Collision Geometry and Jet Quenching

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November 22 2007

Background

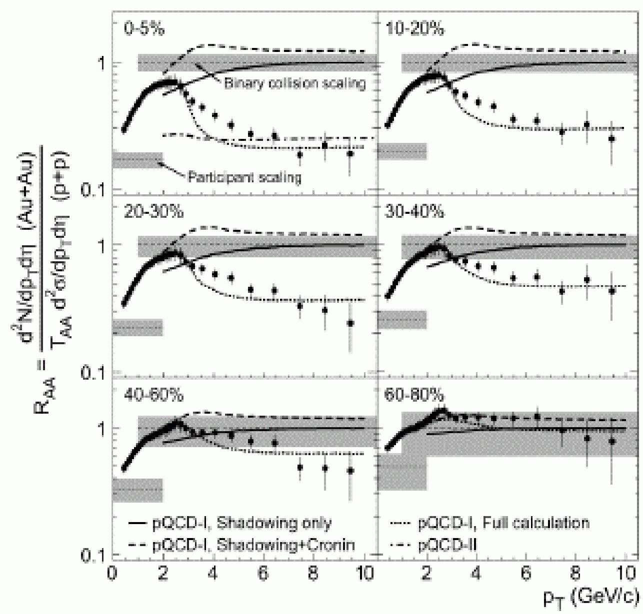


FIG. 3. $R_{AA}(p_T)$ [Eq. (1)] for $(h^+ + h^-)/2$ in $|\eta| < 0.5$, for centrality-selected Au + Au spectra relative to the measured $p + p$ spectrum. The $p + p$ spectrum is common to all panels. Calculations are described in the text.

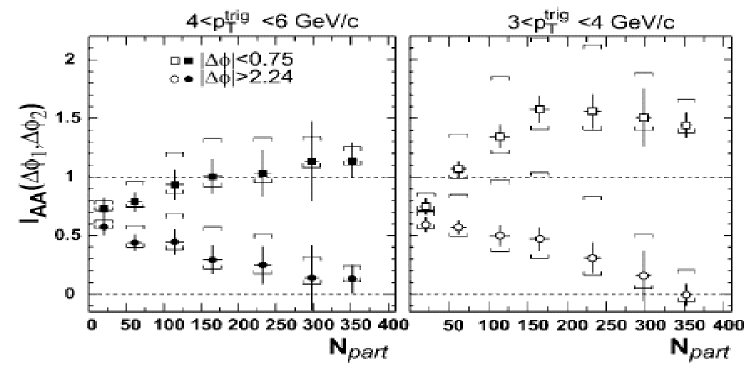


FIG. 3. Ratio of Au + Au and $p + p$ [Eq. (3)] for small-angle (squares, $|\Delta\phi| < 0.75$ rad) and back-to-back (circles, $|\Delta\phi| > 2.24$ rad) azimuthal regions versus number of participating nucleons for trigger particle intervals $4 < p_T^{\rm trig} < 6$ GeV/c (solid) and $3 < p_T^{\rm trig} < 4$ GeV/c (hollow). The horizontal bars indicate the dominant systematic error (highly correlated among points) from the uncertainty in v_2.

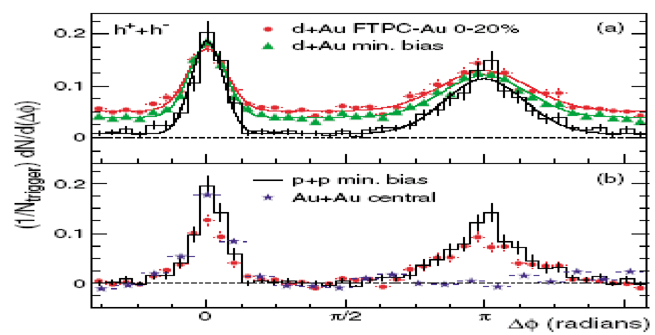


FIG. 4 (color online). (a) Efficiency corrected two-particle azimuthal distributions for minimum bias and central d + Au collisions, and for $p + p$ collisions [6]. Curves are fits using Eq. (3), with parameters given in Table I. (b) Comparison of two-particle azimuthal distributions for central d + Au collisions to those seen in $p + p$ and central Au + Au collisions [6]. The respective pedestals have been subtracted.

- Yield suppression in AA collisions for high p_T particles compared to pp (factor of 5) and dA (process due to final state interactions)

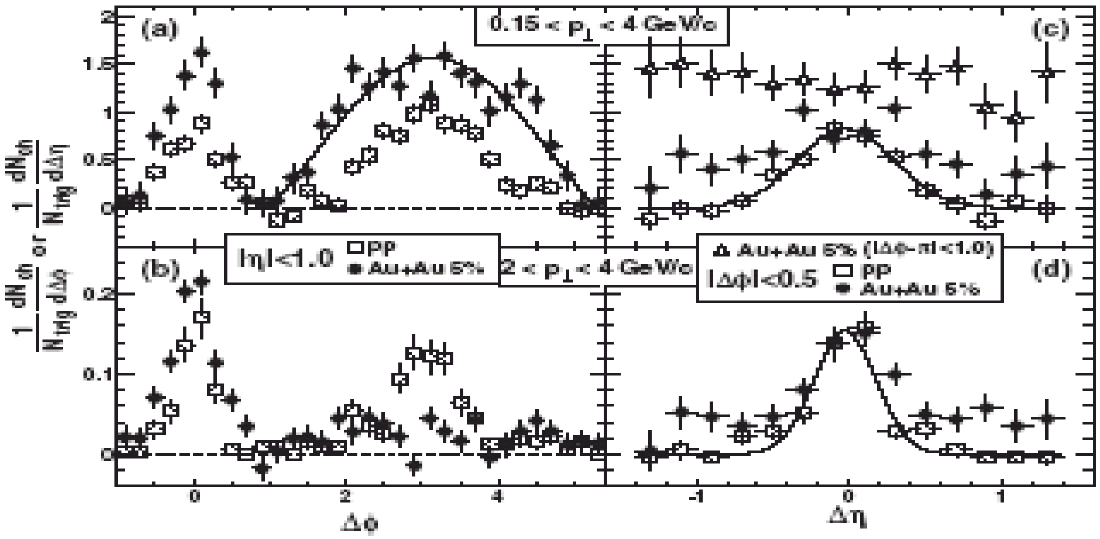


FIG. 1. Background-subtracted (a),(b) $\Delta\phi$ and (c),(d) $\Delta\eta$ distributions for pp and 5%–0% central Au + Au for $4 < p_\perp^{\rm trig} < 6$ GeV/c and two associated $p_\perp$ ranges. The subtracted background level for $p_\perp = 0.15$–4 GeV/c (2–4 GeV/c) is $\frac{1}{N_{\rm trig}} \times \frac{dN_{\rm ch}}{d\Delta\phi} \approx 1.4(0.007)$ in pp and ≈ 211 (2.1) in 5%–0% Au + Au. The curve in (a) shows the shape of an $[A - B\cos(\Delta\phi)]$ function. The curves in (c),(d) are Gaussian fits to the pp data.

- Jet-like correlations (azimuthal) of high p_T triggered particles in “away”(opposite side) also suppressed, near side not suppressed

- When lowering p_T of trigger particles the number of soft hadrons increases *more* in AA than in pp for near and away peak

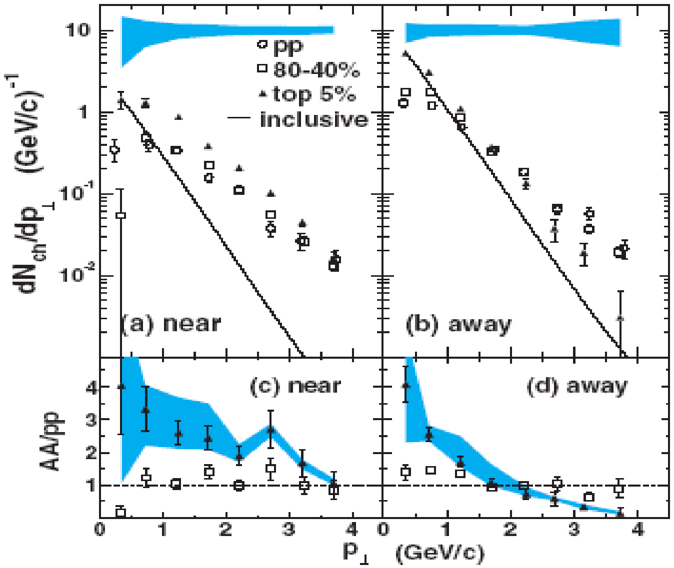


FIG. 3 (color online). Associated charged hadron $p_\perp$ distributions (a),(b) and AA/pp ratios (c),(d) for $4 < p_\perp^{trig} < 6$ GeV/c on near and away sides. Errors shown are statistical. The bands show the systematic uncertainties for the 5%–0% central data. The lines show the inclusive spectral shape for central collisions.

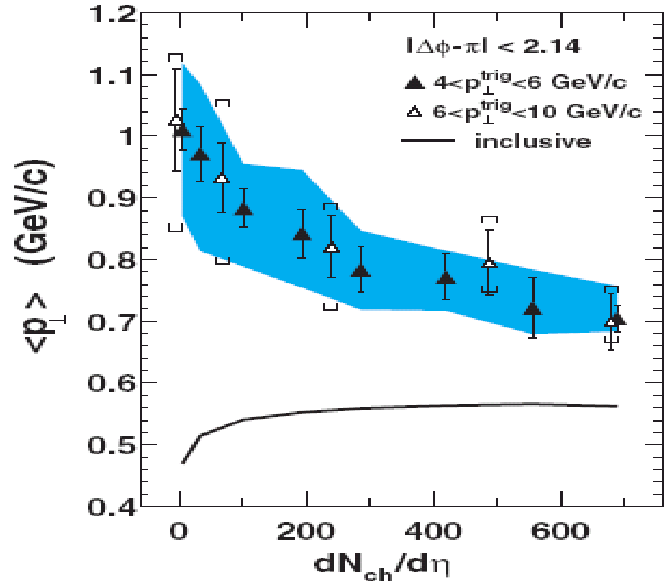


FIG. 4 (color online). Awayside associated hadron $\langle p_\perp \rangle$ for $p_\perp^{trig} = 4$–$6(6$–$10)$ GeV/c with systematic errors in bands (caps).

- dN/dp$_T$ near side broaden (larger than pp up to ~ 3 GeV)
- dN/dp$_T$ far side broaden for low p$_T$ and suppressed for larger p$_T$
- Away side associated hadrons <p$_T$> tends to limit value (progressive equilibrium)

Jet-like particles deposit energy in medium (Energy loss), this energy is then picked up (progressive equilibrium) and may correlated to processes like:

- Recombination
- Scattering
- “Flow”

Theory: how is Energy loss transferred to medium?

- Cronin Multiple scattering – Collective production of high p_T hadrons (rescattering)
- Nuclear shadowing – Coherent interaction of projectile and and target nucleons
- Elastic energy loss – Ellastic scattering with *thermal* partons in medium through one gluon exchange
- Gluon Radiation energy loss

Dominant effects Gluon Radiation and Elastic energy loss

→ High momentum energy transfer processes (harder scattering) suppressed

→ ΔE_{Loss} dependent on jet-like path length (L) e.i. dependent on ion-ion interaction geometry

For example, using BDMPS model:

$$\Delta E_{Loss} \propto \alpha_s C_R \frac{< \mu^2 >}{\lambda_g} L^2$$

- $< \mu^2 >$ → average momentum transfer
- L^2 → path length
- α_s → constant
- C_R → color coupling
- λ_g → gluon mean free path

Application: Dainese, Loizides & Paic PQM (parton quenching model)

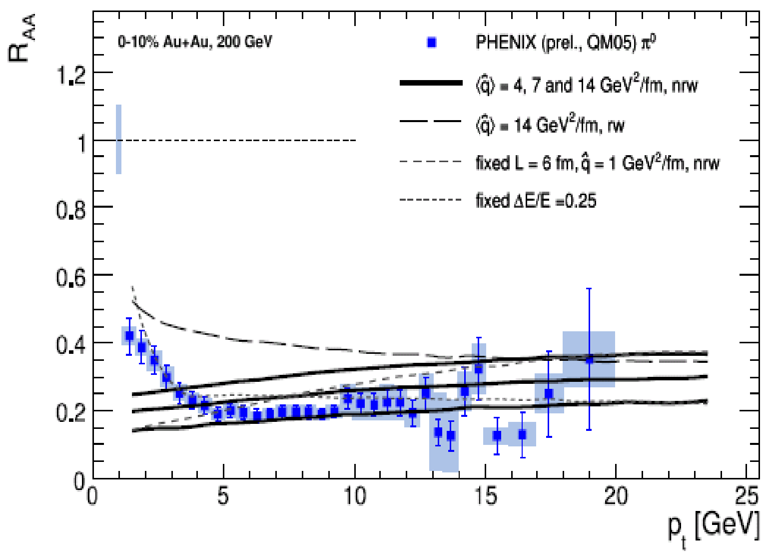


Fig. 2. $R_{\rm AA}(p_{\rm t})$ for neutral pions in 0–10% central Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV (preliminary PHENIX data) with combined statistical and $p_{\rm t}$-dependent systematic errors, as well as $p_{\rm t}$-independent systematic errors (bar at $R_{\rm AA} = 1$) [13]. The PQM curves for $\langle\hat{q}\rangle = 14$ GeV^2/fm are the original PQM results (extended to larger $p_{\rm t}$) for the reweighted and non-reweighted case from Ref. [10]. In addition, results for $\langle\hat{q}\rangle = 4$ and 7 GeV^2/fm for the non-reweighted case are shown, as well as calculations for fixed $L = 6$ fm and $\hat{q} = 1$ GeV^2/fm, or for fixed relative energy loss of $\Delta E/E = 0.25$.

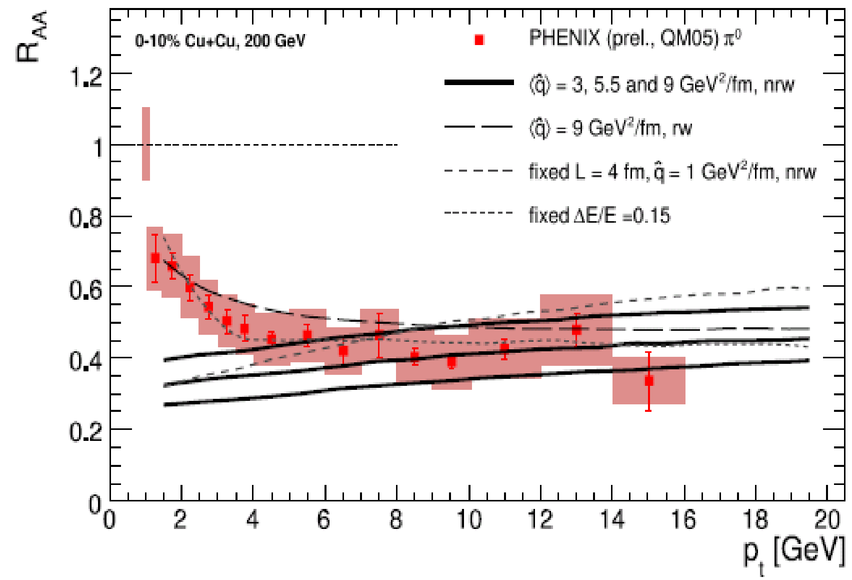


Fig. 3. $R_{\rm AA}(p_{\rm t})$ for neutral pions in 0–10% central Cu+Cu collisions at $\sqrt{s_{\rm NN}} = 200$ GeV (preliminary PHENIX data) with combined statistical and $p_{\rm t}$-dependent systematic errors, as well as $p_{\rm t}$-independent systematic errors (bar at $R_{\rm AA} = 1$) [13]. The PQM curves for $\langle\hat{q}\rangle = 9$ GeV^2/fm are the original PQM predictions for the reweighted and non-reweighted case from Ref. [10]. In addition, results for $\langle\hat{q}\rangle = 3$ and 5.5 GeV^2/fm for the non-reweighted case are shown, as well as calculations for fixed $L = 4$ fm and $\hat{q} = 1$ GeV^2/fm, or for fixed relative energy loss of $\Delta E/E = 0.15$.

ΔE_{Loss} dependent on jet-like path length (L^2)

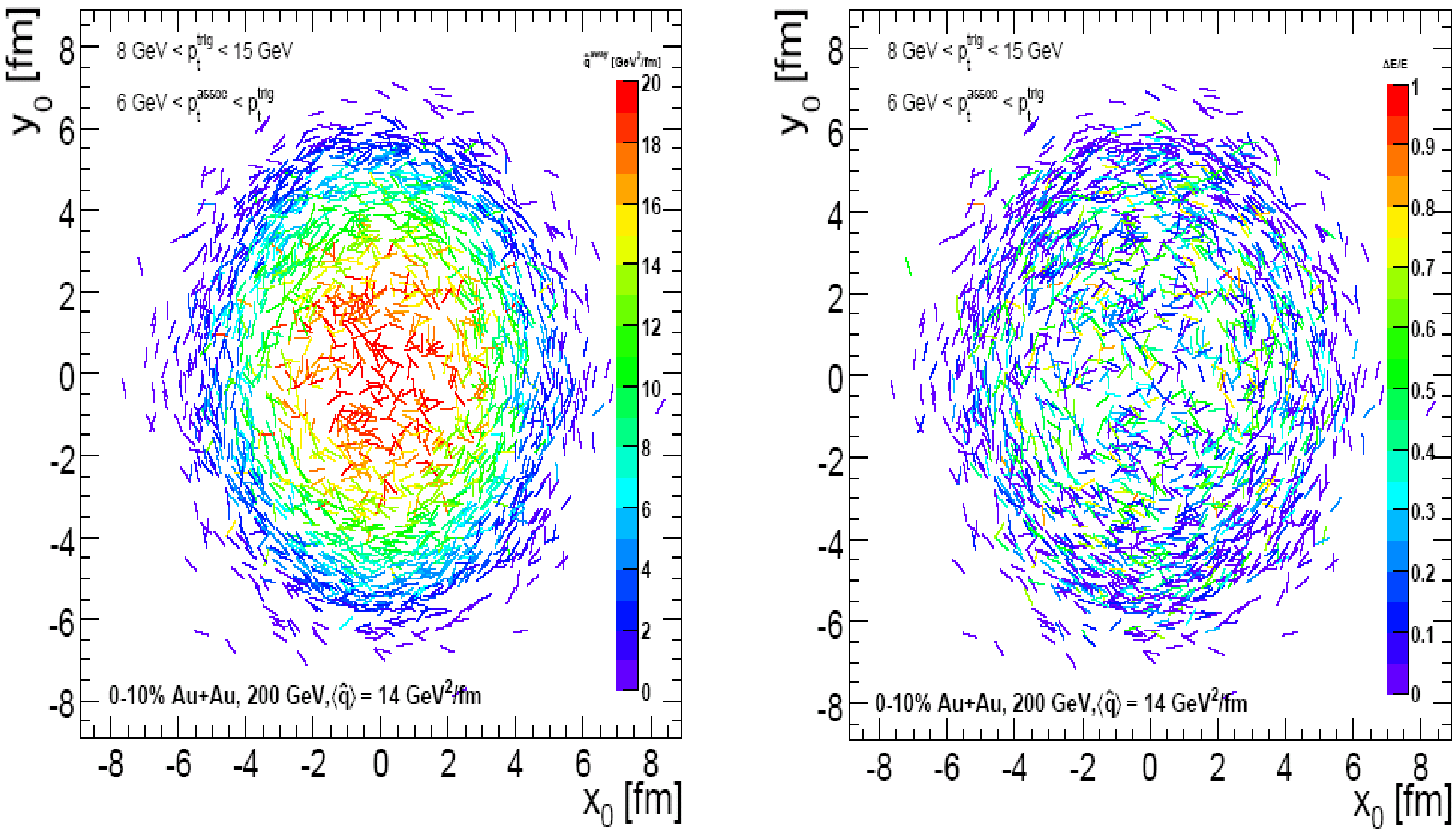
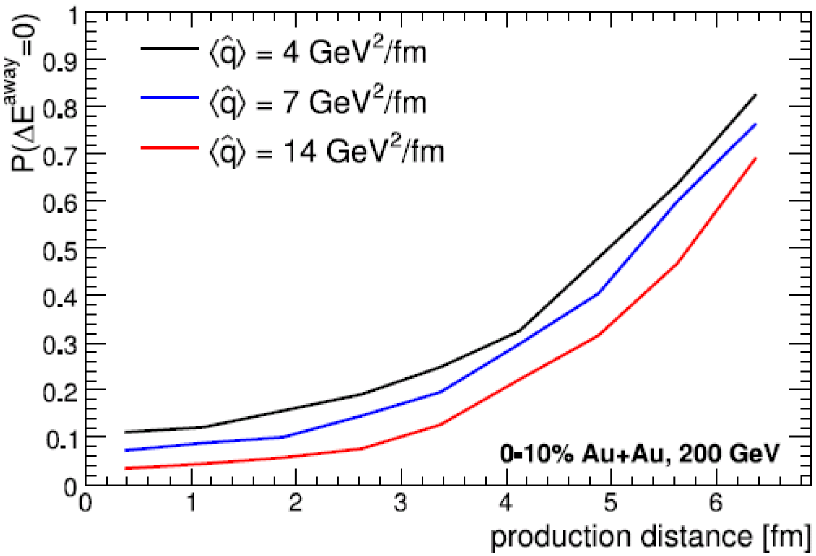
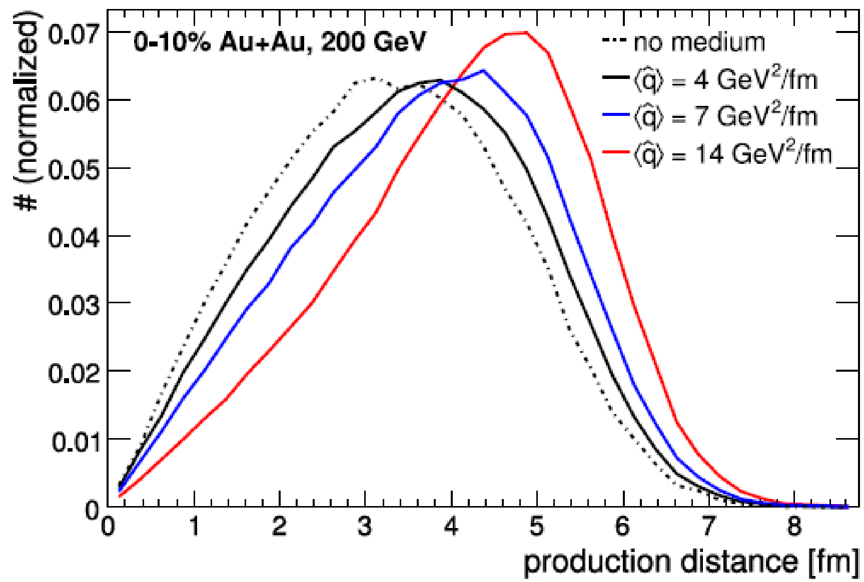
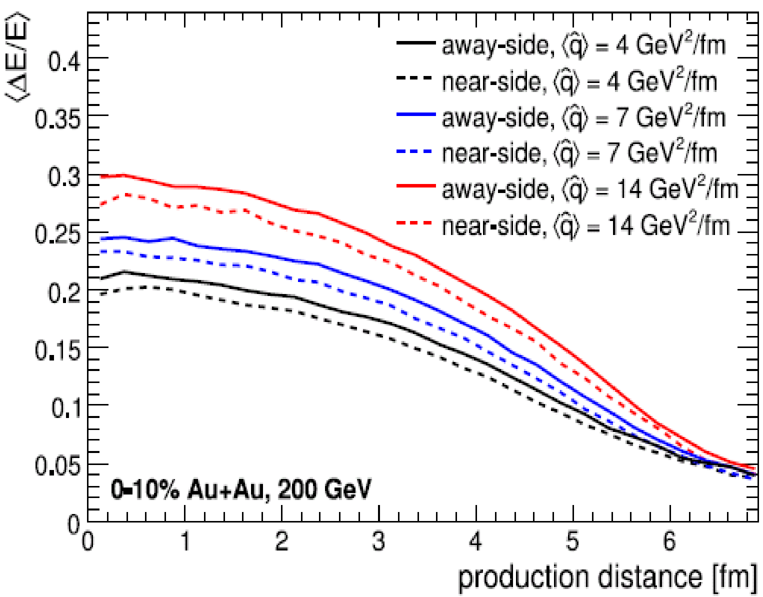


Fig. 7. (Color online) Production points and emission direction for surviving back-to-back parton pairs (yielding hadron pairs within $8 < p_t^{trig} \leq 15$ GeV and 6 GeV $\leq p_t^{assoc} \leq p_t^{trig}$) in the transverse plane for $\langle \hat{q} \rangle = 4$ (bottom), 7 (middle) and 14 GeV^2/fm (top panels) for 0–10% central Au+Au collisions. The line color represents the medium density (relative energy loss) of the away-side parton in the left (right) panel.





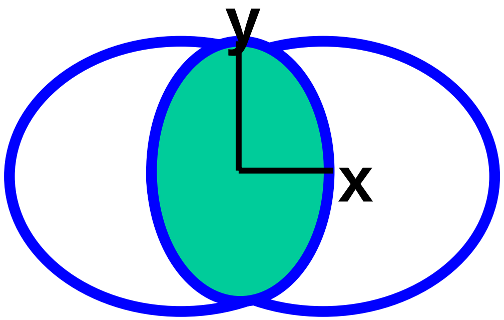


- Particle production in central AA is surface dominated not only for single hadrons but for dijets
- Consistent with data but how to make a better connection for

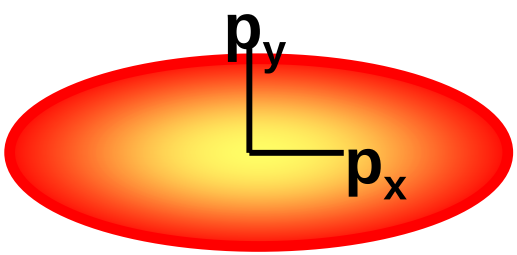
$$\Delta E_{Loss} \Leftrightarrow \text{Reaction Geometry}$$

What about the azimuthal anysotropy?

Initial *spatial* anisotropy



Final *momentum* anisotropy

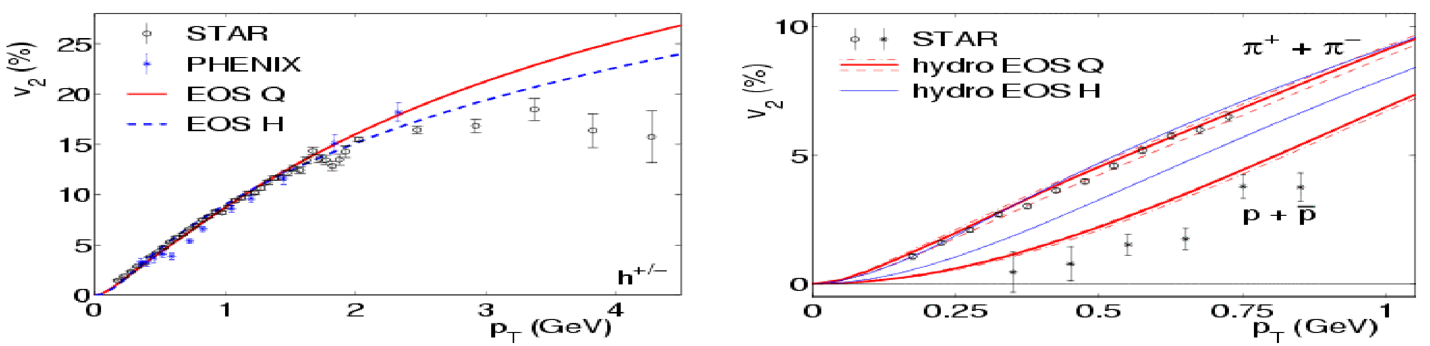


$$\varepsilon = \frac{x_i - y_i}{x_i + y_i} \quad \Longrightarrow \quad v_2 \propto \frac{p_x - p_y}{p_x + p_y}$$

Present situation

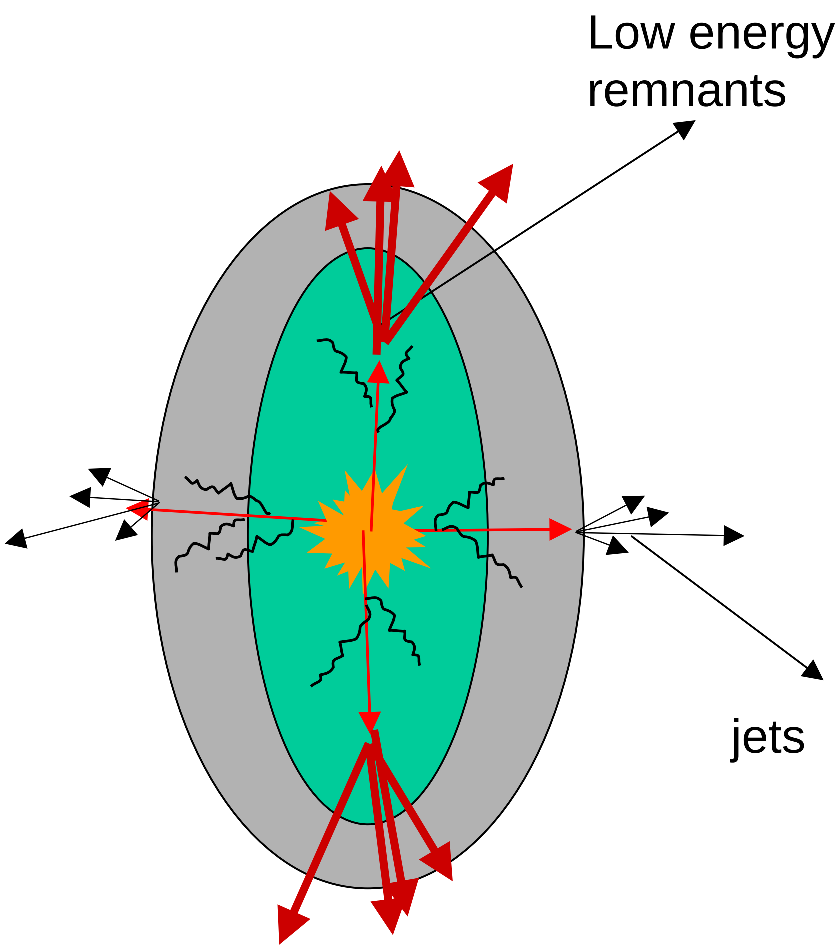
Elliptic flow at RHIC

Important discovery at RHIC:
strong elliptic flow v_2, $v_2(p_\perp \leq 2$ GeV) exhausts hydrodynamic prediction



STAR Coll., PRL 86 (2001) 402; 87 (2001) 182301; PHENIX Coll., nucl-ex/020400512 and QM 2001

Jet quenching and Flow



- The jets produce an excess of low energy particles in the ends of the ellipsoid. This distorts the distribution of particles lowering the v_2 at lower momenta – even possibly changing the sign of the v_2 component!
- Guy Paic's idea was to study this for ALICE
- Is it feasible to measure this at STAR?

Jet quenching and flow – interesting complications

Measuring the Collective Flow with Jets

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(Received 31 May 2004; published 6 December 2004)

In nucleus-nucleus collisions, high-p_T partons interact with a dense medium, which possesses strong collective flow components. Here, we demonstrate that the resulting medium-induced gluon radiation does not depend solely on the energy density of the medium, but also on the collective flow. Both components can be disentangled by the measurement of particle production associated with high-p_T trigger particles, jetlike correlations, and jets. In particular, we show that flow effects lead to a characteristic breaking of the rotational symmetry of the average jet energy and jet multiplicity distribution in the $\eta \times \phi$ plane. We argue that data on the medium-induced broadening of jetlike particle correlations in Au + Au collisions at the Relativistic Heavy-Ion Collider may provide evidence for a significant distortion of parton fragmentation due to the longitudinal collective flow.

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- Flow may be affected by jet quenching, and jets fragmentation functions may also be affected by flow presence → retro-something problem

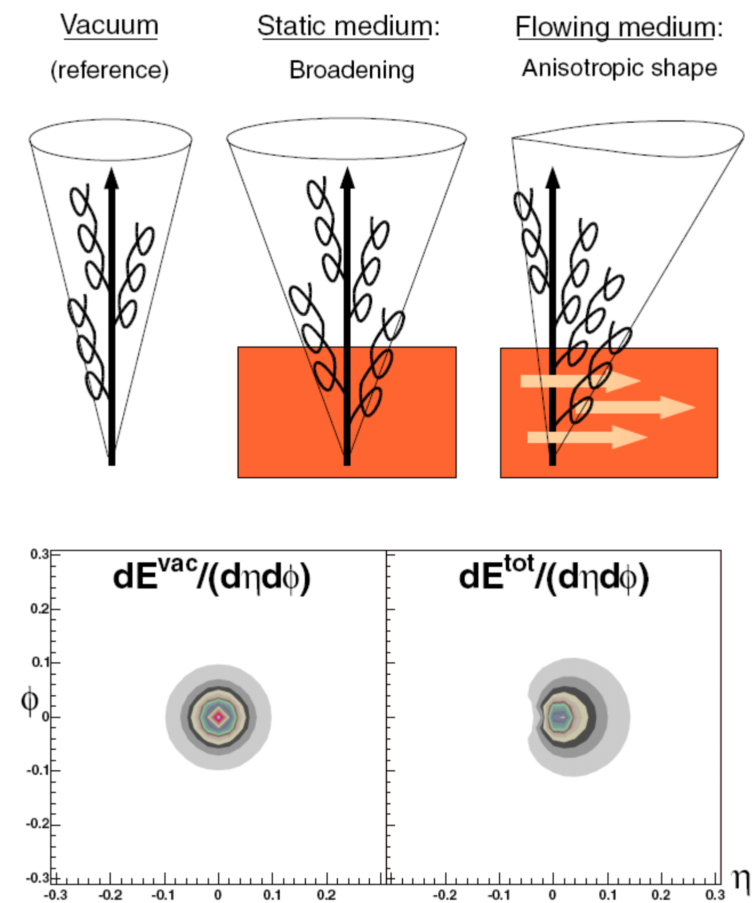
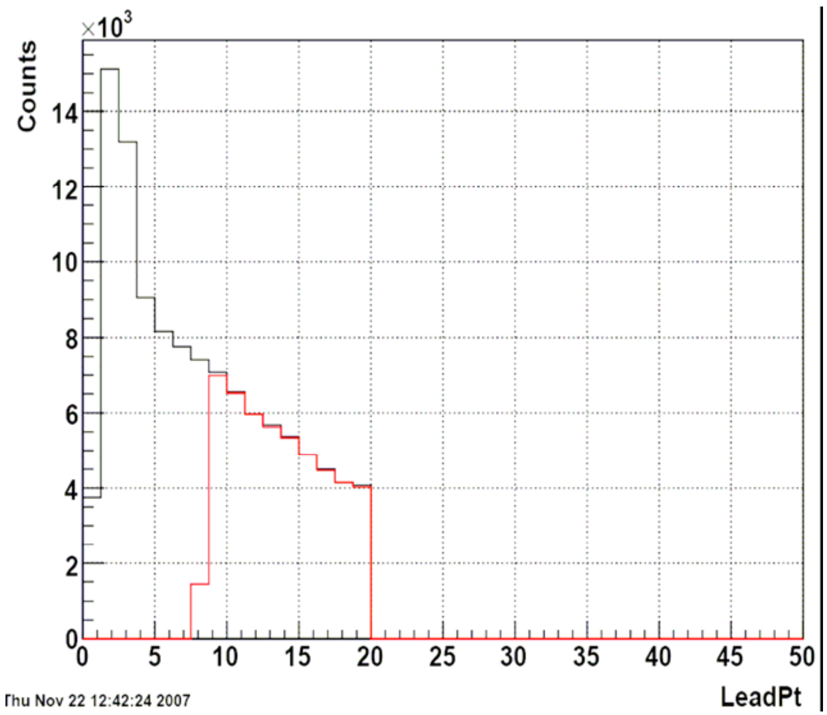
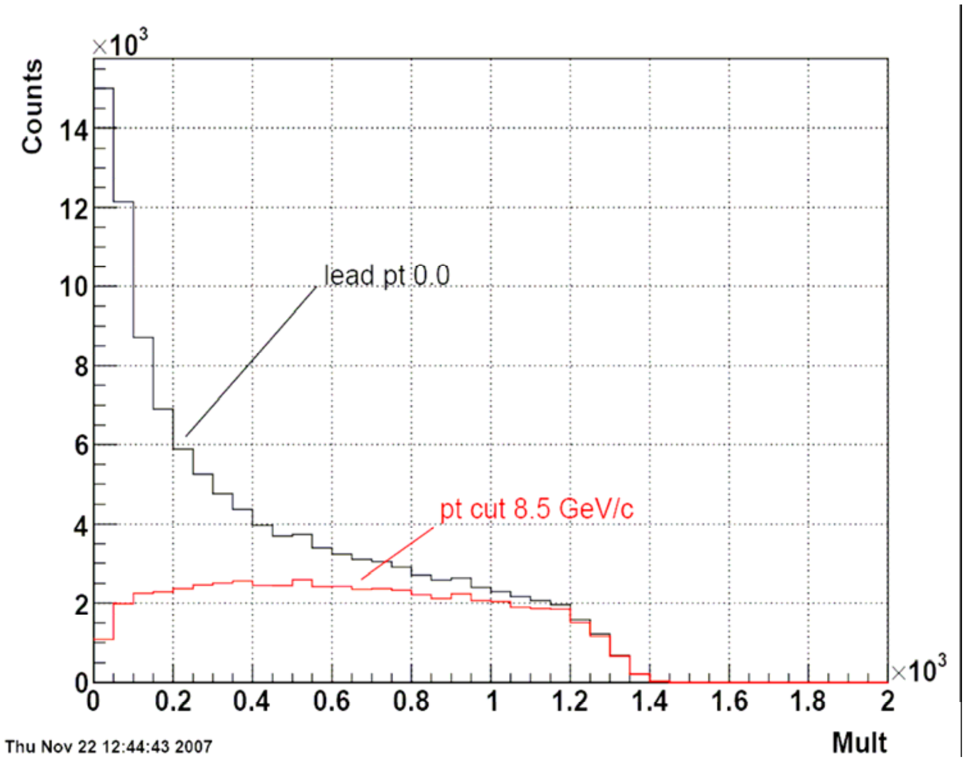


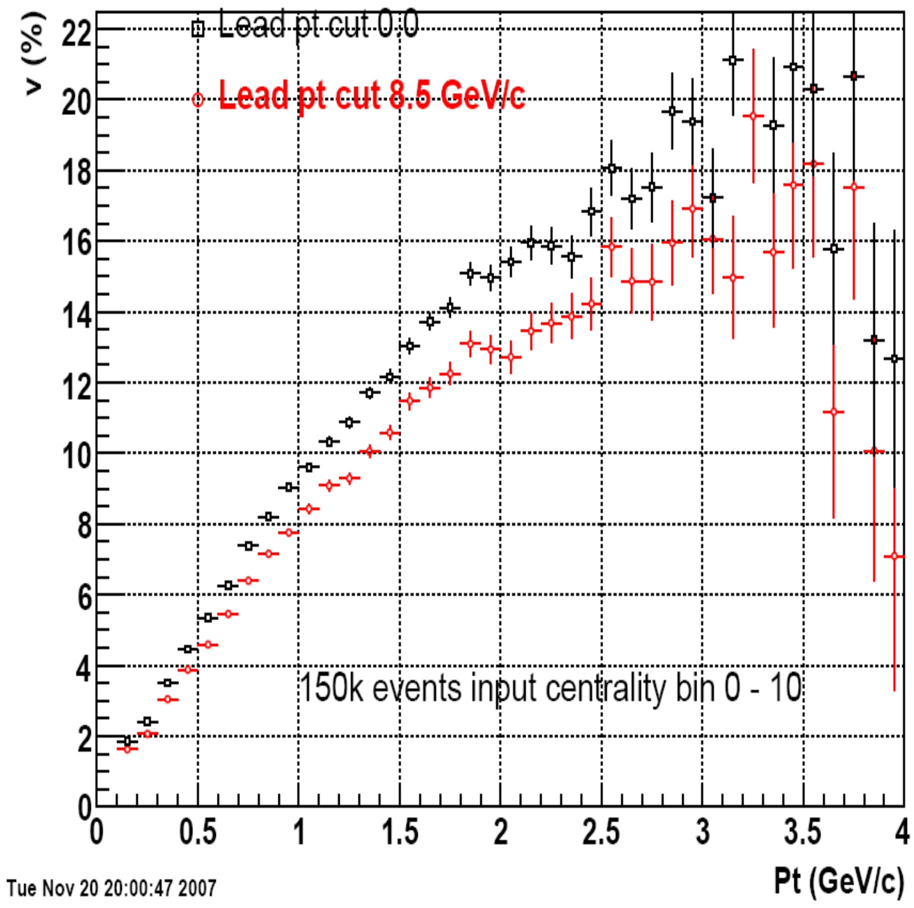
FIG. 1 (color online). Upper part: sketch of the distortion of the jet energy distribution. Lower part: calculated distortion (5) in the $\eta \times \phi$ plane for a 100 GeV jet. The right-hand side is for an average medium-induced radiated energy of 23 GeV and equal contributions from density and flow effects, $\mu = q_0$. Scales of the contour plot are visible from Fig. 2.

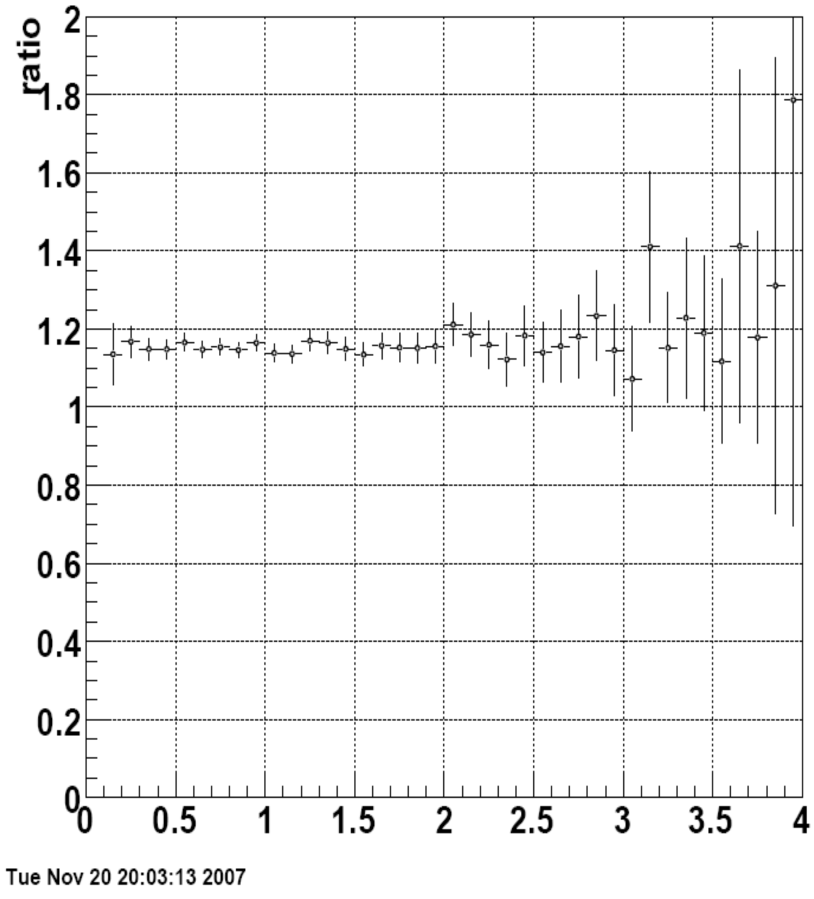
Minimum Bias STAR 200 GeV Au Au



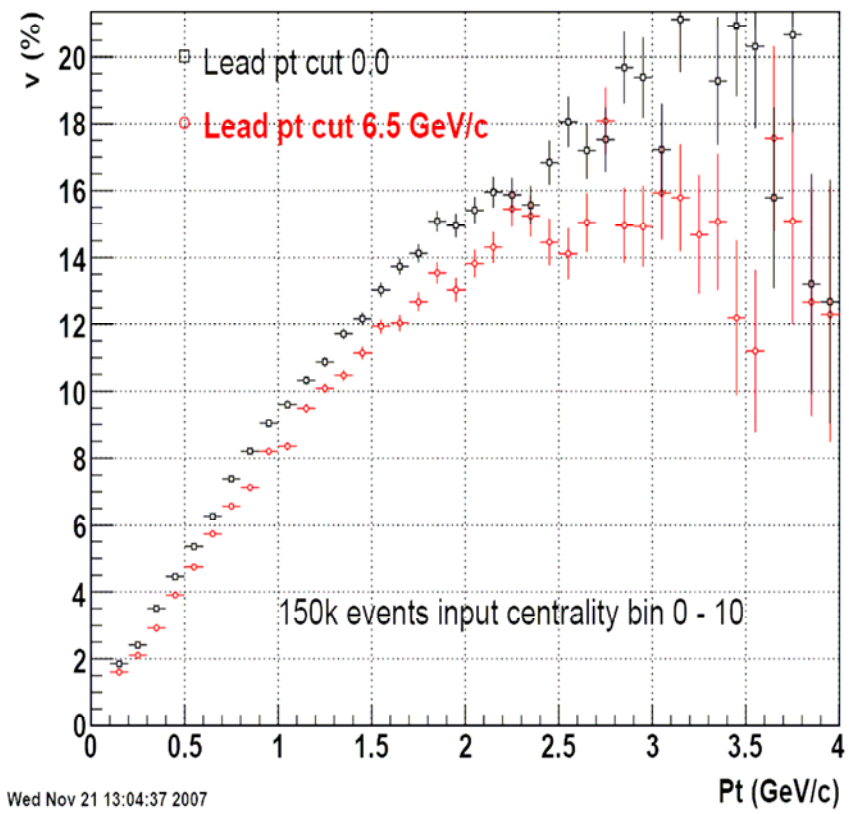


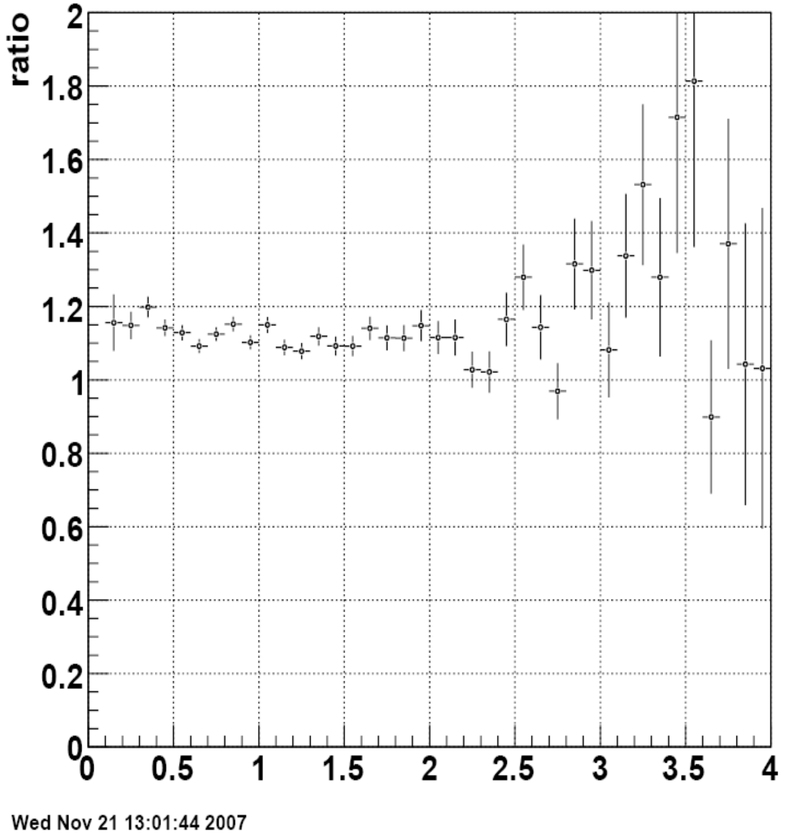
V2 Minimum Bias pt Cut 8.5 GeV/c



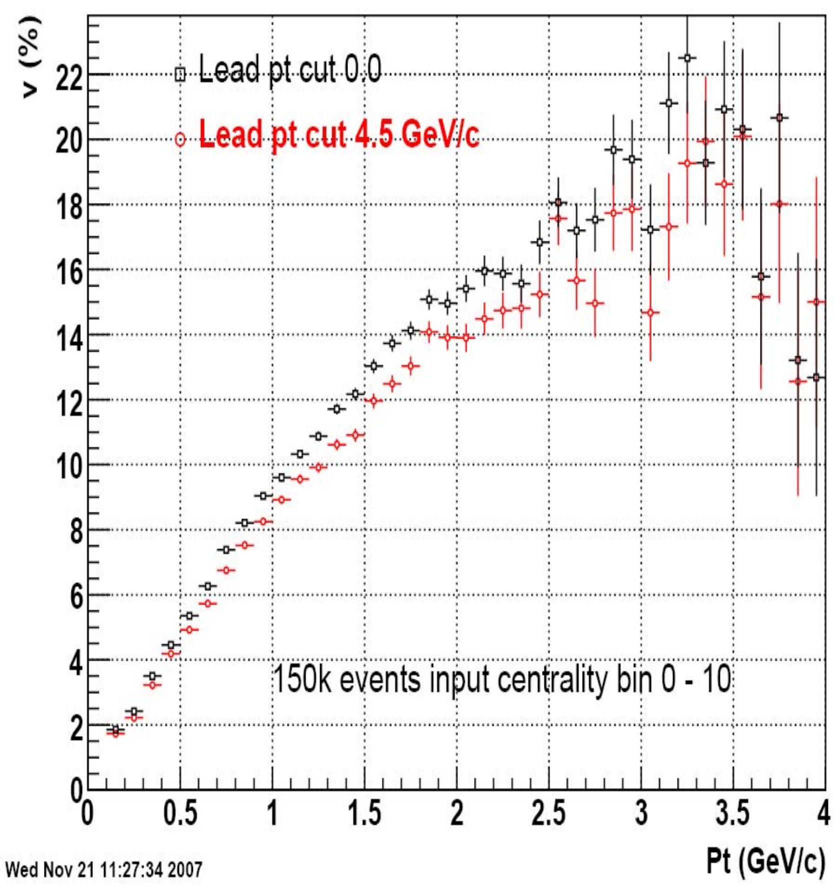


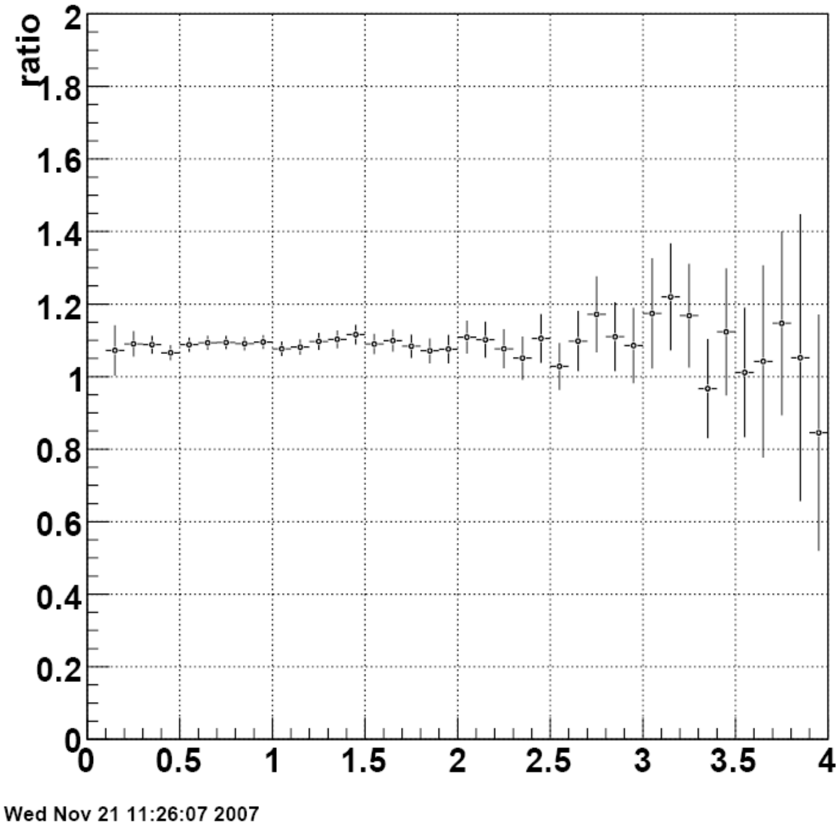
V2 Minimum Bias pt cut 6.5 GeV/c



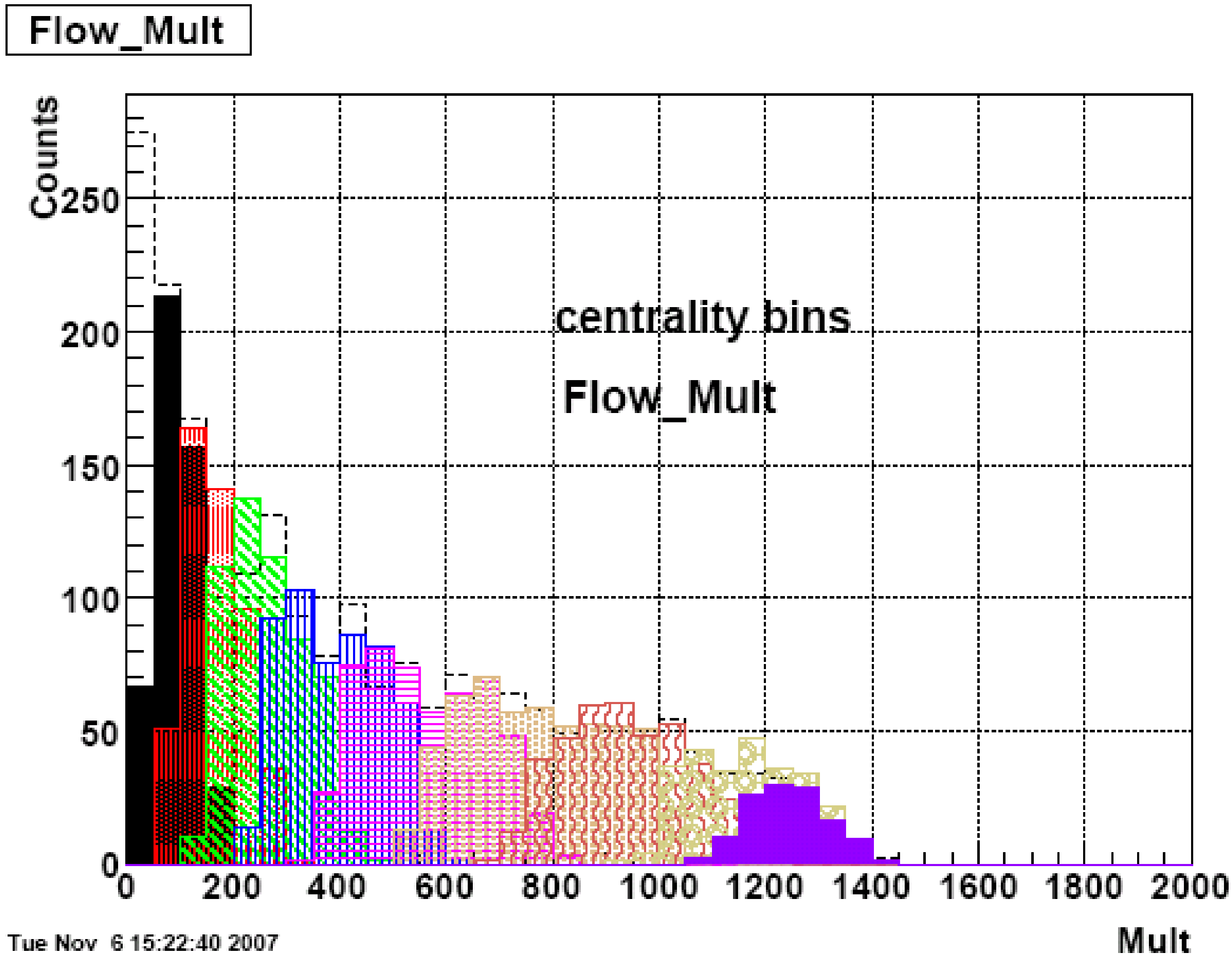


V2 Minimum Bias pt cut 4.5 GeV/c





Centrality



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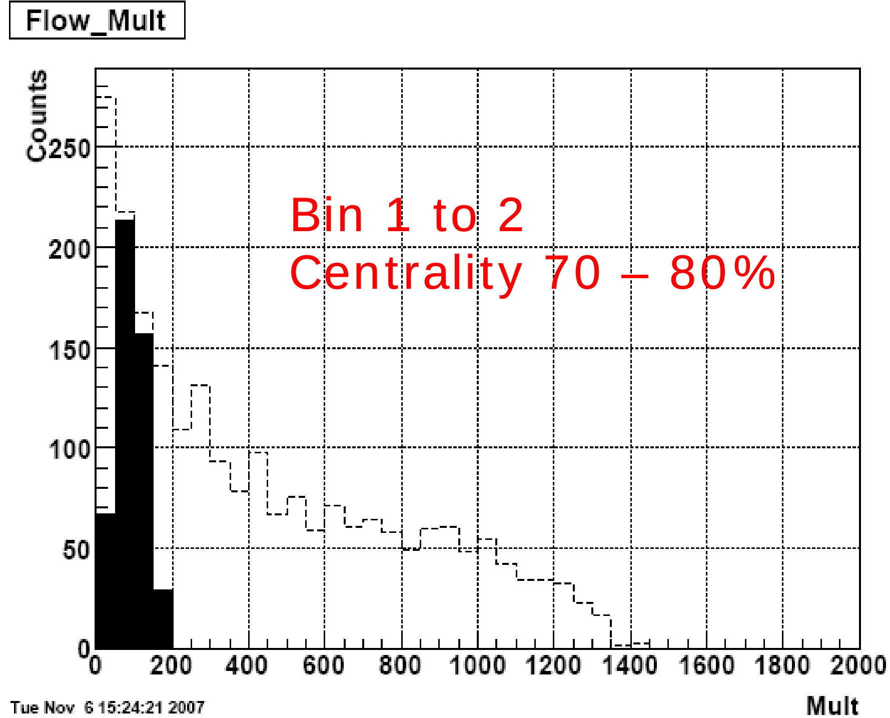
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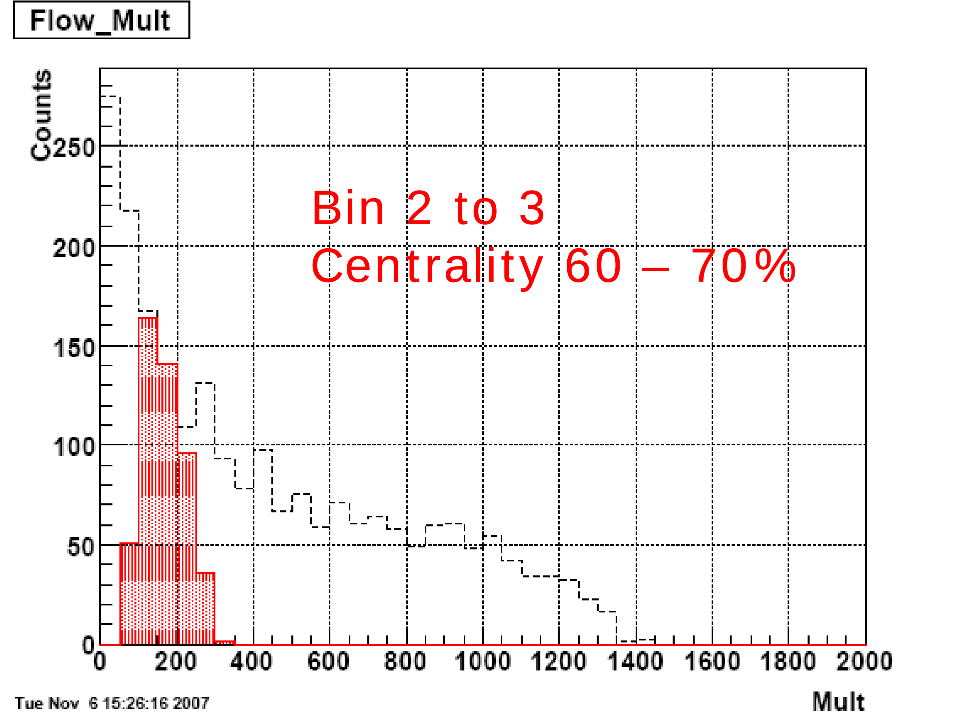
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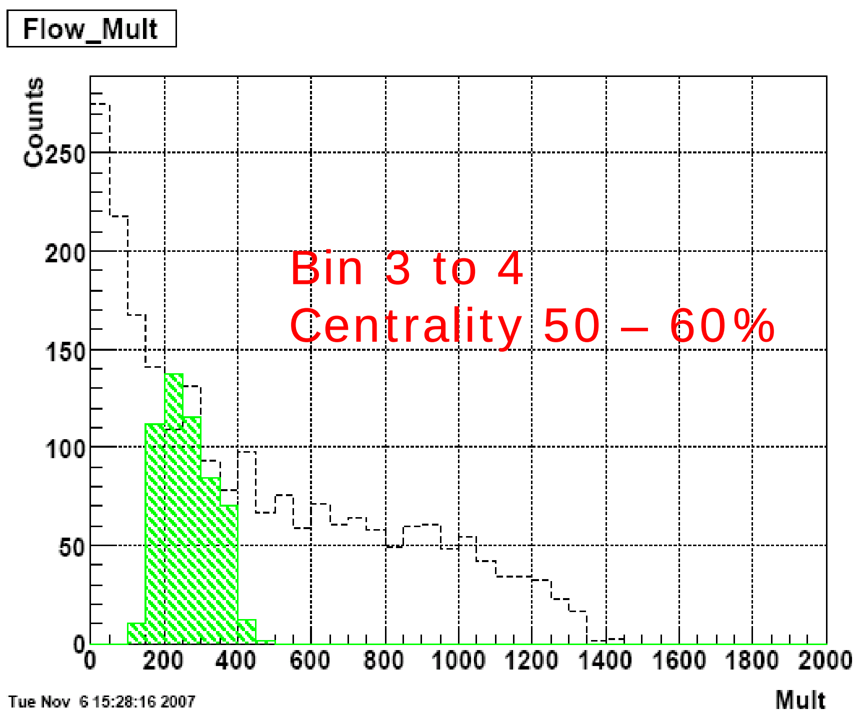
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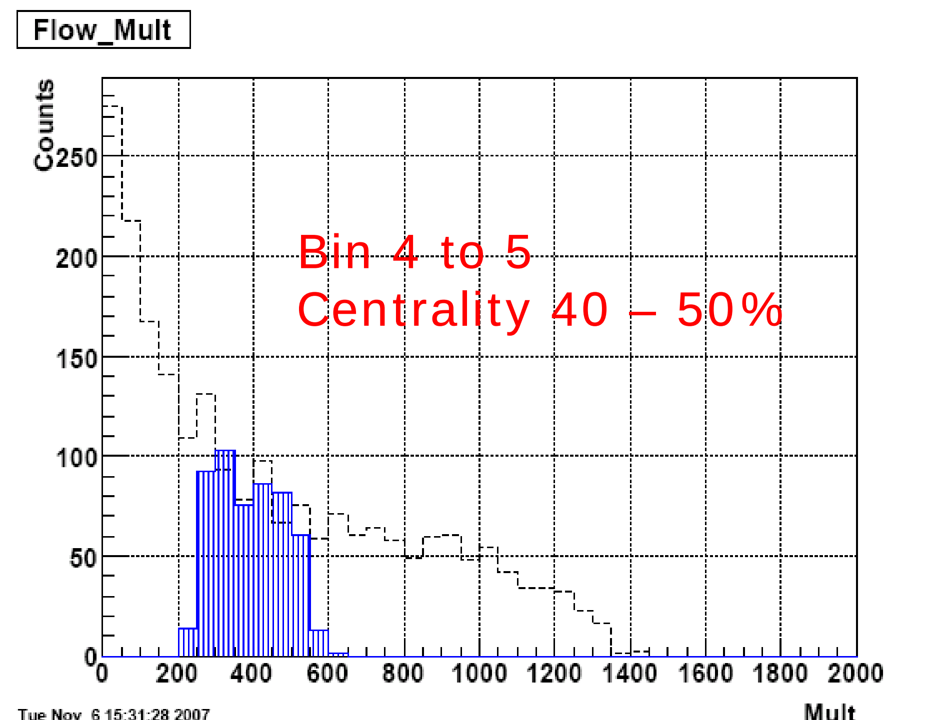
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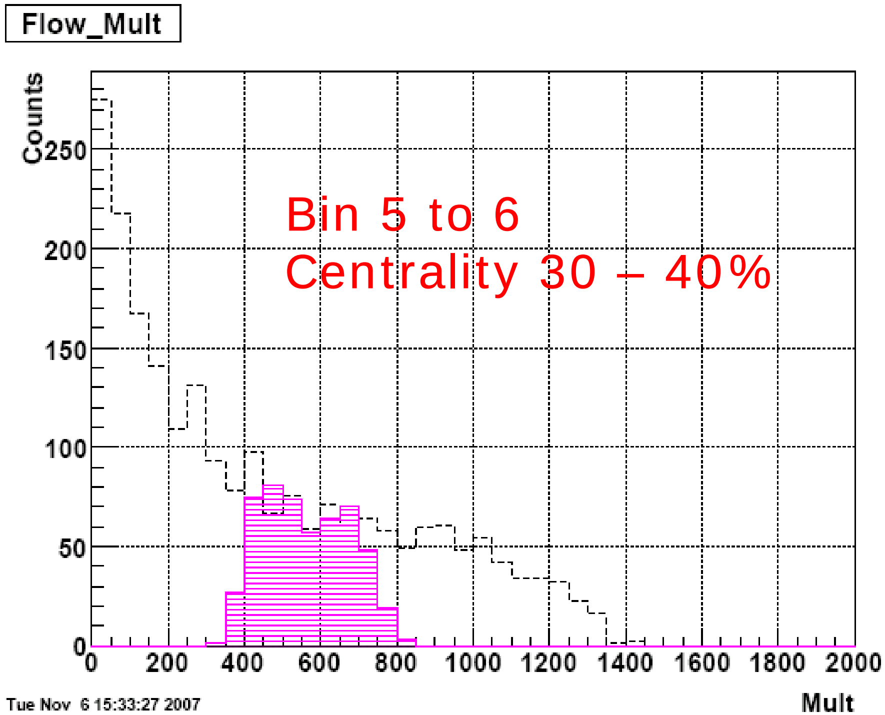
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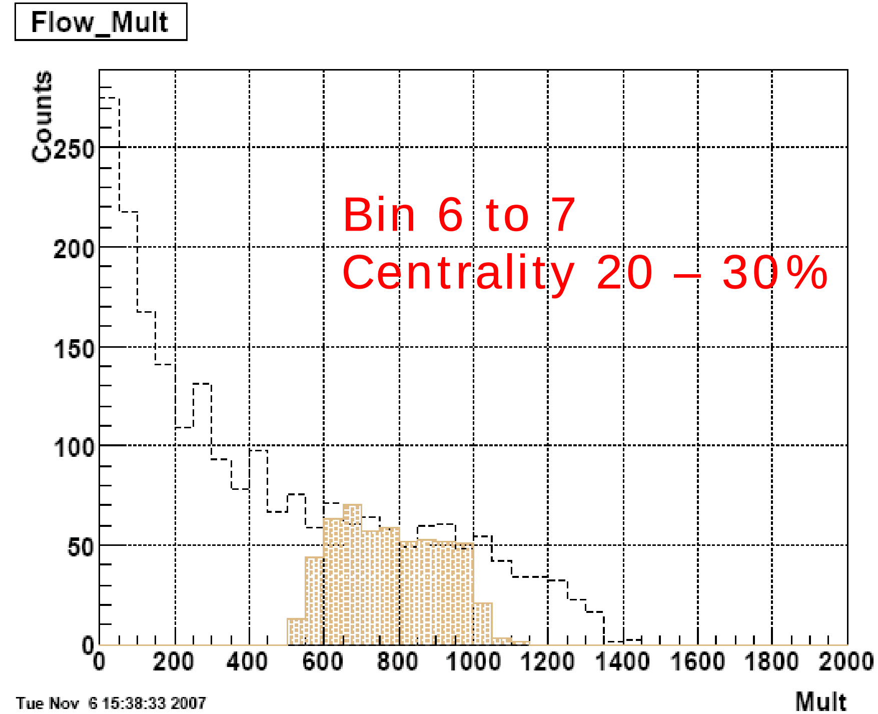
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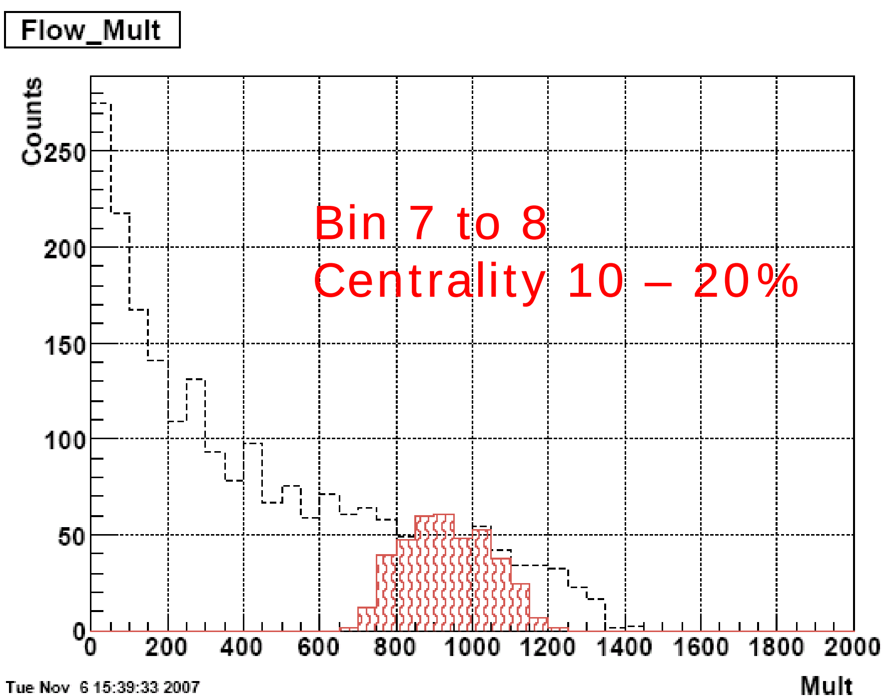
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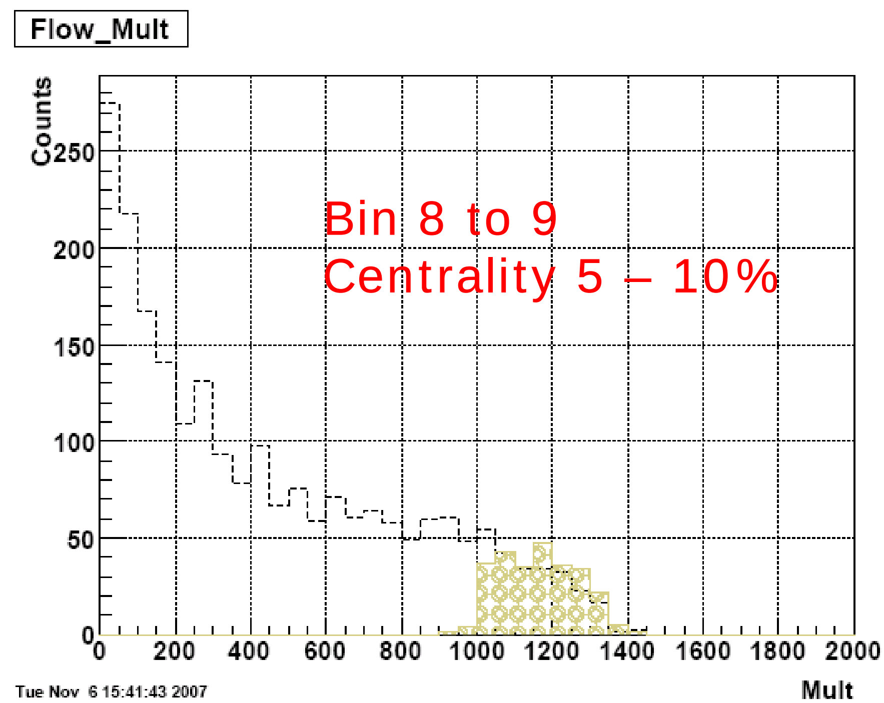
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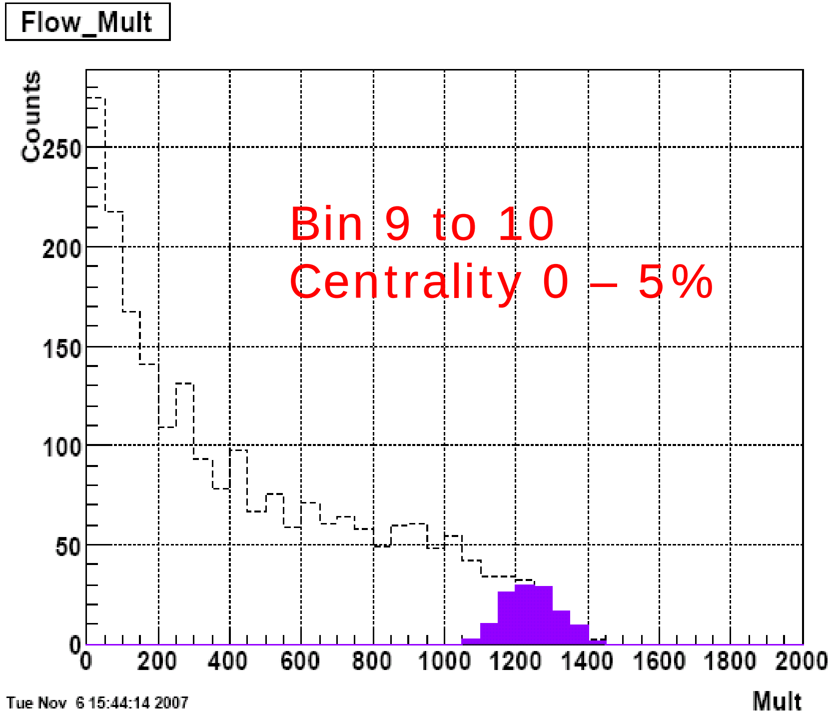
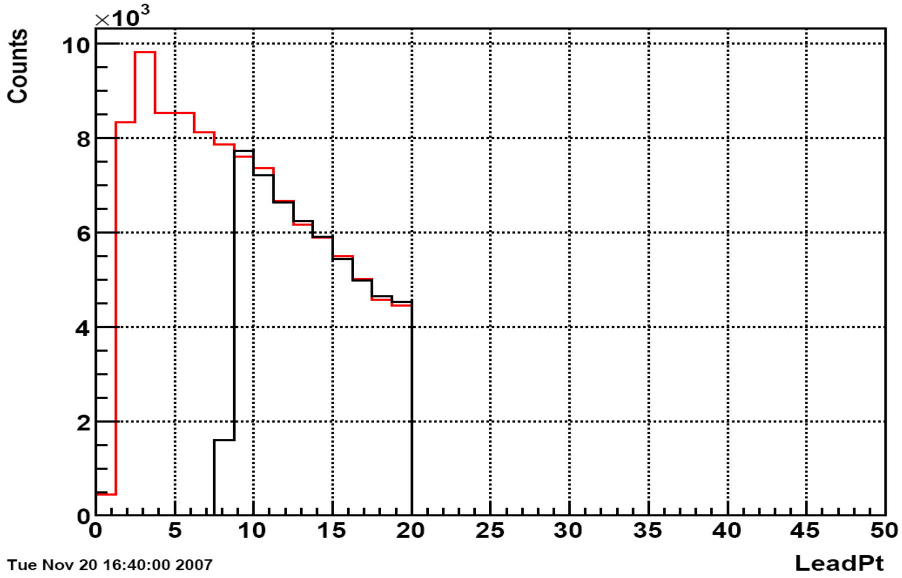
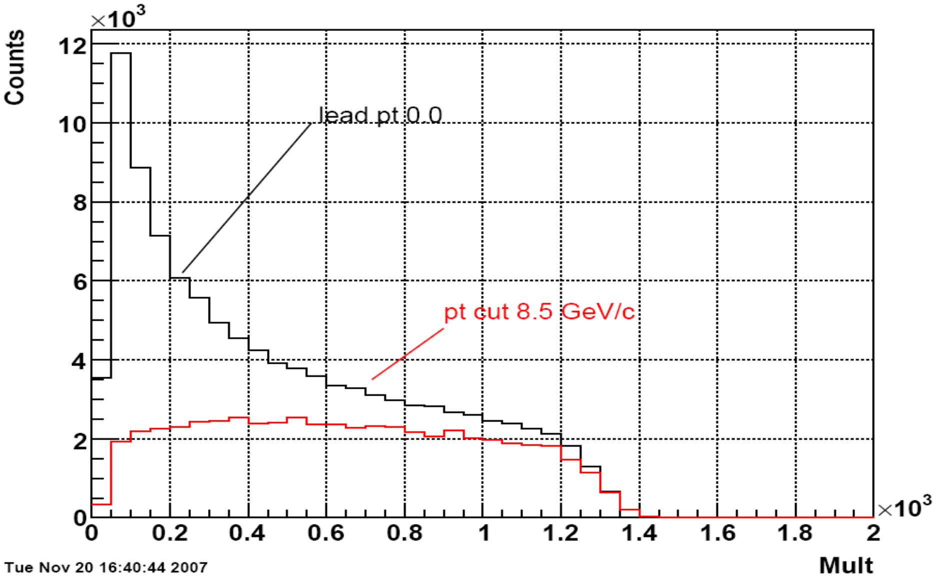
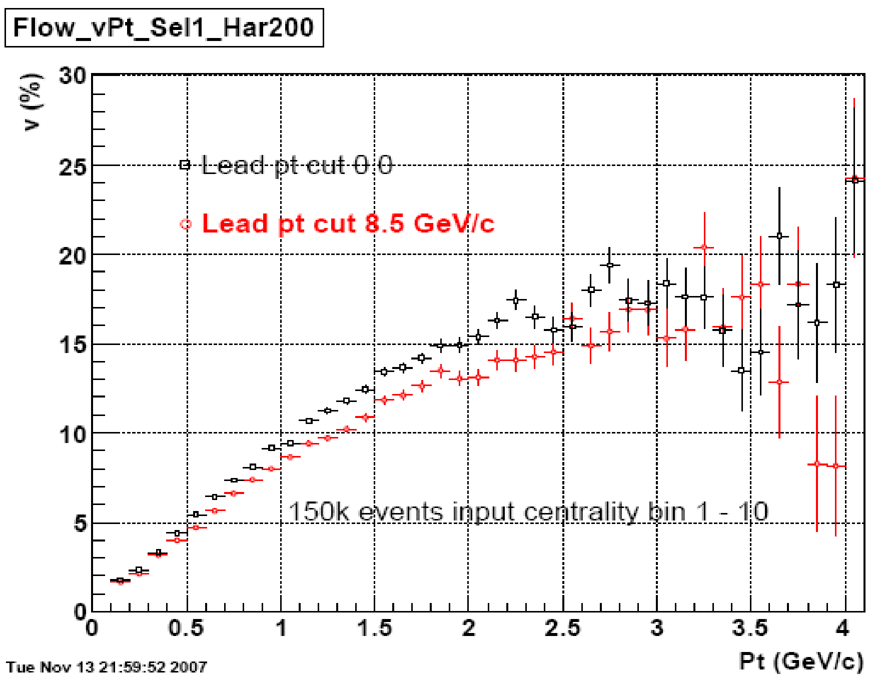


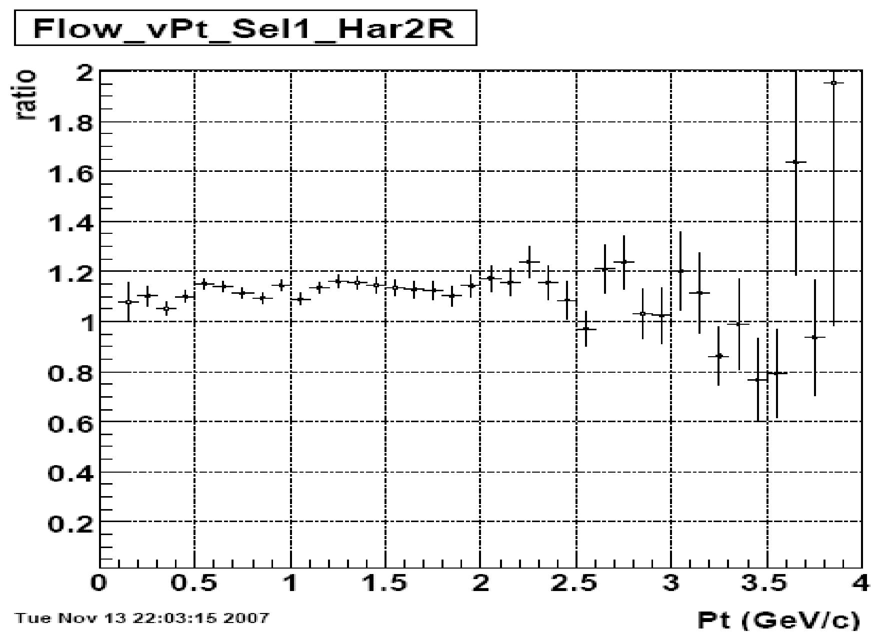
- It is not recommended by the spectra group to work with the 20% most peripheral events since the tracking is very inefficient in that region.
- For the rest of the analysis this bin will be excluded

V2: 0 – 80% Centrality Cut









V2: 10 – 80% Centrality Cut