Inclusive distribution of fully reconstructed jets in heavy ion collisions at RHIC: status report

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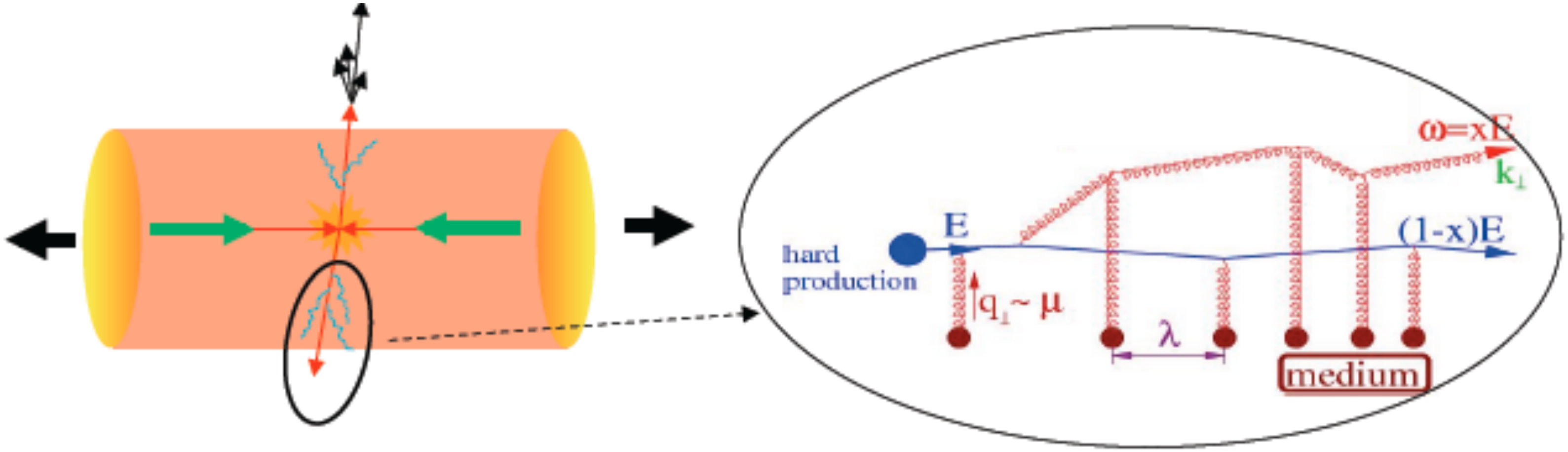
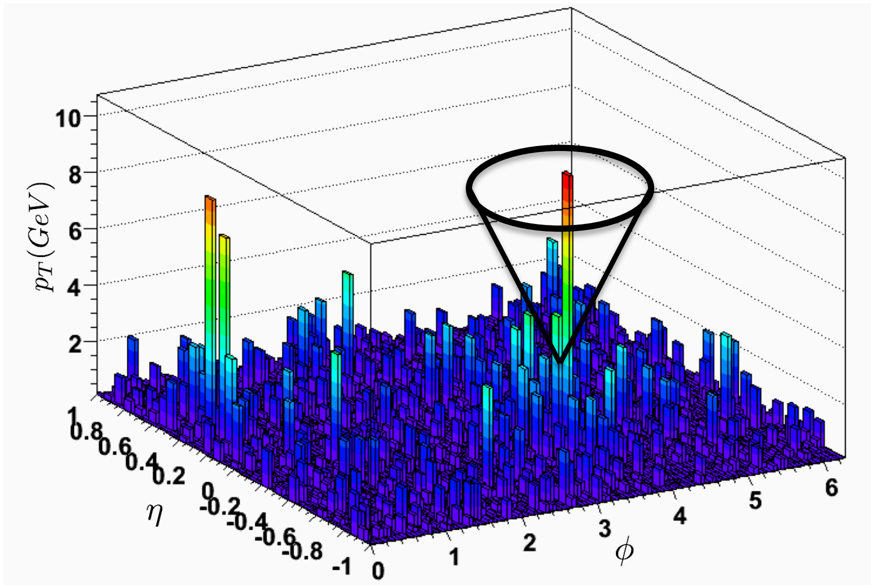
Jet quenching and full jet reconstruction

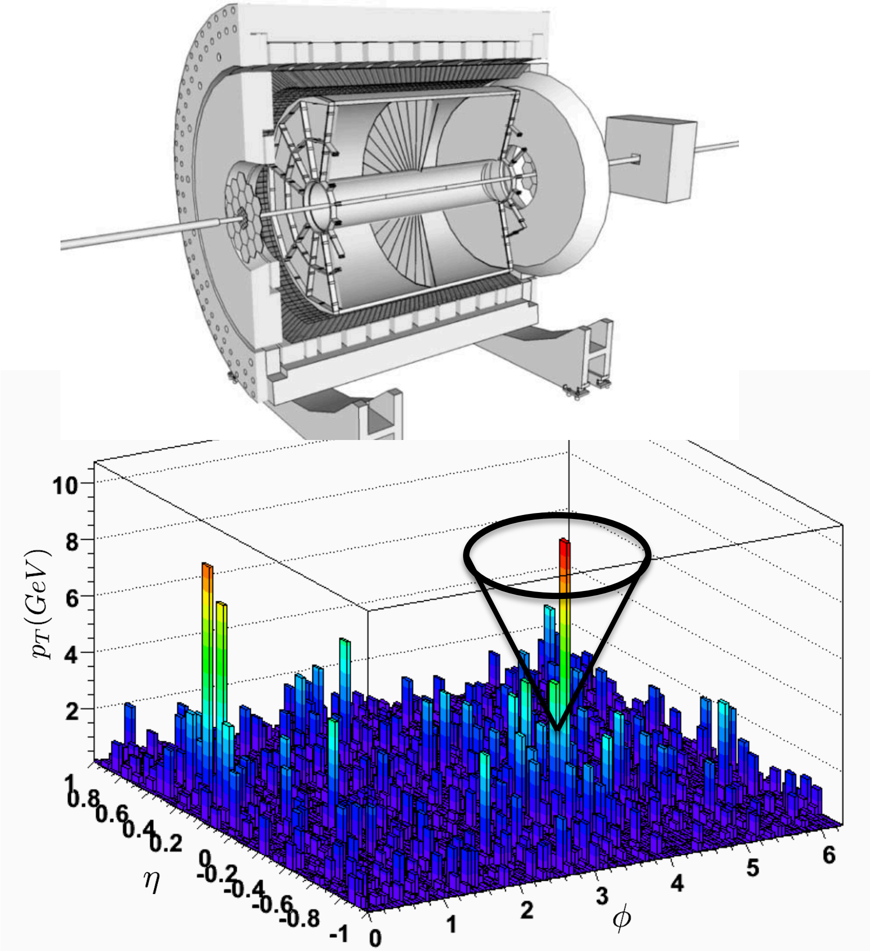
Jet quenching is a **partonic** process:
can we study it at the partonic level?



Jet reconstruction: capture the entire spray of hadrons to reconstruct the kinematics of the parent quark or gluon



Jets Reconstruction in STAR



Jet energy measurement

- Charged particle tracking
- Barrel EM Calorimeter

Jet reconstruction: FASTJET

- Anti-kT algorithm (jet signal)
- kT algorithm (background estimation)
- R = 0.4
- Energy scheme recombination

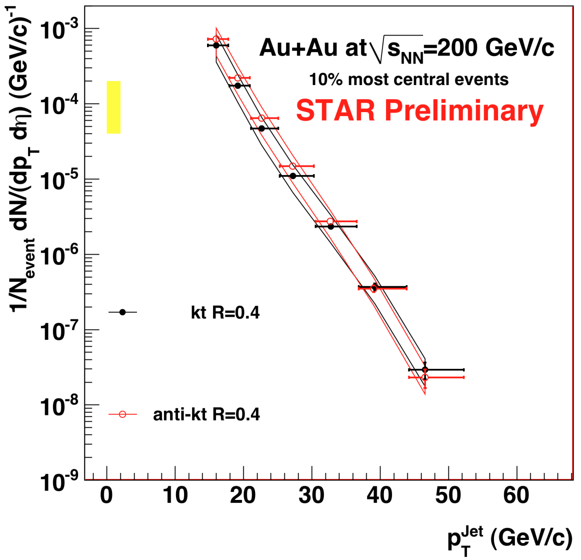
Jet quenching corresponds to softening of the fragmentation

- Cuts on particle p_T suppress background
- But cuts on particle p_T also induce biases in quenched jet population

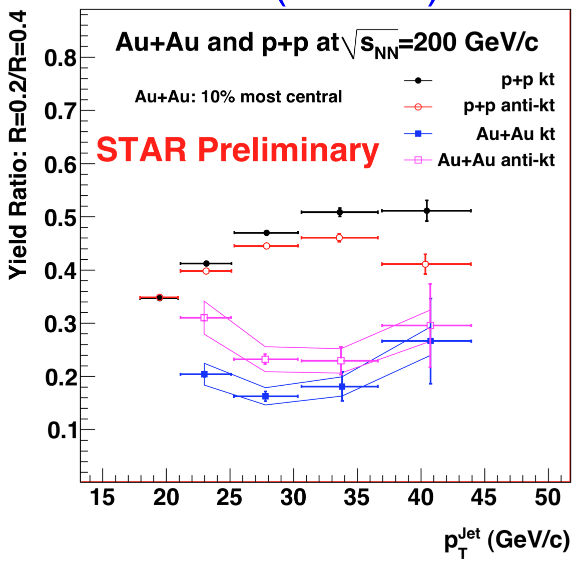
Goal: unbiased reconstruction of quenched jets ➔minimum possible cuts (p_T>200 MeV)
Large backgrounds ➔ very challenging measurement

Inclusive jet production: previous heavy ion results

Inclusive Cross Section



Ratio (0.2/0.4)



Nucl.Phys.A830:255c-258c,2009

Compare inclusive production for R=0.2 and R=0.4 in p+p and Au+Au

- Evidence for jet broadening due to quenching

Analysis based on

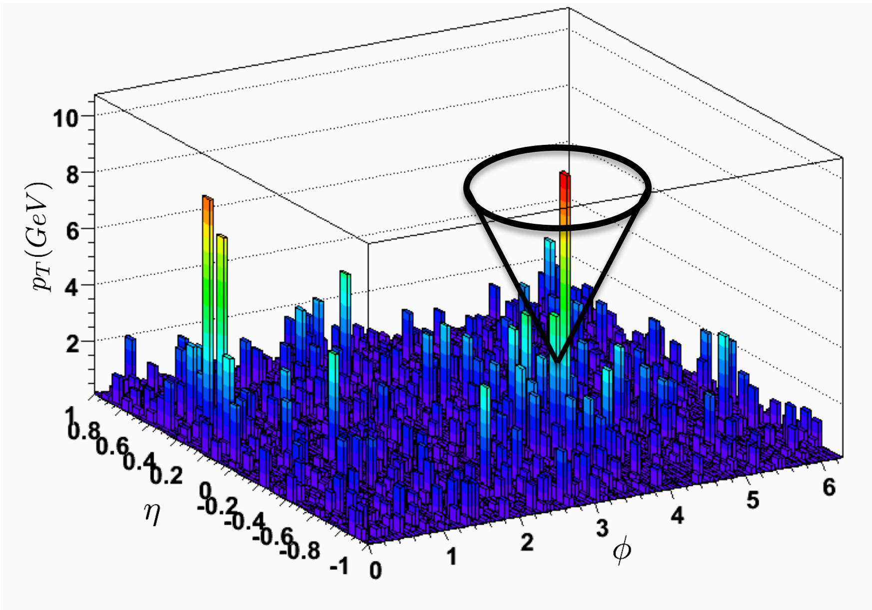
- PYTHIA embedded in real events
- Background via randomized events
- Thresholds imposed on reconstructed jet energy

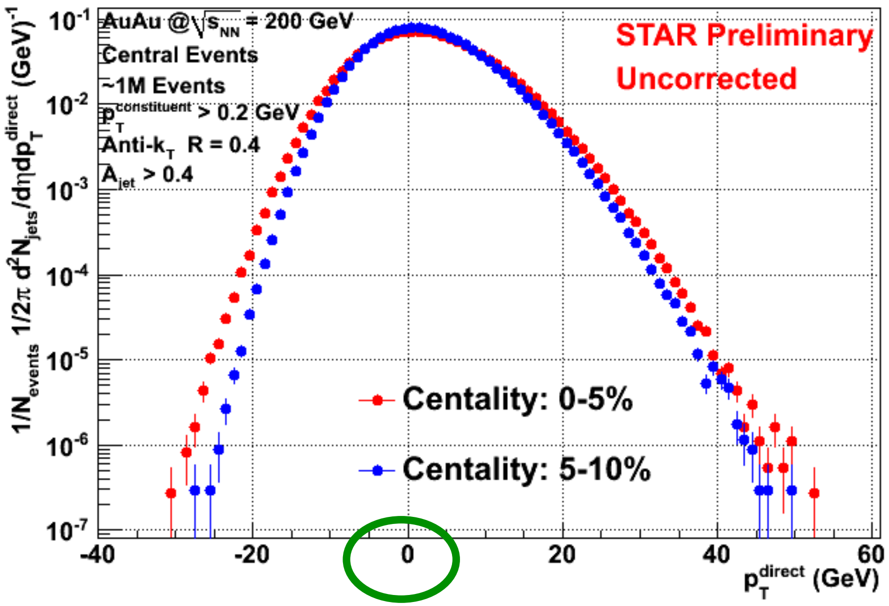
We have been seeking fully data-driven and model-free corrections to assess the systematic uncertainties

- This talk reports further progress in that direction

Directly measured jet spectrum

Jet defined operationally: output of algorithm (need not be interpretable perturbatively)





FastJet: collect all jets in acceptance i=1,…,N

Event-wise estimate of background density:

$$\rho = \text{median}\left\{\frac{p_T^{\text{jet, i}}}{A_{\text{jet, i}}}\right\}$$

$$\boxed{p_T^{\text{direct}} = p_T^{\text{reco}} - \rho \cdot A_{\text{reco jet}}}$$

Hard jets bias towards $p_T^{direct}>0$

"Combinatorial jets": soft background

- Local fluctuations relative to event-wise density estimate ρ
- ~50% of population are "negative energy jets"

➔carry vital information about fluctuation structure of events!

Cutting away soft jets via threshold on p_T^{direct} introduces complex biases, not well-justified

Anti-k_T response: sensitivity to fragmentation

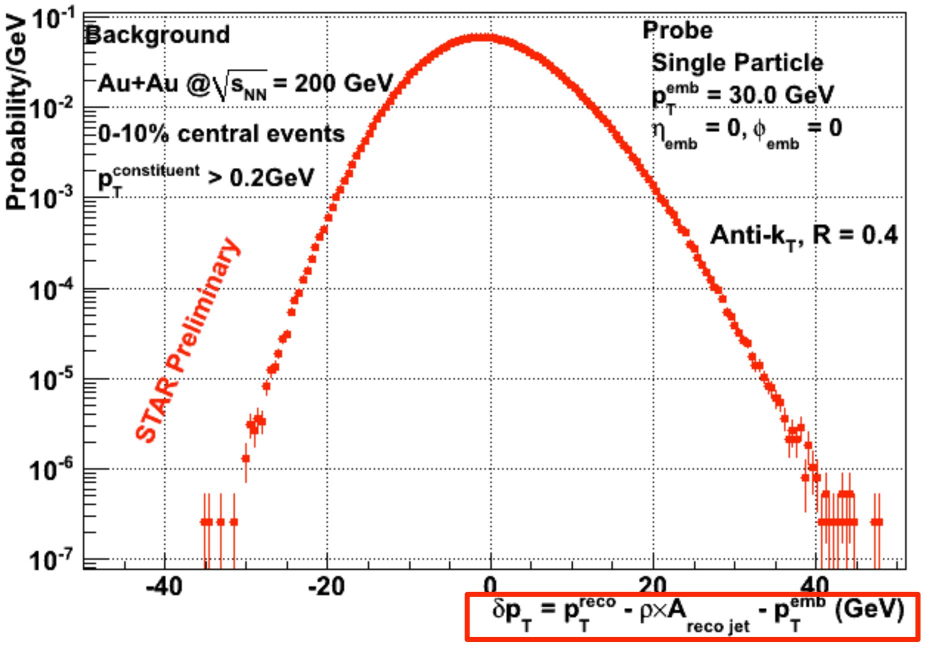
- Embed object of known p_T
- Reconstruct event
- Match jet containing embedded object and remove its p_T

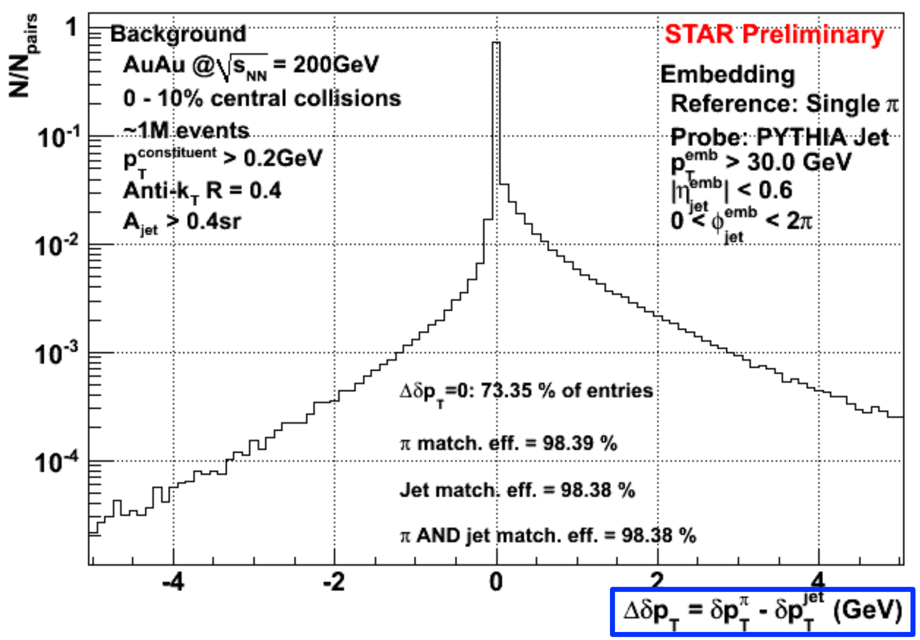
Resolution function: $$\delta p_T = p_T^{\mathrm{reco}} - \rho \cdot A_{\mathrm{reco\ jet}} - p_T^{\mathrm{emb}}$$

Embed single p_T=30 GeV pion
in to 8M central STAR events

Event-wise comparison:
PYTHIA jet pT>30 GeV
Single pion with same p_T, η, ϕ
➔Calculate event-wise

$$\Delta\delta p_T = \delta p_T^{\pi} - \delta p_T^{\mathrm{jet}}$$



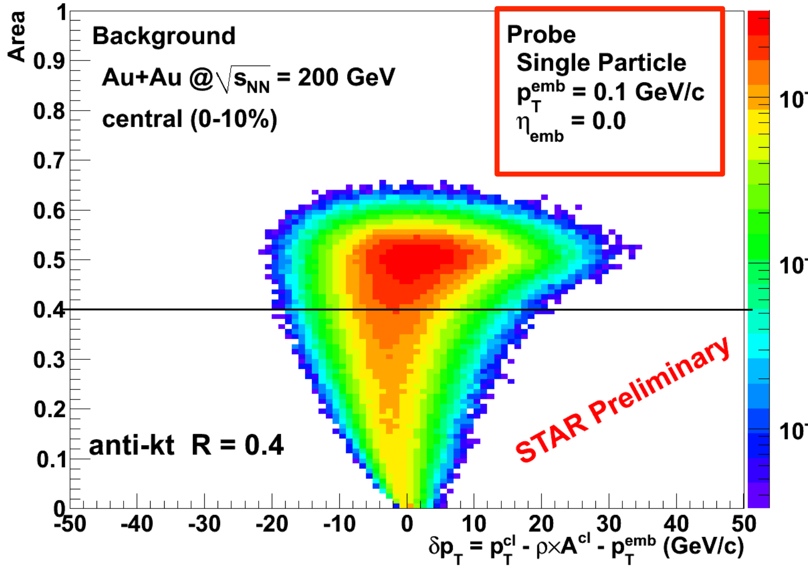


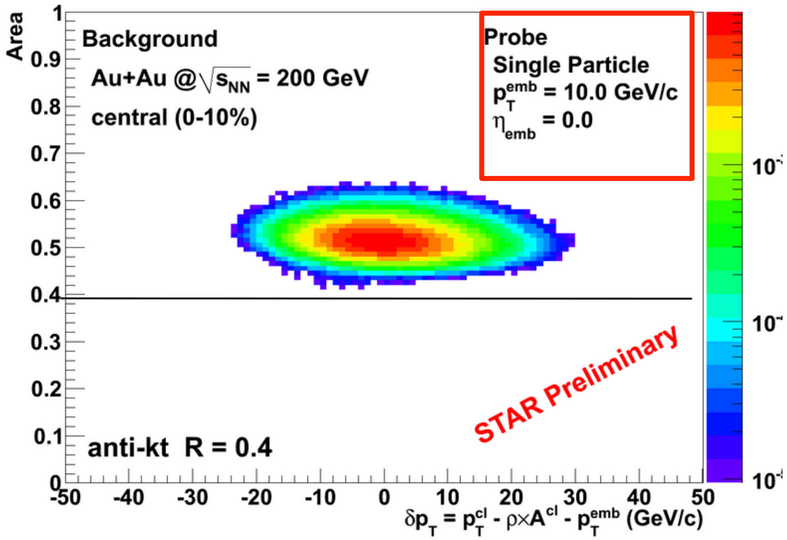
Similar results for wide range of p_T, fragmentation patterns (incl QPYTHIA)
➔anti-k_T response is geometric (acts like rigid cone)

Anti-k_T response: jet area

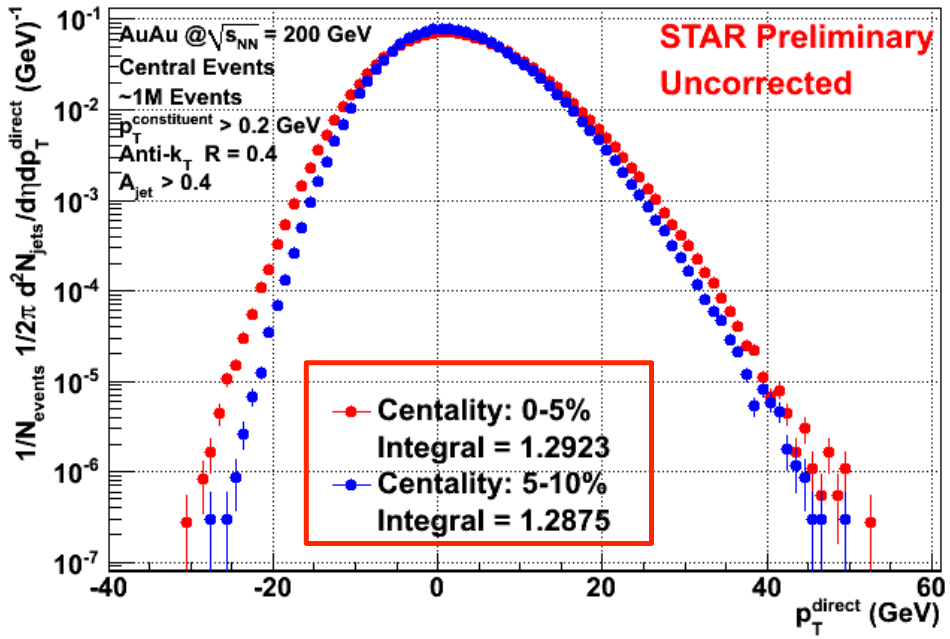
Jet area vs δp_T for different embedded p_T

➔A>0.4: Unbiased for hard embedded jets





Direct jet spectrum (A>0.4) for different event centralities



- Average charged part. multiplicity changes by ~12%
- Jet multiplicity consistent within ~0.3%

Density of jets (A>0.4) is invariant with multiplicity
➔anti-k_T response is geometric (acts like rigid cone)

Inclusive jet distribution: analysis strategy

Goal: measure hard jet distribution in heavy ion collisions

Elementary collisions (e^+e^-, pp):

- Modest underlying event
- Hard production (large Q^2) strongly correlated with large measured jet p_T

Heavy ions:

- Huge underlying event
- Hard production (large Q^2) poorly correlated with large measured jet p_T

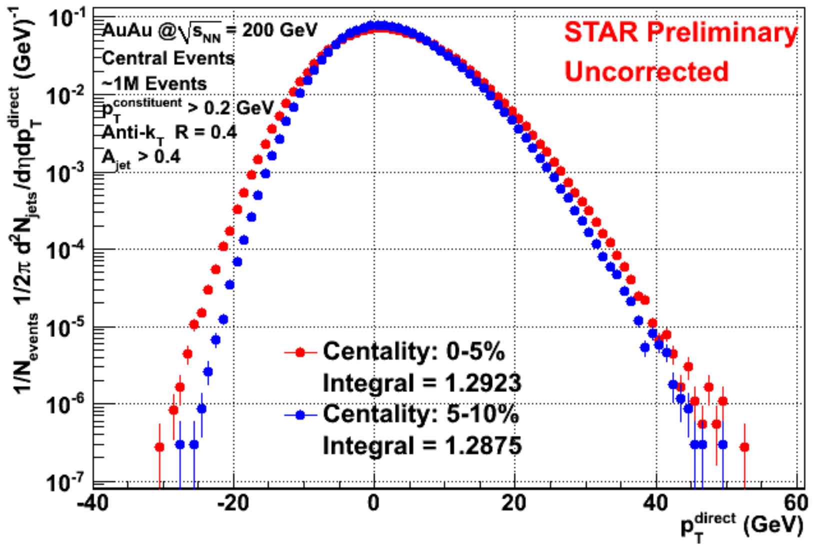
→ Thresholds on p_T^{direct} induce complex biases that are difficult to disentangle
→ Need a different approach

Utilize measured anti-kT property:
Acts like rigid cone: jet multiplicity is invariant with particle multiplicity

Utilize heavy ion phenomenology + Glauber theory:

- Production rate of hard processes scales as equivalent number of binary collisions
  Nbin(0-5%) ~ 1050
  Nbin(5-10%) ~ 850

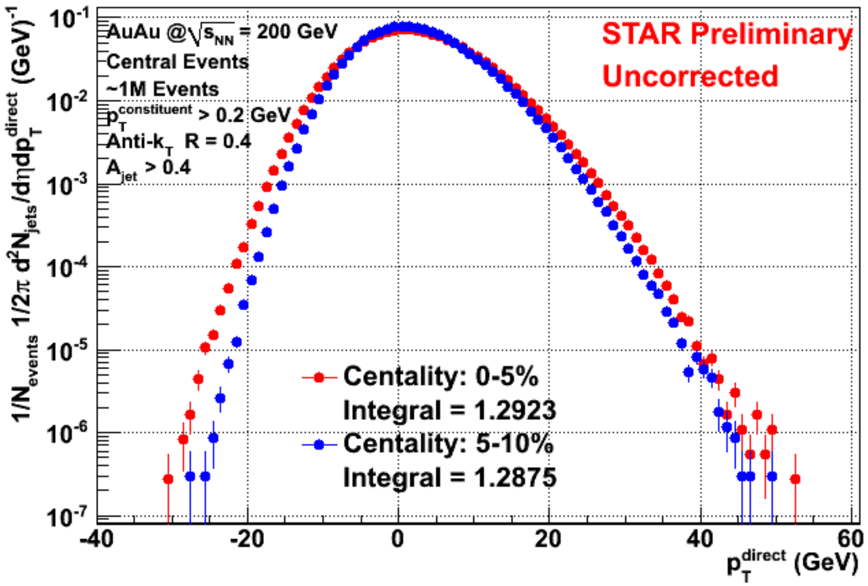
highly correlated uncertainties



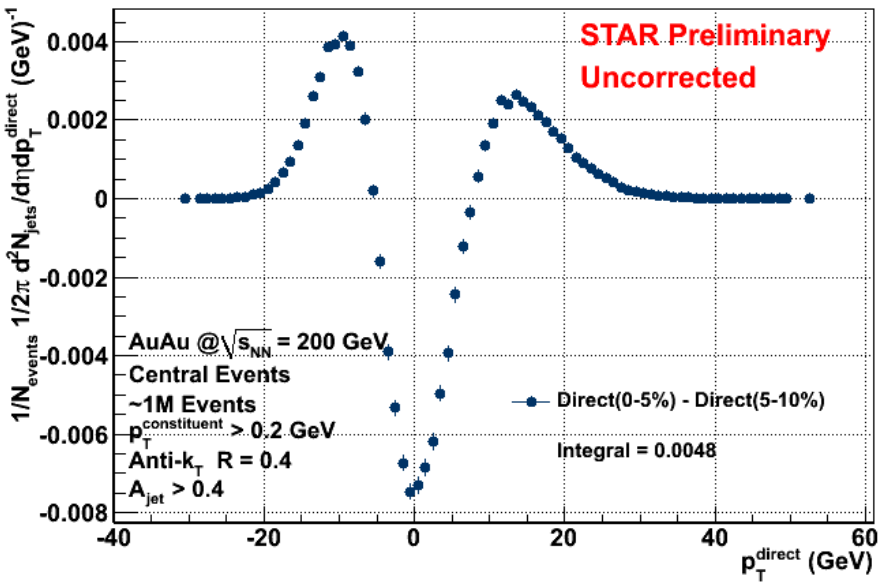
Hard jet signal lies in redistribution of p_T^{direct} with change in centrality!

Evolution of Direct jet spectrum with centrality

Direct spectra



Difference of Direct spectra



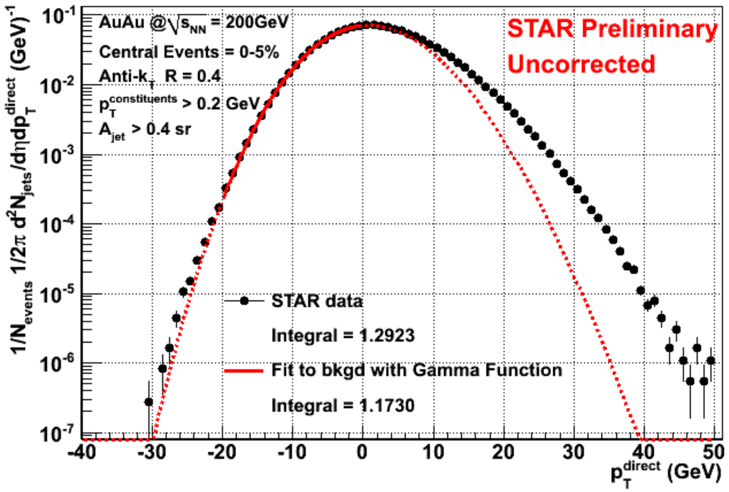
Difference between centrality bins: 200 binary collisions with additional underlying event

Qualitative features of difference spectrum are as expected:

- Jet number is conserved ➔ p_T^{direct} redistributed
- p_T^{direct}<0: incremental underlying event
- p_T^{direct}>0: incremental underlying event plus hard jets

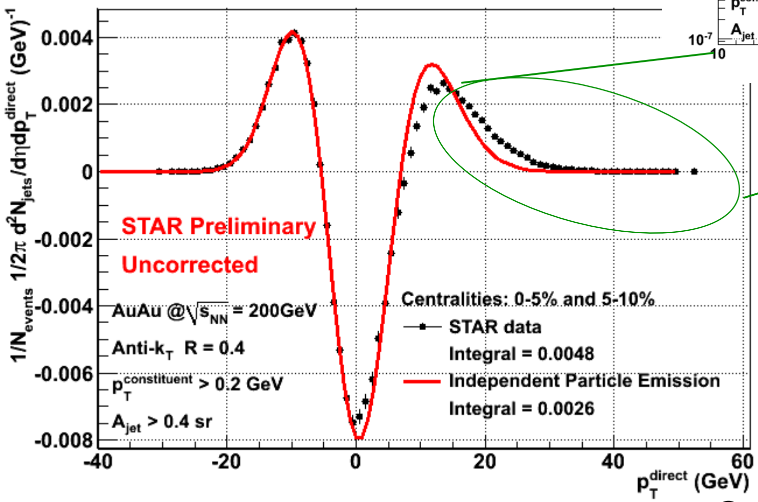
Still need to model additional underlying event, but relative contribution is strongly reduced

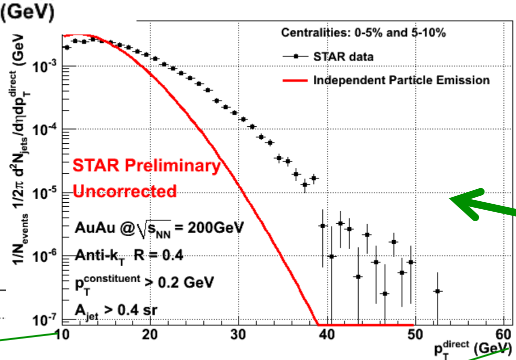
Background estimate I: statistical model



- Gamma Function: E_T distribution in finite acceptance for n independent particles from exponentially distributed source (M. Tannenbaum, Phys. Lett. B 498 (2001) 29–34)
- Fit to $p_T^{direct} < 0$ (background-dominated)
- Extrapolation to $p_T^{direct} > 0$
  - good description over 3 orders of magnitude.

Difference of direct spectra (0-5% - 5-10%)

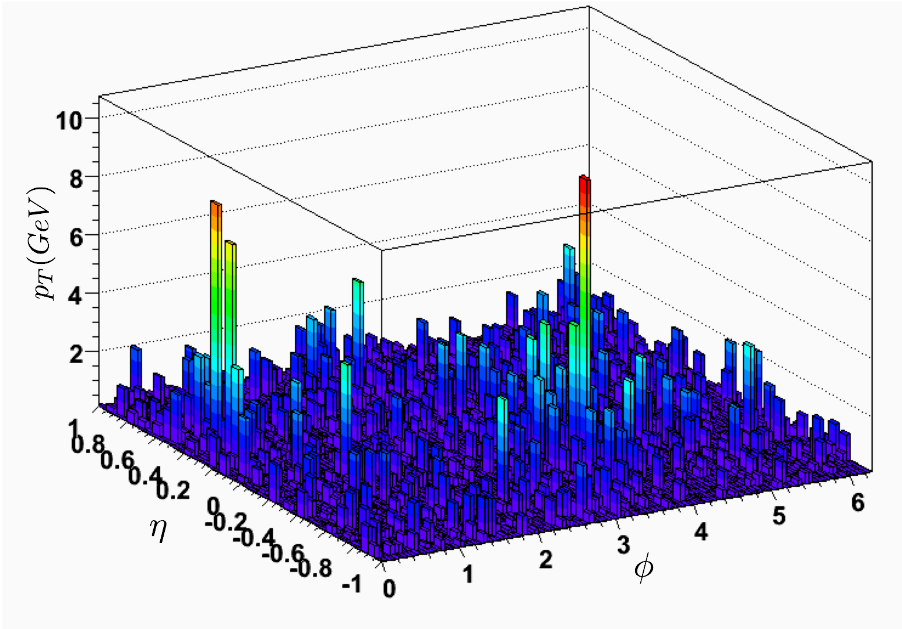


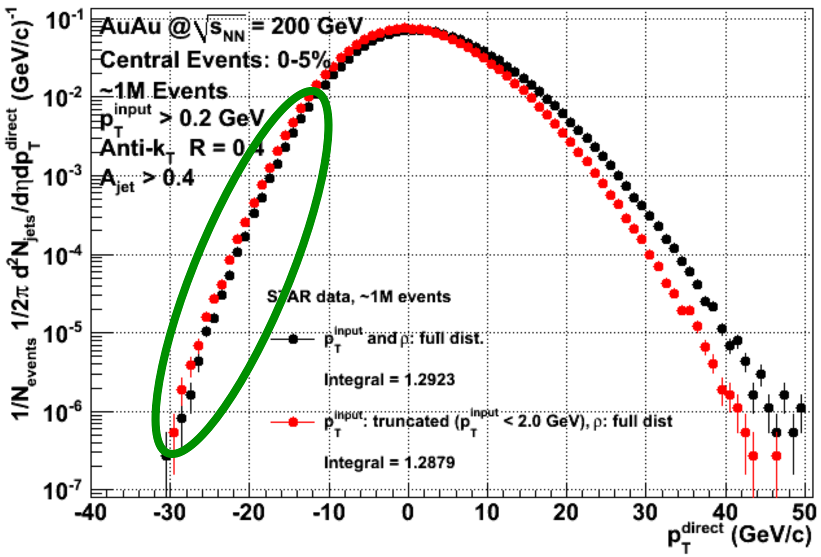


- Difference of fit fns:
  - Background model undershoots data where hard jets expected to dominate, i.e. difference of spectra is more than just difference in underlying event – good
  - Background model exceeds data at moderate p_T^{direct}>0
    ➔as expected: hard jets displace soft jets + total jet number conserved

Qualitatively: model OK
To do: explore systematics

Background estimate II: data-driven





Classify Direct jet population:

Background jet: all constituents (tracks and calorimeter towers) have p_T<2 .0 GeV/c

Signal jet: everything else

In other words: signal jets are those with at least one constituent having p_T>2.0 GeV/c

➔mild bias on quenched jets (can still be dominated by softer constituents)
➔vary p_T cut to explore systematics

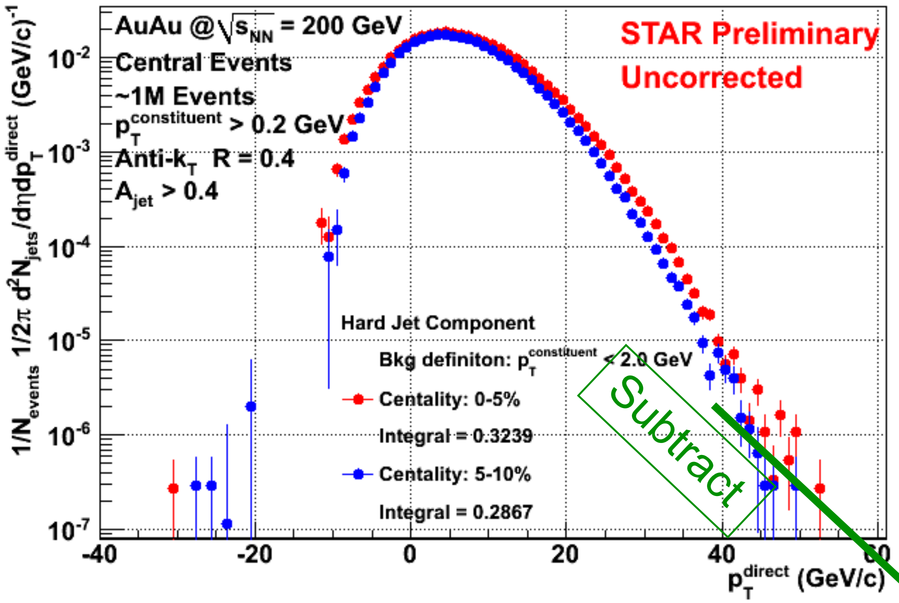
Compare:

- full Direct spectrum
- "Background-only" event ($p_T^{constituent}$<2GeV)

LHS (p_T^{direct}<0): should be dominated by backgd

- shape of distributions identical over 3 decades
- small shift in normalization
  ➔conservation of jet number in acceptance

Data-driven background: hard jet distribution



"Hard jet" definition: at least one constituent with pT>2.0 GeV/c

Expect mild bias on fragmentation:

- Simulations in progress to assess bias in p+p
- Bias will be less for quenched jets

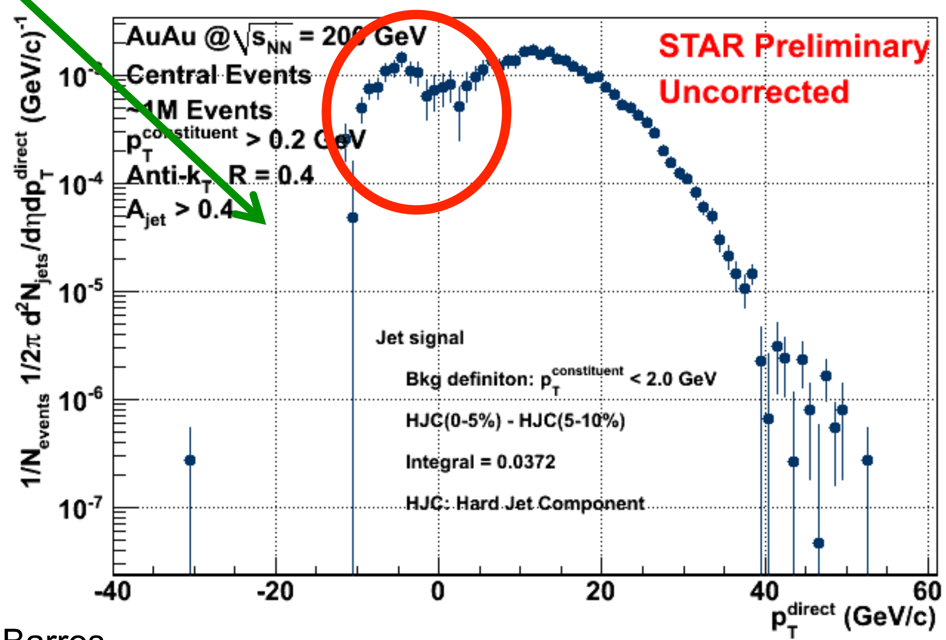
Effects of residual soft background and jet number conservation

Compare centralities

- 0-5%
- 5-10%

Difference is due to

- Addition of ~200 binary collisions
- Additional soft background



Summary and Outlook

Inclusive jet distribution in heavy ion collisions: challenging measurement

- Jet quenching: need unbiased analysis methods
  - ➔minimize cuts on jet constituents
- Large underlying event
  - ➔ spectrum of “negative energy jets” measures structure of fluctuations

Anti-k_T: measured properties in presence of background

- behaves like rigid cone (A > 0.4)
- jet multiplicity is independent of particle multiplicity

Opportunity for new approach to extract hard jet component:

- compare centralities ➔add known number of binary collisions
- Jet signal lies in redistribution of jet energy distribution

Background estimation (combinatorial jets):

- Statistical model
- Data driven ($p_T^{constituent} <$ ~1-2 GeV)

To do: systematic exploration of background estimates

Promising approach to fully data-driven inclusive jet measurement over large kinematic range

Backup slides

Anti-k_T response: sensitivity to fragmentation

Resolution function: $\delta p_T = p_T^{\text{reco}} - \rho \cdot A_{\text{reco jet}} - p_T^{\text{emb}}$