Recent RHIC Results on Bulk Properties

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RHIC & AGS Users' Meeting

The Road Ahead

- Bulk properties measurements at RHIC
  - New measurements and expanded systematics
- Scaling with N_{part}, N_{ch} or ε_{part}
- Simple Scaling Rules

Systematic Studies

- RHIC input
  - Energy
  - Collision system (species)

- Varied Cross-section
  - esp. hard collisions
  - Influence toward bulk properties
- Study dominating effect
  - N_{part} or fractional cross-section

- Experimental input
  - Rapidity
  - Species
  - System size/configuration

- Probe range of x_F
- Relative enhancement of baryons to mesons
- Path length and collective effects

Do systematic studies paint a consistent picture of bulk particle production?

Total Charged Hadron Distributions

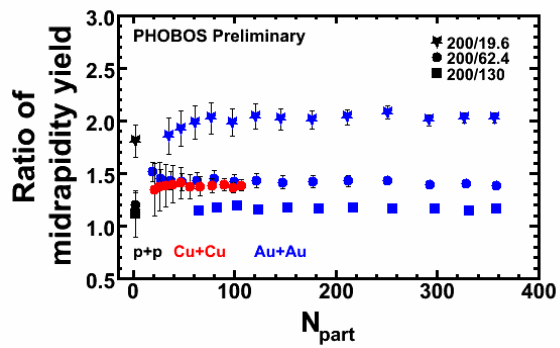
$dN/d\eta$

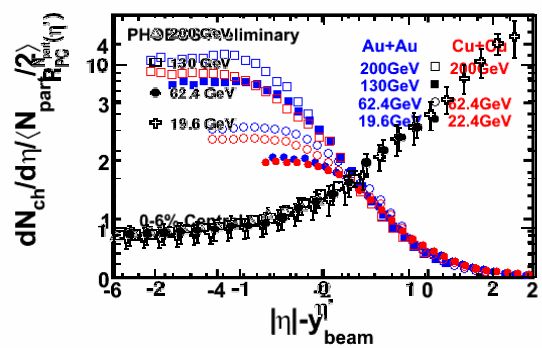
flow$\{v_2, v_1, \sigma(v_2)/v_2\}$

Multiplicity

QM2006

- Latest Results
  - Au+Au (Peripheral)
  - Cu+Cu (22.4 GeV)
- Mid-rapidity
  - Factorization in energy and centrality
- 4π
  - Extended longitudinal scaling – factorizes in energy and centrality



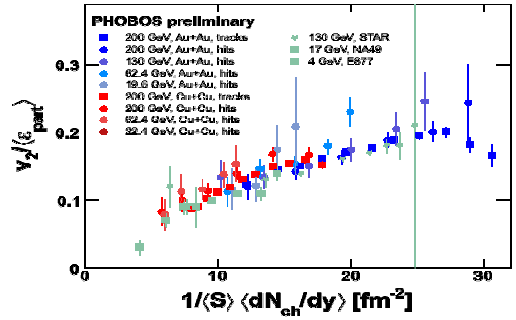


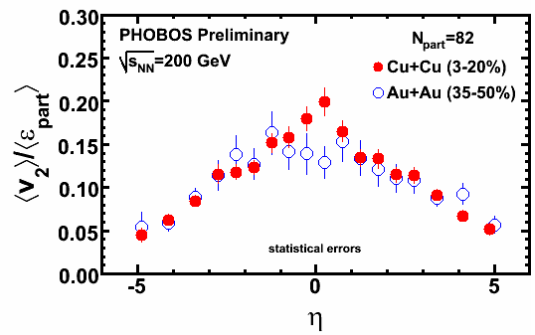
Factorization persistent across all systems

Elliptic Flow

QM2006

- Similar systematic dependencies as multiplicity
- Mid-rapidity:
  - v_2/ε_{part} scaling holds over a broad range of collision energy and system sizes
- η dependence
  - v_2/ε_{part} holds over large η range
  - Extended longitudinal scaling



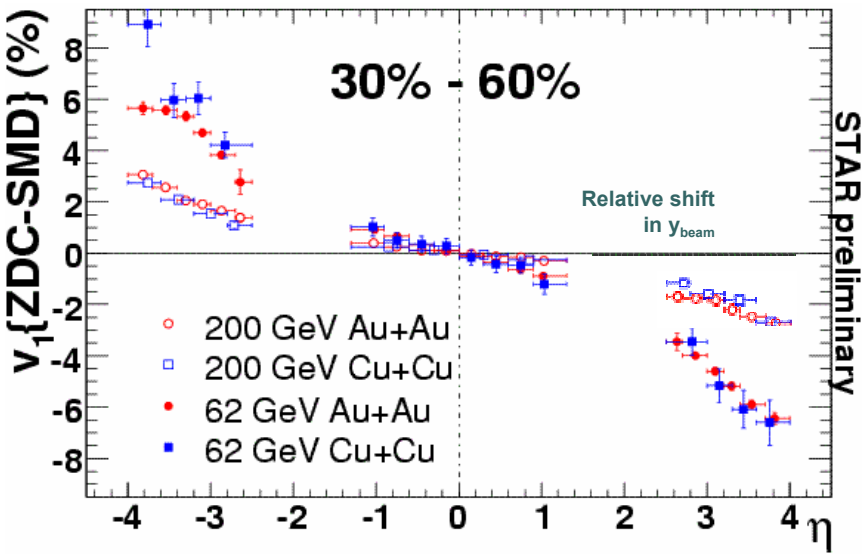


Matched N_{part}

Geometrical scaling with ε_{part}

Directed Flow

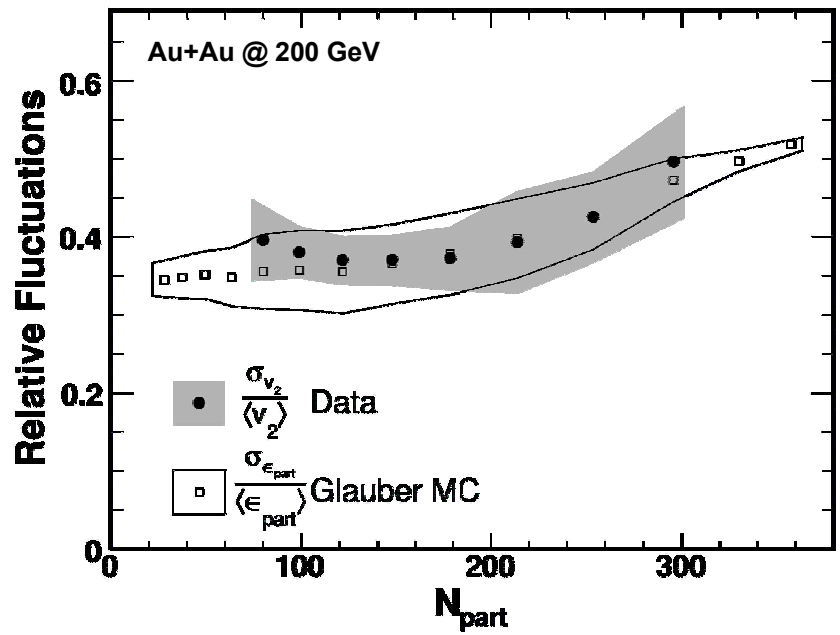
- v_1 is found to scale with collision energy, not collision species
  - Comparison of same overlap geometry
- Extended longitudinal scaling applies



Elliptic Flow Fluctuations

arXiv:nucl-ex/0702036

- Large fluctuations in the v_2 signal
- Geometrical Properties are imprinted on the data:
  - Eccentricity via Flow



Final Charged Particle Distribution Summary

- Final distributions provide a consistent picture of particle production driven by simple scaling laws:
  - Energy, centrality factorization
  - Detailed initial geometrical configuration (ε_{part})
- How do differential measurements compare

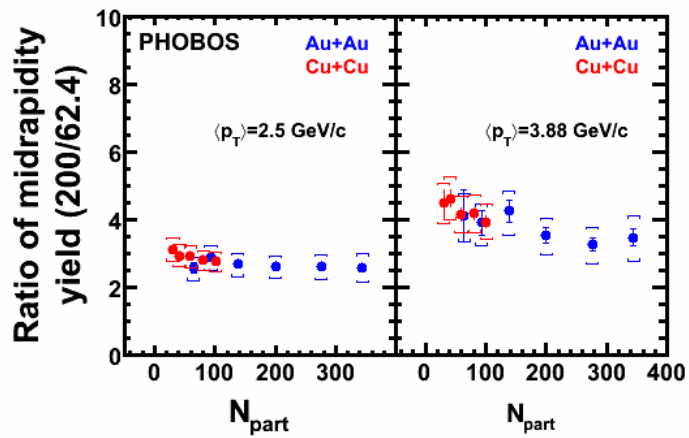
p_T Distributions

Yield versus p_T
$v_2\{p_T\}$
Freeze-out properties

Yield versus p_T

QM2006

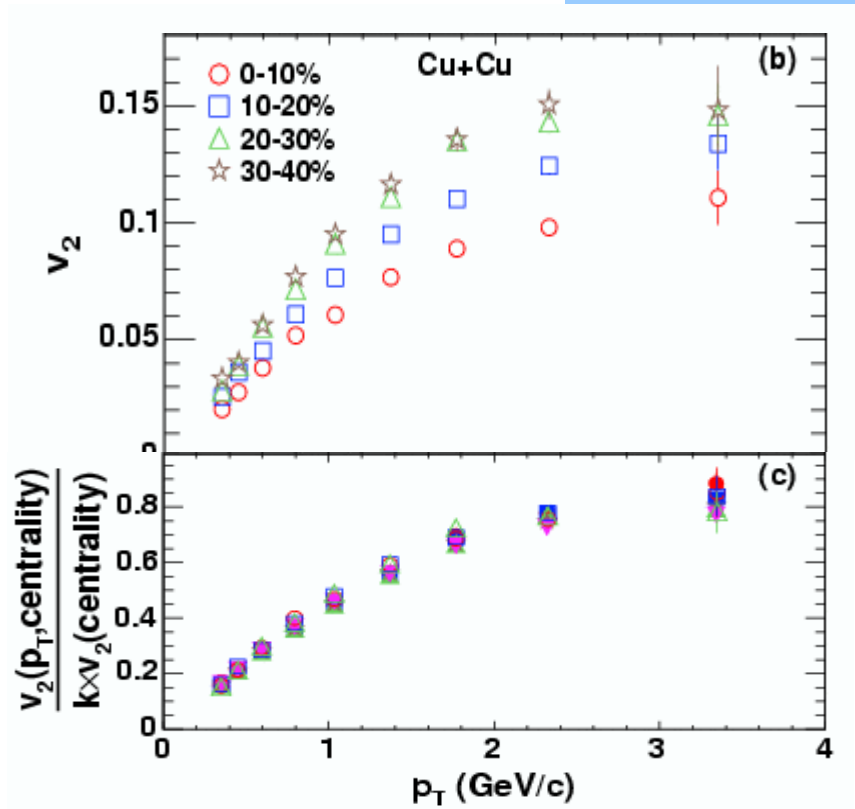
- Mid-rapidity yields versus p_T
  - Factorization in energy and centrality
- Similar behavior to bulk yields



Elliptic flow at mid-rapidity

PRL 98, 162301 (2007)

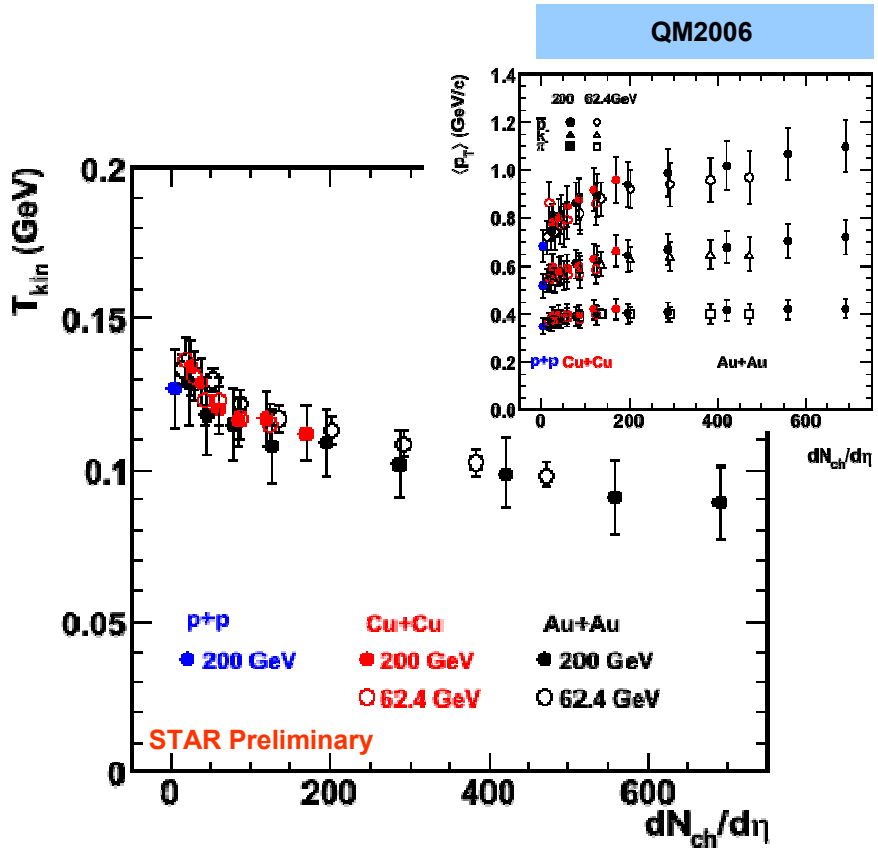
- Latest Results:
  - $v_2\{p_T\}$ (200 GeV)
- $v_2\{p_T\}$ *shape* independent of centrality and system size



$v_2\{p_T\}$: universal scaling?

Kinetic freeze-out properties

- Latest Results:
  - Freeze-out properties
- Freeze-out temperature and flow velocity follow a common dependence with number of charged particles at mid-rapidity
- Mean-p_T follow same trend



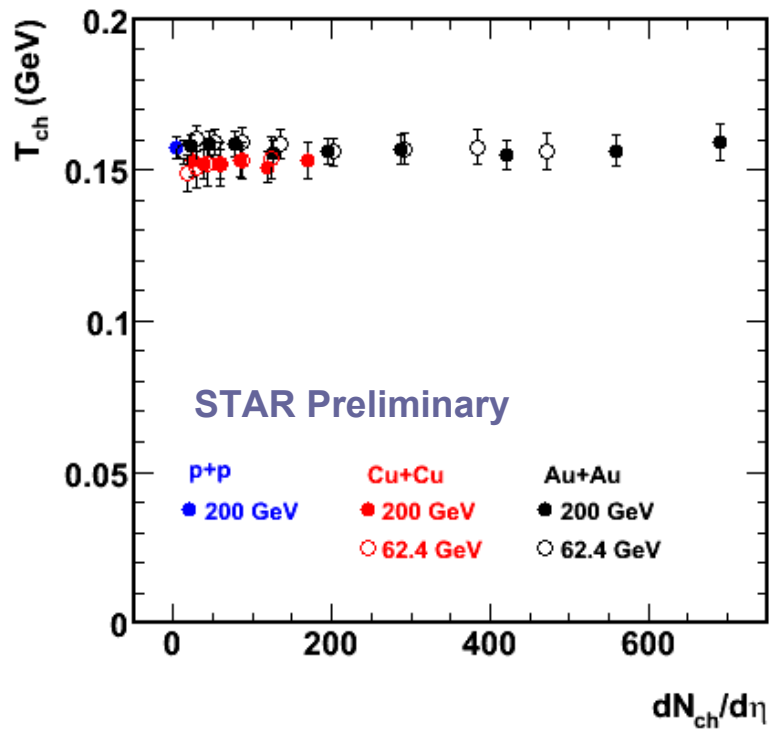
Similar dependence noted by PHENIX (JPS 2007)

Scaling of low-p_T properties with N_{ch}

Chemical freeze-out properties

QM2006

- Latest Results:
  - Cu+Cu at 200 and 62.4 GeV
- Universal chemical freeze-out temperature, T_{ch}, is observed for all studied systems



p_T Distributions Summary

- First differential measurements:
  - "Universal scaling" of elliptic flow versus p_T
  - N_{ch} scaling of kinetic freeze-out properties

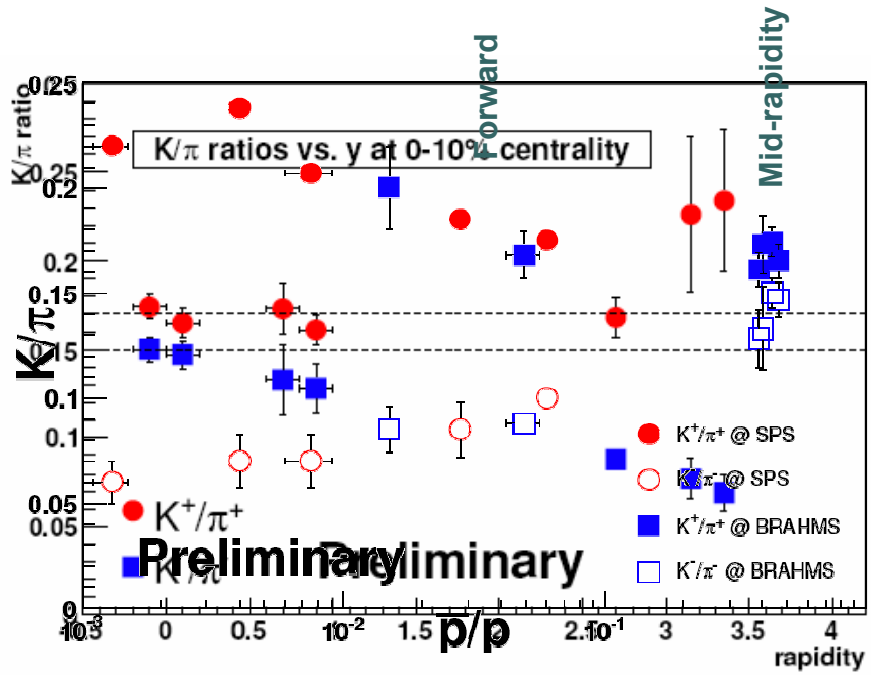
Chemical properties

Strangeness production
Baryon enhancement
$v_2\{KE/n_q,y\}$

Strangeness production – $K^{\pm}$

QM2006

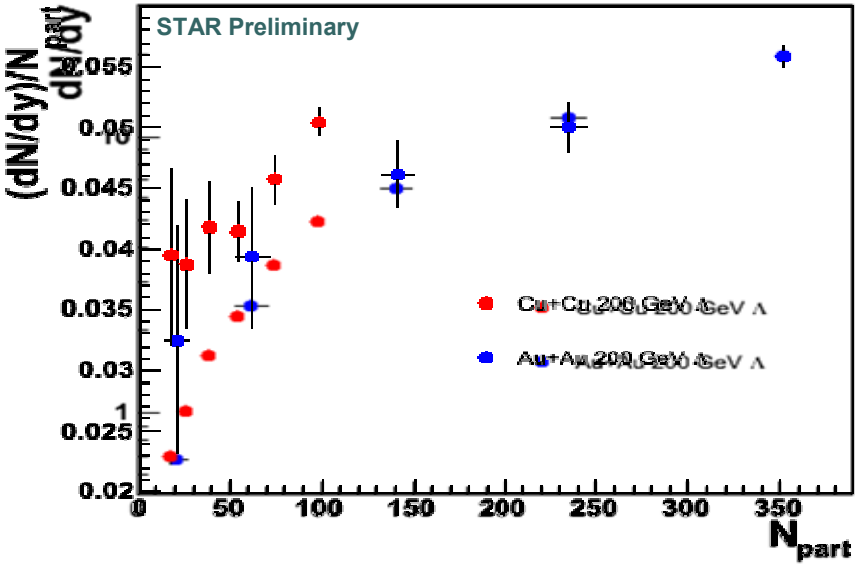
- Latest Results:
  - 62.4 GeV Au+Au
- Charge "splitting" of K/π as observed at SPS
- "Chemical equivalence" with SPS energies



Strangeness production – Λ

QM2006

- Latest Results:
  - Λ scale reasonably with N_{part} for the same energy
- Enhanced strangeness production due to ***core*** of core/corona model
  - More ***core*** per N_{part} in Cu+Cu collisions

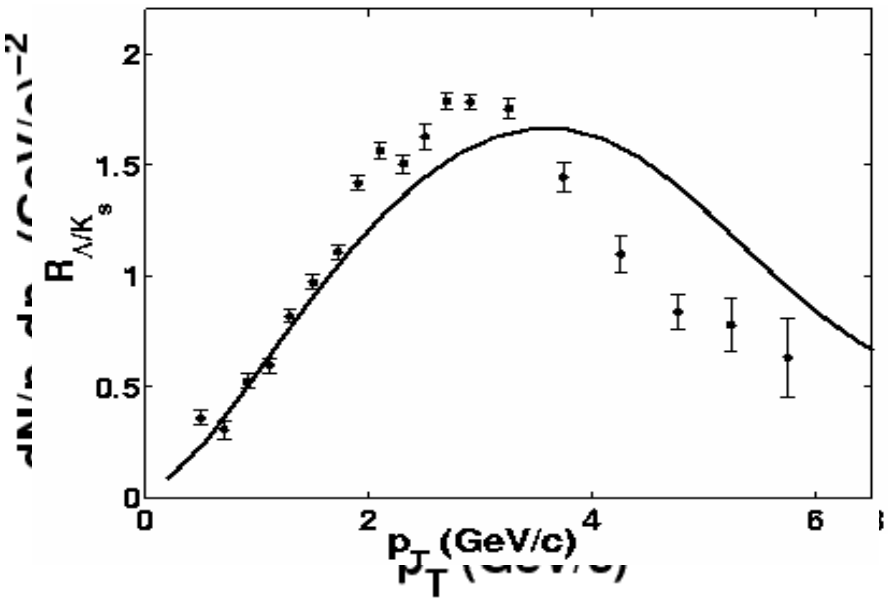


Phys. Rev. Lett. 98, 152301 (2007)

Recombination Model

nucl-th/0602024

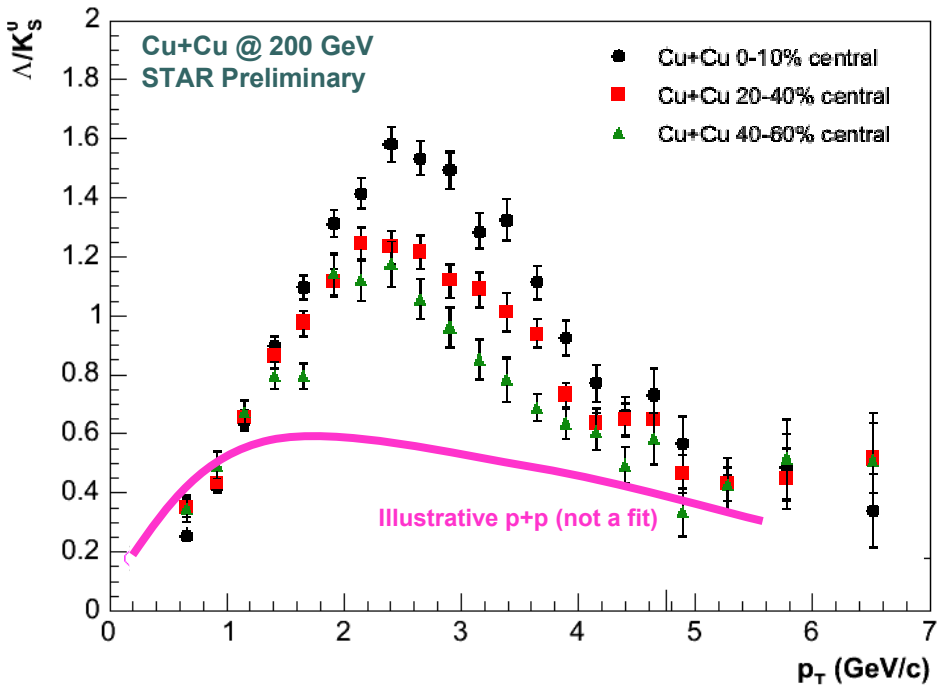
- Recombination Model
  - Describes the p_T dependence of strange particles
    - K,Λ
- Fits provide good agreement with data
- Qualitatively reproduces Λ/K^0_S ratio



Baryon Enhancement

QM2006

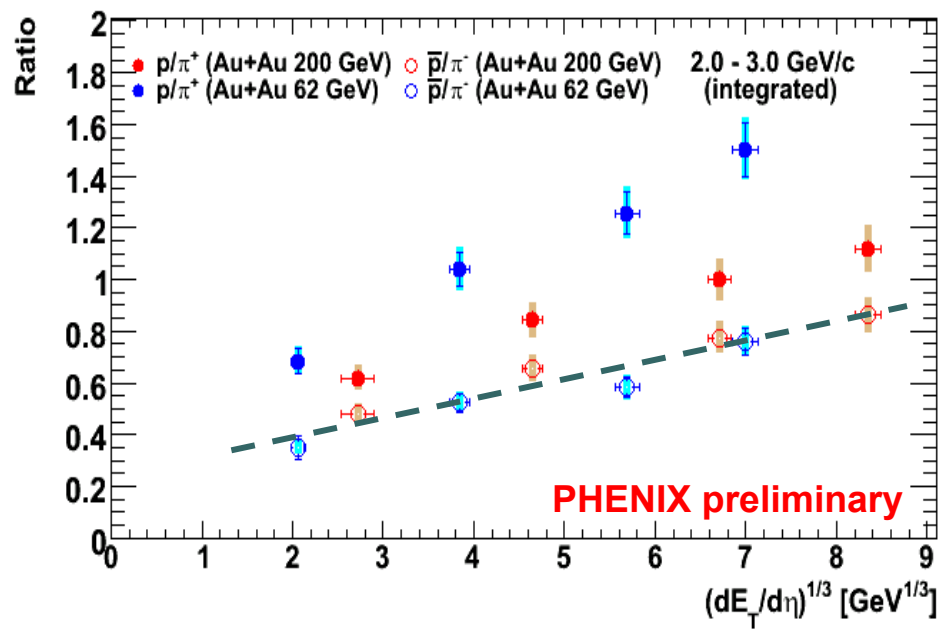
- Enhancement is maximal in the intermediate-p_T region
  - Cu+Cu data exhibit the same systematic trends as for Au+Au system



Baryon Enhancement

JPS 2007

- N_{part} scaling for p/π
  - Integrated intermediate-p_T region
- Moreover, E_T scaling exists between 200 and 62.4 GeV (pbar/π^-)
  - Baryon transport contributes at 62.4 GeV for protons

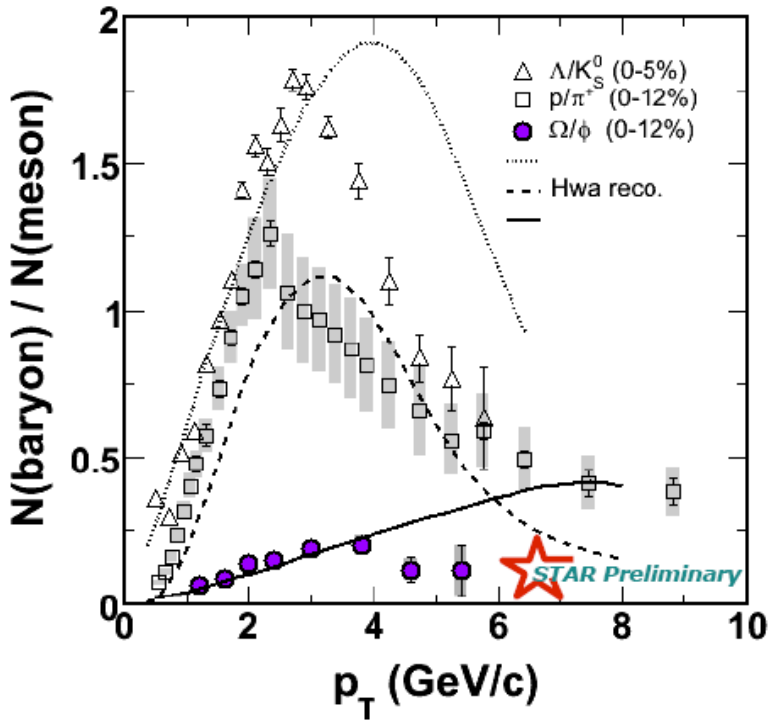


Scaling of intermediate-p_T properties with E_T

Recombination Revisited

QM2006

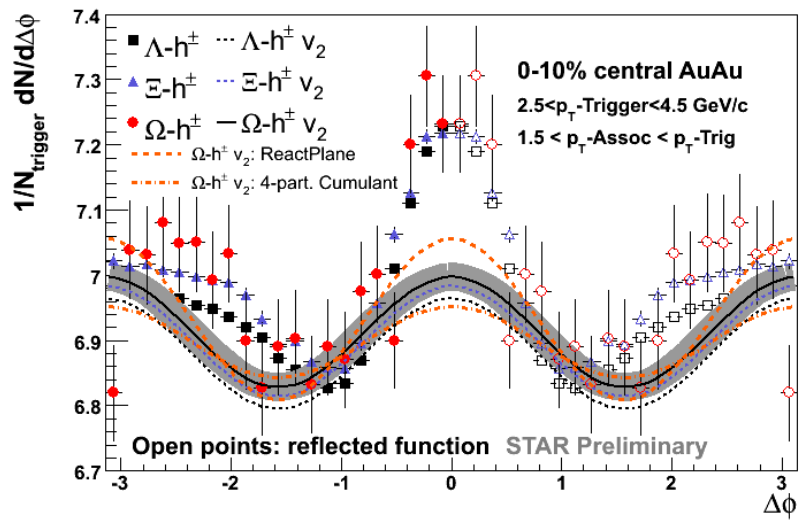
- Recombination predicts other B/M ratios
  - Qualitative agreement.
- s-quark dependence on peak position is predicted
  - But at higher-p_T than data suggests



Recombination Revisited

WQM 2007

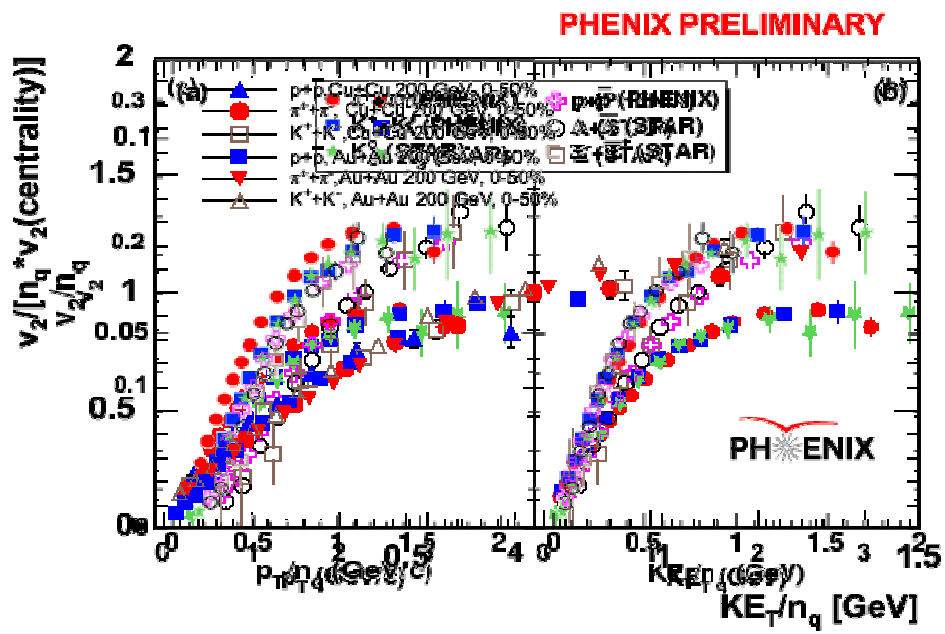
- Validity test:
  - Ω,ϕ
- A good description of the multi-strange spectra
  - Ω: dominated by thermal term
  - Look at Ω correlations
    - No near-side correlation expected
- Correlation observed
  - Magnitude of near-side correlation is independent of strange-quark content



Quark scaling of elliptic flow

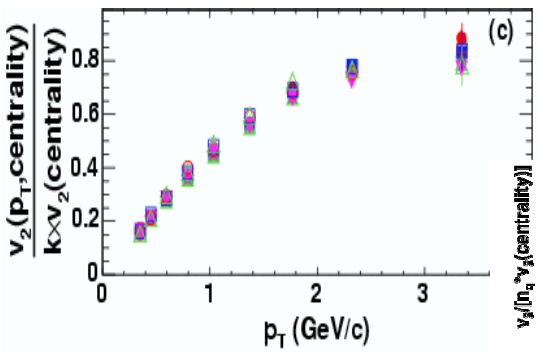
PRL 98, 162301 (2007)

- Latest Results:
  - v_2/n_q scales with KE_T/n_q
- Holds for Cu+Cu data
  - Once ε is accounted for

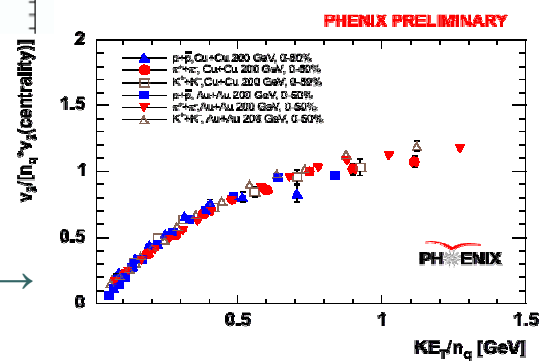


Identified v_2

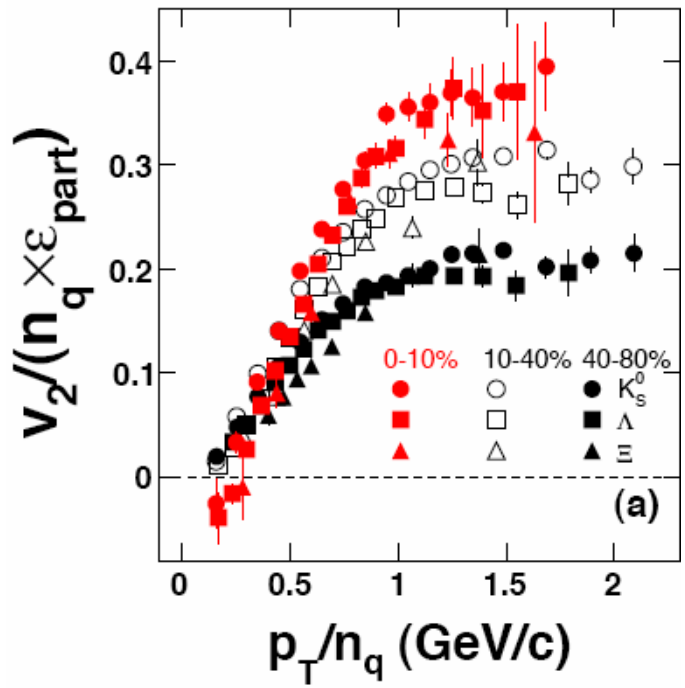
- For different centrality bins:
  - No ***universal*** scaling



←Centrality Dependence



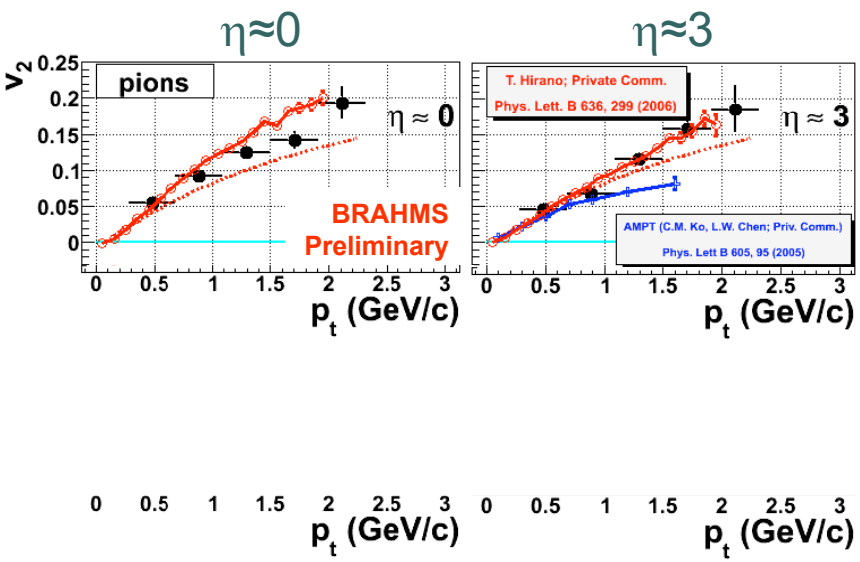
Min-bias, particle id'd→



Elliptic flow versus rapidity

Xi'an 06

- Identified flow versus p_T and rapidity
  - No appreciable difference in shape
    - cf. PHENIX flow at mid-rapidity
  - No difference in magnitude



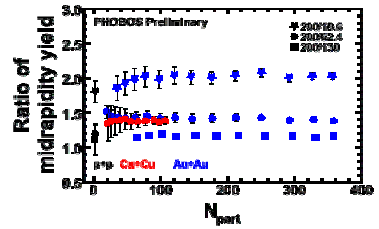
Systematics fit into existing data

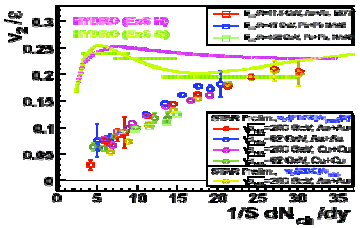
Chemical Summary

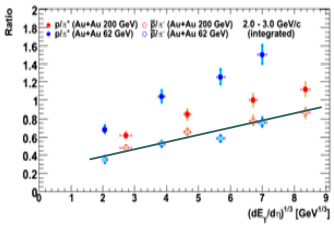
- Further differential measurements:
  - pbar/π – N_{part} scaling
  - Qualitative description of B/M ratios in the recombination picture
    - But fails to describe the multi-strange correlations
  - Universal scaling of identified $v_2\{p_T\}$
    - Observed for min-bias across system size
    - Not observed versus centrality

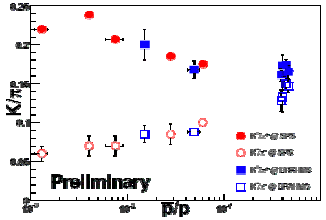
Summary

- Bulk properties measurements at RHIC
  - New measurements and expanded systematics
- Scaling with N_{part}, N_{ch} or ε_{part}
  - For the bulk to intermediate-p_T regions
- Simple Scaling Rules
  - Applicable over a broad range of centrality, energy and colliding species



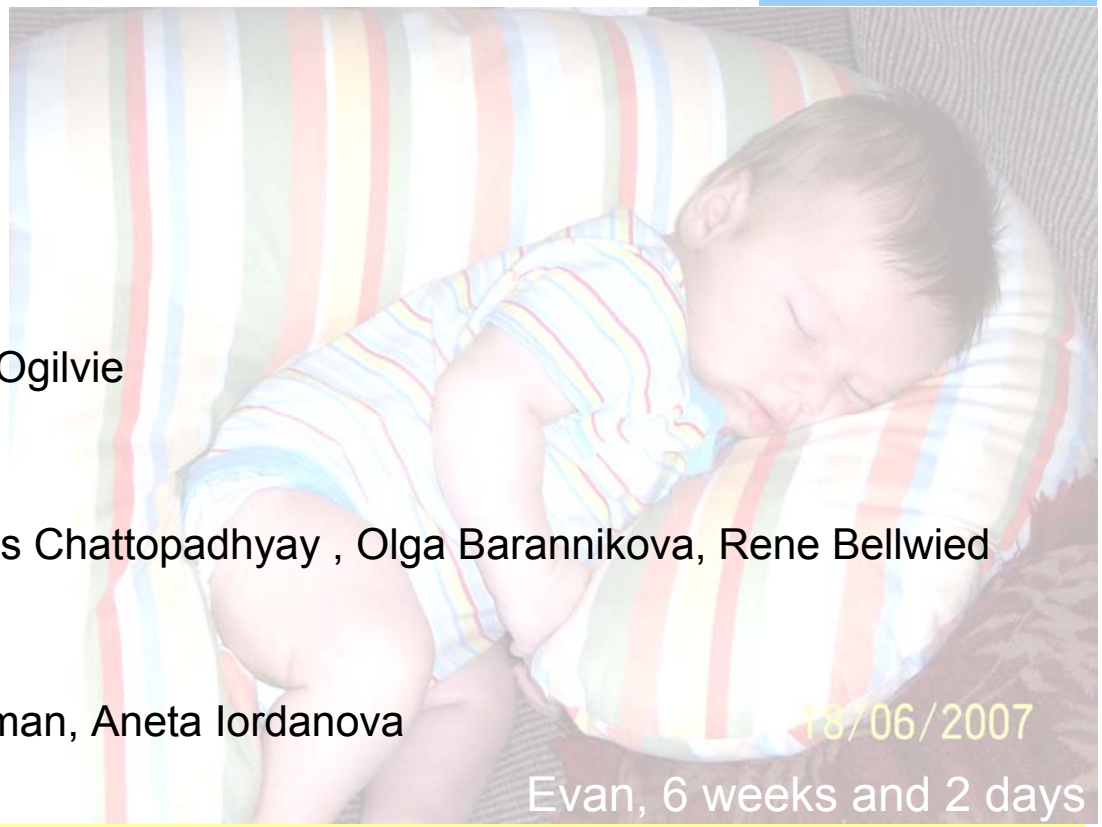






Thanks!

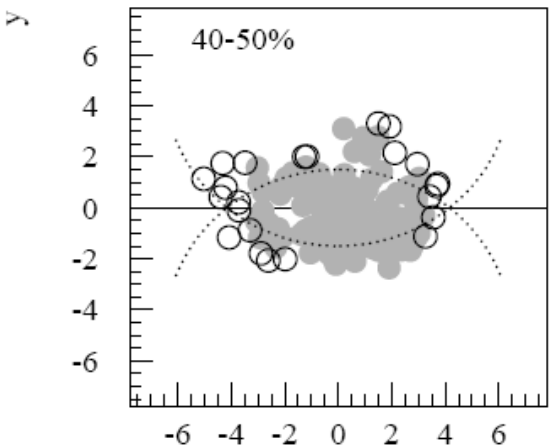
- Credits:
  - BRAHMS
    - Flemming Videbaek
  - PHENIX
    - Barbara Jacak, Craig Ogilvie
  - STAR
    - Aihong Tang, Subhasis Chattopadhyay , Olga Barannikova, Rene Bellwied
  - PHOBOS
    - Wit Busza, David Hofman, Aneta Iordanova

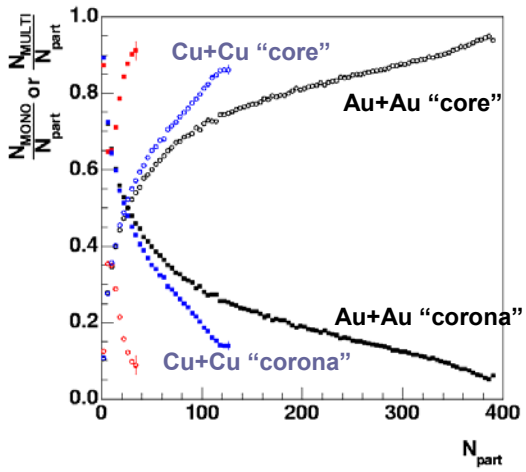


Back-up Slides

- Core/corona
  Phys. Rev. Lett. 98, 152301 (2007)
  - Core – high density region
  - Corona – low density region around the edge

- My own simulations
  Thesis (2005)
  - Based on similar ideas

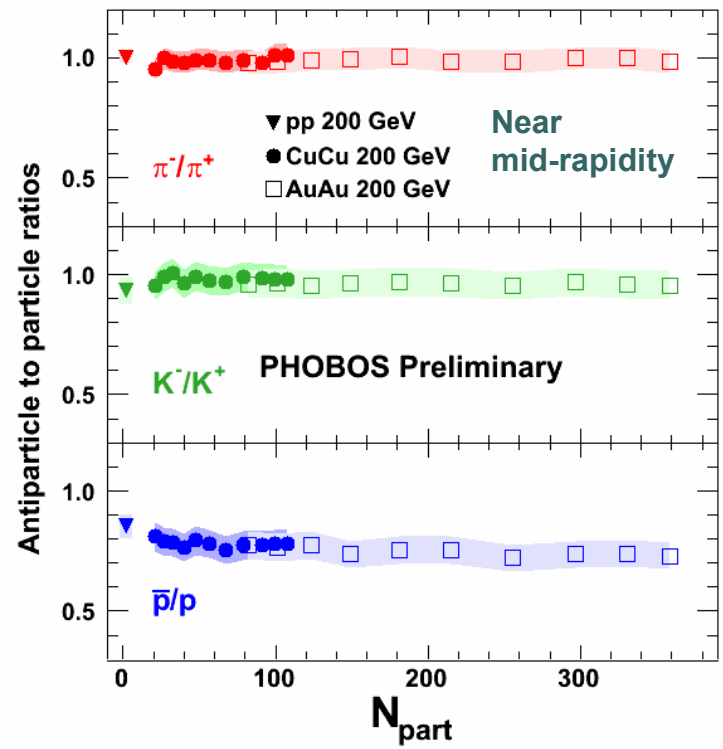


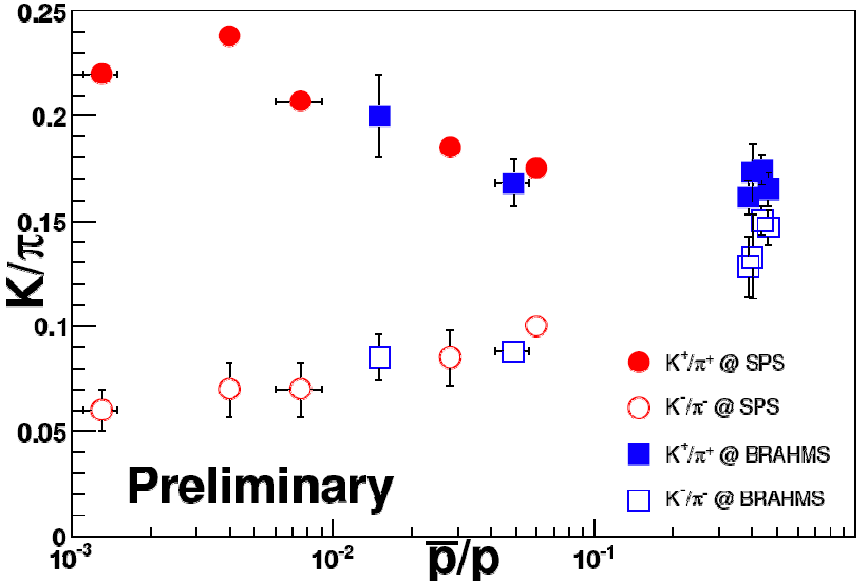


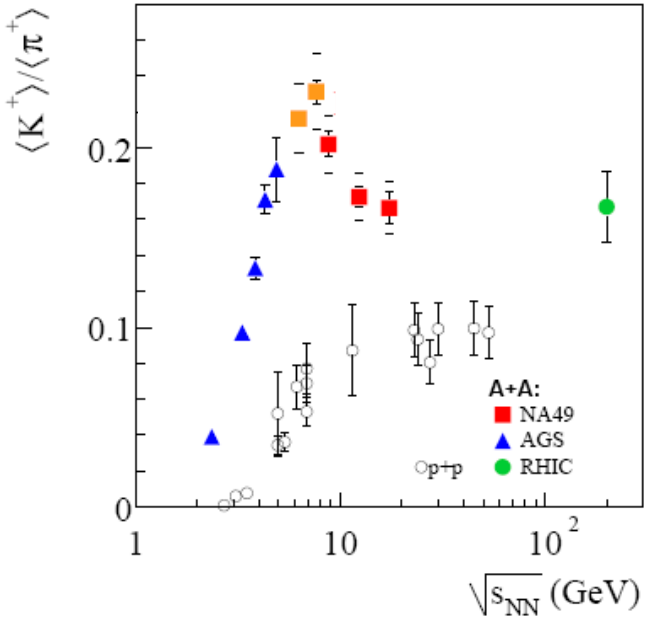
Particle Ratios versus system size

QM2006

- Particle Ratios
  - 200 and 62.4 GeV
  - Au+Au and Cu+Cu
- Weak centrality dependence, no system size dependence of particle ratios




0.25
0.2
0.15
0.1
0.05
0
K/π
Preliminary
10^{-3}
10^{-2}
10^{-1}
$\bar{p}/p$
K^+/π^+ @ SPS
K^-/π^- @ SPS
K^+/π^+ @ BRAHMS
K^-/π^- @ BRAHMS


$\langle K^+\rangle/\langle\pi^+\rangle$
0.2
0.1
0
1
10
10^2
$\sqrt{s_{NN}}$ (GeV)
A+A:
NA49
AGS
RHIC
p+p