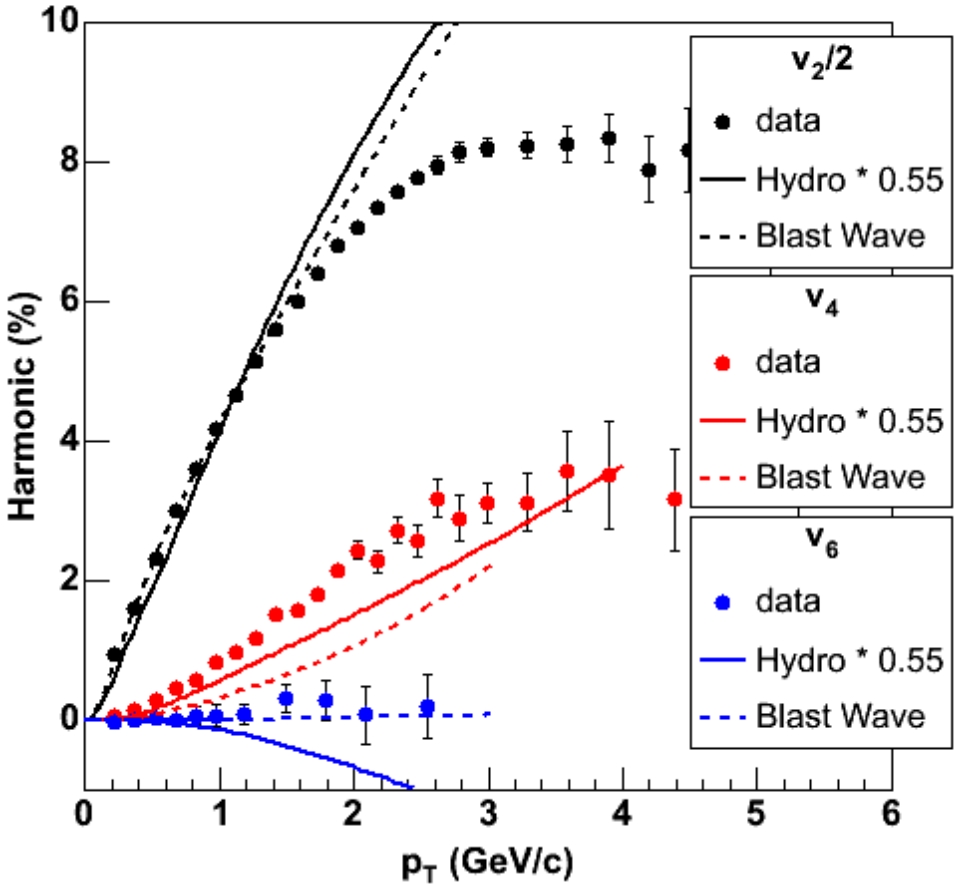
M.Oldenburg's poster (STAR)

Higher harmonics v_4 and v_6

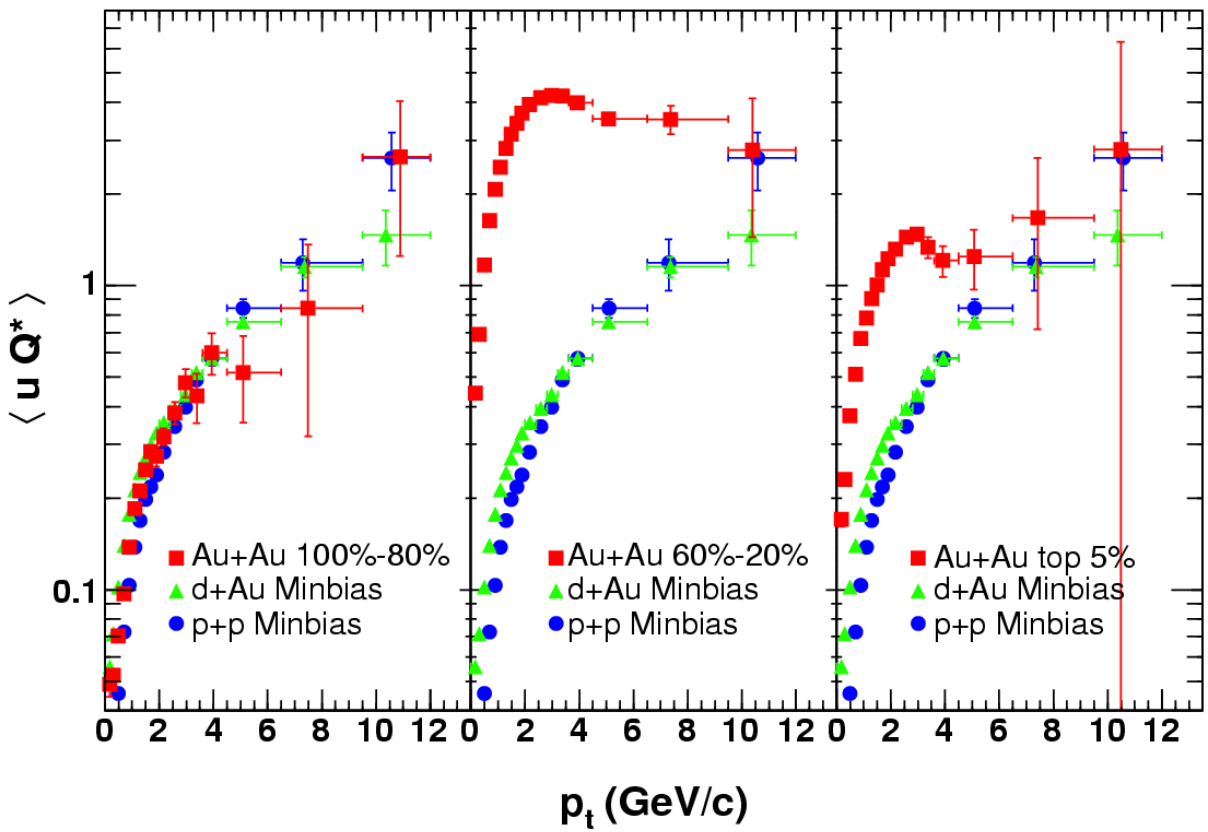
STAR, Au-Au √s=200 GeV
Talk by A. Poskanzer



- New constraints to models
  - Hydro* does not get v_2 and v_4 simultaneously
    - v_2 scaled by 0.55 to match data
  - Blast wave
    - Parameters fixed to fit v_2
    - requires a 4th order parameters (see A. Poskanzer's talk)

*P.Kolb
Phys.Rev. C68 (2003) 031902

Non-flow issues



p-p is the non-flow baseline

- v2
  - Scalar products(1)
    - Sensitive to both flow and non-flow
  - $\Delta\phi$ correlation
    - Disentangle jets from flow
  - Lee-Yang zeroes(2) and high order cumulants
    - Cumulants even from PHENIX(3)

(1) A. Tang's talk
(2) N. Borghini's talk
(3) M. Issah's poster

Other data sensitive to flow are also becoming available

- Spectra
  - Different energy
    - AGS energies
    - SPS: 20, 30 40, 80, 60
    - RHIC: 19.6, 130, 200
  - Many particle species, e.g.
    - Ξ, Ω, ϕ
    - Charm
  - Many centralities
  - Different rapidities
- Two-particle correlations
  - Source size (HBT)
    - Different energy
    - Different centrality
    - Different rapidity
    - Kaons
    - Wrt reaction plane
  - Source shift (Non-id correlation)
    - Tuesday's talk by A.Kisiel
    - Including π–Ξ correlation!

Understanding flow

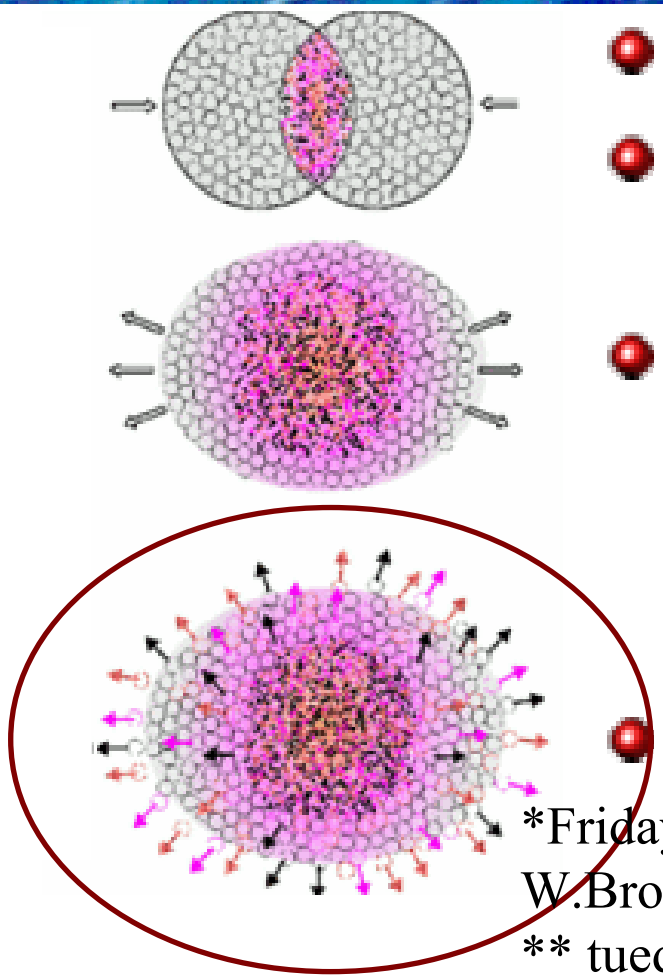
- Requires to describe the data (spectra, anisotropic flow, two-particle correlations):
  - Self-consistently
  - Quantitatively
- And understand the **evolution of the system**
  - No definite conclusions can be made with only freeze-out parameterizations

Understanding flow: models

- Hadronic cascades (RQMD, uRQMD, …)
  - Do well at SPS, except too long source size
  - Flow too weak at RHIC
- Partonic cascades (MPC, AMPT, …)
  - Do a reasonable job at RHIC with huge partonic x-sections
- Hydro
  - Do well for spectra and v_2
  - Do not reproduce source size and lifetime (from HBT)

See for details:
- Following talk by T.Hirano
- This afternoon's talks by S.Bass, U.Heinz, D. Molnar, E.Shuryak, D.Teaney

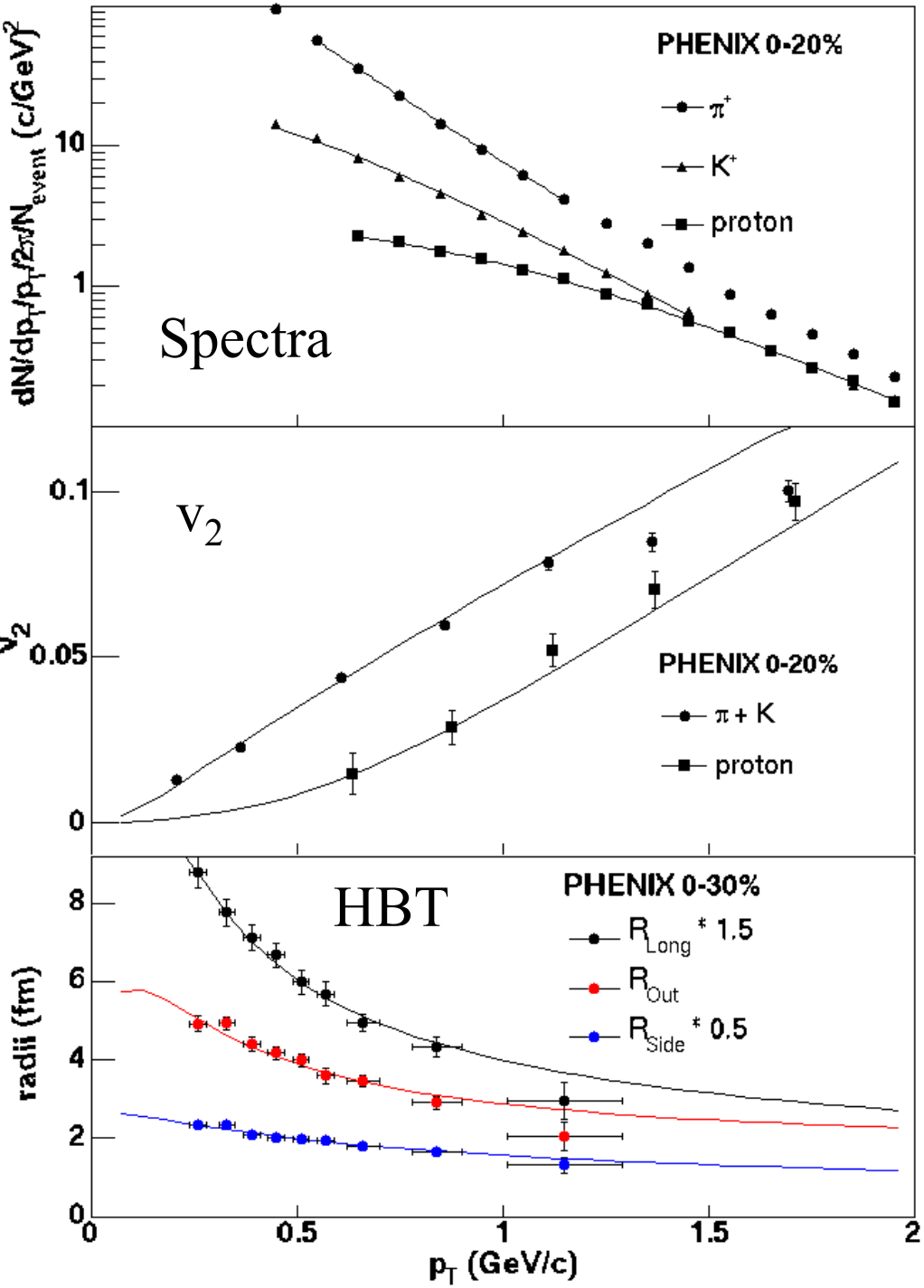
Understanding flow: parameterizations



- Self-consistent
- Quantitative characterization of the freeze-out stage
- On the market
  - "Krakow" single freeze-out*
  - BudaLund**
  - Blast Wave
- Do not describe the system evolution

*Friday's talk by W.Florkowski
W.Broniowski et al., nucl-th/0212052, nucl-th/0212053, …
** tuedsay's talk and poster by M.Csanad
M. Csanád, T. Csörgő, B. Lörstad and A. Ster, nucl-th/0311102 and nucl-th/0310040, …

Snapshot of the freeze-out stage



Blast-wave

T=106 ± 1 MeV

$\langle\beta_{InPlane}\rangle = 0.571 \pm 0.004$ c

$\langle\beta_{OutOfPlane}\rangle = 0.540 \pm 0.004$ c

$R_{InPlane} = 11.1 \pm 0.2$ fm

$R_{OutOfPlane} = 12.1 \pm 0.2$ fm

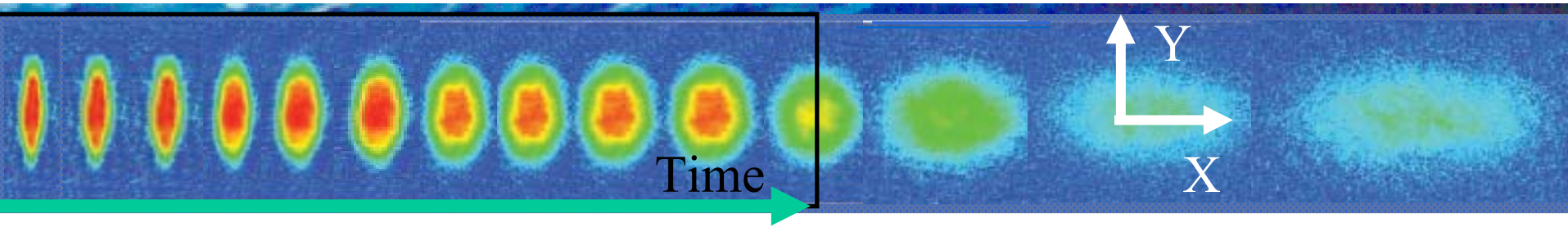
Life time (τ) = 8.4 ± 0.2 fm/c

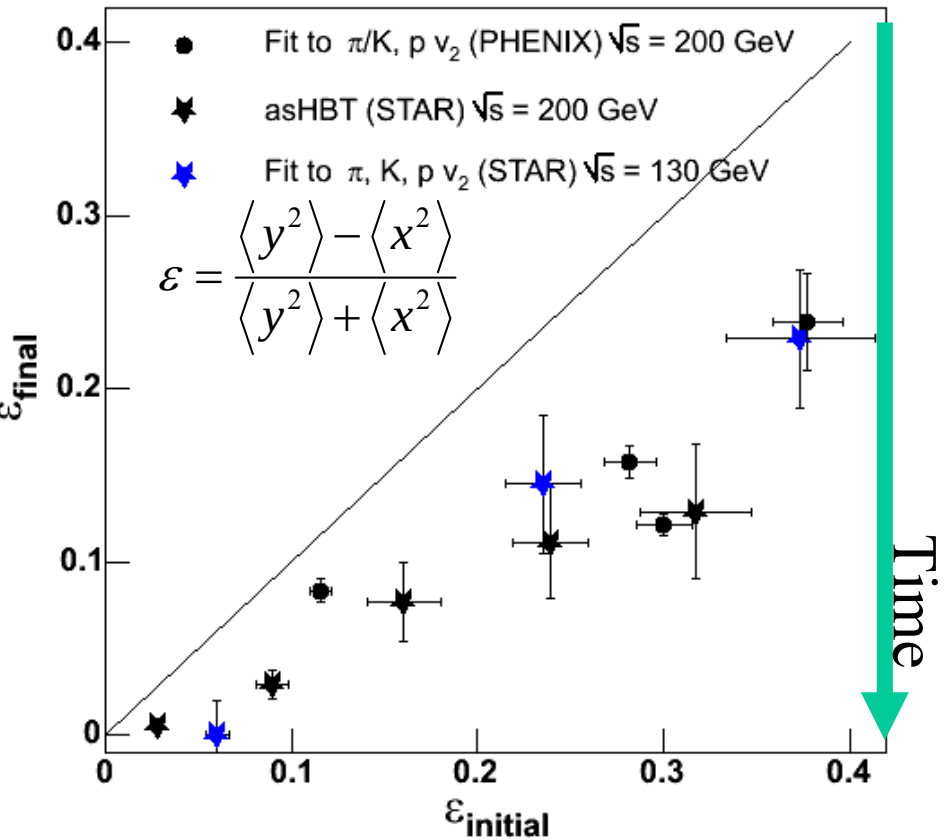
Emission duration = 1.9 ± 0.2 fm/c

χ^2/dof = 120 / 86

Latest paper (long legacy),
F.R and M.Lisa
nucl-th/0312024

Parameterization ⇒ parameters
System deformation in the Blast Wave





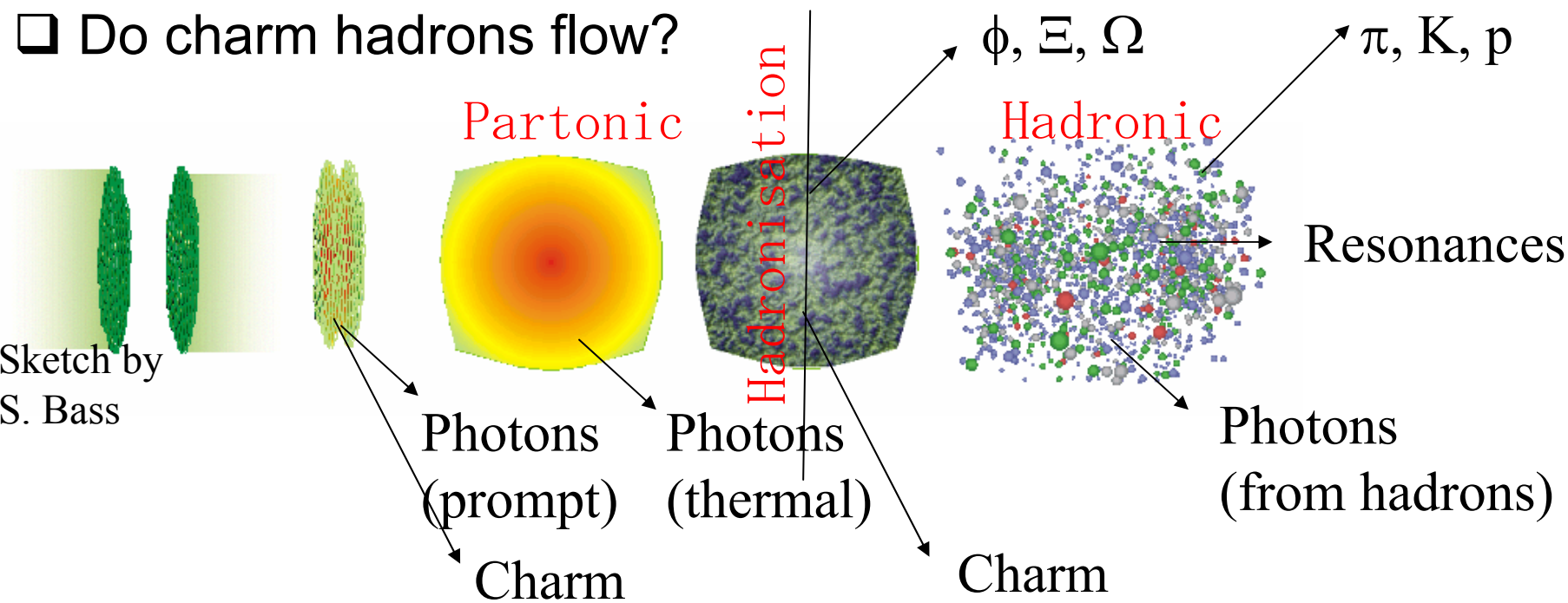
- Final state eccentricity from
  - v_2
  - HBT with respect to reaction plane

Now, that we can characterize flow,
let's ask the most important question:

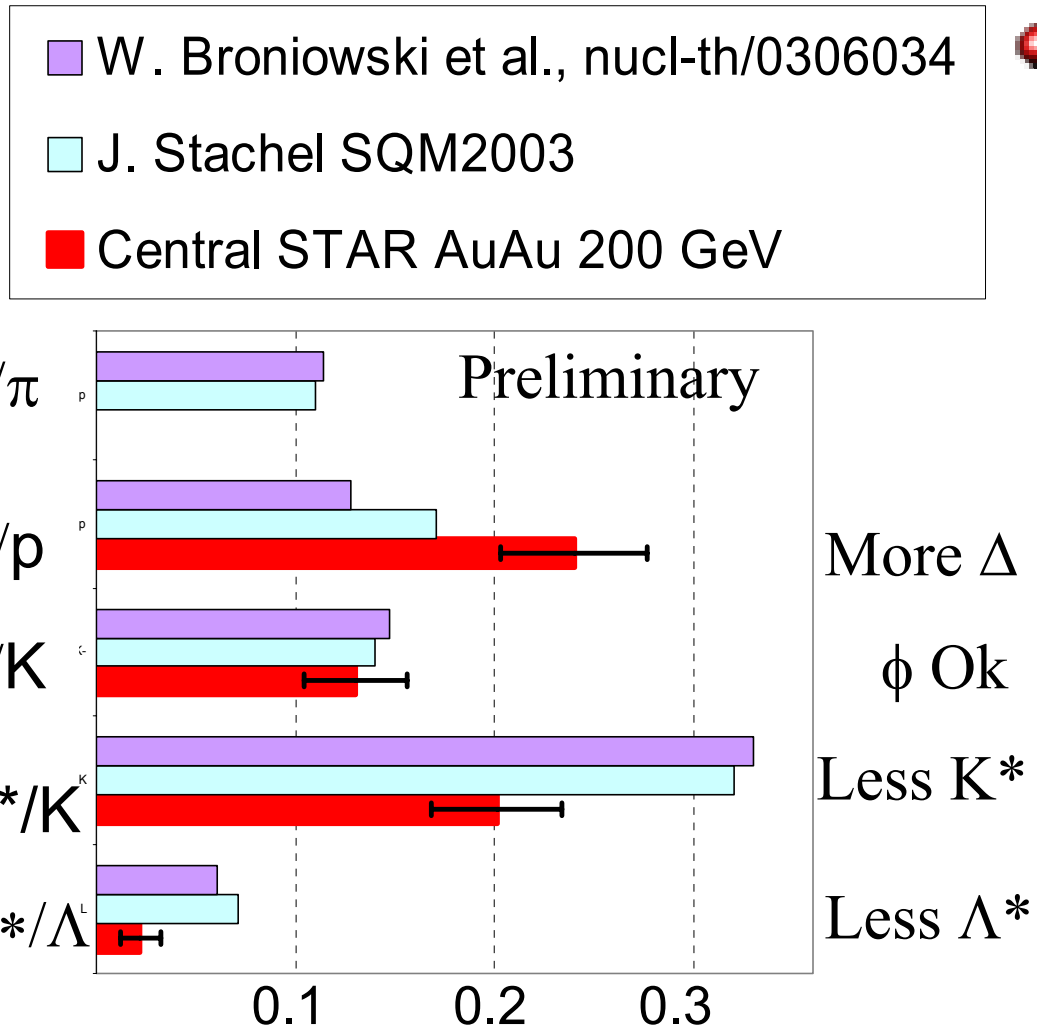
Is flow partonic, hadronic or both?

Is flow partonic, hadronic or both?

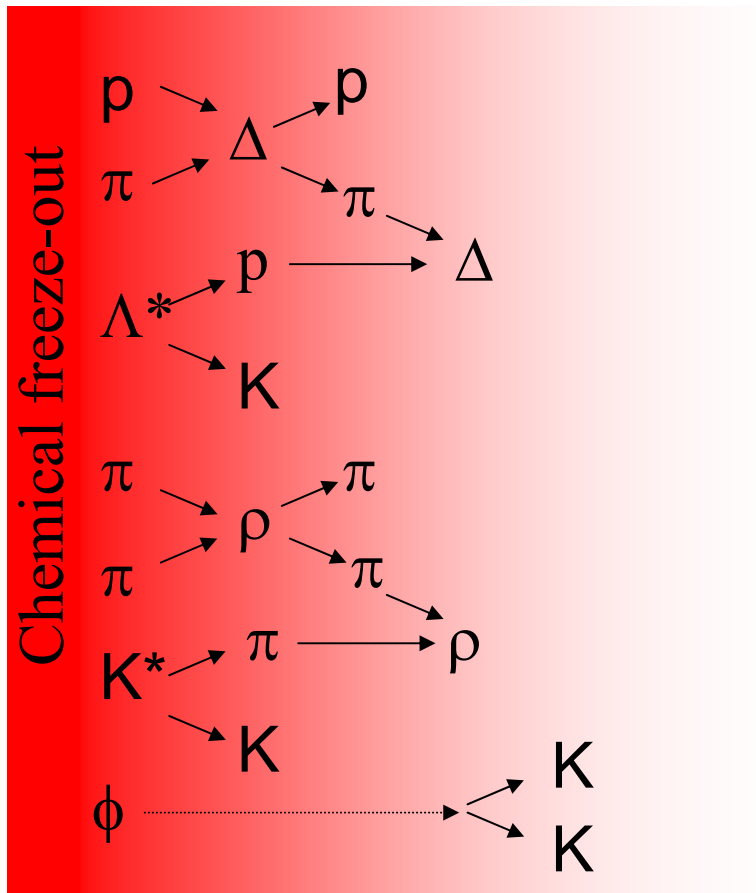
- ✓ Only the models with a partonic stage *reproduce* flow data
- ✓ Hadronisation by quark coalescence. Wait for R. Fries' talk.
- ❑ Are resonance yields affected by a hadronic rescattering stage?
- ❑ Do ϕ, Ξ and Ω flow? Do they flow as π, K, p?
- ❑ What is the flow of photons not coming from hadron decay?
- ❑ Do charm hadrons flow?



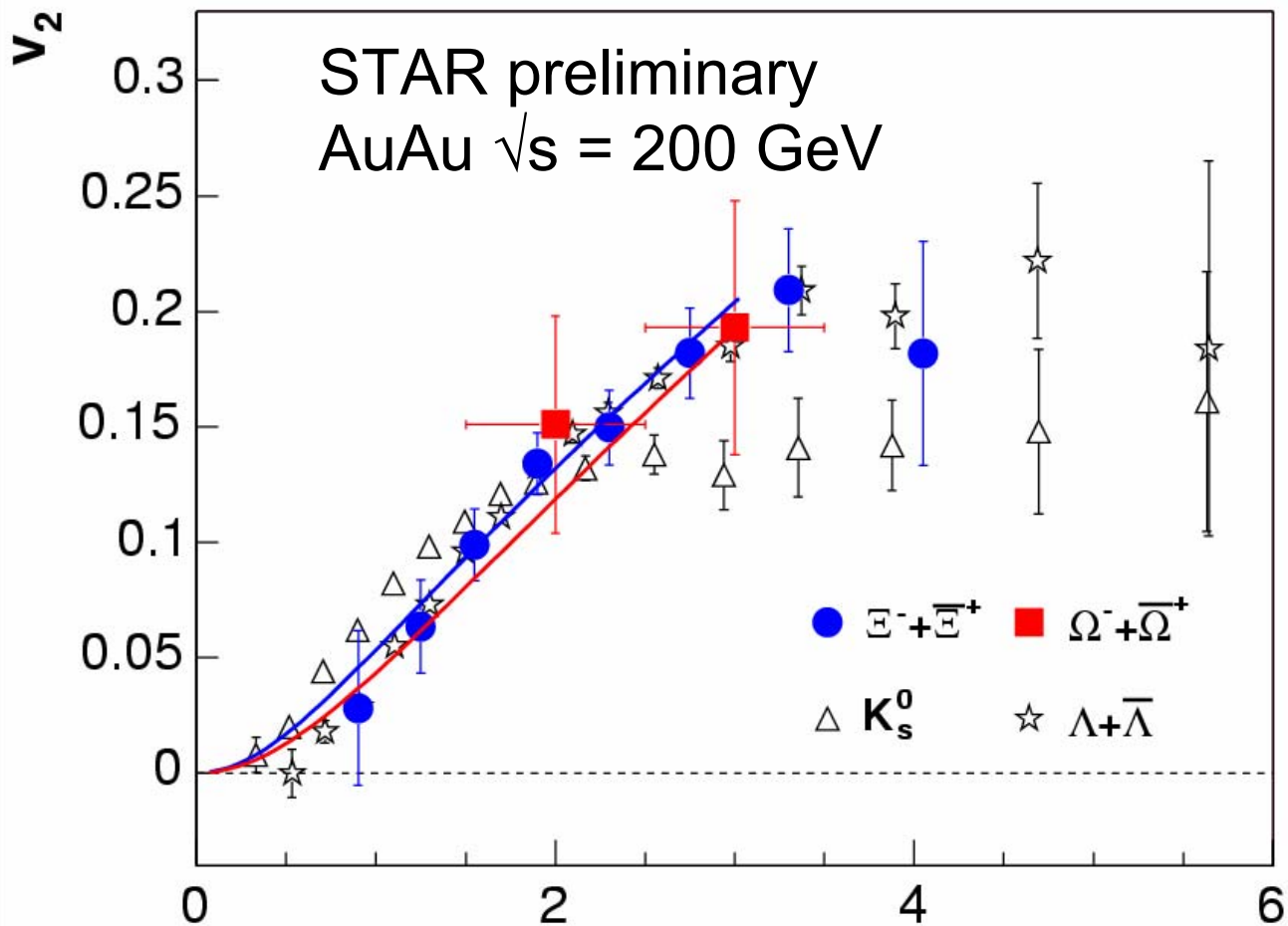
Resonance yields consistent with a hadronic re-scattering stage



- Generation/suppression according to x-sections



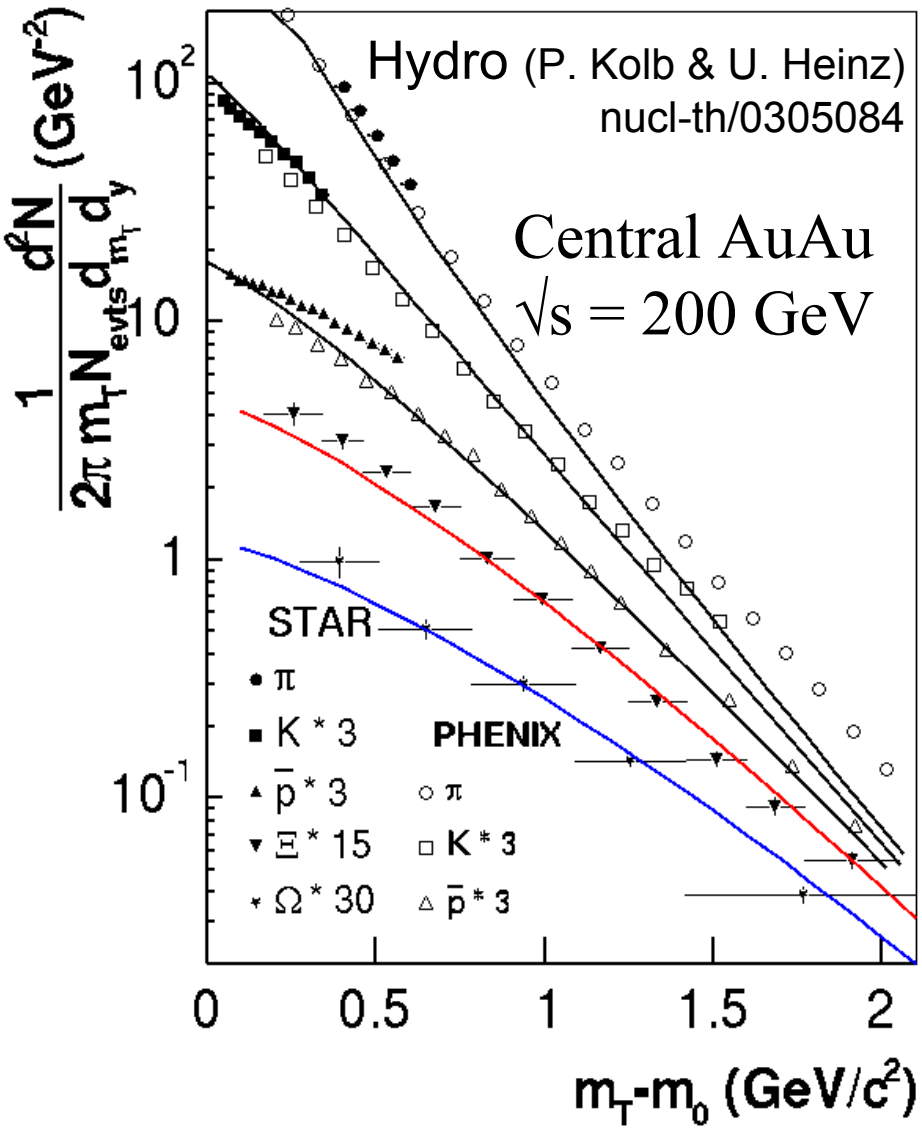
Significant Ξ and Ω v_2 Multi-Strange Baryon flow



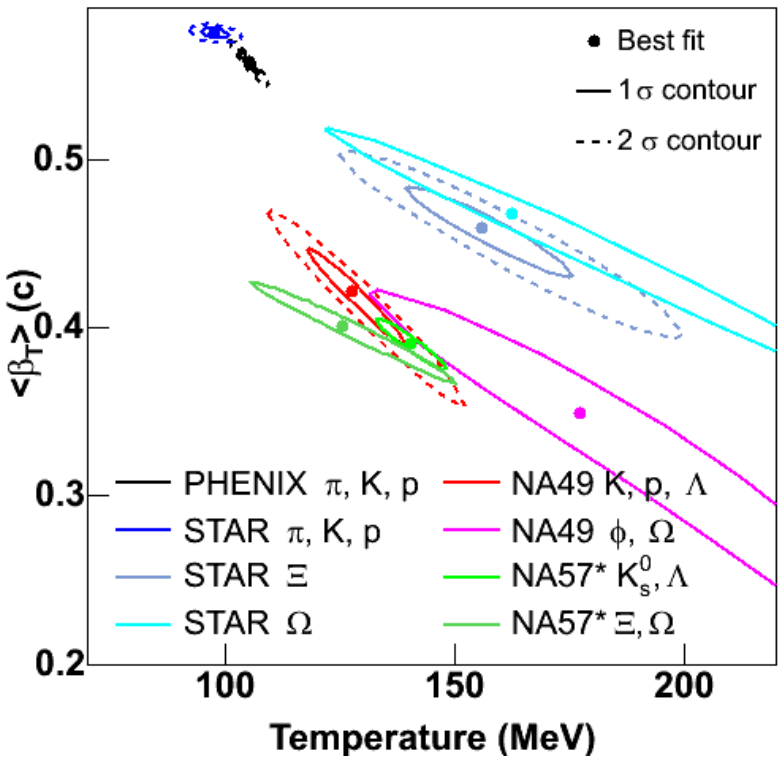
This afternoon's talk by J. Castillo

Do Ξ and Ω flow as π, K, p?

Blast Wave ⇒ no (RHIC), hydro ⇒ ?



Blast wave fits

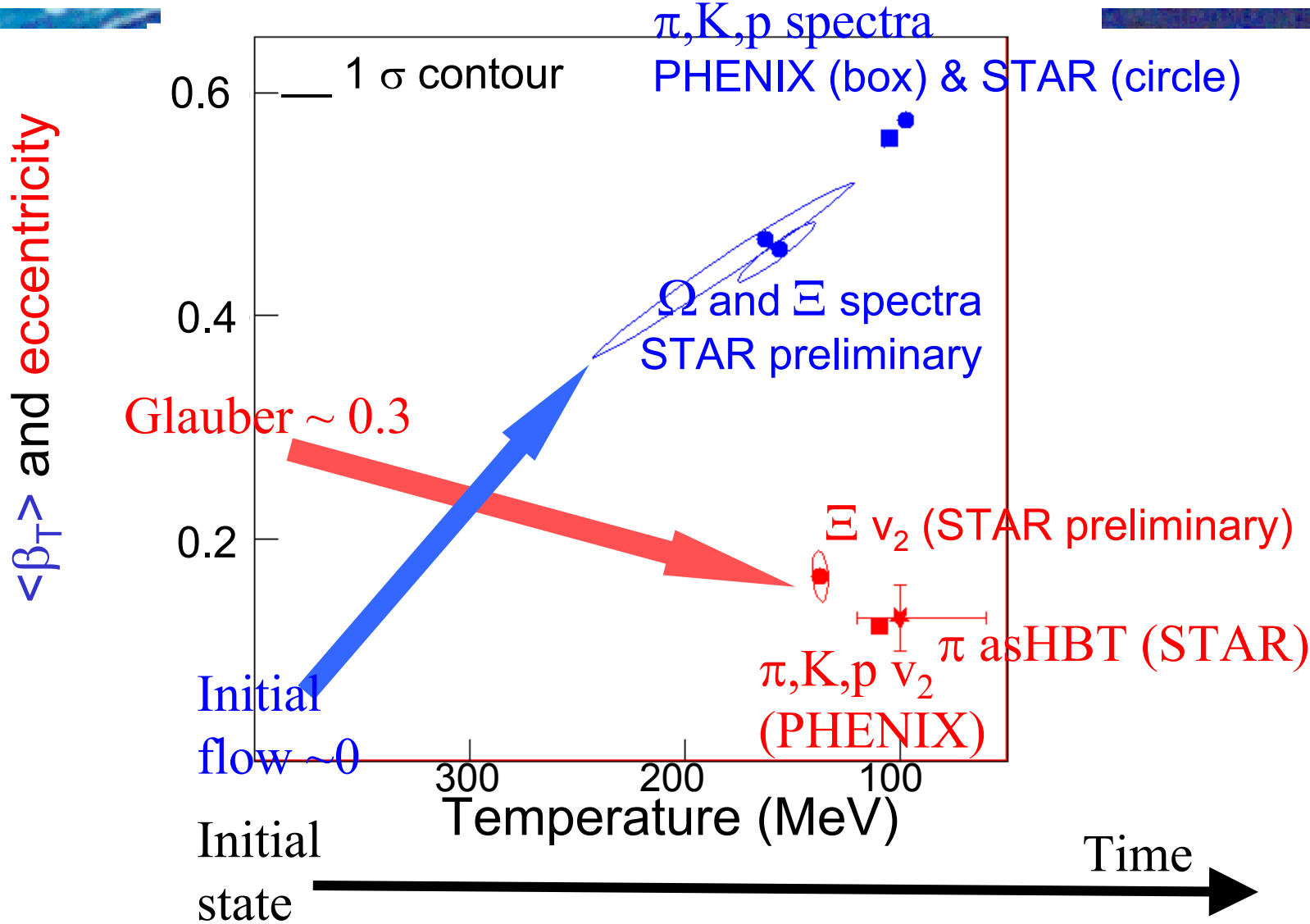


Ξ and Ω, STAR preliminary

Preliminary NA57 and NA49 data

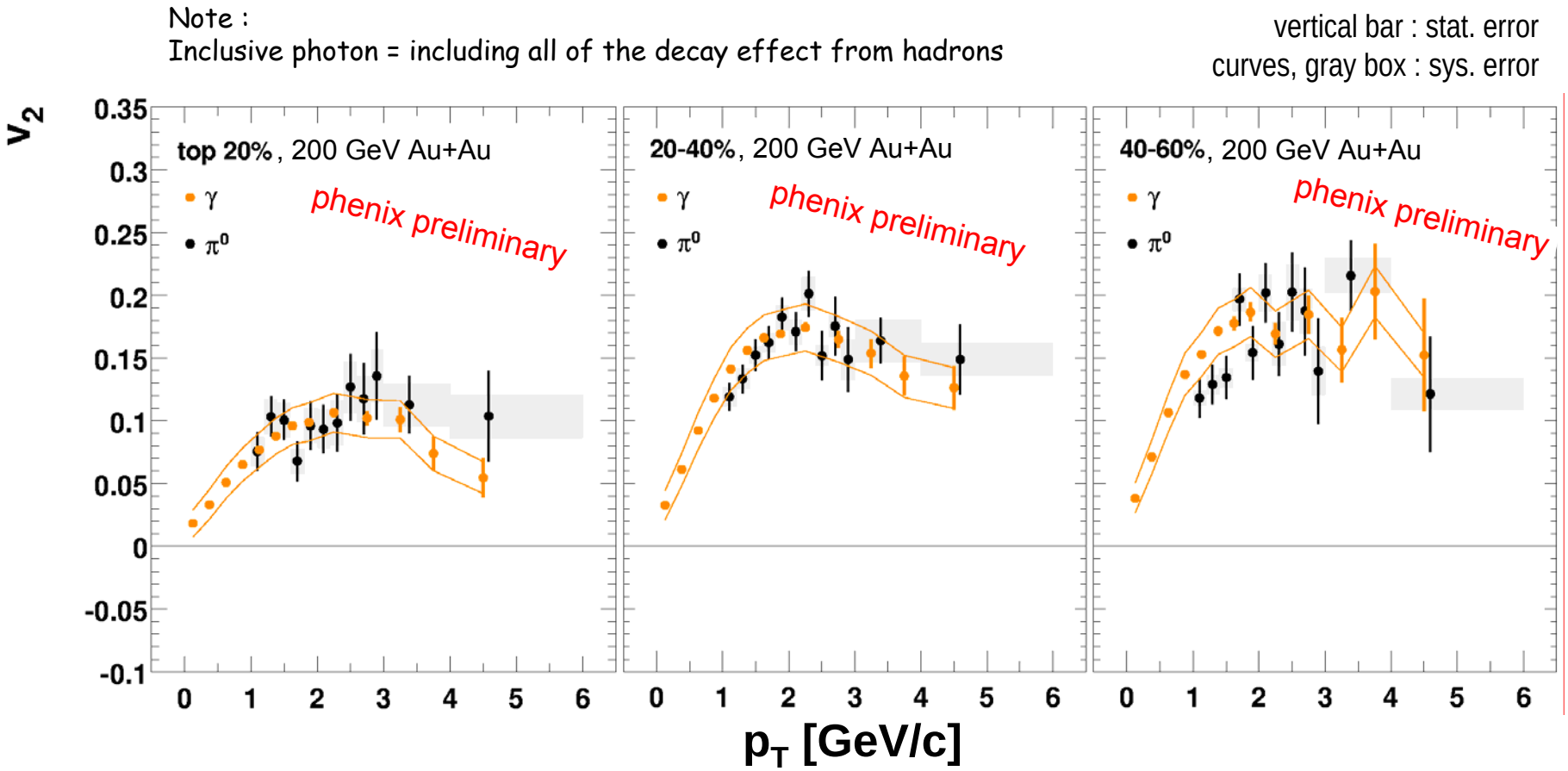
Different flow profile for NA57

The Blast Wave side of the story
Early freeze-out of Ξ and Ω



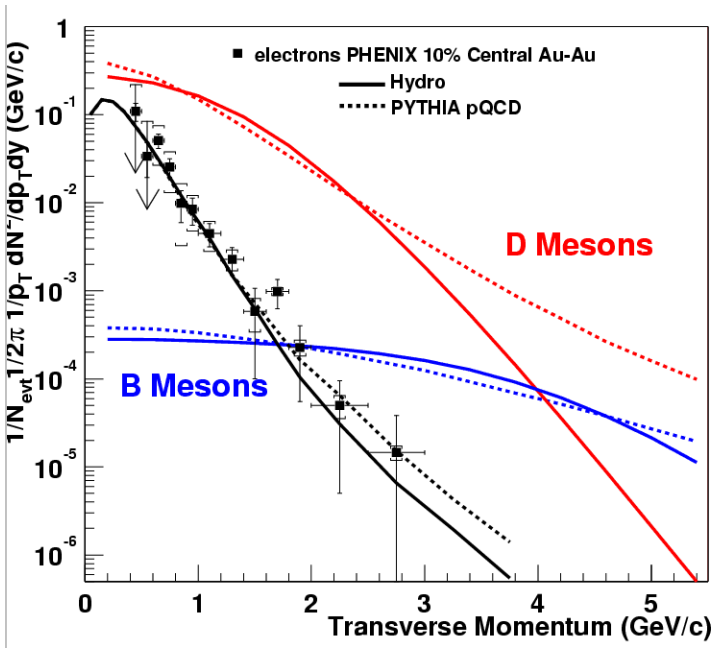
Photon flow fully driven by π_0 flow?

This afternoon's talk by M. Kaneta

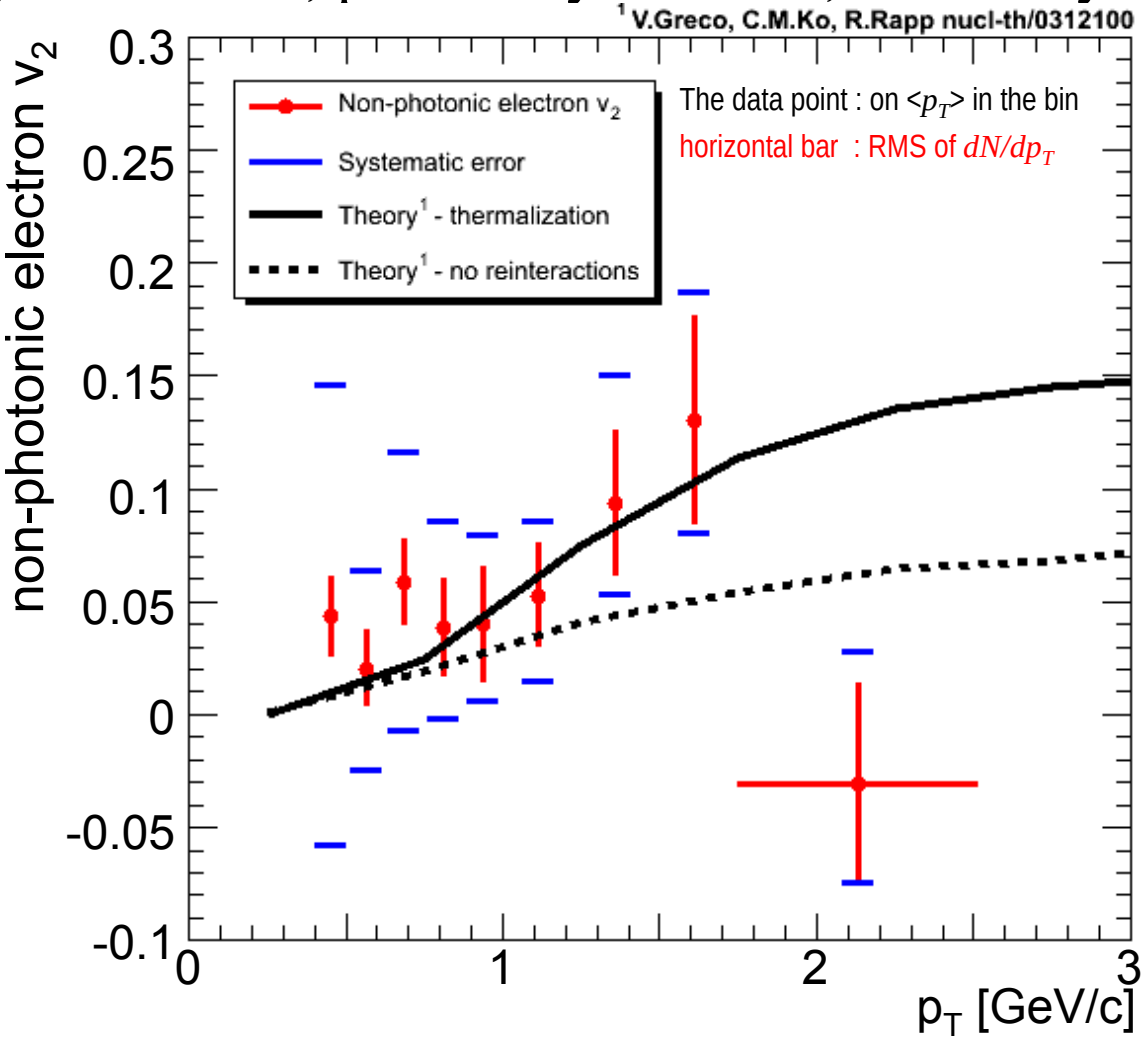


Electron v_2 and Charm flow

Talk by M. Kaneta, posters by S. Sakai, T. Hashiya



J. Nagle, S. Kelly,
M. Gyulassy, S.B. JN,
Phys. Lett. B 557, pp 26-32
And talk by S.Kelly



Summary

- A wealth of data probing flow becoming available
  - v_1, v_2, v_4, v_6, spectra, and two-particle correlations
  - Data described quantitatively and self-consistently by parameterizations
    - What about models? (please release your code)
- Data pointing to flow being a combination of partonic and hadronic flow at RHIC
  - Final conclusion pending …
- Outlook:
  - More ϕ, Ξ, Ω, charm, photons, non-id correlations
  - My wish: so much data will make the models converge


2004

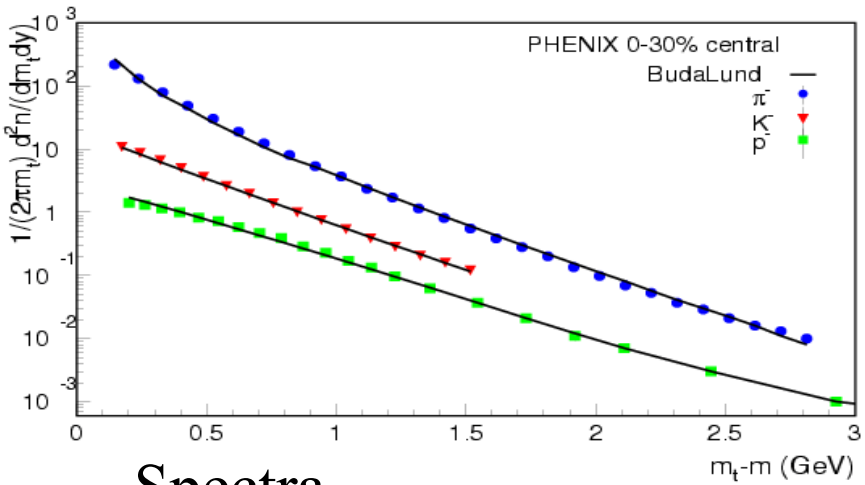

BERKELEY LAB

BudaLund

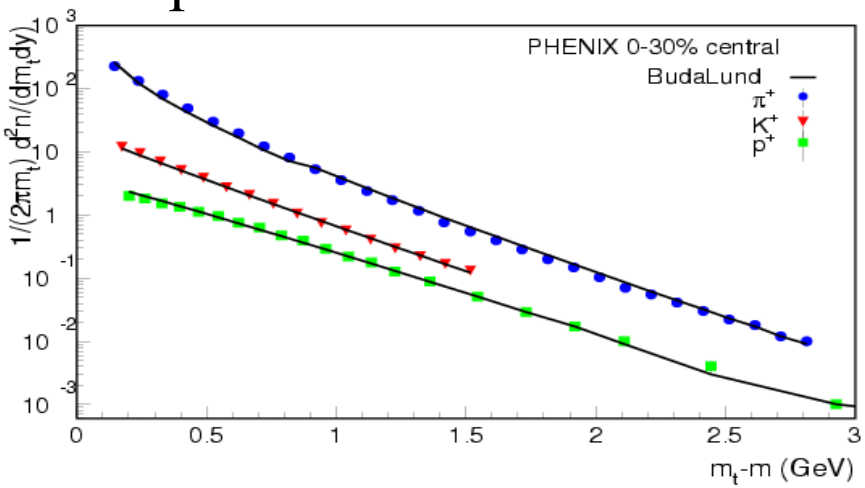
M. Csanád, T. Csörgő, B. Lörstad and A. Ster

(Tuesday's talk and poster)

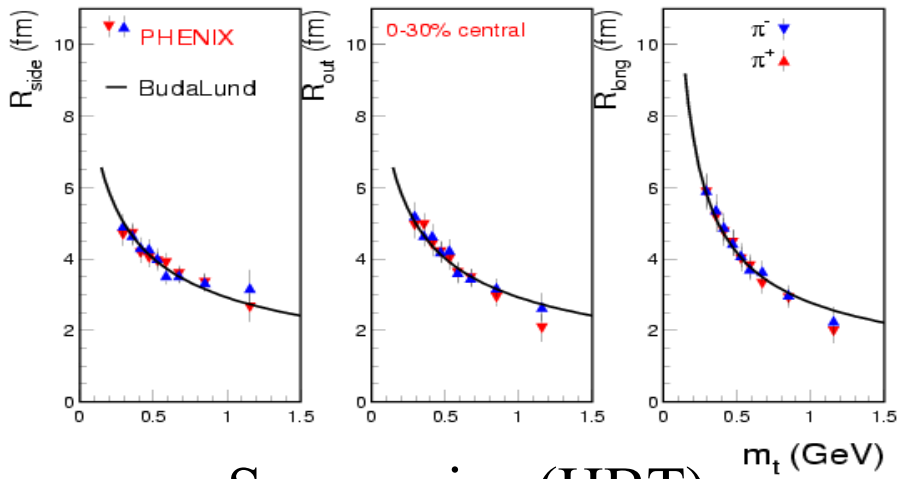
BudaLund v1.5 hydro fits to 200 AGeV Au+Au



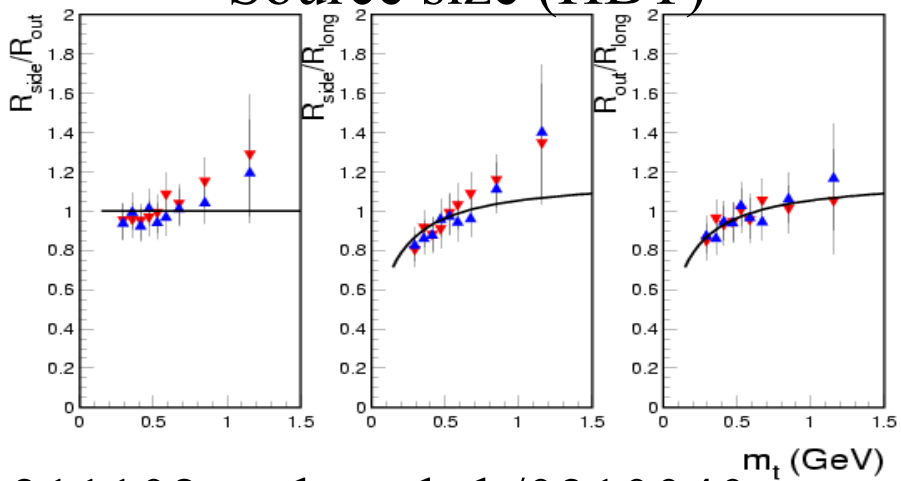
Spectra



PHENIX and BudaLund v1.5, 200 GeV Au+Au

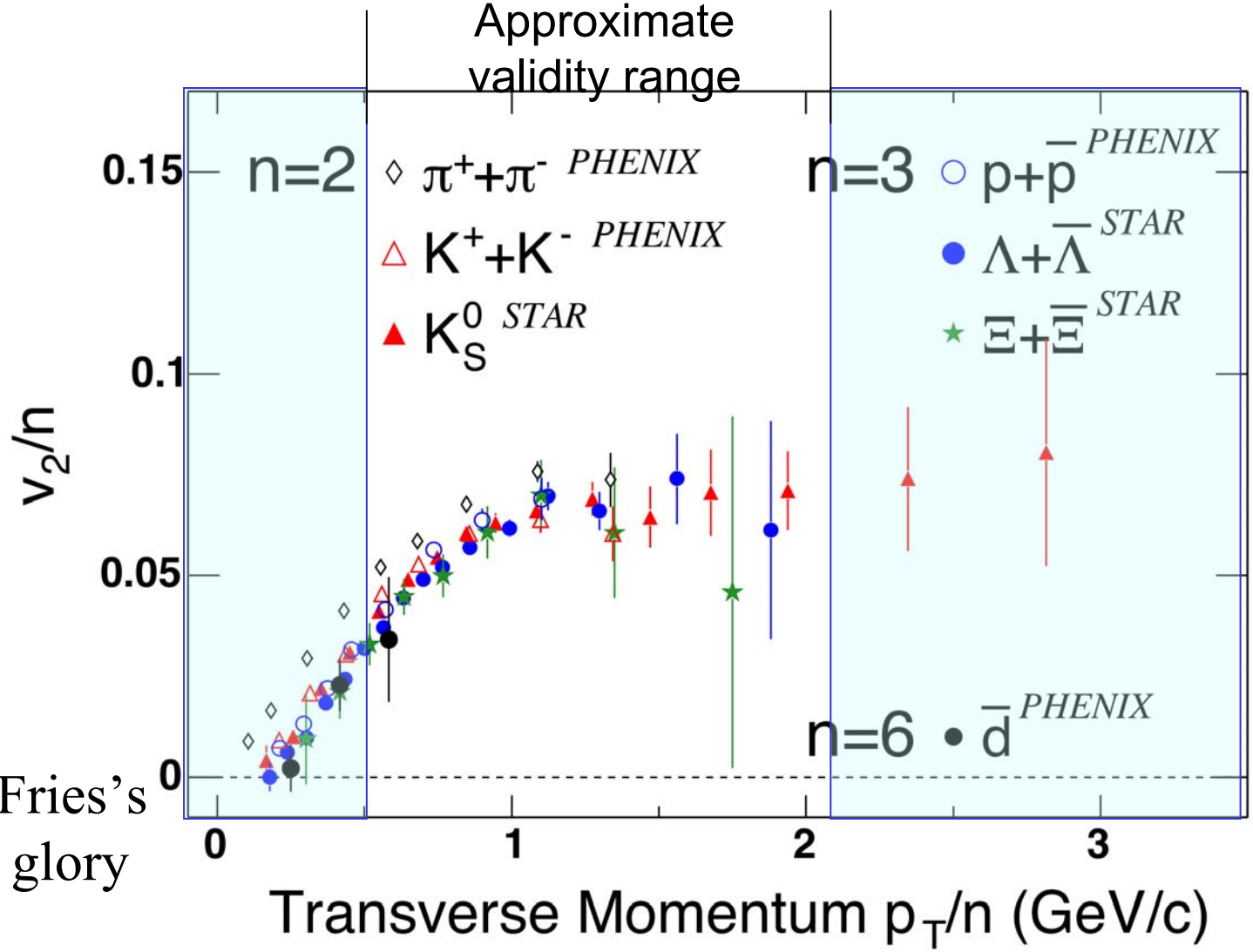


Source size (HBT)



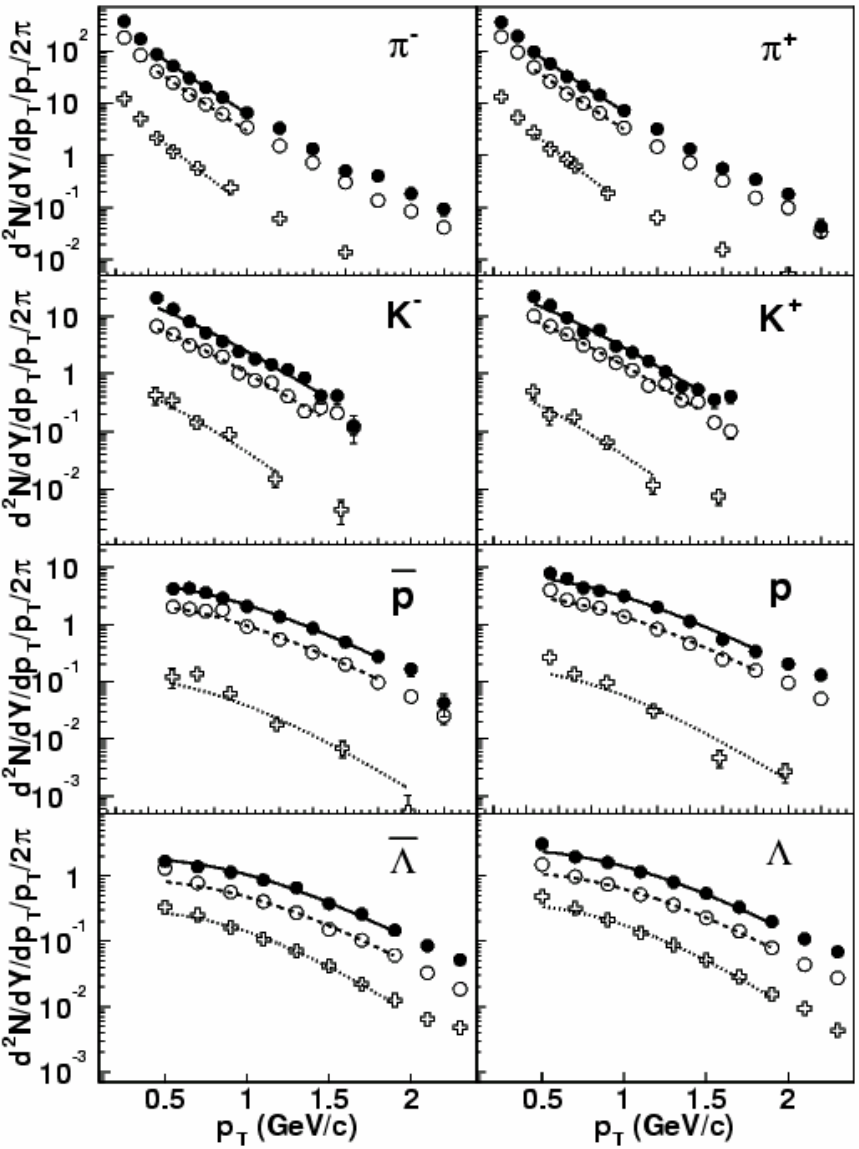
nucl-th/0311102 and nucl-th/0310040

Hadronization by quark coalescence: v_2 scaling by quarks



Wait for R.Fries's talk for full glory details

Example of self-consistency
The Blast Wave parameterization



- Simultaneous fit to
  - Spectra
  - v_2
  - HBT radii

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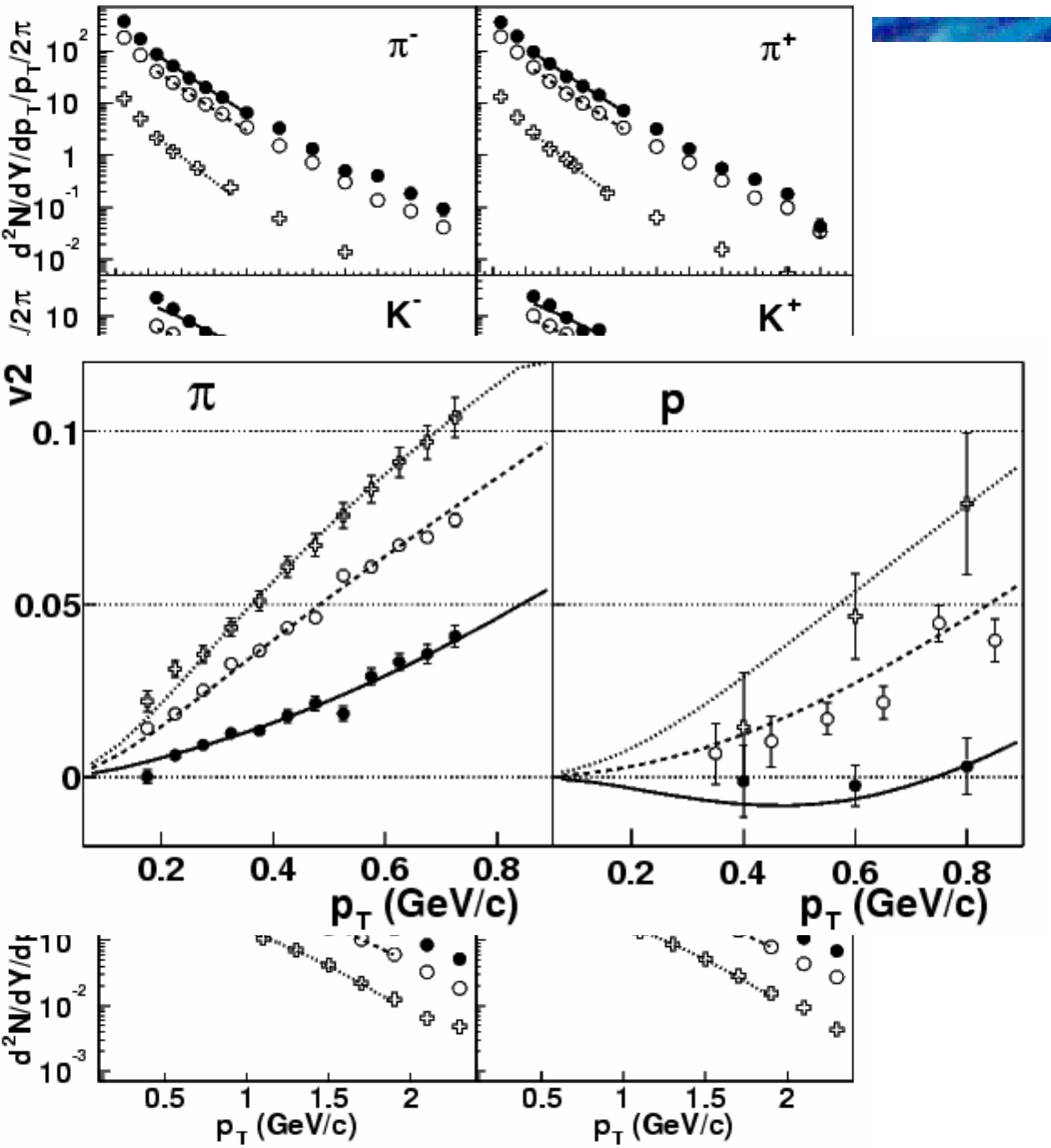

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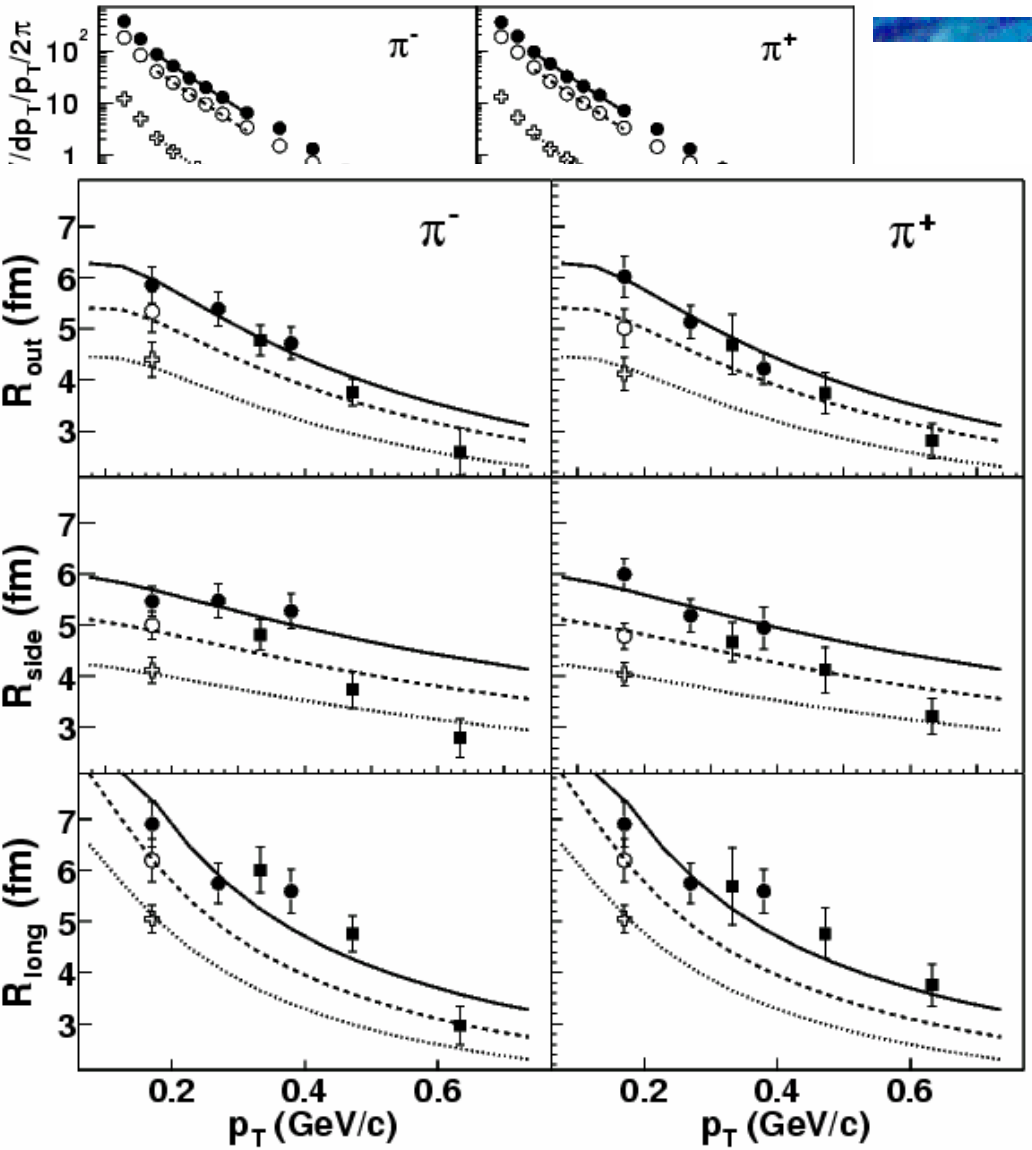
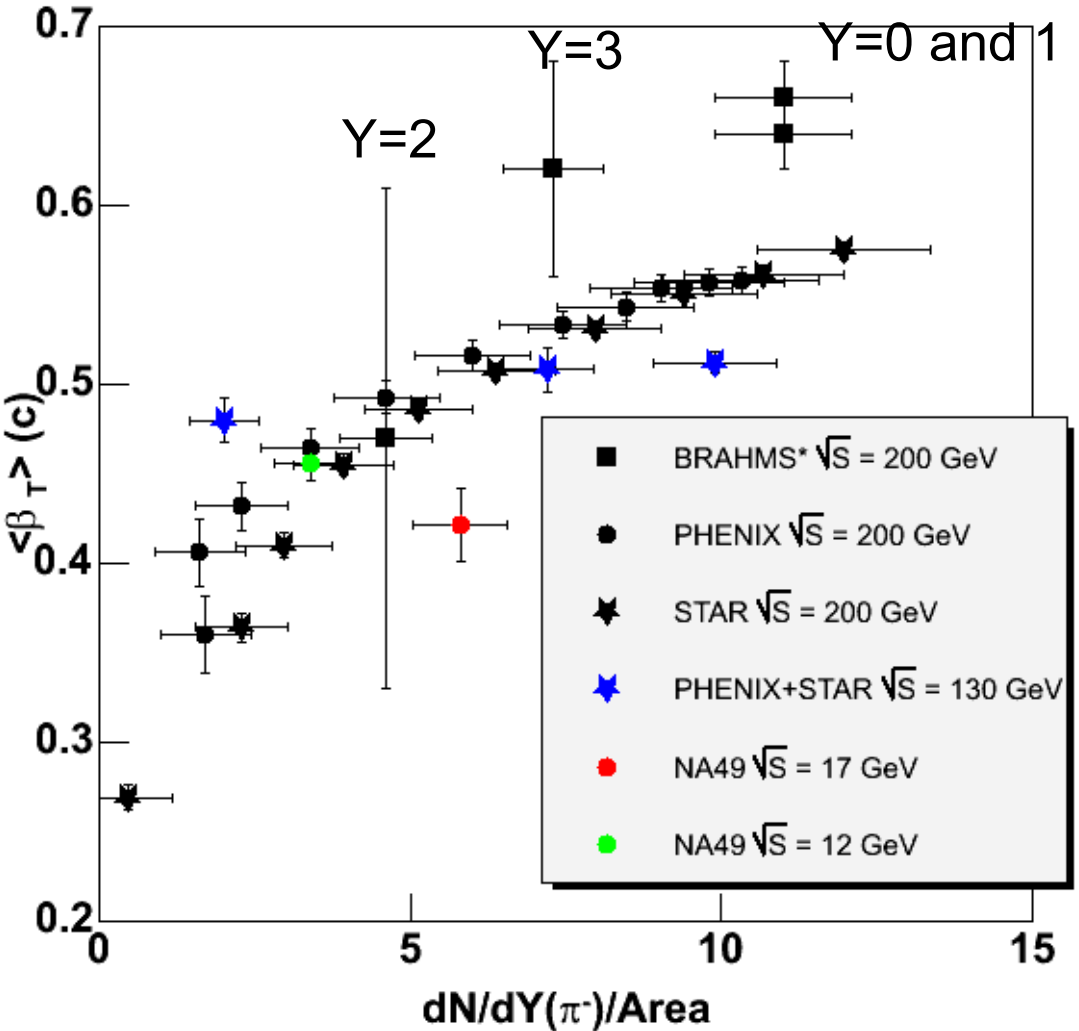


- Simultaneous fit to
  - Spectra
  - v_2
  - HBT radii

Quantifying the flow strength



- Mean flow velocity higher than 0.5 c
- Flow increases with energy density as quantified by dN/dY/Area
  - No scaling with s
  - No scaling rapidity
    - But different flow profile used by BRAHMS