Reconstructed Jet Results
in p+p, d+Au and Cu+Cu collisions
at 200 GeV from PHENIX

Dennis V. Perepelitsa
Columbia University
for the PHENIX Collaboration

28th Winter Workshop on Nuclear Dynamics
Dorado del Mar, Puerto Rico

8 April 2012

PH☆ENIX

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

D.V. Perepelitsa

Introduction

Jets in PHENIX
Gaussian Filter
Analysis Techniques

p+p
Fragmentation

d+Au
k_T Broadening

Cu+Cu
$\Delta\phi$ broadening

Outlook
Jets at RHIC

Acknowledgements

Jets in Heavy Ion Collisions

PHENIX
Jet Results
(2/ 22)

D.V. Perepelitsa

Introduction
Jets in PHENIX
Gaussian Filter
Analysis Techniques

p+p
Fragmentation

d+Au
k_T Broadening

Cu+Cu
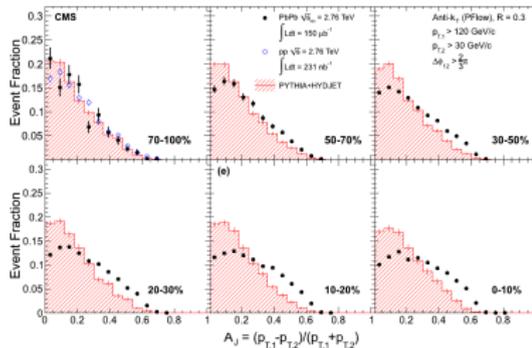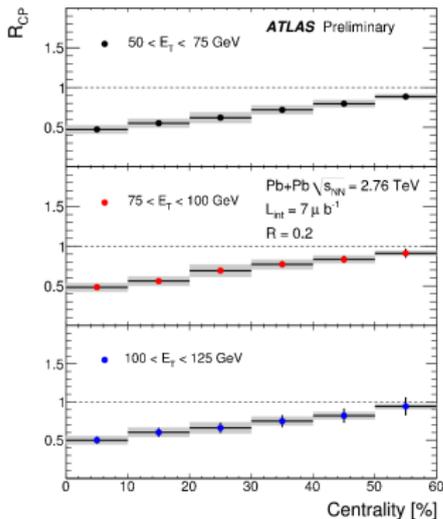$\Delta\phi$ broadening

Outlook
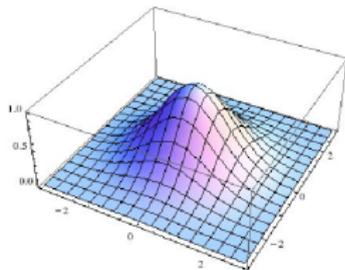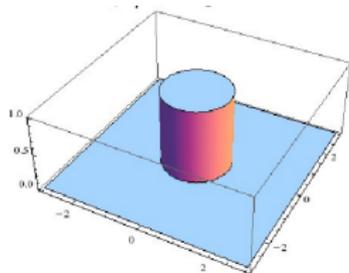Jets at RHIC

Acknowledgements

- ▶ Jet reconstruction is being done in heavy ion collisions at RHIC and the LHC:

  - ▶ Reconstruct full fragmenting parton kinematics at LO.
  - ▶ Sensitive probe of suppression/quenching effects.

Why Jets at RHIC?

D.V. Perepelitsa

▶ Complementary set of measurements from two high statistics colliders!

▶ Can measure jet modification at:

  ▶ lower energies due to smaller underlying event

  ▶ different x and Q^2 (different mixture of quark and gluon jets)

▶ Versatility of collision species provides:

  ▶ ability to vary system size, energy density, geometry

  ▶ control against cold nuclear matter effects

$\Rightarrow$ $Cu+Au$, $U+U$ collisions in the next 1-2 months!

PHENIX detector

▶ Drift Chamber (DC), Pad Chambers (PC) and Ring Imaging Čerenkov Detector (RICH) measure charged hadrons and electrons

▶ Electromagnetic Calorimeter (EMCal) clusters photons, π^0's, (some) neutral hadrons

▶ EMCal/RICH Trigger (ERT) and the high PHENIX DAQ rate allow complementary Minimum Bias and high-p_{T} triggered datasets

Gaussian Filter algorithm

1. Seedless, cone-like algorithm with a Gaussian angular weighting
   (nucl-ex/0806.1499)

$$p_{\mathrm{T}}^{\mathrm{jet}} \equiv \max \left\{ \int \int d\eta' d\phi' \, p_{\mathrm{T}} \left(\eta', \phi'\right) e^{-(\Delta\eta^2 + \Delta\phi^2)/2\sigma^2} \right\}$$

2. Focuses on the energetic core of the jet, optimizing S/B

3. Stabilizes the jet axis in the presence of background

Fake jet rejection
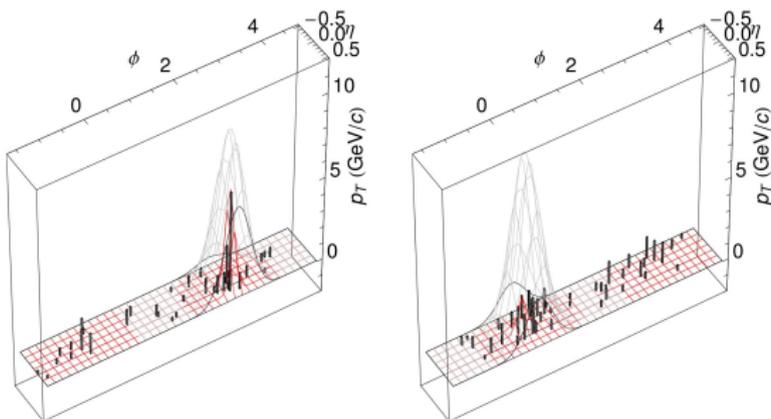
9.6 GeV/c jet passing fake rejection   Rejected 10.8 GeV/c background fluctuation

▶ Technique to separate low-$p_{\rm T}$ jets from underlying event fluctuations in HI collisions on a *jet by jet basis*.

▶ g-discriminant (with $\sigma_{\rm dis} <$ typical distance between underlying event particles):

$$g_{\sigma_{\rm dis}}(\eta, \phi) \equiv \sum_{i \in \text{fragment}} (p_T)_i^2 \exp\left(-(\Delta\eta^2 + \Delta\phi^2)/2\sigma_{\rm dis}^2\right)$$

▶ Similar to "angularly-weighted" $p_{\rm T}$ which rewards jets with a tight core of energy and punishes diffuse jets.
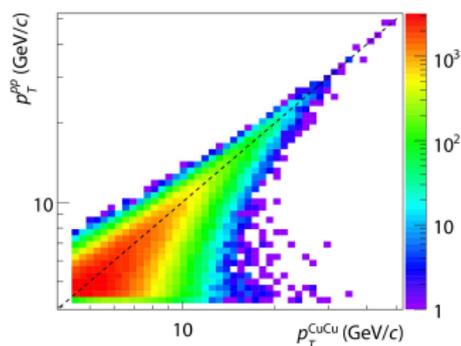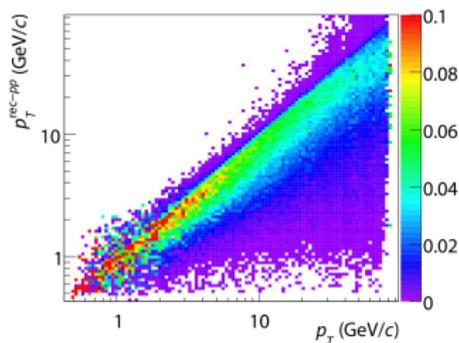
Fake jet rejection

$$g_{\sigma_{\rm dis}}(\eta, \phi) \equiv \sum_{i \in \text{fragment}} (p_T)_i^2 \exp\left(-(\Delta\eta^2 + \Delta\phi^2)/2\sigma_{\rm dis}^2\right)$$

▶ Require $g_{\sigma_{\rm dis}} > g_{\rm min}$:

   ⇒ efficient saturation with reconstructed $p_{\rm T}$

   ⇒ trade reconstruction efficiency for sample purity

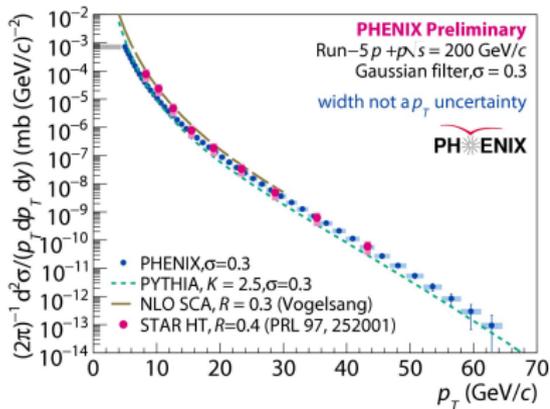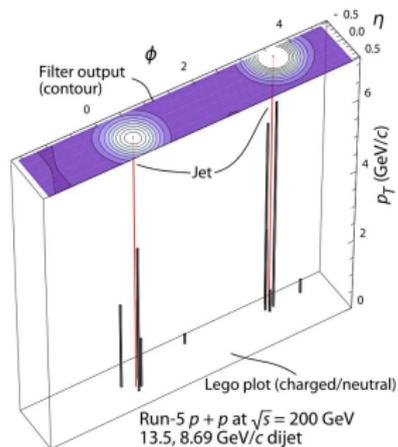▶ Data-driven approaches used to set fake jet rejection threshold $g_{\rm min}$.

D.V. Perepelitsa
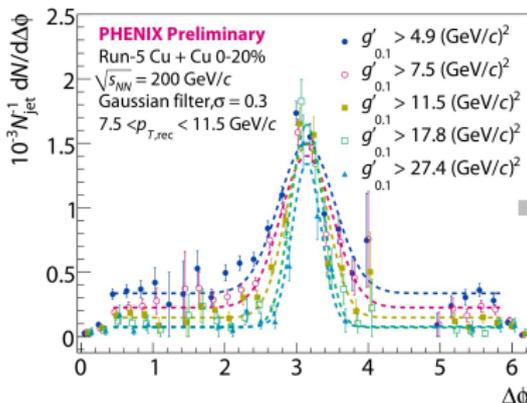
Energy Scale

▶ In PHENIX, energy "resolution" driven by tracking inefficiency, loss of n, K_L^0 neutral energy, edge of acceptance effects.

▶ PYTHIA Tune A $2 \to 2$ QCD events from $Q^2 = 0.5$ to 64 GeV.

  $\Rightarrow$ Cross-checks with HERWIG, other PYTHIA tunes

  $\Rightarrow$ Embedding into real heavy ion background.

▶ NLO calculation + hadronization correction in progress that will allow proper comparison to data.

Jets in $p+p$ at $\sqrt{s} = 200$ GeV

Run-5 $p + p$ at $\sqrt{s} = 200$ GeV
13.5, 8.69 GeV/c dijet

PHENIX Preliminary
Run-5 p +p, $\sqrt{s} = 200$ GeV/c
Gaussian filter, $\sigma = 0.3$
width not a p_T uncertainty

PH✷ENIX

- PHENIX, $\sigma = 0.3$
- PYTHIA, $K = 2.5$, $\sigma = 0.3$
- NLO SCA, $R = 0.3$ (Vogelsang)
- STAR HT, $R = 0.4$ (PRL 97, 252001)

▶ Demonstration of PHENIX jet reconstruction capability.

▶ Comparison with NLO pQCD across ten orders of magnitude.

    ▶ residual differences from jet definition

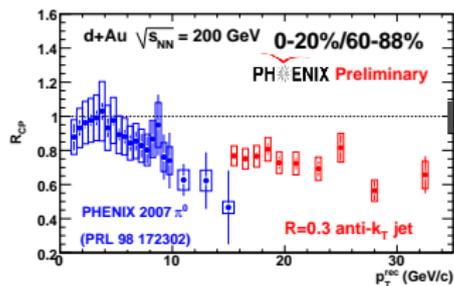▶ Analysis being finalized, moving towards publication.

Jets in $p+p$: Fragmentation Function
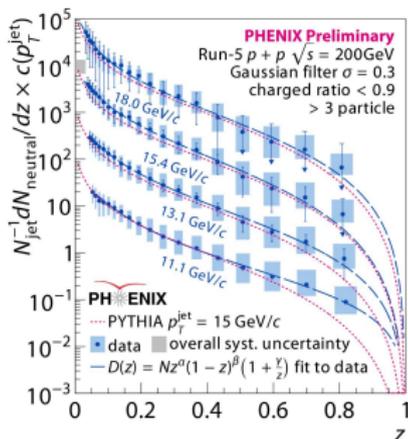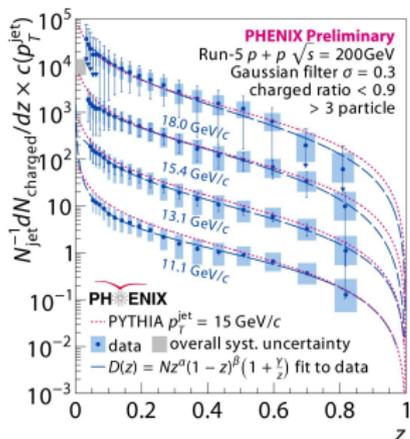
▶ Proof of principle measurement of fragmentation function
  ($z = p_{||}^{\mathrm{particle}}/p^{\mathrm{jet}}$)

▶ n-dimensional generalization to GURU SVD unfolding
  implementation:

$$\left(p_{||}^{\mathrm{particle}}, p_{\mathrm{T}}^{\mathrm{jet}}\right)^{\mathrm{rec}} \rightarrow \left(p_{||}^{\mathrm{particle}}, p_{\mathrm{T}}^{\mathrm{jet}}\right)^{\mathrm{truth}}$$

Jets in $d+Au$ at $\sqrt{s} = 200$ GeV
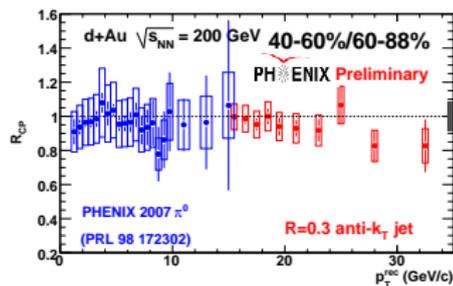
- anti-k_{T} jet reconstruction with $R = 0.3, 0.5$

- Reconstructed jet R_{CP} at the $p+p$ reconstructed scale.

    - p_{T}-feeding from modest underlying event evaualied with embedding procedure and unfolded

- Suppression effect consistent with single-particle π^0 measurement.

    $\Rightarrow$ Cold nuclear matter energy loss?

    $\Rightarrow$ Centrality dependent nPDF modification?

Jets in $d+Au$ at $\sqrt{s} = 200$ GeV
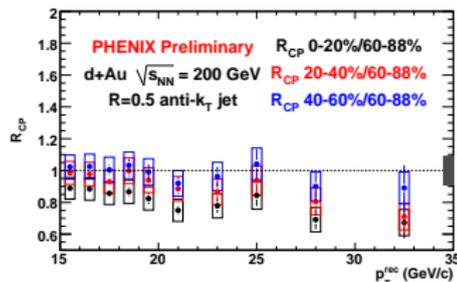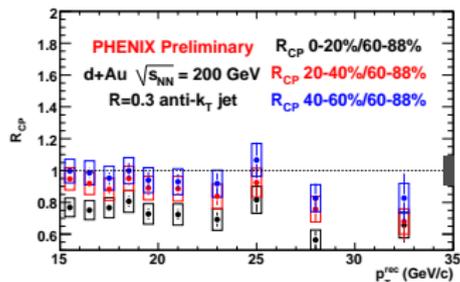
- Systematic change in R_{CP} with centrality selection

- Consistency between cone sizes

- Ongoing improvements to analysis will produce:

    - R_{dA}
    - lower p_{T} behavior
    - results at p_{T}^{truth} scale
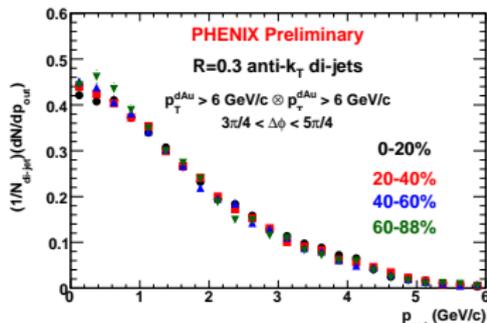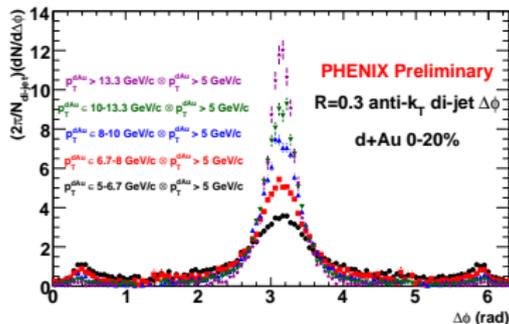
$\Rightarrow$ critical for refining our understanding of $Au+Au$ results!

Jets in $d+Au$: k_T Broadening

▶ Reconstructed di-jets can be used to examine multiple scattering effects in the cold nuclear medium.
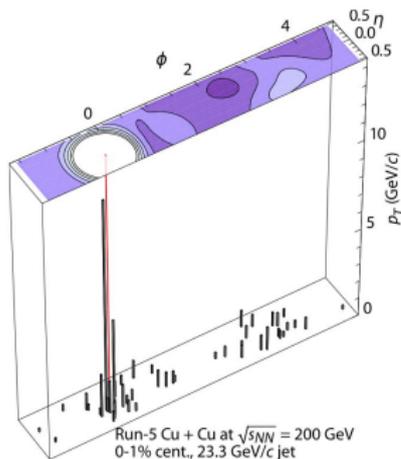
▶ Search for possible broadening by examining:

$$p_{\text{out}} \left(= \langle k_T \rangle \right) \equiv (p_T)_{\text{low}} \cdot \sin \Delta\phi$$

▶ Kinematic requirements on away-side jet removes combinatorial contribution.

⇒ constraint on centrality-dependent broadening.

Jets in $Cu+Cu$ at $\sqrt{s} = 200$ GeV
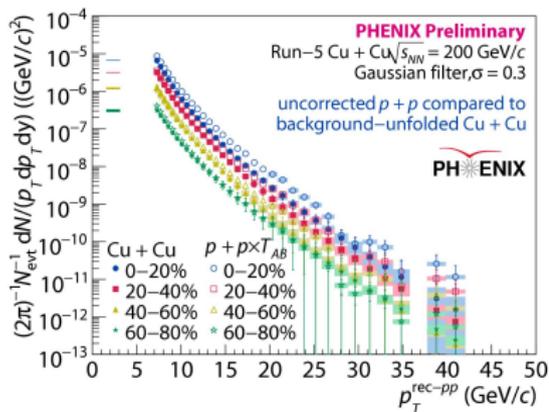
- p_T-feeding from underlying event:
  - subtraction of centrality- and z-vertex parameterized average background

- p_T-smearing from UE fluctuations:
  - evaluated through embedding $p+p$ jets into $Cu+Cu$ minimum bias events
  - results shown here unfolded to $p+p$ reconstructed scale

Jets in $Cu+Cu$ at $\sqrt{s} = 200$ GeV
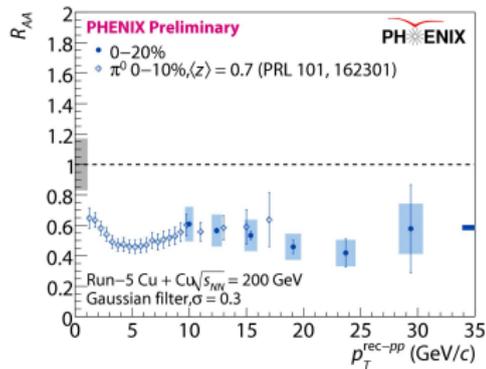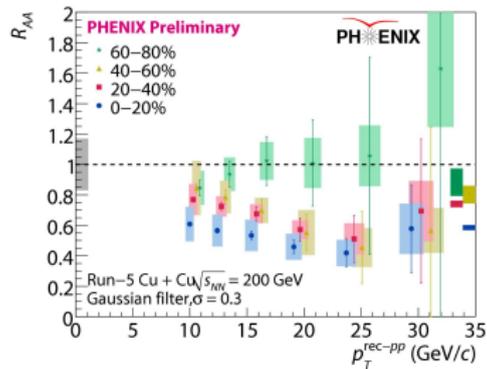
▶ Suppression of reconstructed jet R_{AA}:

⇒ over a wide p_T range

⇒ systematic with centrality

⇒ comparable to single-particle suppression

▶ Potential out-of-cone radiation or other jet modification?

Jets in $Cu+Cu$: $\Delta\phi$ broadening
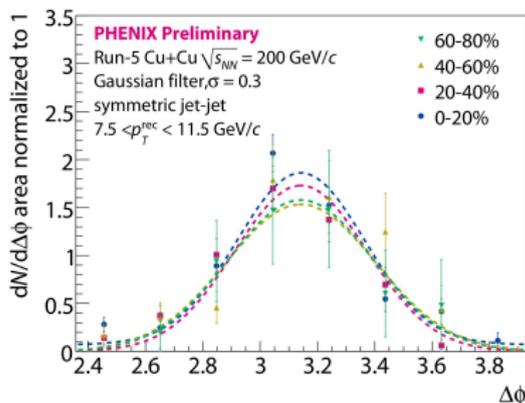
Centrality	$\Delta\varphi \approx \pi$ width σ
0–20%	0.223 ± 0.017
20–40%	0.231 ± 0.016
40–60%	0.260 ± 0.059
60–80%	0.253 ± 0.055

▶ Changes in the width of $\Delta\phi$ distribution would be a possible signal of cold nuclear matter effects.

$\Rightarrow$ No centrality-dependent broadening observed within sensitivity.

Outlook

- Jet reconstruction efforts are ongoing.
  - Current set of measurements being finalized!
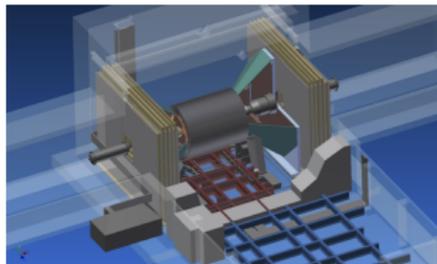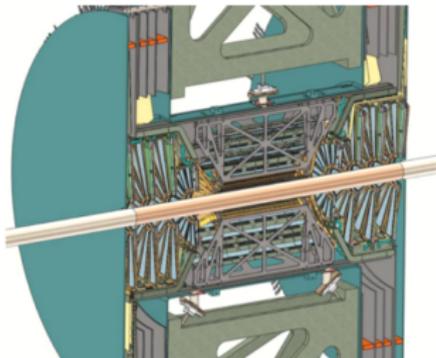
- PHENIX capability for jet measurements improving:
  - VTX (silicon vertex tracker) and FVTX (forward silicon vertex tracker) to provide superior tracking and b/c separation
- "sPHENIX" upgrade plan:
  - dedicated jet detector with acceptance, hermiticity, hadronic calorimetry
  - **see A. Hanks talk, Tuesday 6:30pm**

Jets at RHIC Study

▶ In support of the sPHENIX program:

▶ "Jet - Underlying Event Separation Method for Heavy Ion Collisions at the Relativistic Heavy Ion Collider" (`nucl-ex/1203.1353`)

  ▶ Test ability to associate truth jets with reconstructed jets at RHIC energies.

  ▶ Proof of principle that reconstructed jets produced at RHIC rates can be separated from fake jets.

▶ 0.75×10^9 $Au+Au$ HIJING events at $\sqrt{s_{NN}} = 200$ GeV

▶ $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ segmented "ideal" calorimeter with $\phi \in (0, 2\pi)$, $\eta \in (-1, +1)$

Jets at RHIC Study
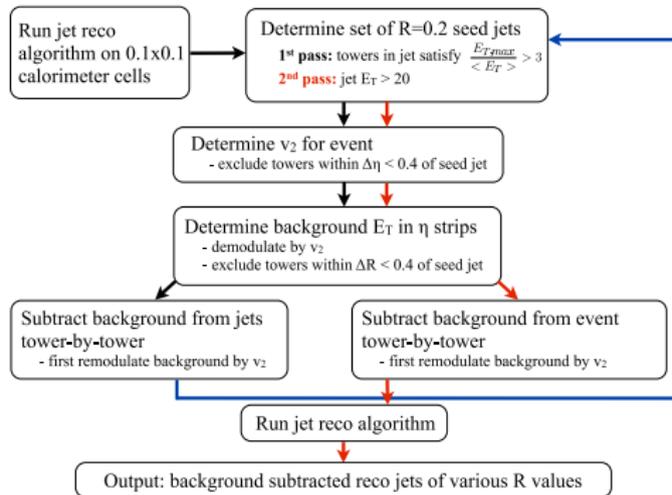
- Iterative background subtraction evolved from ATLAS procedure:

  - exclusion of jet energy from background determination

  - proper v_2 modulation

Jets at RHIC Study
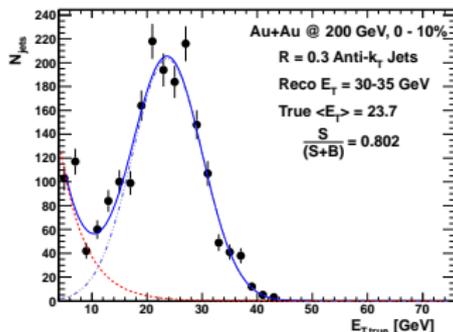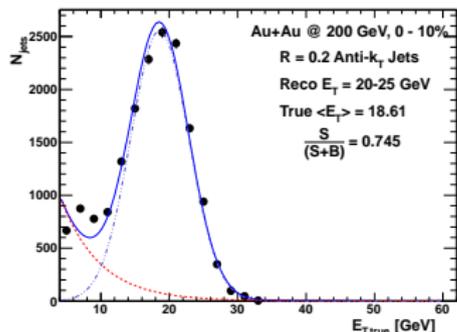
▶ High purity of reconstructed jets:

  ▶ Appropriate regime for well-controlled unfolding to $E_{\mathrm{T}}^{\mathrm{true}}$

  ▶ *Before any fake jet rejection scheme!*

Jets at RHIC Study
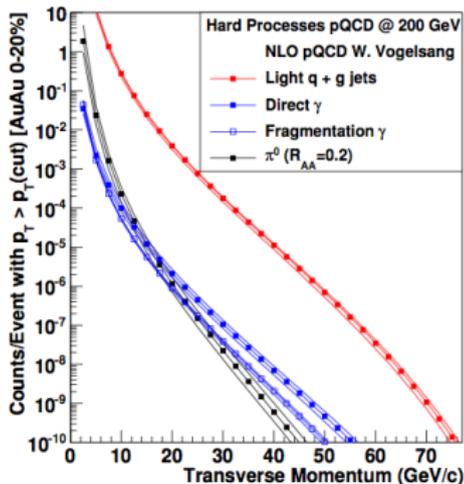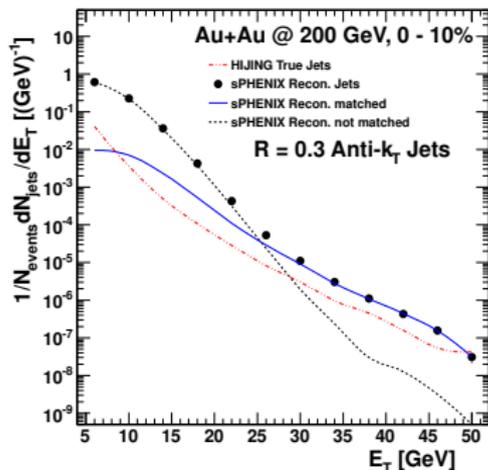
- Jets from hard scatterings dominate above $E_{\mathrm{T}}^{\mathrm{reco}} > 20, 30, 40$ GeV for $R = 0.2, 0.3, 0.4$ anti-k_{T}, respectively.

- RHIC luminosity upgrade: 10^{10} central $Au+Au$ collisions / year

  ⇒ capitalize on high PHENIX data rate
  ⇒ high statistics inclusive jet, di-jet, γ-jet measurements!

- **see A. Hanks talk, Tuesday 6:30pm**

Many Thanks To. . .

- Brian Cole, Nathan Grau, Yue-Shi Lai

- Ali Hanks, Jamie Nagle, Anne Sickles for sPHENIX discussions

- PHENIX Collaboration

- WWND12 Organizers