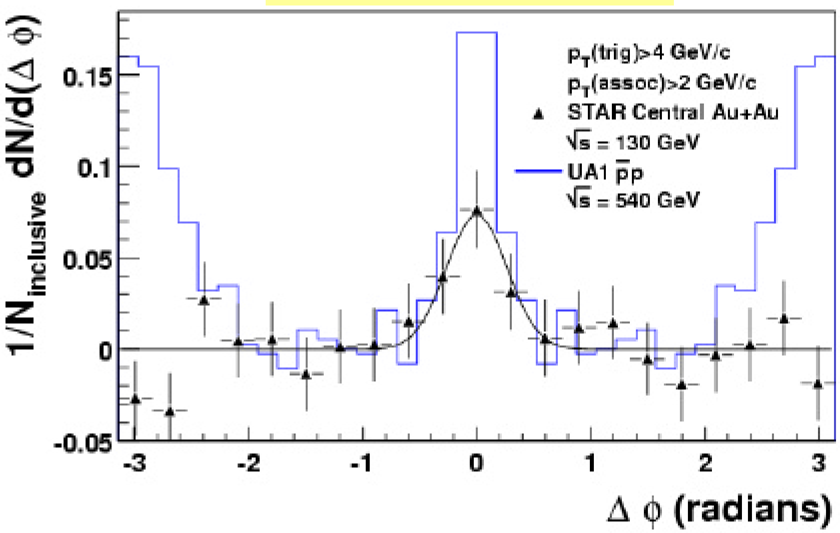
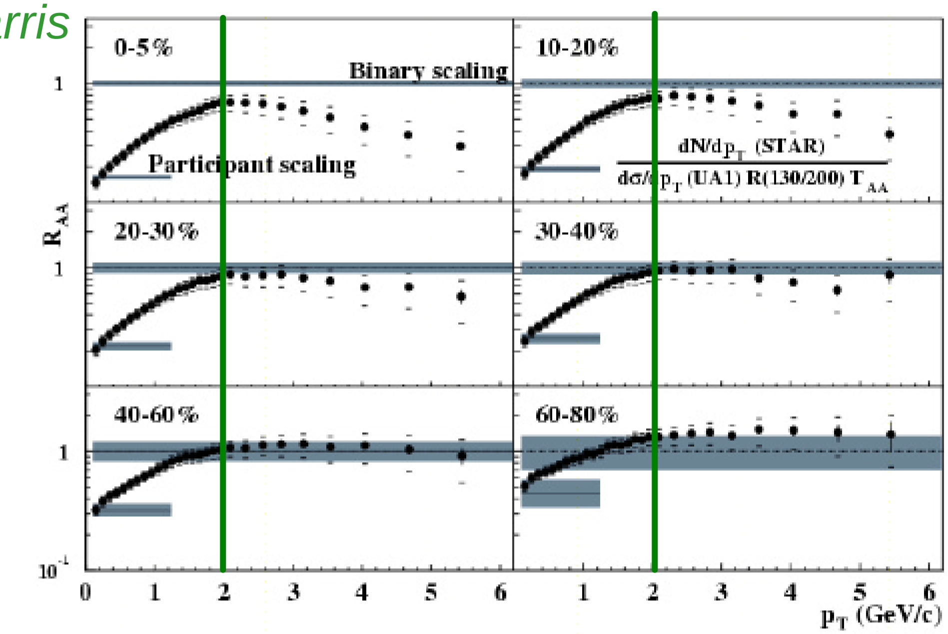
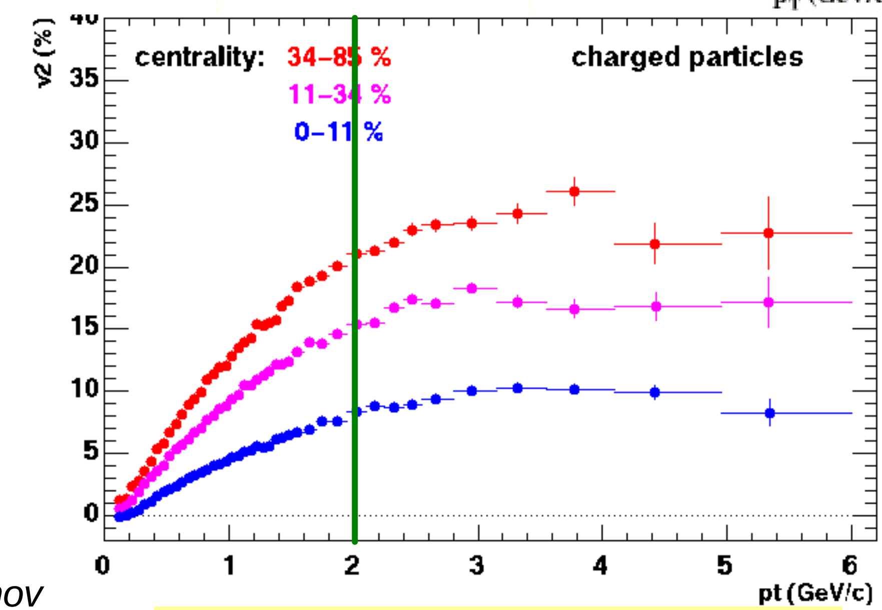
Evidence for Hard Scattering at RHIC & Its Effects….

ITP Discussion - Miklos Gyulassy & John Harris

Jet structure!





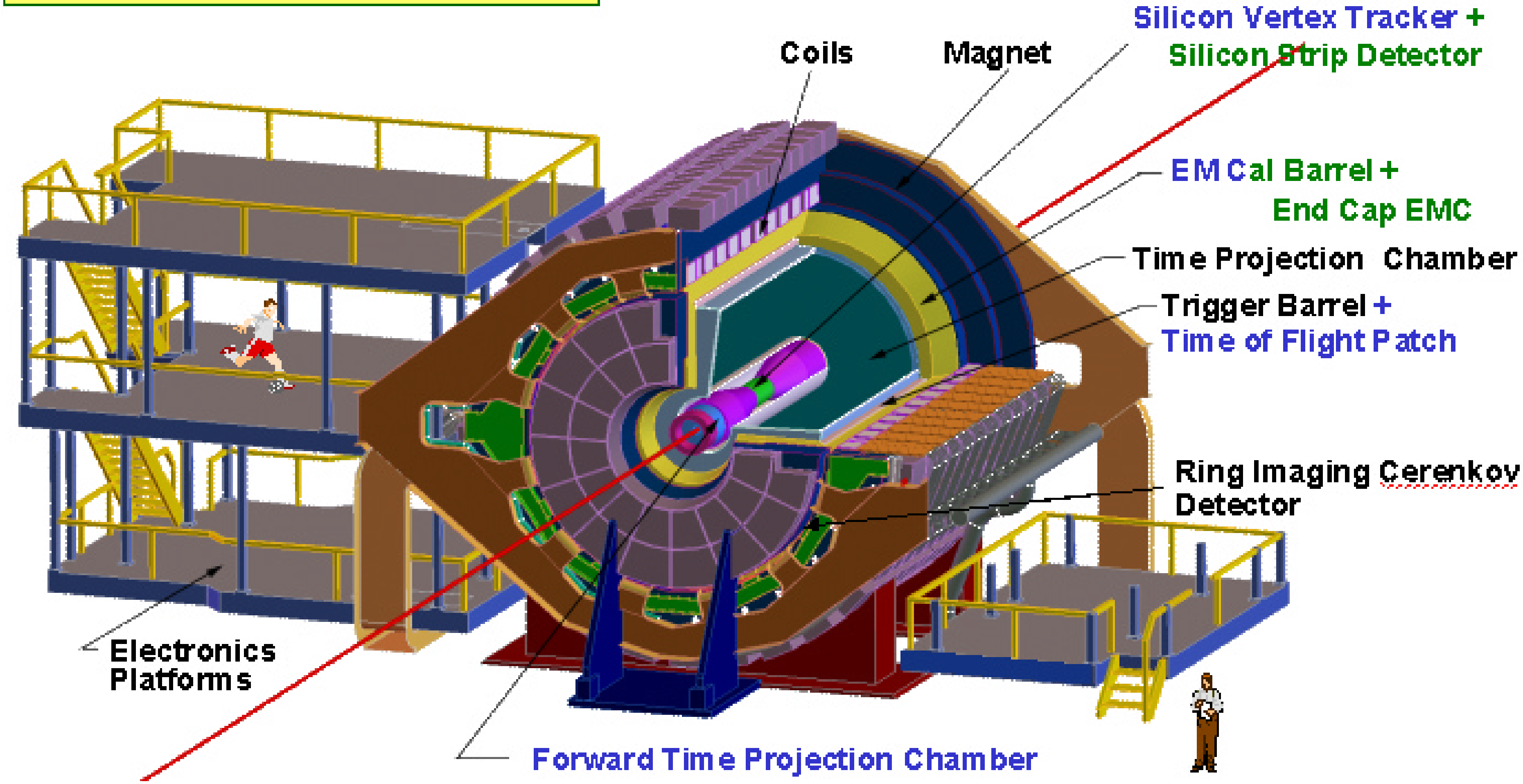


Qualitative changes ~ 2 GeV/c

Special thanks: P. Jacobs, D. Hardtke, M. Miller, K. Filimanov & STAR

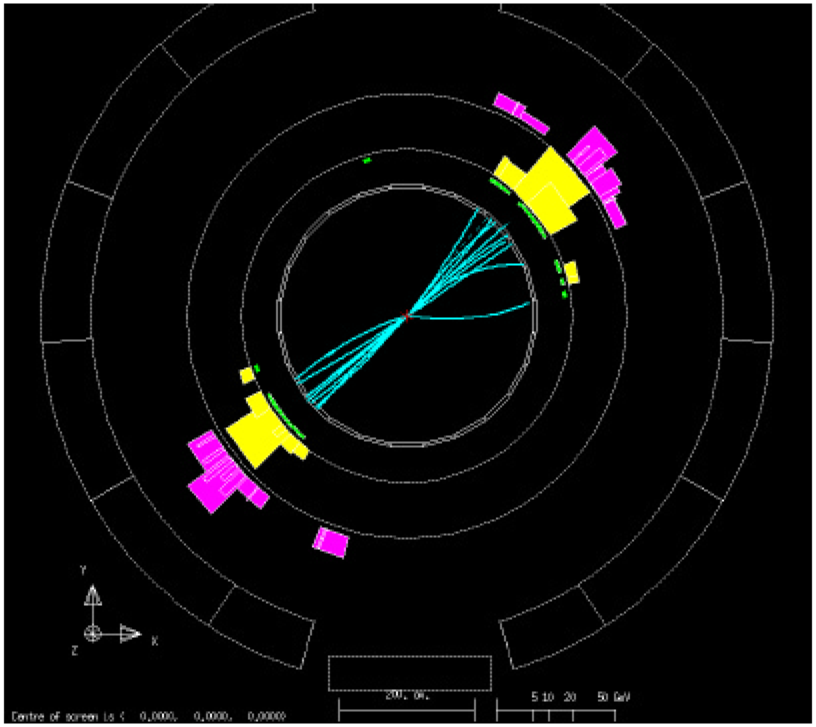
STAR Detector at RHIC

"Large acceptance hadronic detector"

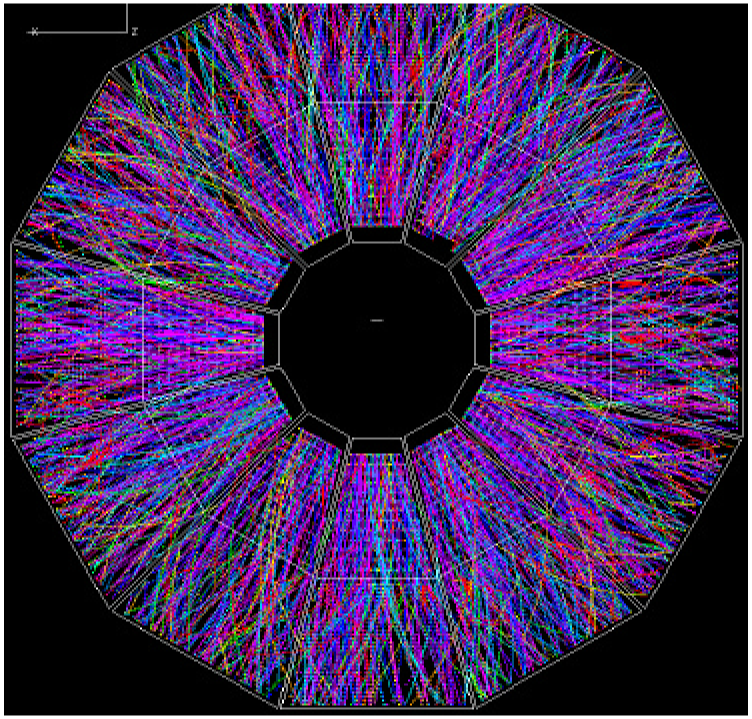


Jets at RHIC?

OPAL jet event



130 GeV STAR Au+Au



Can we observe / measure jets in Au+Au?

- **Jet-finding?   tbd…..**
- **Try: leading particles and particle correlations**
  azimuthal correlations

STAR

Two-Particle Azimuthal Correlations

Technique:

- Identify jet candidates using trigger particle with 4 < p_T < 6 GeV/c
- Associate with other charged tracks with 2 < p_T < p_T(trigger).
- Azimuthal correlation function:

$$C_2(\Delta\Phi) = \frac{1}{N_{trigger}} \frac{1}{efficiency} \int d(\Delta h) N(\Delta\Phi, \Delta h)$$

Sources of azimuthal correlations:

- Short-range (localized in Dh):
  - Intra-jet correlations
  - Resonances
- Long-range (not localized in Dh):
  - Momentum conservation
  - Inter-jet correlations (back-to-back)
  - Flow

Our approach: estimate long-range correlations by measuring the large Dh correlation function

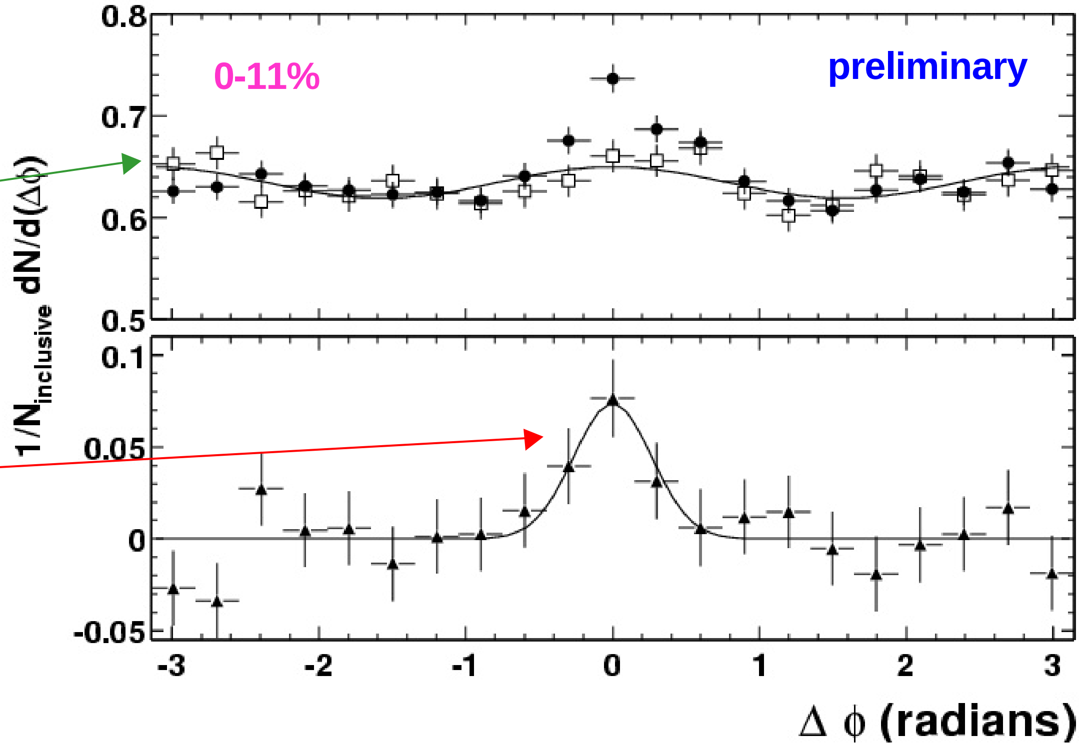
Two Particle Correlation Data

- Trigger particle p_T > 4 GeV/c at -0.7 < h < 0.7
  - azimuthal correlations for p_T > 2 GeV/c
  - short range h correlation: jets + elliptic flow
  - long range h correlation: elliptic flow

Þ subtract correlation at $|h_1 - h_2| > 0.5$
also eliminates the away-side jet correlations

- extracted v_2 consistent with reaction-plane method

- remainder: jet-like structure
Þ first indication of jets at RHIC!



UA1

ref: PLB 118, 173 (1982)

$\sqrt{s}$ = 540 GeV p + p

$|\eta| < 2.5$

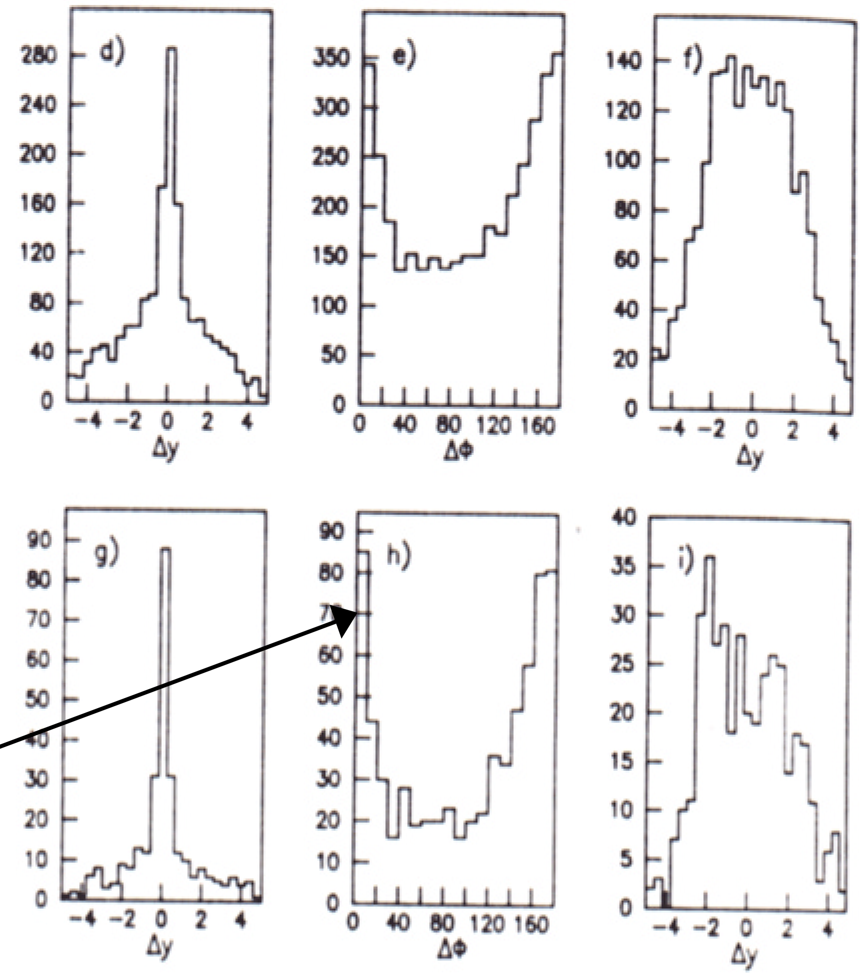
Trigger $p_T > 4$ GeV/c

Minbias and High E_T

Δy (towards) Δφ Δy (away)

$p_T > 1$ GeV/c

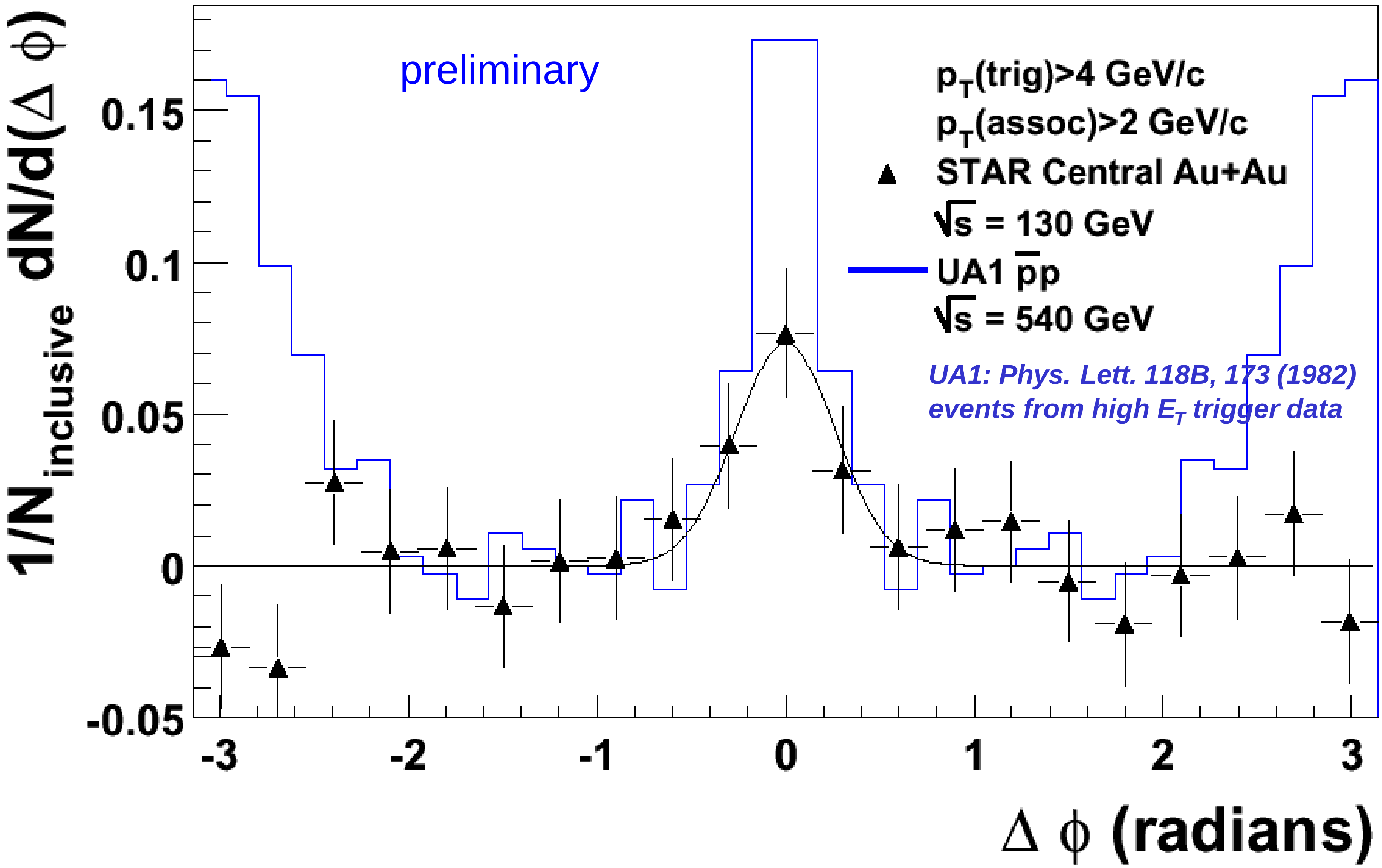
$p_T > 2$ GeV/c



Jet Cone: $\Delta\phi < 30°$

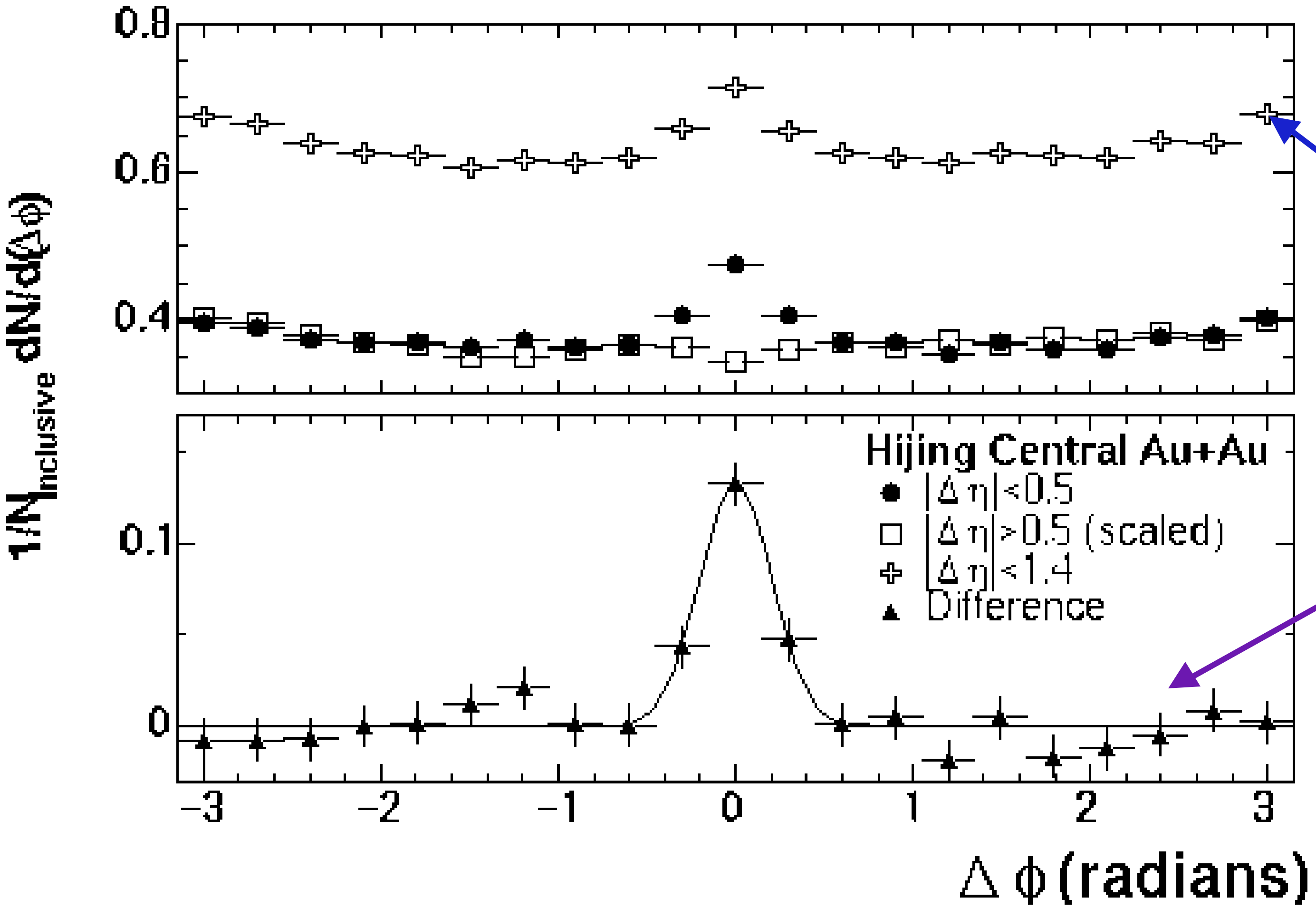
$|\Delta y| < 0.5$

STAR & UA1 High p_T Azimuthal Correlations ® Jets!



- UA1 & STAR: very similar analyses (trigger p_T > 4 GeV/c)
- UA1 dissimilar in $\sqrt{s}$ = 540 GeV, $|\eta|$ < 3.0

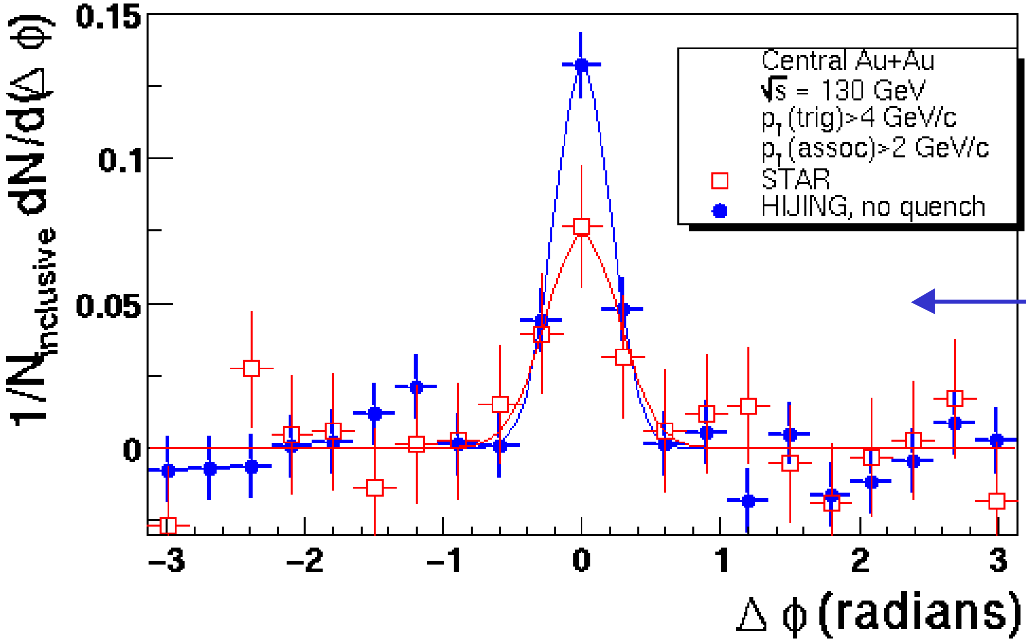
Hijing Analysis (130 GeV Au + Au)



Back-to-back jets in STAR acceptance

Removed by large |η| subtraction

Hijing Comparisons



HIJING:

σ= 0.21+-0.02 rad

Area = 6.8+-0.6 %

STAR:

σ= 0.27+-0.09 rad

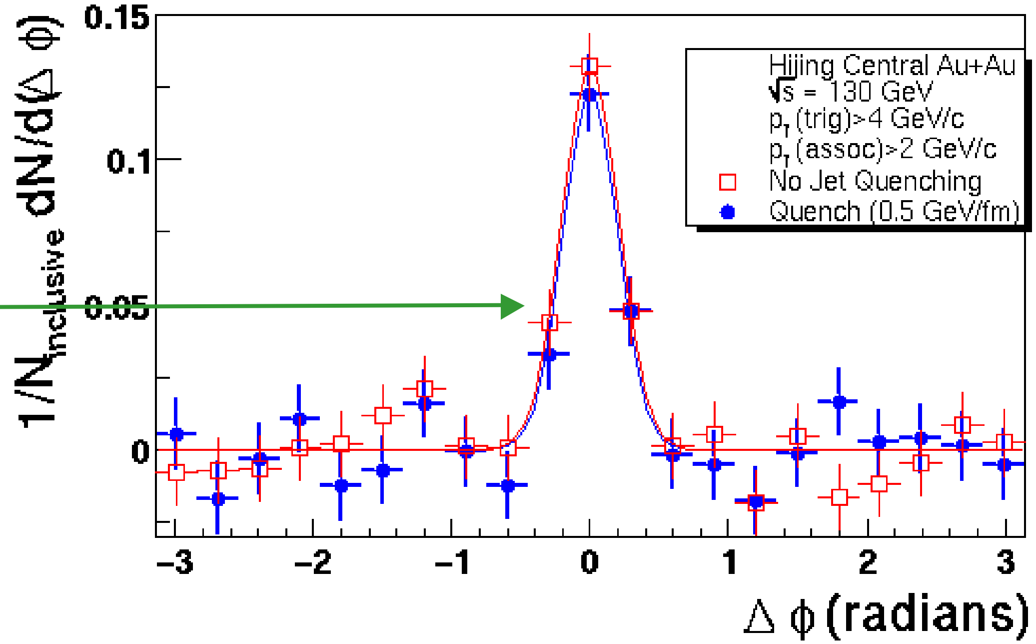
Area = 4.9+-1.7 %

Ratio of integrals over correlation peak: 1.3

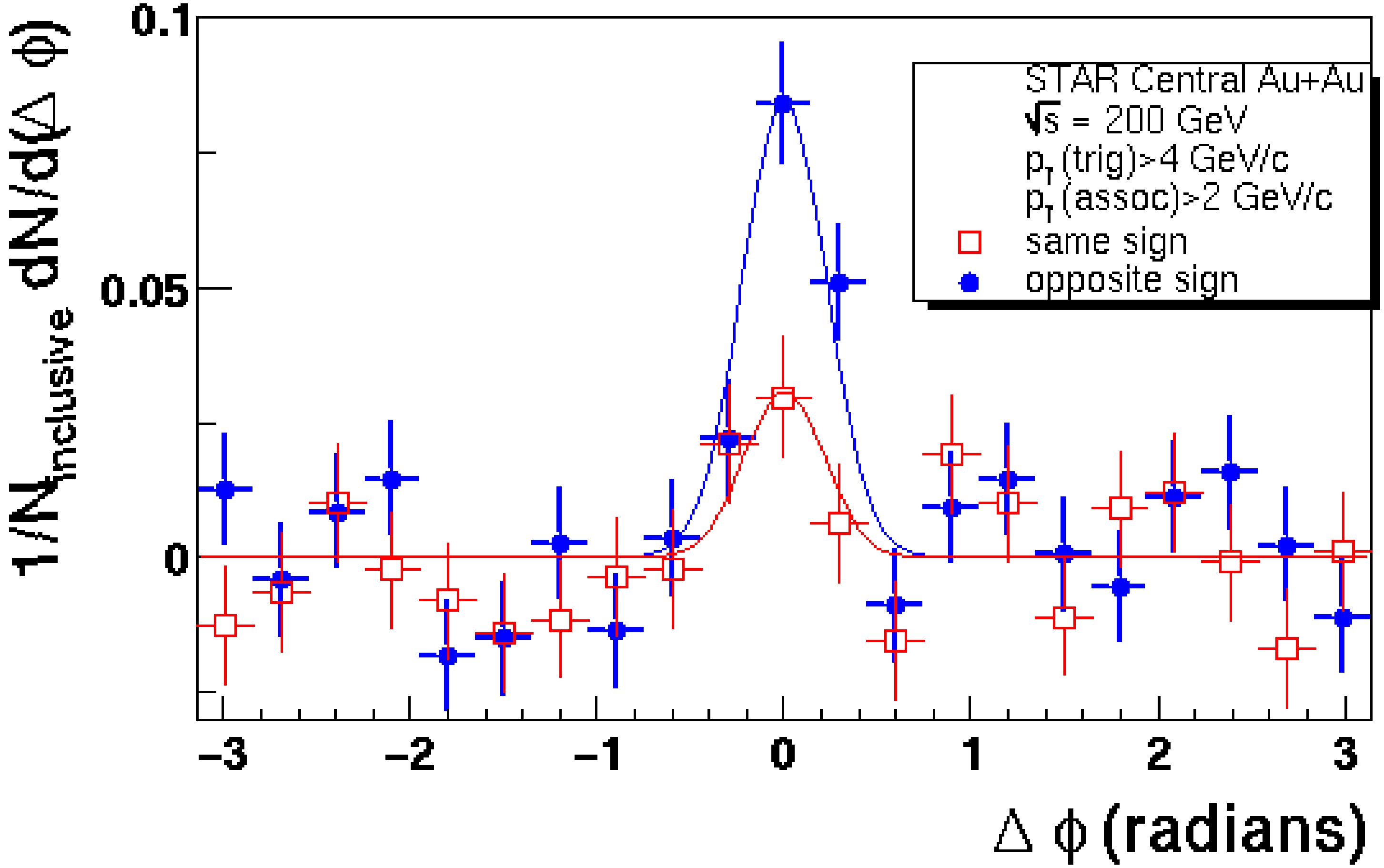
Quenching:

negligible effect on

correlations near Df = 0.



Charge Dependence



opposite sign/same sign = 2.8+-0.9

Jet Charge (DELPHI)

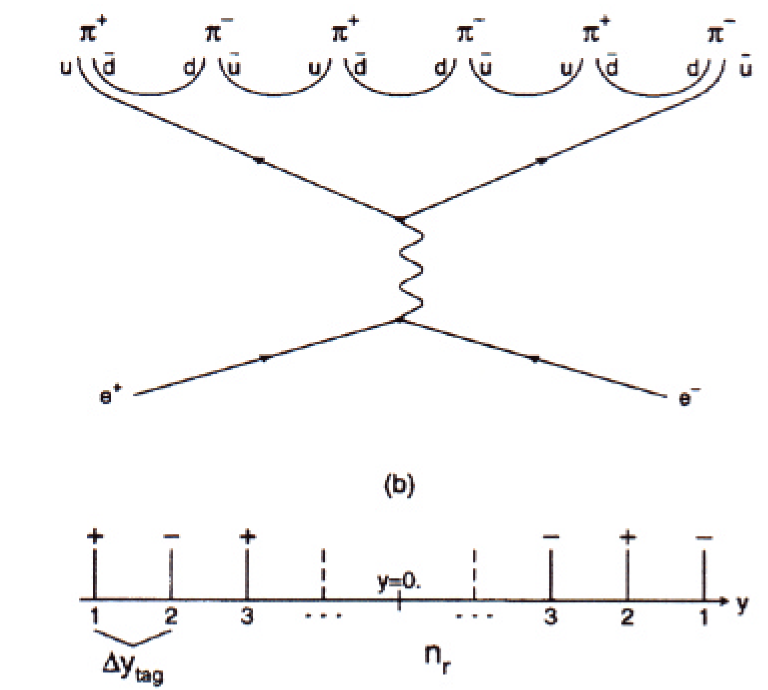
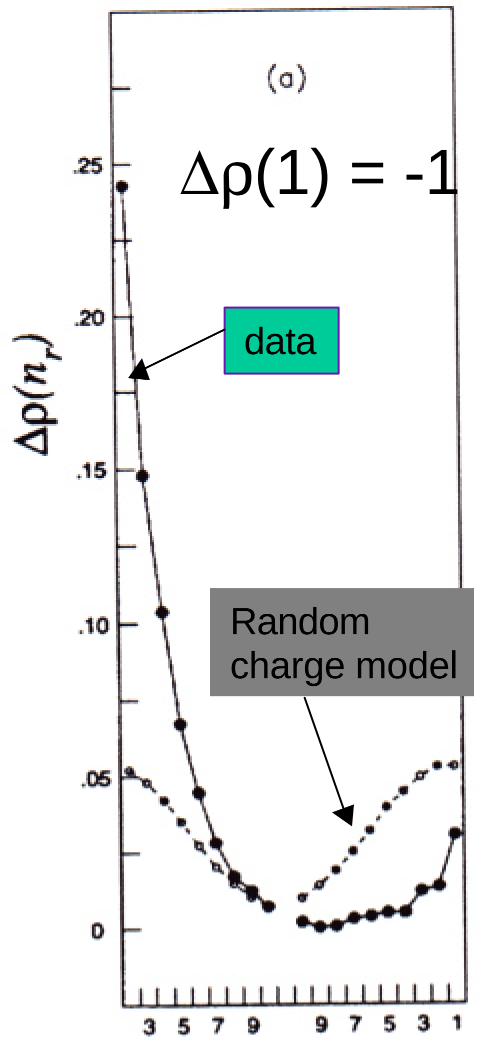


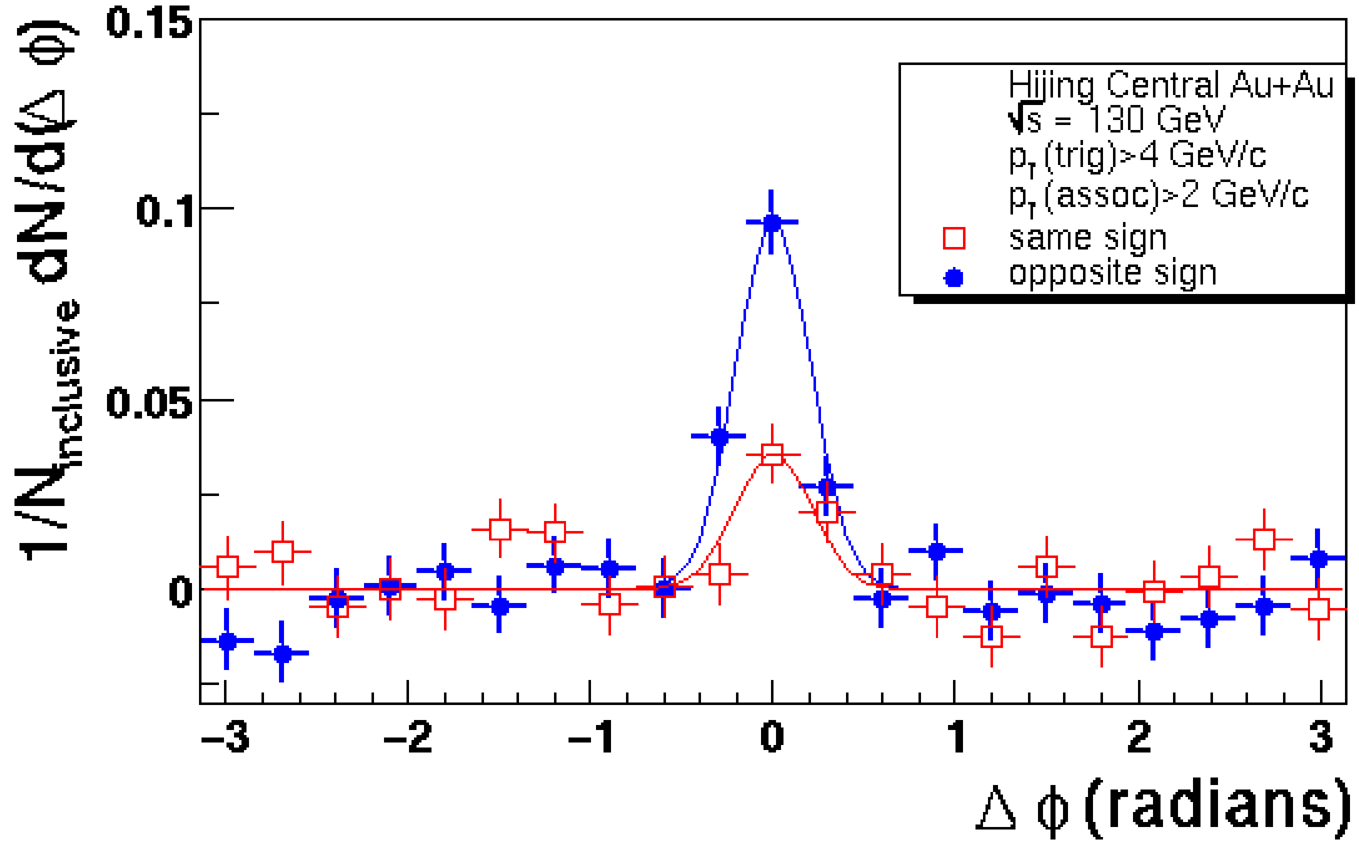
Fig. 1. (a) Annihilation event with flavor-ordered chain production The particles at the ends of the chain are 'rank 1', those adjacent are 'rank 2', etc. (b) Event with charged particles ordered according to their rapidity values in the thrust direction. The quantity n_r indicates the rapidity-rank, and Δy_{tag} is the rapidity gap adjacent to a 'tagged' particle ($n_r = 1$), shown here for one side.



Tagged hemisphere on left side of plot (starting with $n_r = 2$)

Data pt for tagged particle ($n_r = 1$) at -1.0 (not shown)

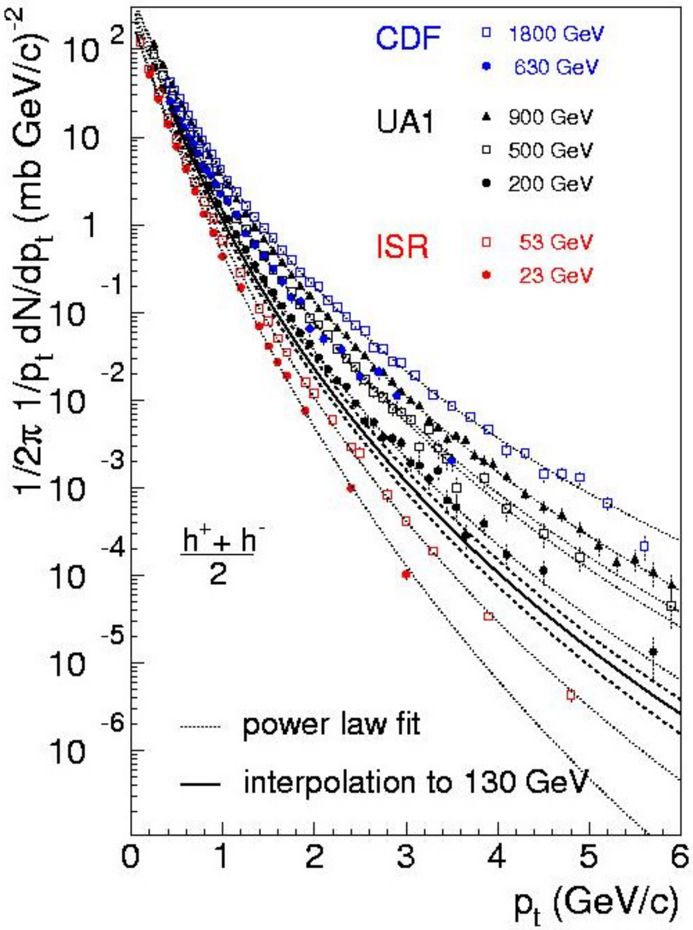
Charge Dependence in Hijing



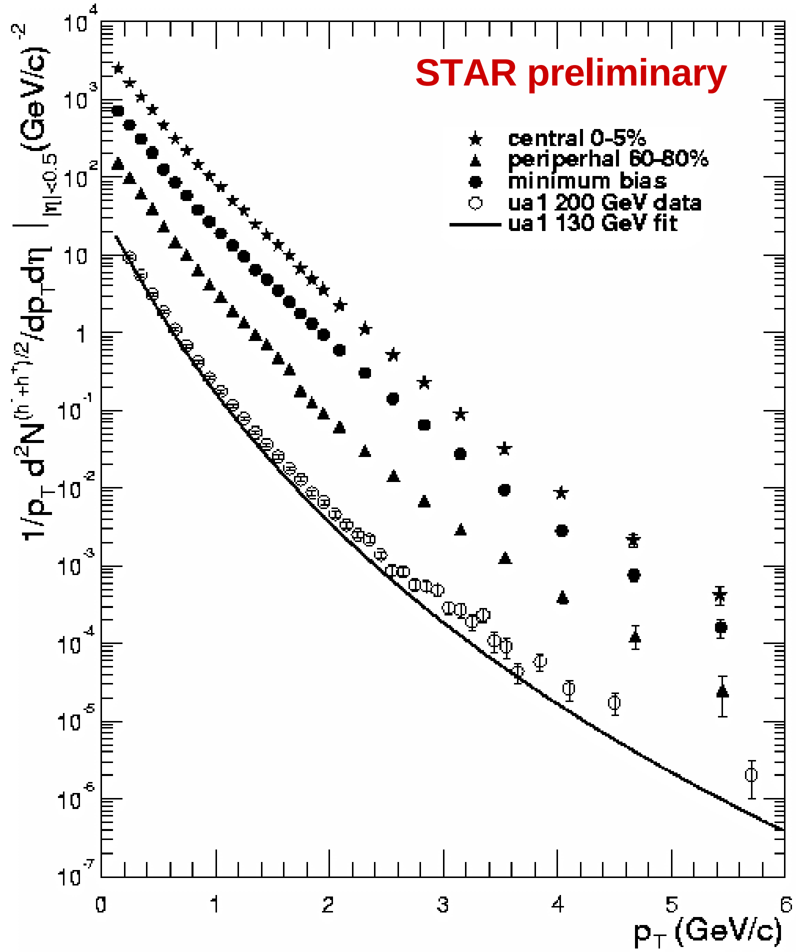
opposite sign/same sign = 2.6+-0.7
property of LUND fragmentation picture

Inclusive Negative Hadron p_t-distributions

elementary collisions



Ös = 130 GeV Au + Au

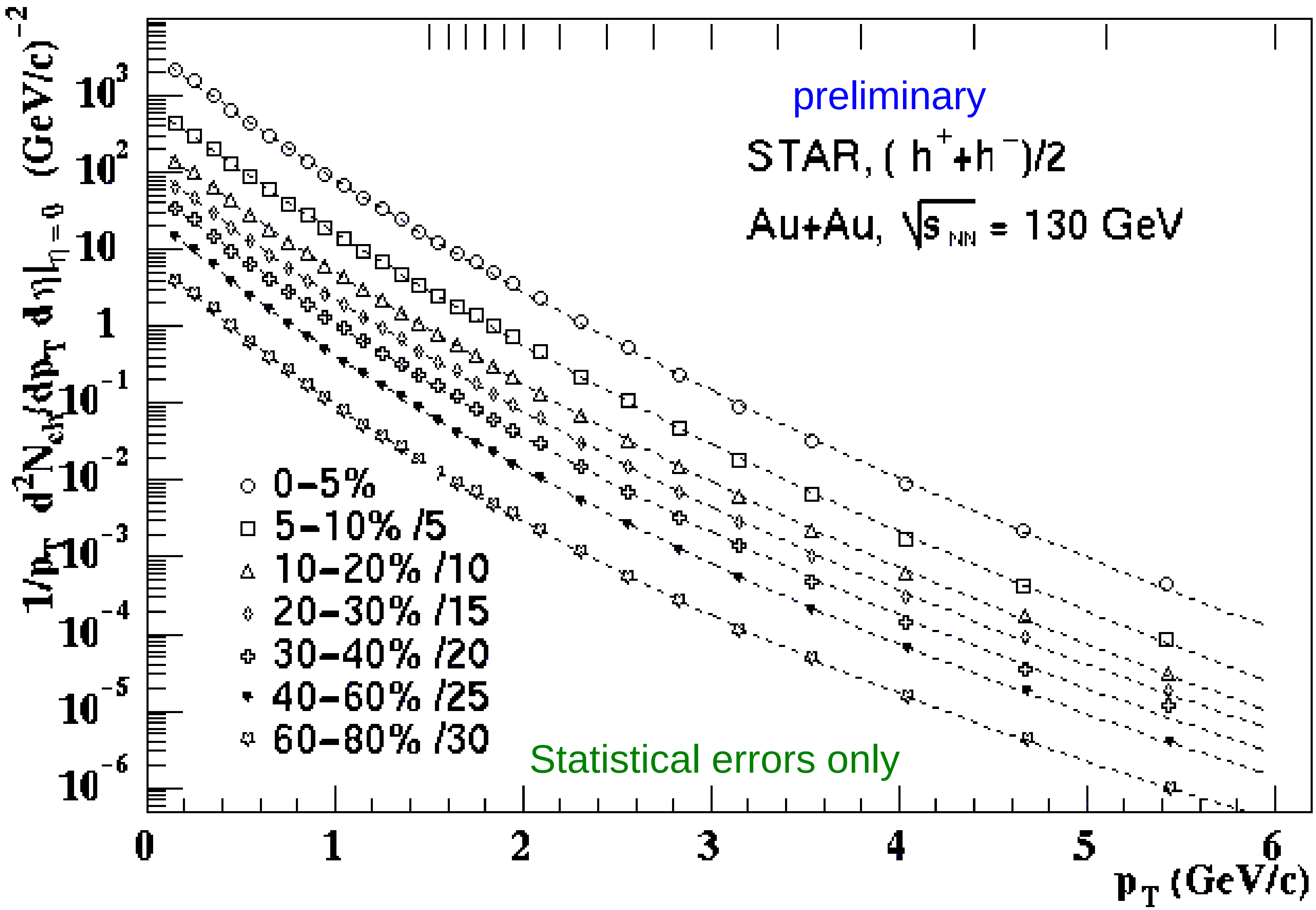


Good power law fits:

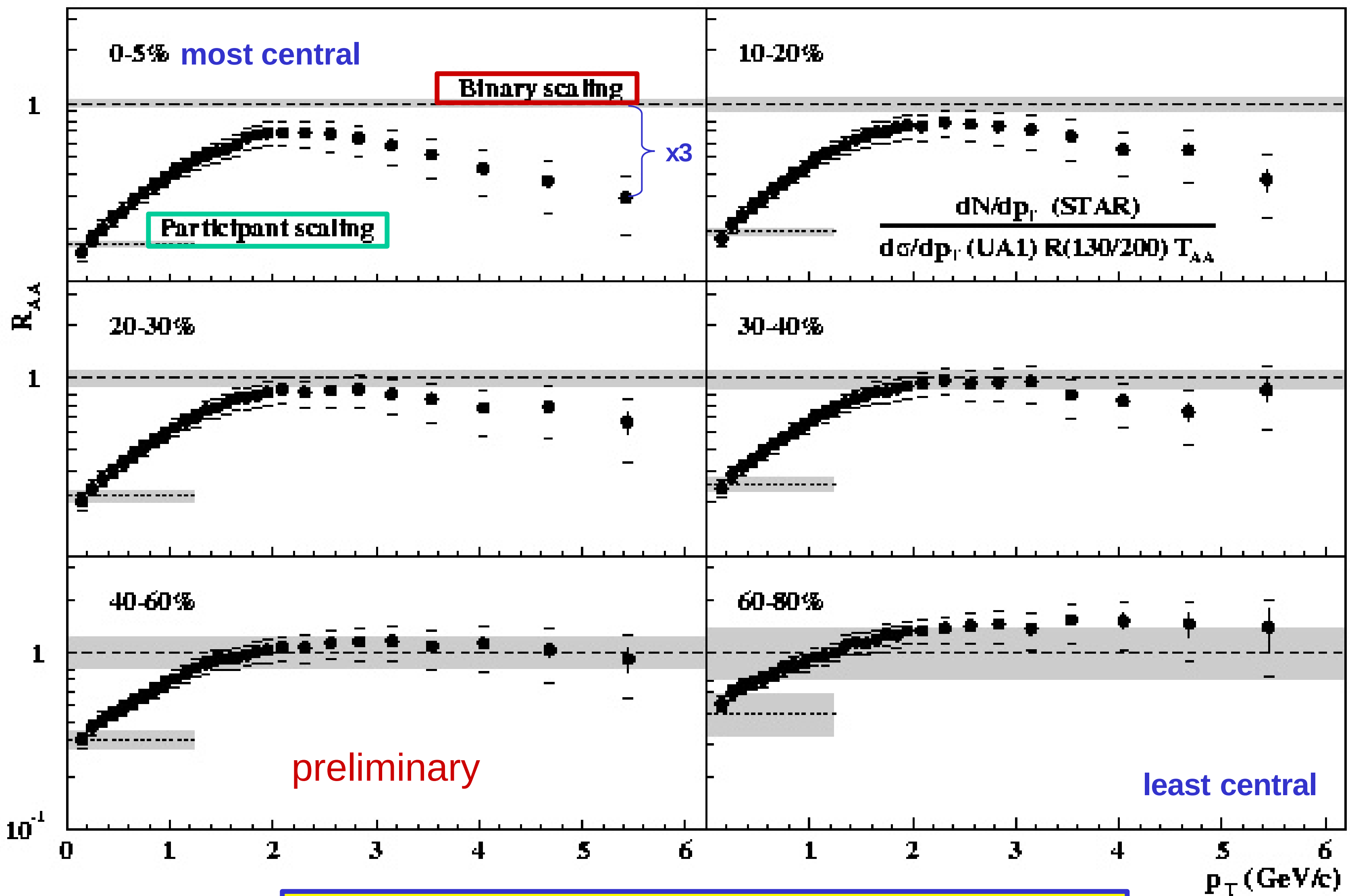
$s_{pp} = d^2N/dp_t^2 = A\,(p_0+p_t)^{-n}$

interpolate A, p_0, n to 130 GeV

Inclusive Hadron Spectra: Centrality Dependence



STAR Centrality Dependence Relative to UA1



• central bin: factor ~ 3 suppression

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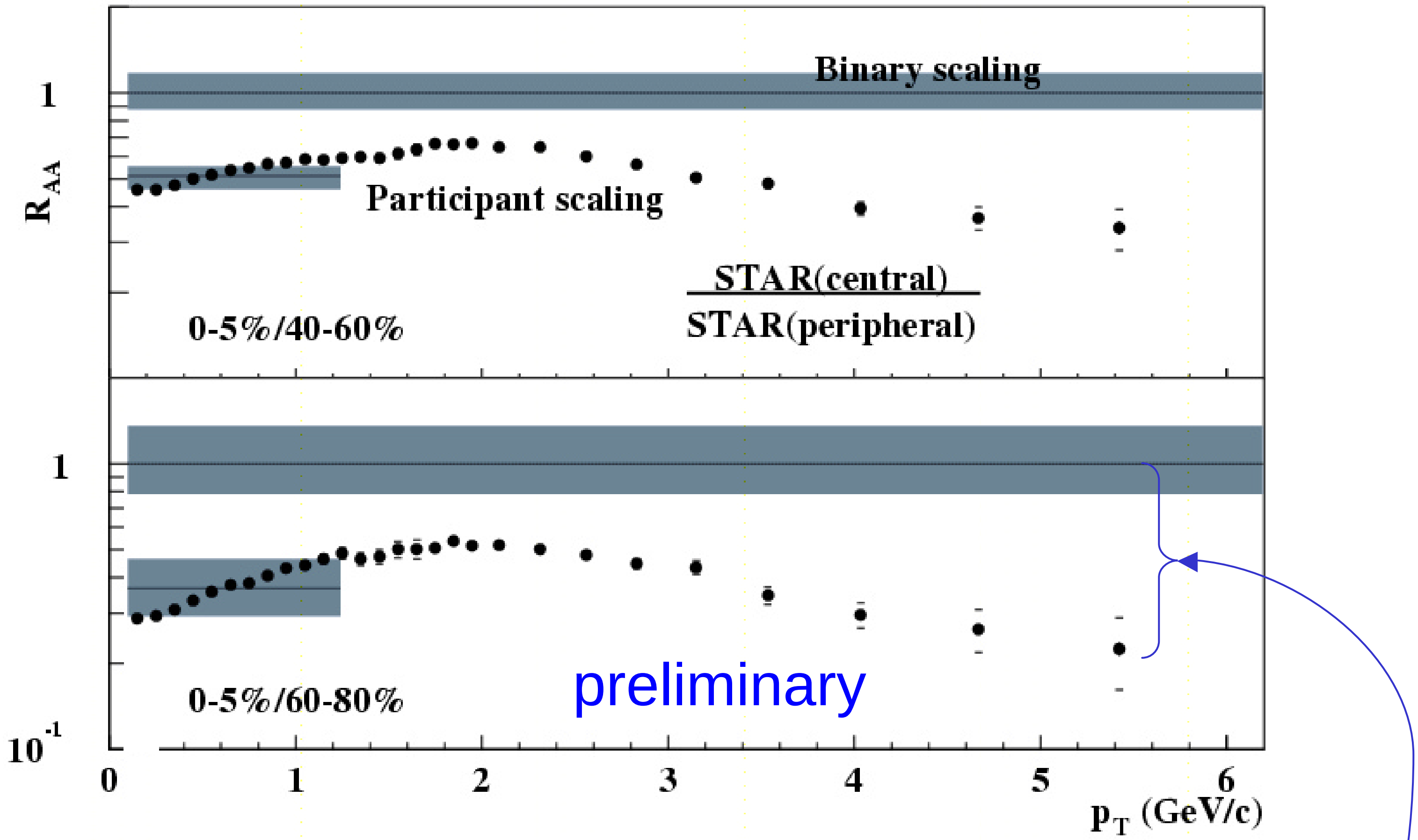
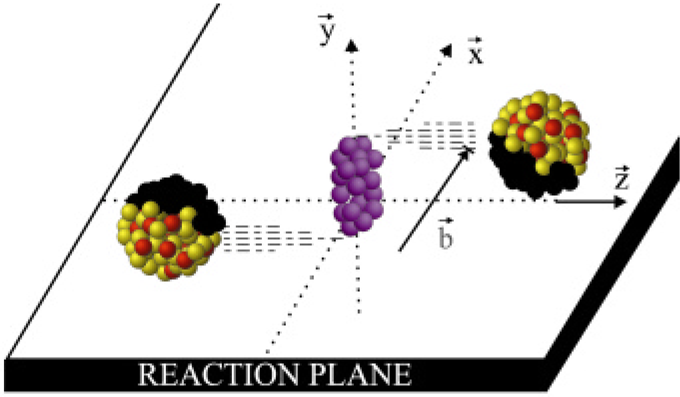
Central/peripheral Ratio (<N_{binary}> norm.)



- Same features without NN reference uncertainty
- Cent/peripheral has factor ~4 suppression

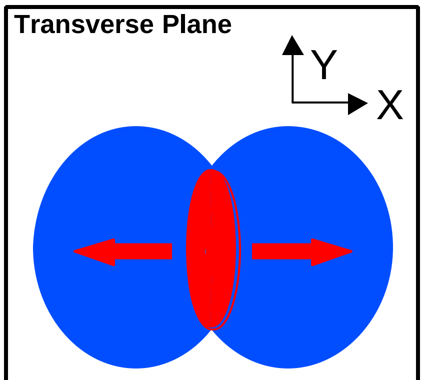
Elliptic Flow - A Sensitive Probe of Early Dynamics



Elliptic flow measures:

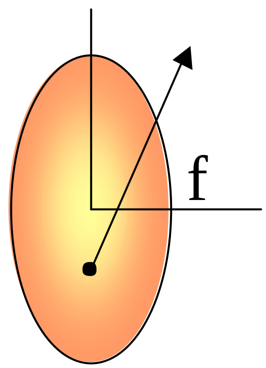
- ® **response of the system to early pressure**
- ® **the system's ability to convert original spatial anisotropy into momentum anisotropy**

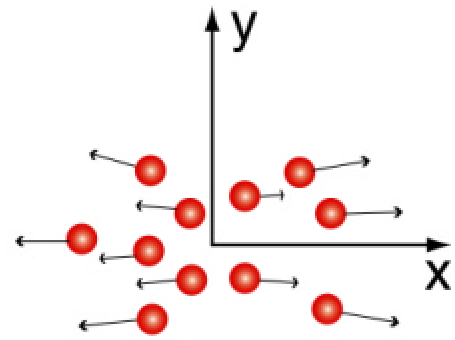
• **Elliptic flow** predictions from hydrodynamic models sensitive to **early dynamics of initial system**



$$e = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

XZ-plane - the reaction plane





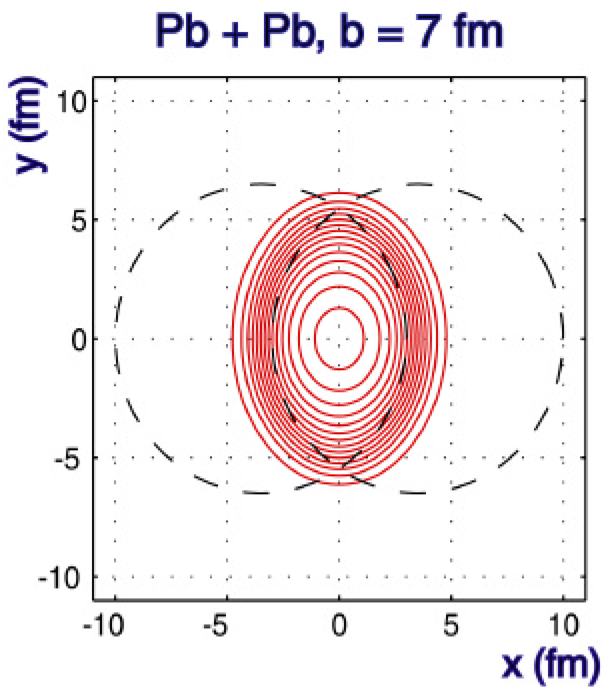
$$f = \text{atan}\frac{p_y}{p_x}$$

$$v_2 = \langle \cos 2f \rangle$$

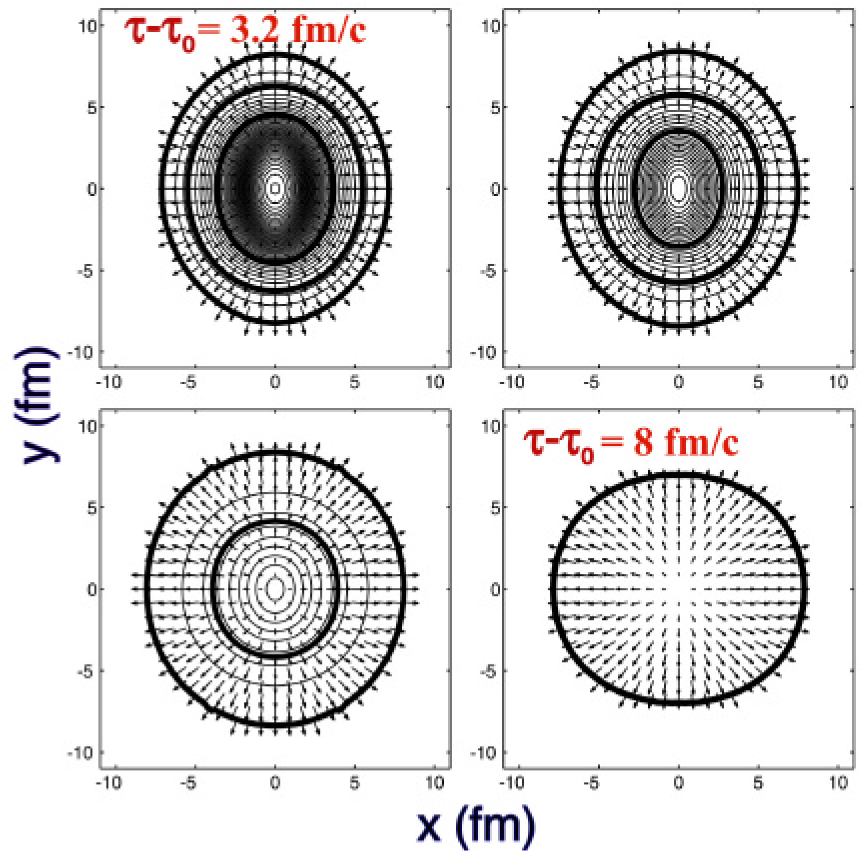
v_2: 2nd Fourier harmonic coefficient of azimuthal distribution of particles with respect to the reaction plane ® measures elliptic flow

STAR Hydrodynamic Calculation of Elliptic Flow

P. Kolb, J. Sollfrank, and U. Heinz



Equal energy density lines



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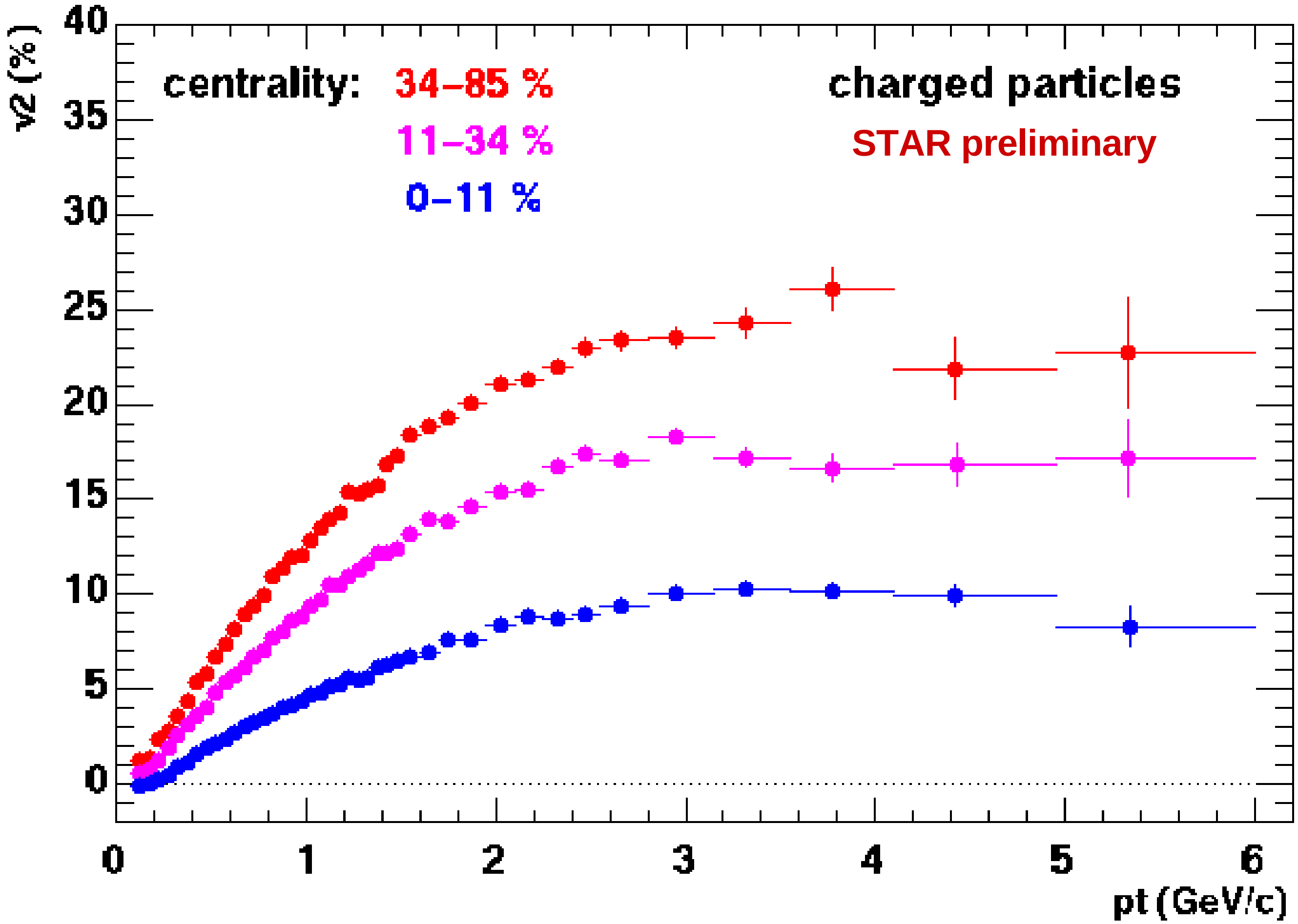
Centrality Dependence of $v_2(p_t)$

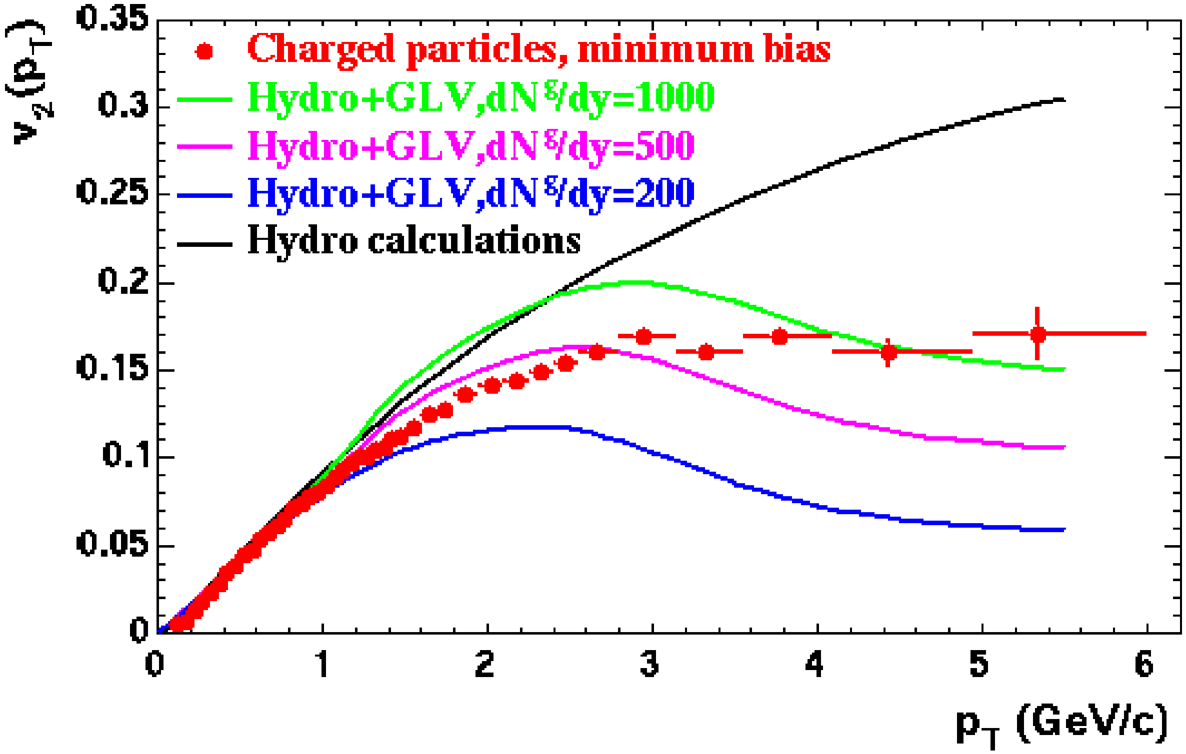


- Measured v_2 increases with increasing p_t and flattens above ~ 3 GeV/c.
  - also observed in STAR for p and p, and Kº and L out to 3 GeV/c
- Relatively large values of v_2 out to p_t ~ 6 GeV/c.
- Larger values of v_2 for more peripheral collisions

STAR Charged Particle Anisotropy at High Pt in STAR

Calculation: Hydrodynamics + hard scattering

(M. Gyulassy, I. Vitev & X.N. Wang, nucl-th/00012092, PRL)



Hydro + hard scattering model and data:

- hydrodynamic behavior up to ~1.5 GeV/c
- v_2 flattens / decreases (?) at high p_t
  - reflects gluon density at high p_t
- data ® compatible with scenario of parton energy loss in deconfined medium