Full jet reconstruction in 200 GeV p+p, d+Au and Au+Au collisions by STAR

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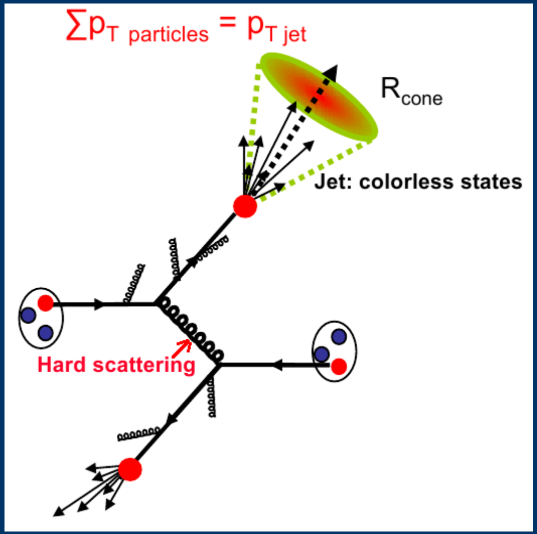
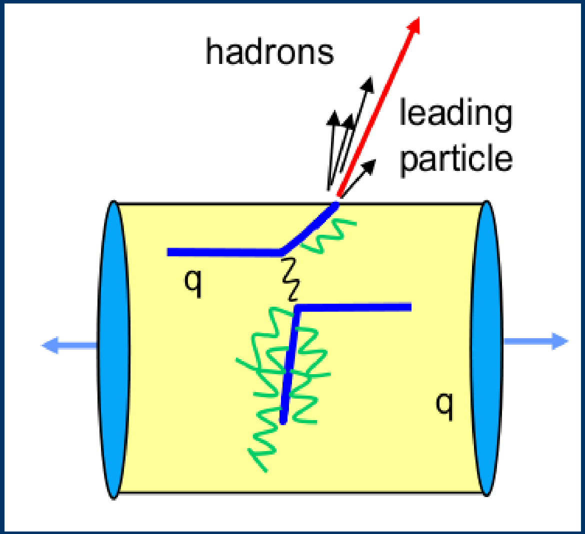
Outline

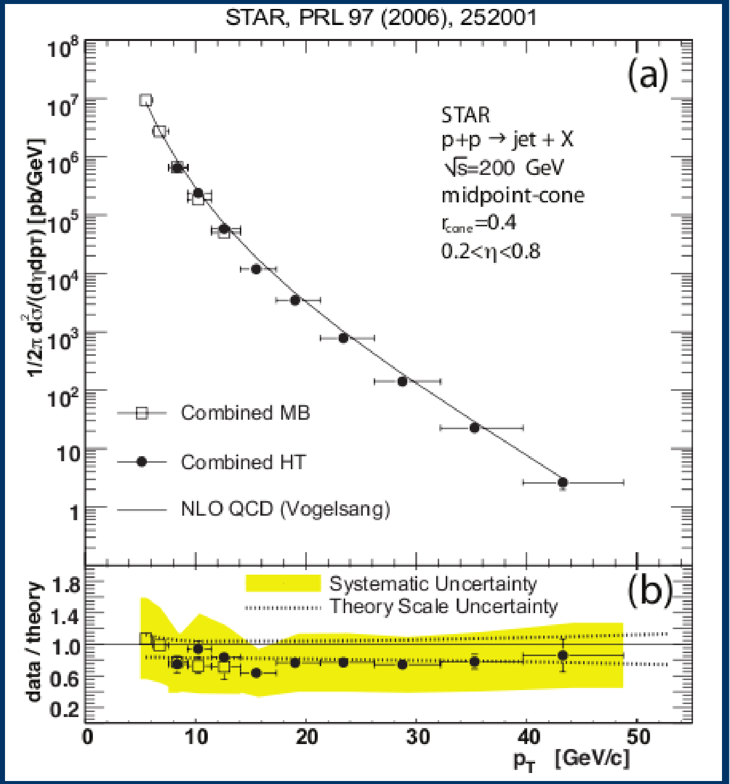
- motivation
- STAR experiment at RHIC
- jet reconstruction technique
- probe the initial state: p+p and d+Au collisions
- probe the final state/medium: Au+Au (p+p as reference)

Motivation

- di-hadron correlations:
  - surface & fragmentation biases
  - indirect method to study jet quenching
- study the quenching directly with jets:
  - access the partonic kinematics
  - well calibrated probe (pQCD)
  - ?unbiased jet reconstruction (N_{bin} scaling)
  - ?modified fragmentation due to quenching

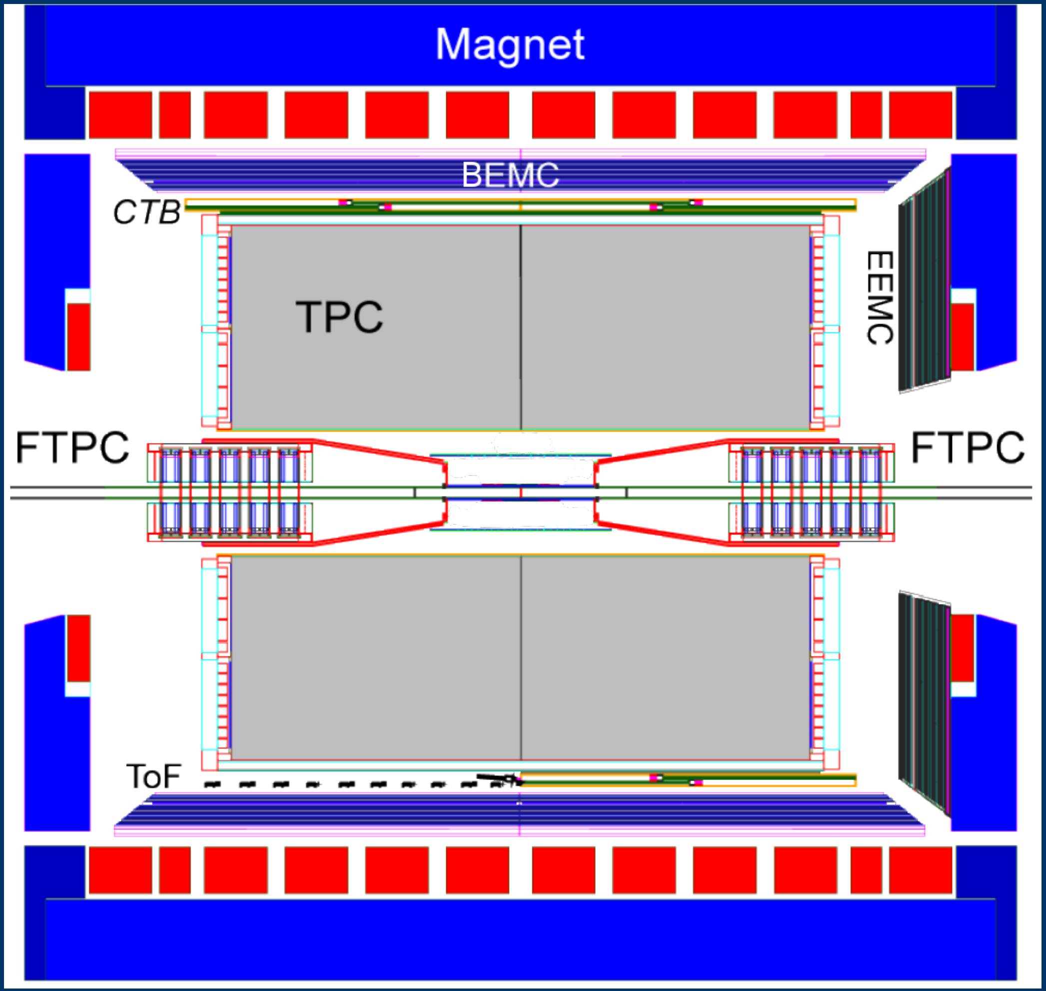






STAR p+p jet spectrum: agreement with theory over 7 orders of magnitude

STAR experiment at RHIC



RHIC (BNL):

d+Au, Cu+Cu, Au+Au, (U+U):

$\sqrt{s_{NN}} \leq 200$ GeV

p+p: $\sqrt{s} \leq 500$ GeV

magnetic field 0.5 T

<u>detectors used ($|\eta|<1$, Φ: 2π):</u>

- Time Projection Chamber: tracking
- Barrel EM Calorimeter (BEMC):
  - -neutral energy (towers 0.05x0.05)
  - -trigger

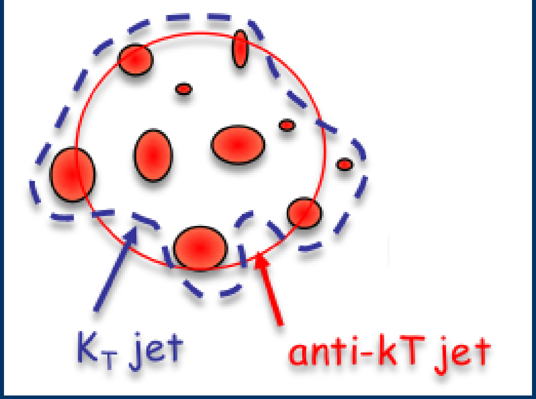
100% electron/hadronic correction for matched tracks: avoid double-counting

data used in this analysis: p+p 2006, Au+Au 2007, p+p & d+Au 2008

Jet reconstruction

- recombination algorithms from FastJet* package
  *: Cacciari, Salam and Soyez, JHEP0804 (2008) 005, arXiv:0802.1188.
  - kt: clustering starts with low p_T particles
  - anti-kt: clustering starts with high p_T particles
  - resolution parameter R (~radius)

anti-kt expected to be less susceptible to bg effects in heavy-ion col.



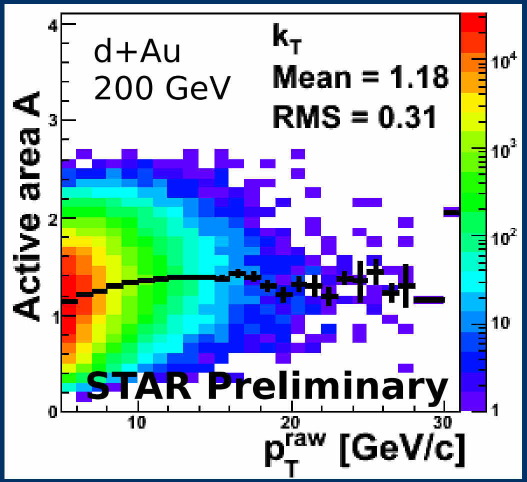
- background and its fluctuations:
  - crucial for Au+Au collisions
  - reduce background by: smaller R, low p_T cut
  - background subtraction:
    - $p_{T,jet,observed} = p_{T,jet,true} + \rho * A$
    - background fluctuation: resolution: $\sigma * \sqrt{A}$
  - A – jet active area (obtained using ghost particles)
  - ρ, σ – event-by-event from p_T/A distribution (kt algorithm):
    - ρ: median
    - σ: one-sided sigma (avoid bias from hard jets)

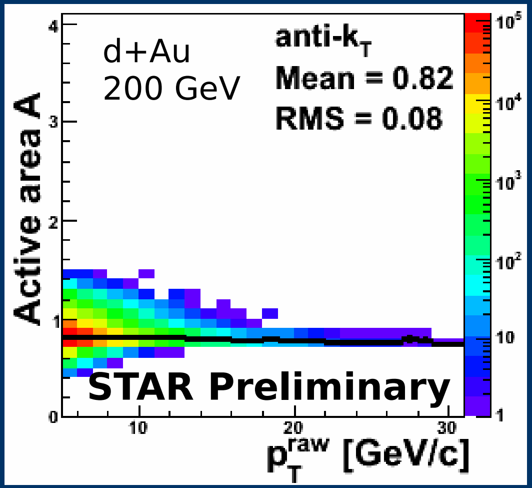
Jets in d+Au collisions

- run 8 RHIC d+Au data: 20% most central collisions
- compare to run 8 p+p data
- trigger: BEMC tower E_T>4.3 GeV (p+p, d+Au)

} similar systematics

- using p_T > 0.5 GeV/c, R = 0.5, fiducial jet acceptance |η| < 0.9-R





jet areas for kt and anti-kt algorithms

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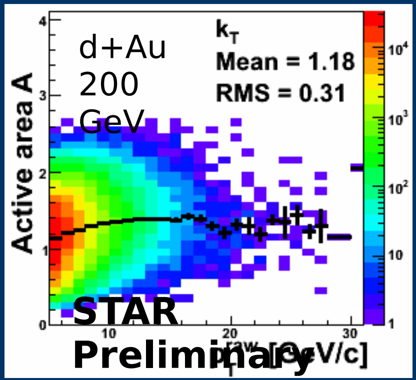
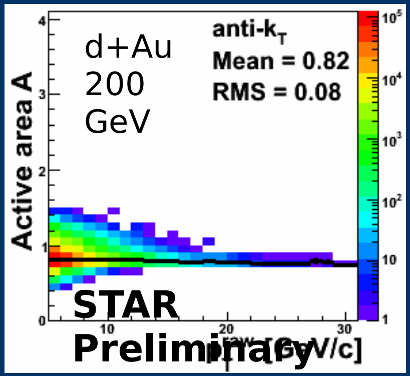
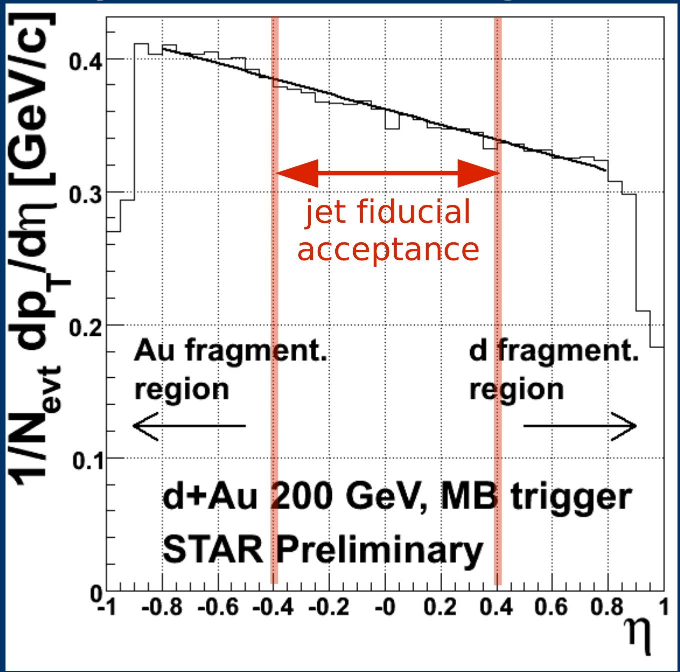
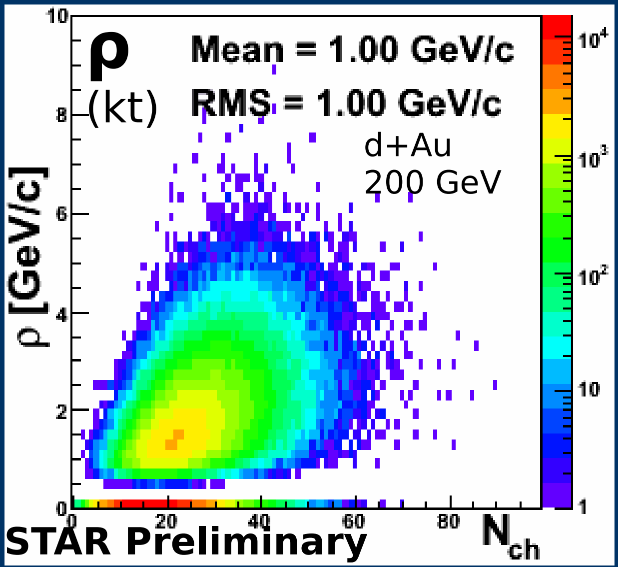


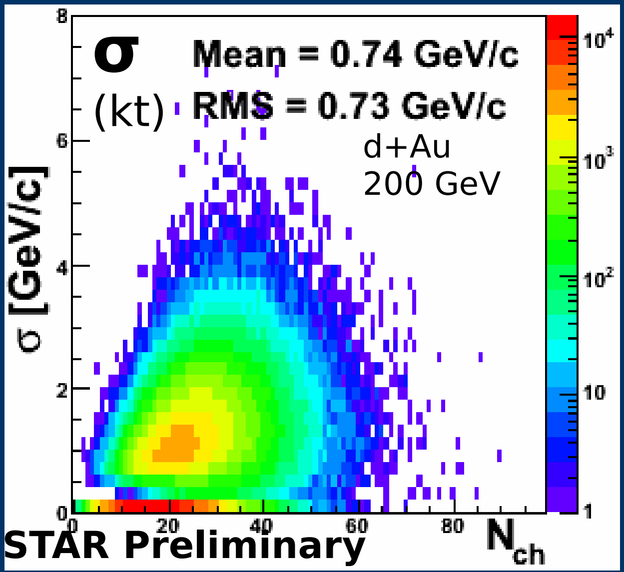


jet areas for kt and anti-kt algorithms

d+Au: asymmetric system
- asymmetric background:







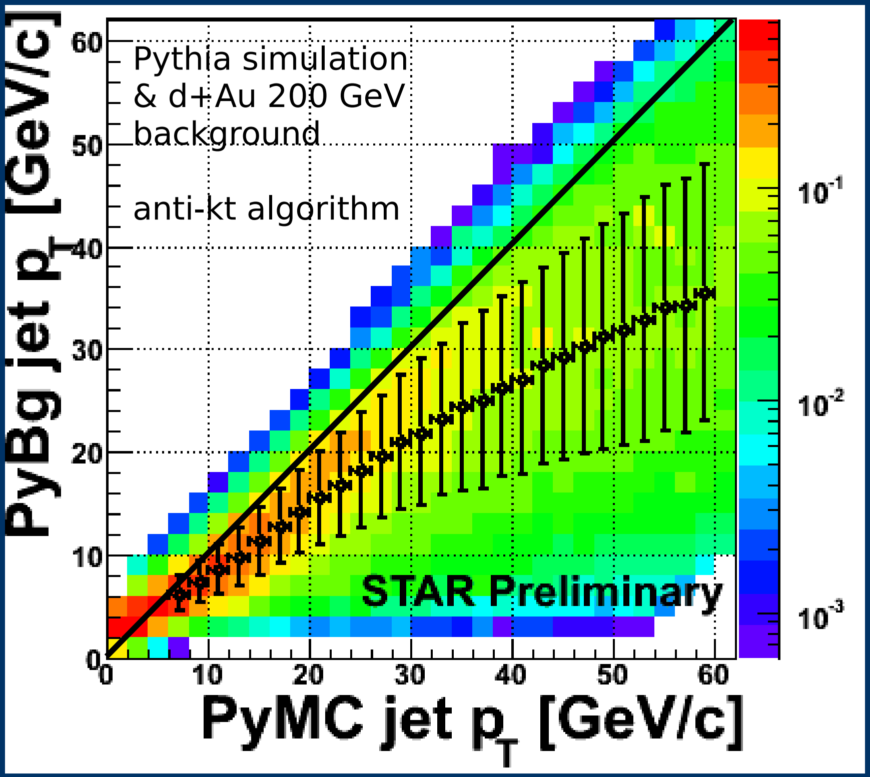
Pythia simulation

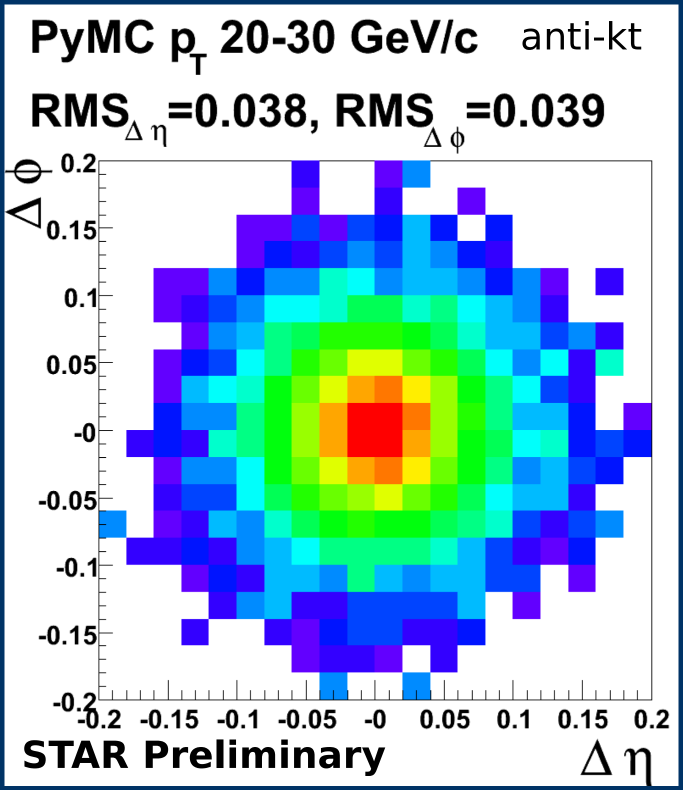
- Pythia 6.410, GEANT, STAR reconstruction software
- PyMC (particle level), PyGe (detector level), PyBg (detector level + bg)

jet p_T resolution:

roughly 20%

shift: unobserved neutral energy, tracking efficiency, dead towers

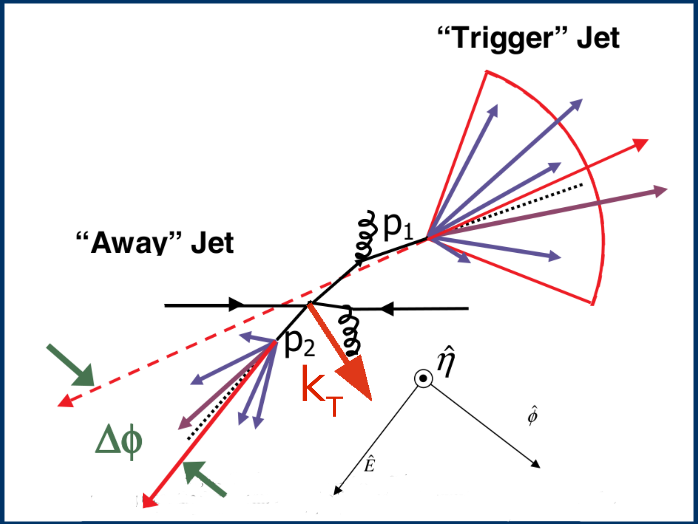




very good angular resolution

Towards k_T measurement: di-jets in d+Au

- select two highest energy jets in event:
  - $p_{T,1} > p_{T,2}$
- use cut on $p_{T,2}$ to suppress background/fake jets



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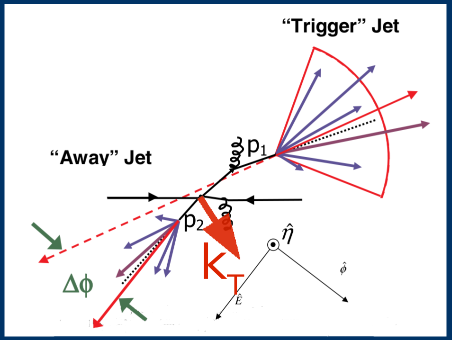
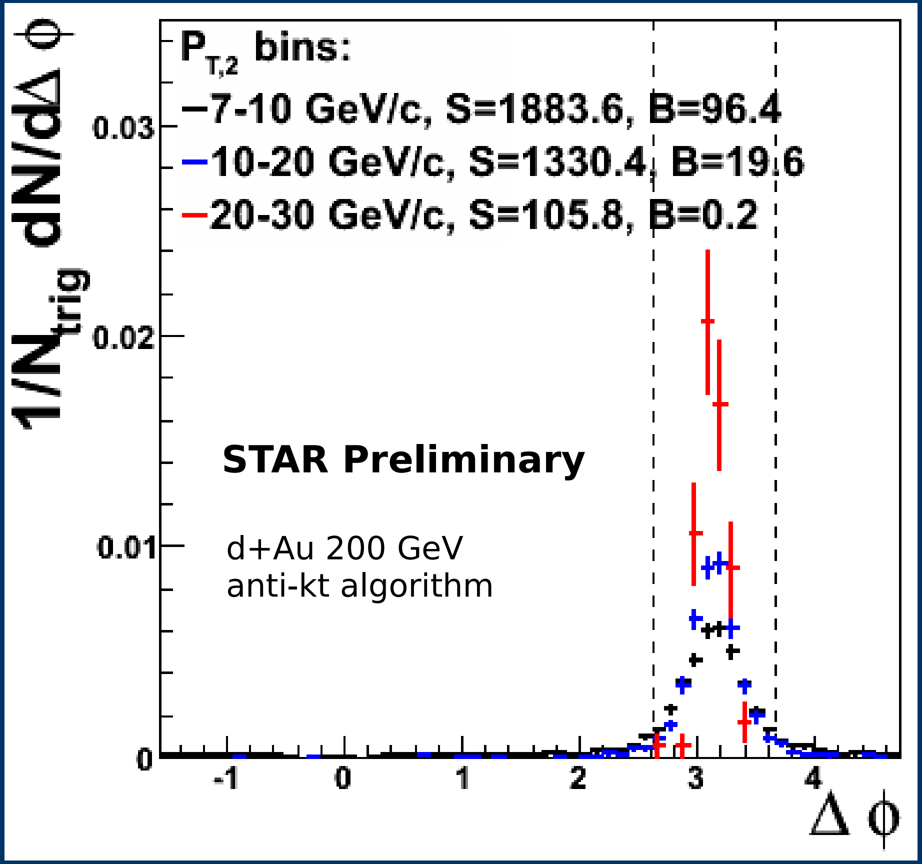
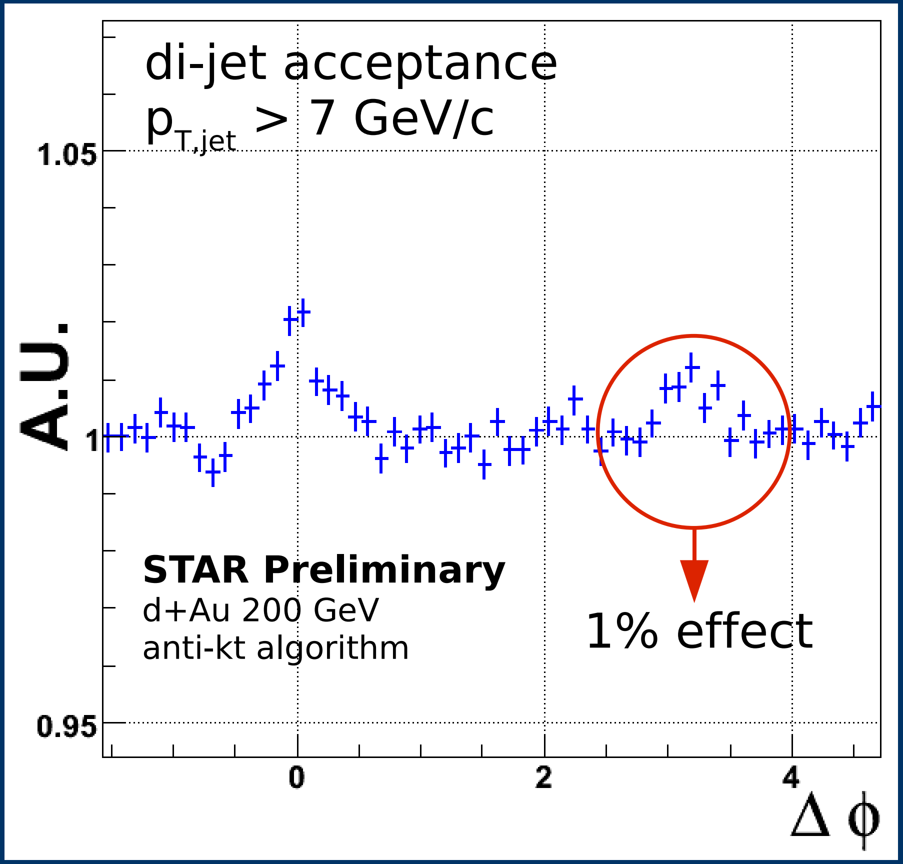


clear back-to-back di-jet peak in ΔΦ:

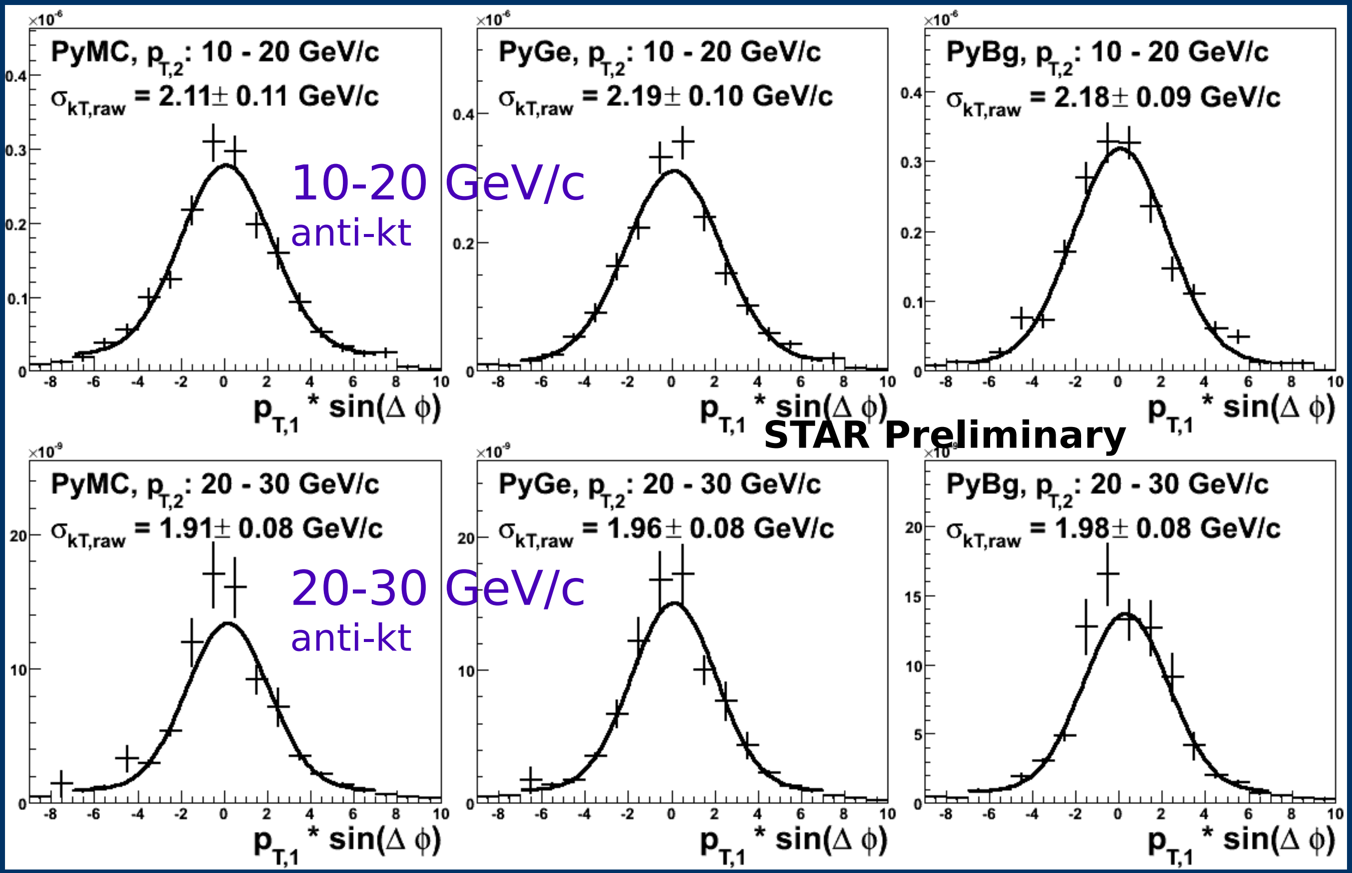




Measurement of k_T effect

- di-jet ΔΦ broadening: intrinsic k_T + ISR,FSR (incl. CNM effects)
- measure in d+Au collisions and compare to p+p
- $\mathbf{k_{T,raw} = p_{T,1} * \sin(\Delta\Phi)}$, $|\sin(\Delta\Phi)| < 0.5$, Gaussian fit

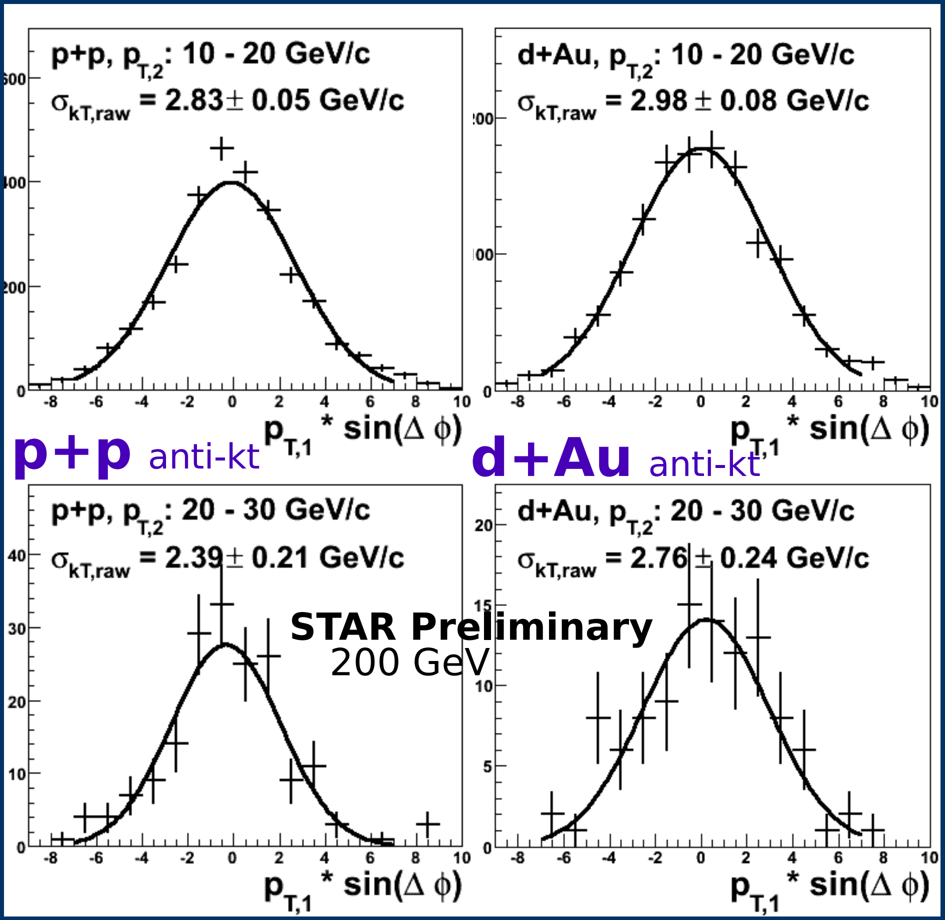
detector effects on k_T measurement:



...resulting detector effects are small, due to interplay of jet p_T and di-jet ΔΦ resolutions

Do we see CNM effects in k_T?

- the same analysis technique in p+p and d+Au collisions
- average over 2 $p_{T,2}$ bins and 2 algorithms: kt, anti-kt



$\sigma_{kT,raw}$ (p+p) = 2.8 ± 0.1 GeV/c

$\sigma_{kT,raw}$ (d+Au) = 3.0 ± 0.1 GeV/c

?decrease at high p_T (quark jets?):

higher jet energies to be studied

systematic uncertainties:

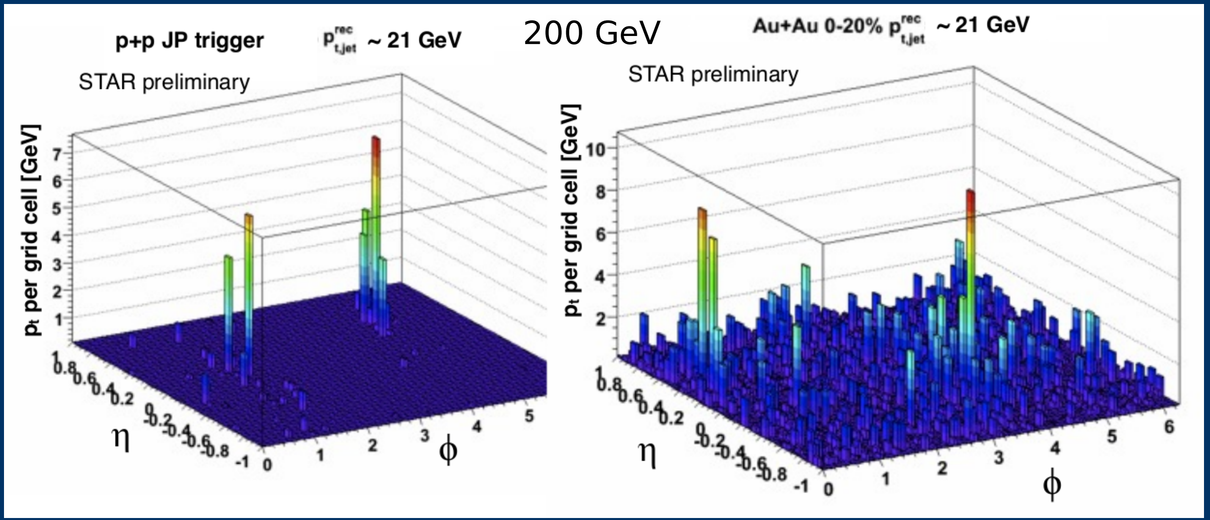
- neglecting detector effects, p_T-dependence
- BEMC calibration
- TPC tracking at high luminosity
- → no values yet: under study now
- → largely correlated between p+p and d+Au

conclusion: no strong Cold Nuclear Matter effect on jet k_T broadening seen

Jet reconstruction in Au+Au

- jet spectra: unbiased jet reconstruction (N_{bin} scaling: $R_{AA} = 1$)?
- fragmentation functions: modification due to quenching?

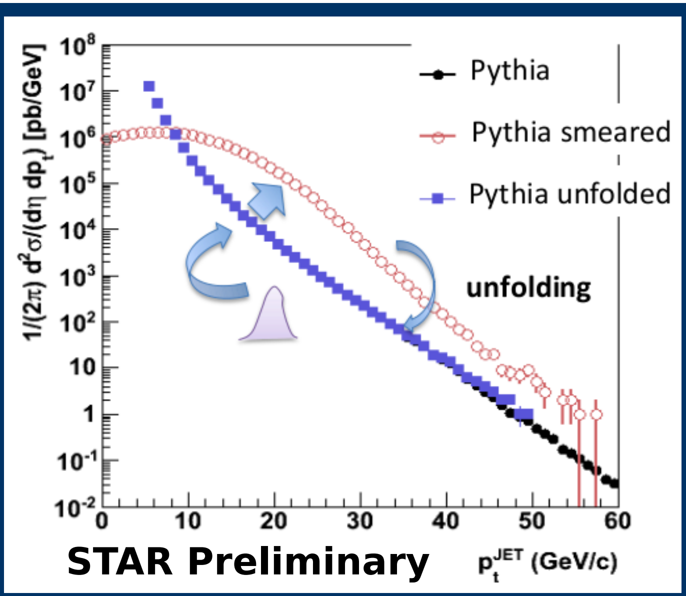
challenge:
large background



- central collisions: bg fluctuations due to elliptic flow negligible
- using R=0.4 to reduce background (~45 GeV per jet)
- bg fluctuations: jet p_T smearing

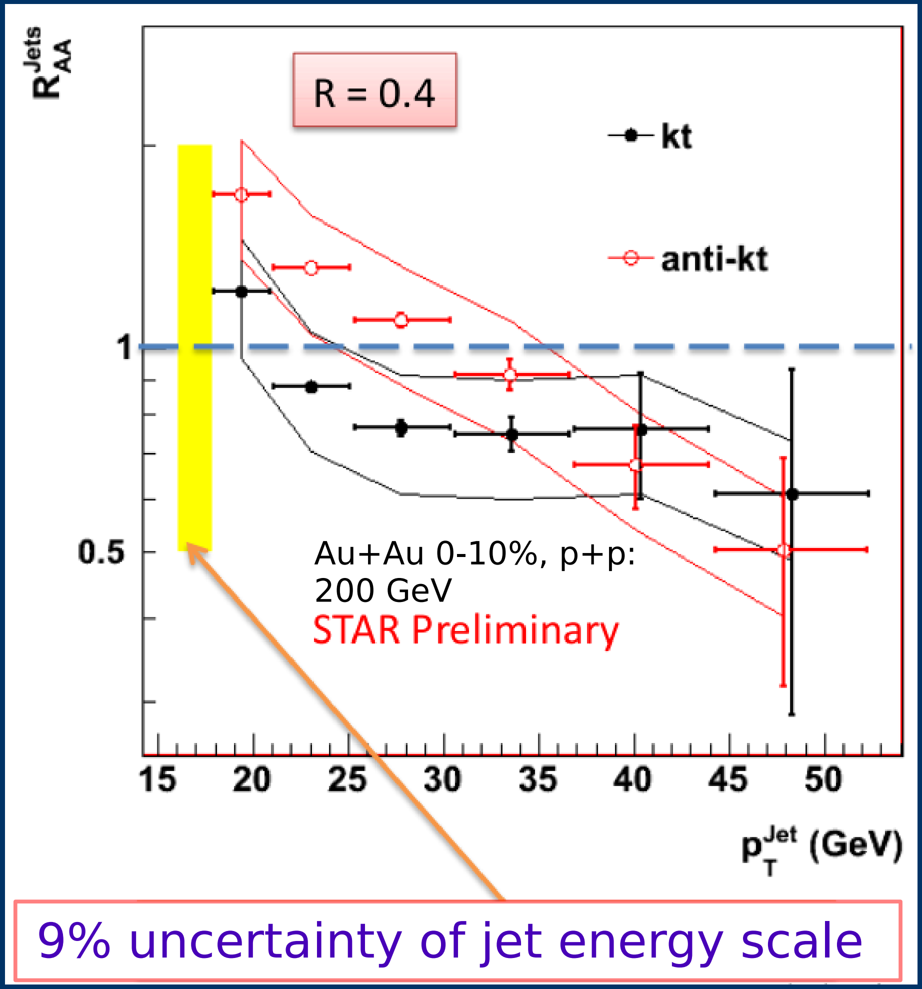
$\sigma * \sqrt{A} \sim 6$ GeV

unfold background fluctuations to be able to compare to jets in p+p:



...main systematic uncertainty: taking σ ± 1 GeV

Medium modification of jet p_T spectra



- uncorrelated point-to-point systematic error
- work in progress to improve systematic uncertainties
- R=0.4 unsufficient for unbiased jet reconstruction?

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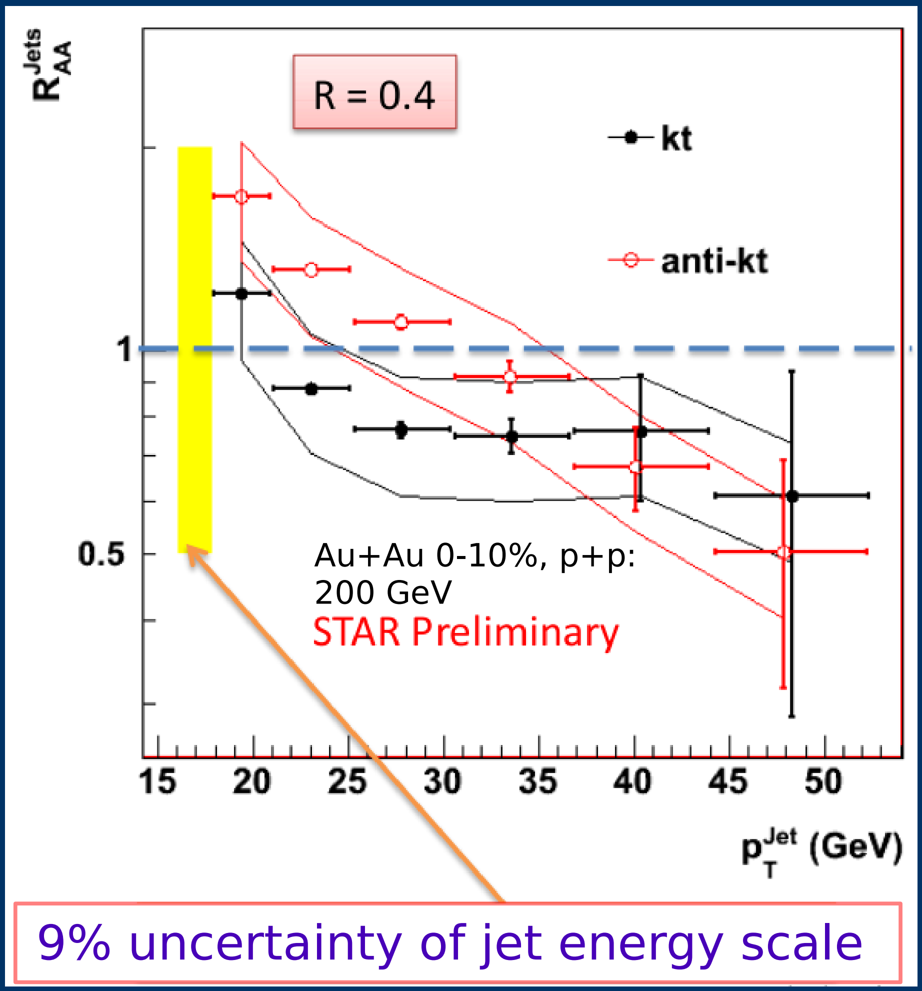
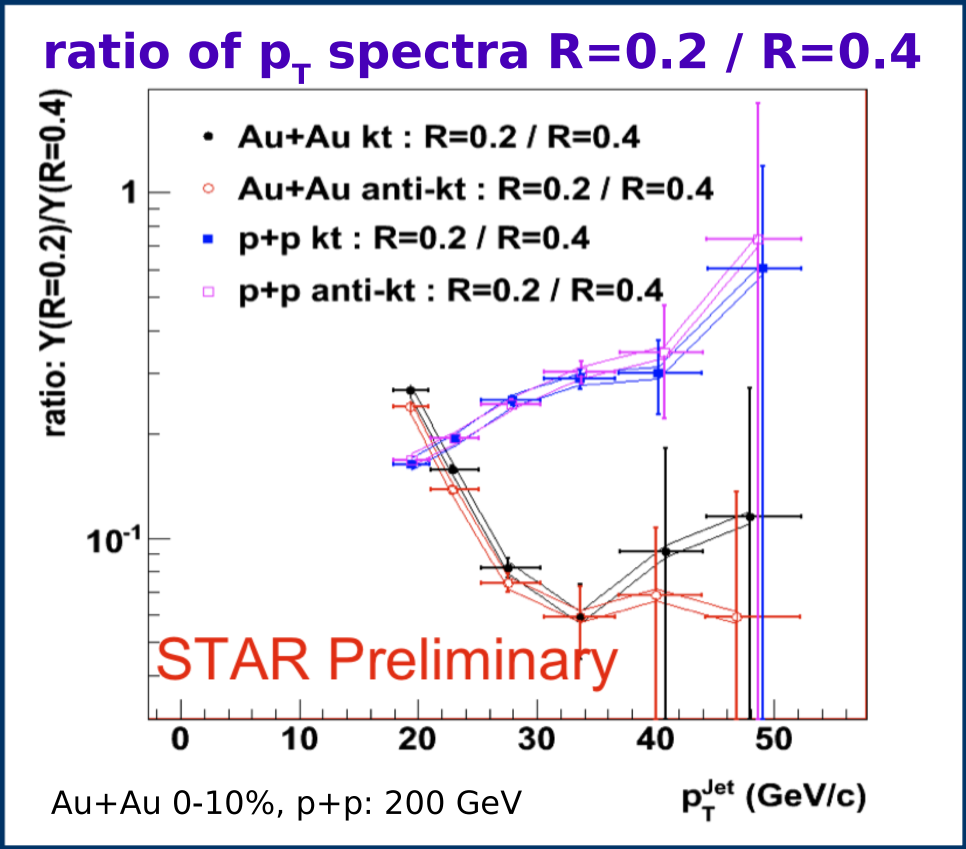
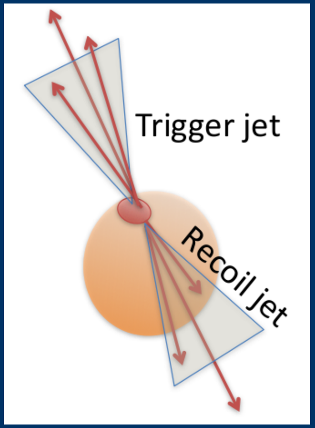




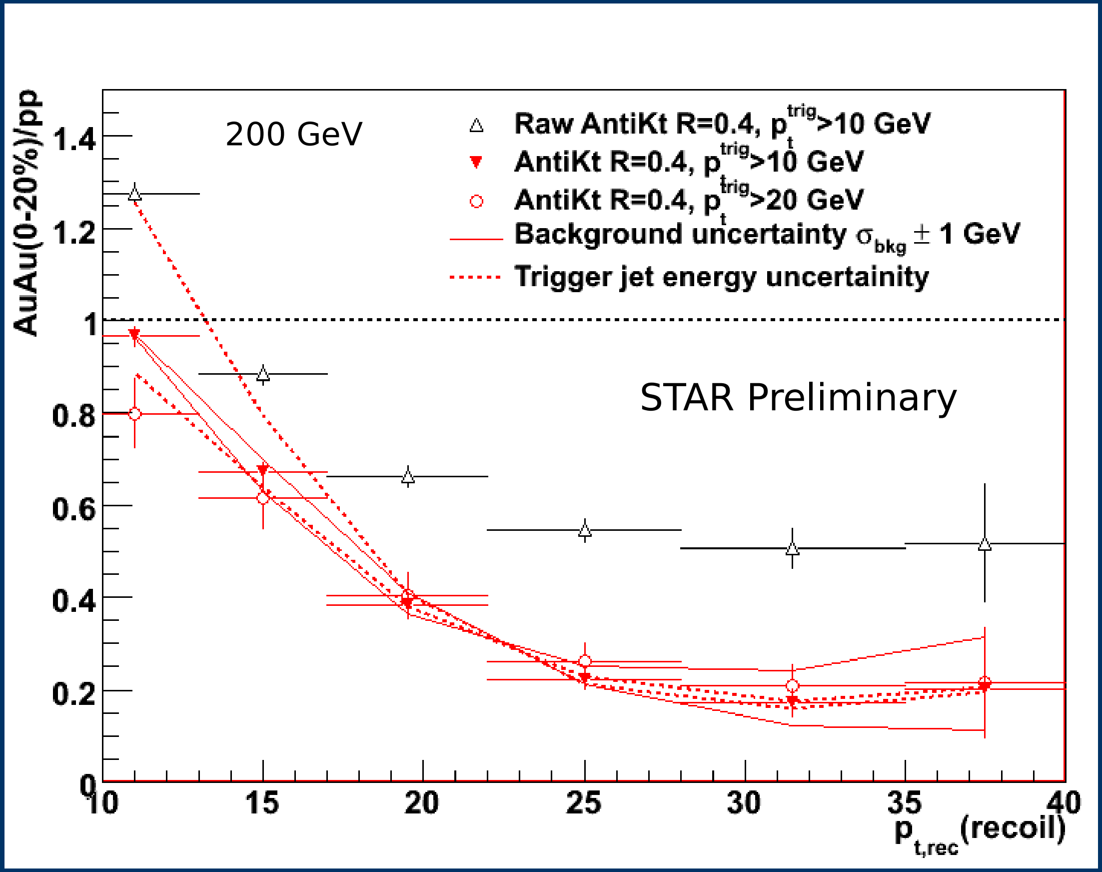
- p+p: “narrowing” of jet structure
- Au+Au: indication of jet broadening (deficit of energy in R=0.2)

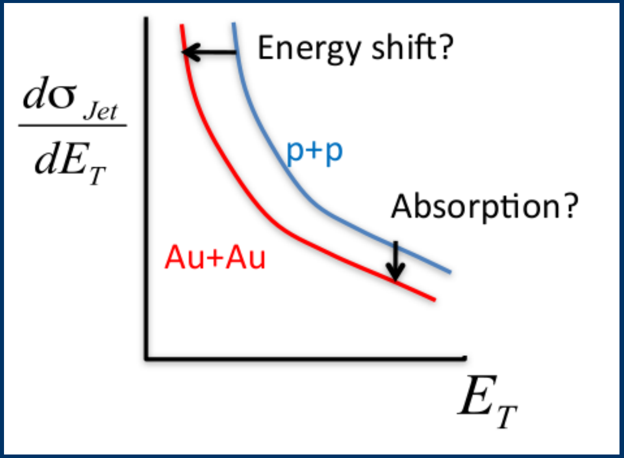
- uncorrelated point-to-point systematic error
- work in progress to improve systematic uncertainties
- R=0.4 unsufficient for unbiased jet reconstruction?

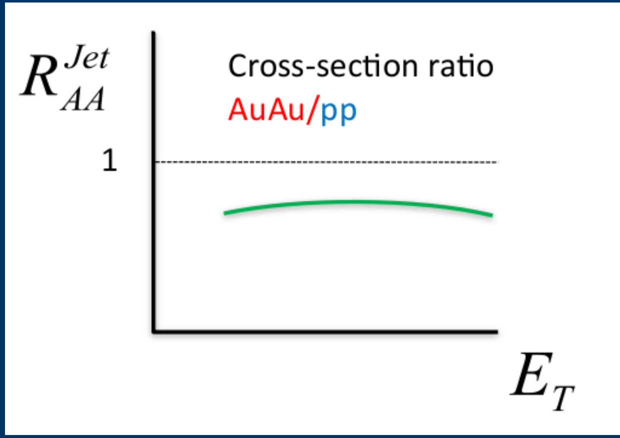
Recoil jet analysis



- use High Tower trigger: E_T > 5.4 GeV
- maximizing medium path-length of the recoil jet



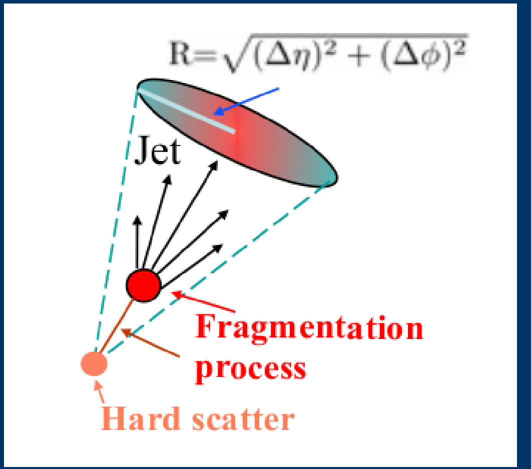


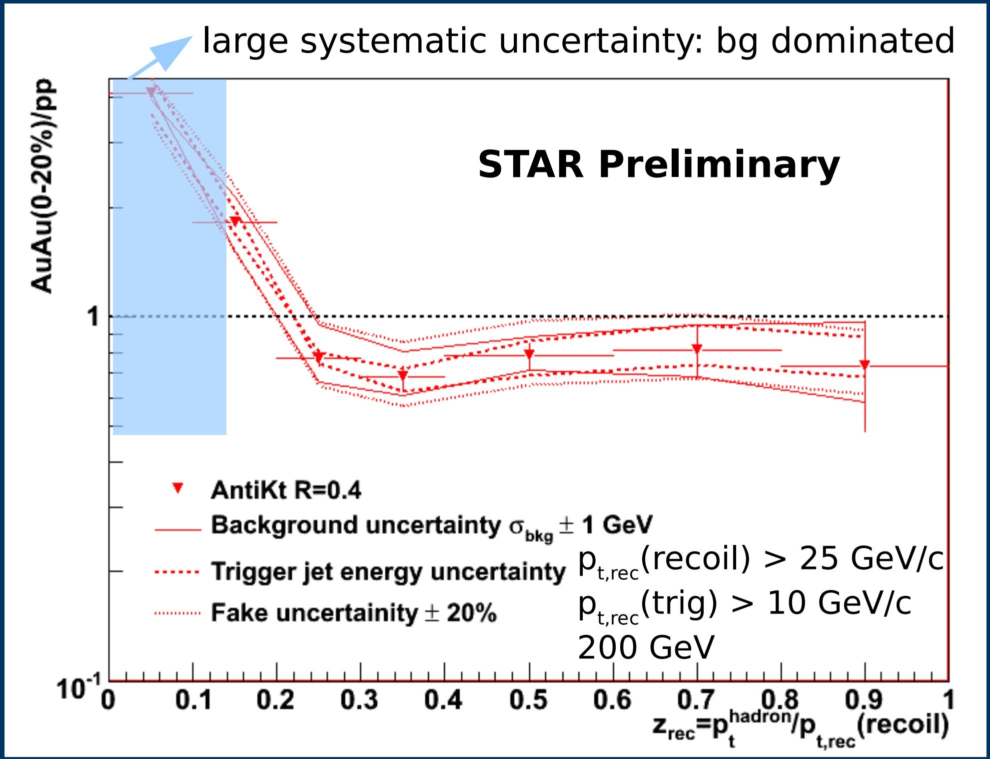


significant suppression of recoil jets seen:
?absorption/energy shift

Fragmentation functions

- use recoil jet and its unfolded energy to measure FF
- FF: $z = p_T$ (charged hadron) / p_T (jet)
- R=0.4 for jet energy
- R=0.7 for particles to construct FF
- subtract bg particles p_T distribution (out of jet area)





no significant modification of FF for recoil jets $p_{T,rec}$ (recoil) > 25 GeV/c

?dominated by non-interacting jets, such as tangential emission / punch-through jets

Conclusions

- Cold Nuclear Matter effects:
  - ➔ no strong evidence of k_T broadening in d+Au collisions

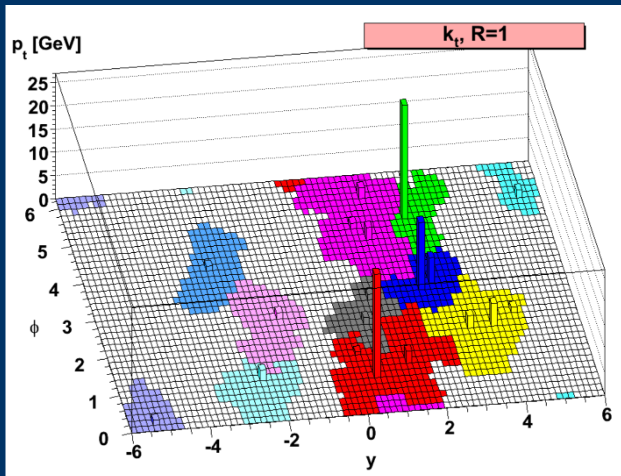
- Medium modification via full jet reconstruction in central Au+Au collisions:
  - ➔ R_{AA} hints sensitivity to different jet algorithms
  - ➔ unbiased jet reconstruction not achieved for R=0.4?
  - ➔ work in progress to improve systematic uncertainties

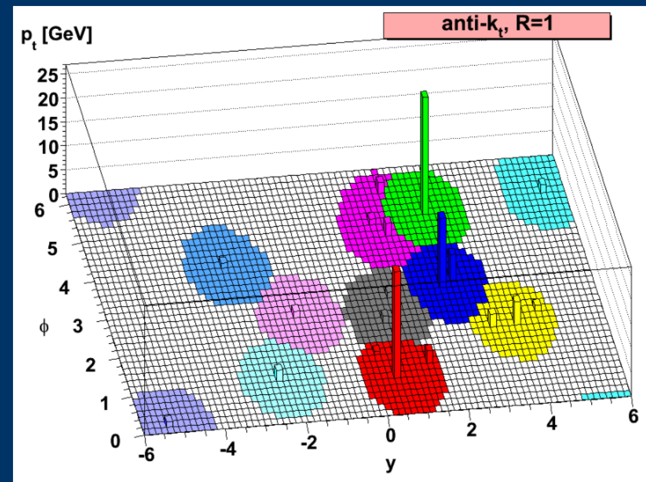
  - ➔ R=0.2/R=0.4 p_T spectra ratio decreasing with p_T (in contrast to p+p)
  - ➔ quenching leads to jet broadening?

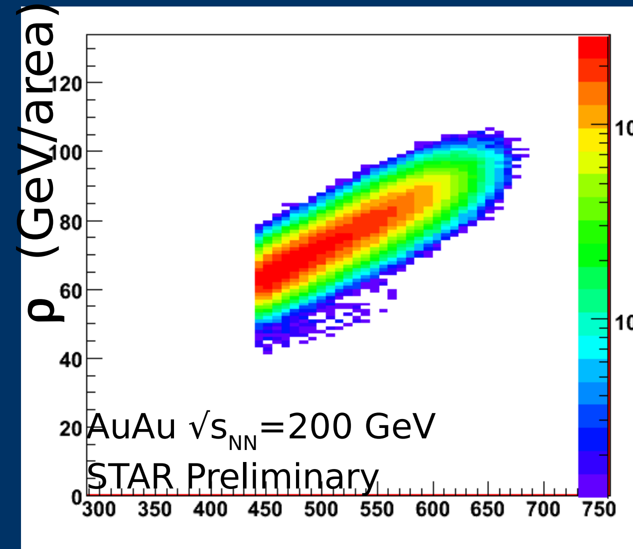
  - ➔ no strong FF modification for high energy (>25 GeV/c) recoil jets
  - ➔ surviving recoil jets are those non-interacting?

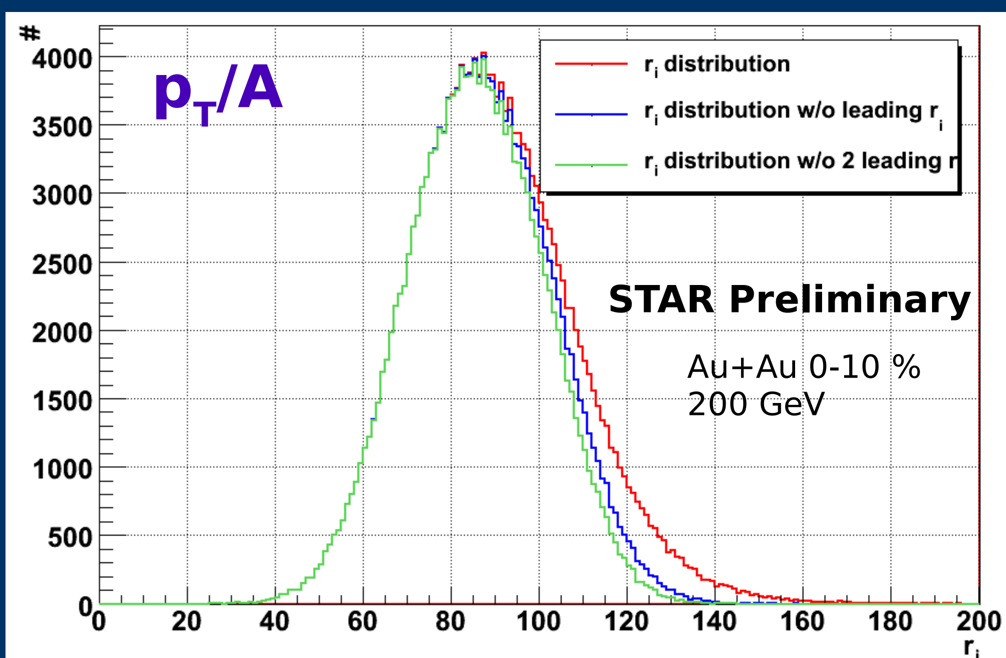
Backup

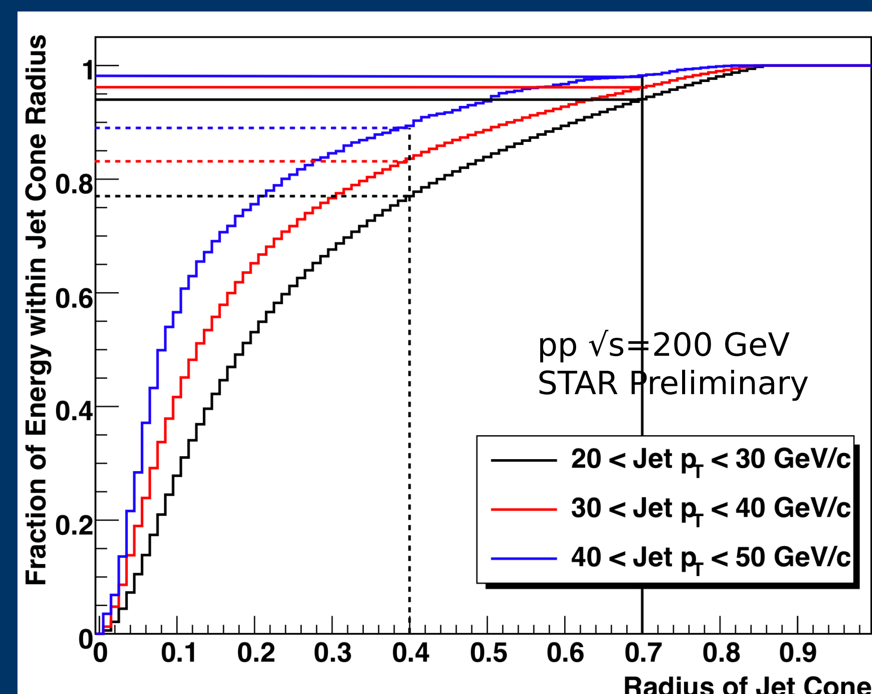
Jet finding


k_t, R=1
p_t [GeV]
ϕ
y

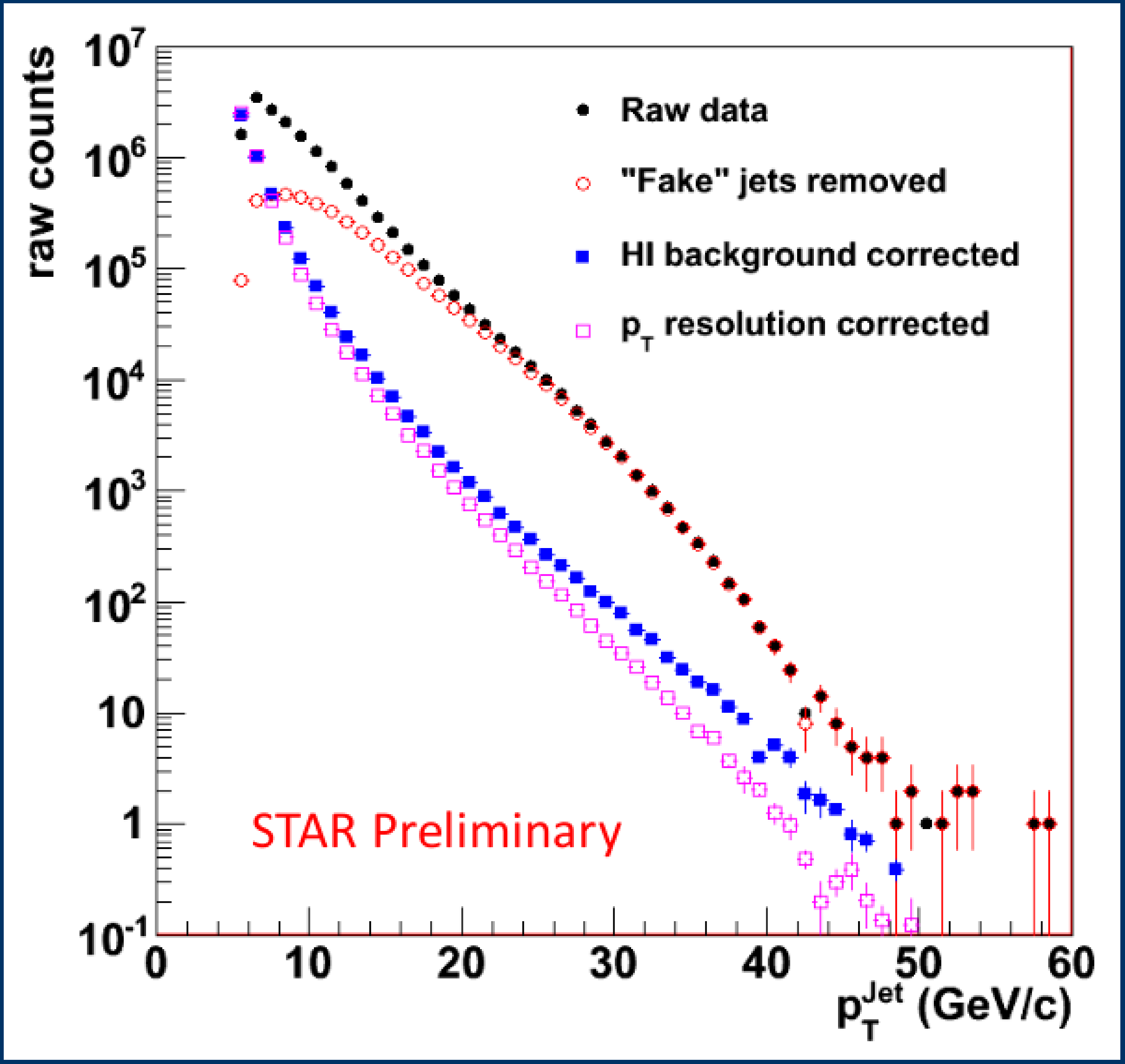

anti-k_t, R=1
p_t [GeV]
ϕ
y


ρ (GeV/area)
AuAu $\sqrt{s_{NN}}$=200 GeV
STAR Preliminary

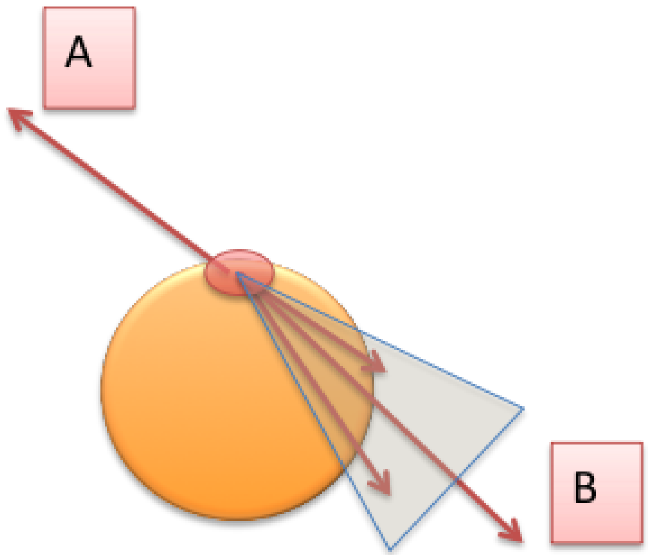

p_T/A
#
r_i distribution
r_i distribution w/o leading r_i
r_i distribution w/o 2 leading r_i
STAR Preliminary
Au+Au 0-10 %
200 GeV
r_i

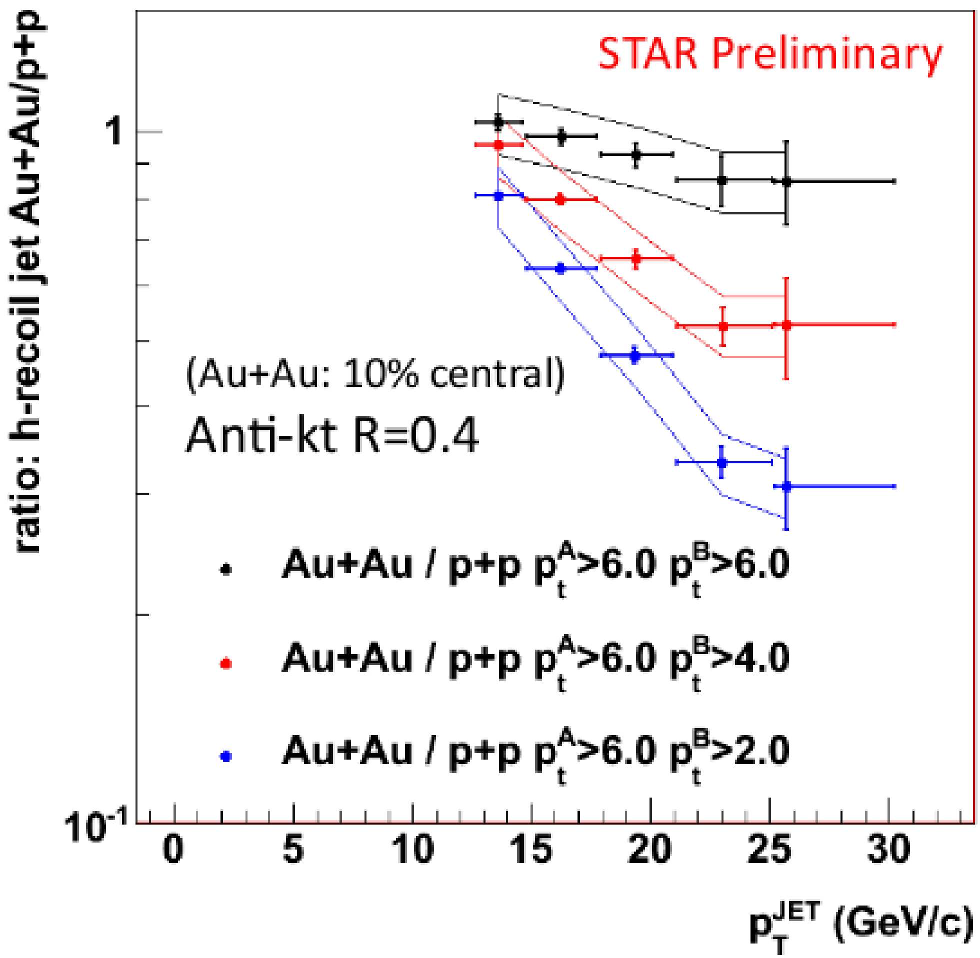

Fraction of Energy within Jet Cone Radius
pp $\sqrt{s}$=200 GeV
STAR Preliminary
20 < Jet p_T < 30 GeV/c
30 < Jet p_T < 40 GeV/c
40 < Jet p_T < 50 GeV/c
Radius of Jet Cone

Jet spectra - unfolding



H – recoil jet coincidences





Fragmentation functions