Jets in 200 GeV p+p and d+Au collisions from the STAR experiment at RHIC

Jan Kapitán

Nuclear Physics Institute ASCR, Czech Republic
(for the STAR Collaboration)

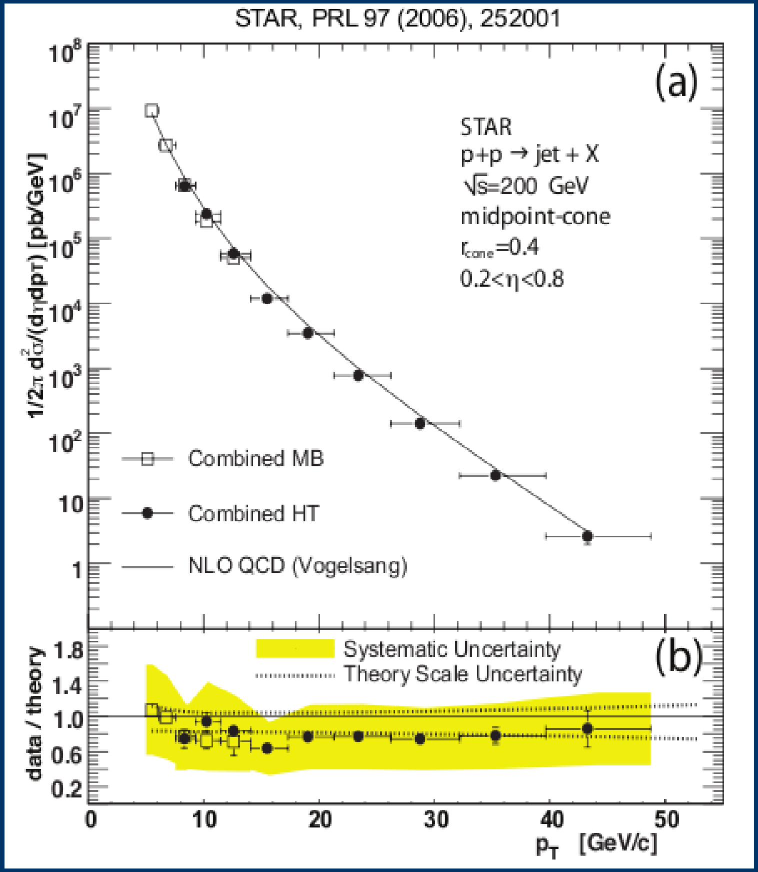
Outline

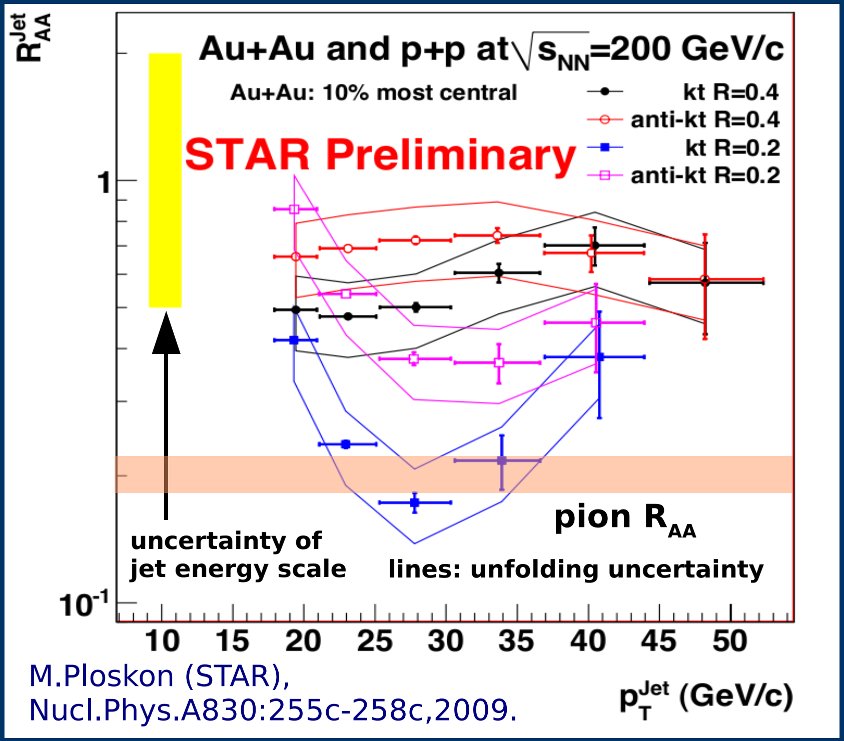
- motivation
- STAR experiment at RHIC
- jet reconstruction technique
- di-jets in p+p and d+Au collisions
- jet p_T spectrum from d+Au collisions

Motivation

jets in heavy ion collisions

- well calibrated probe (pQCD)
- direct study of jet quenching
- access the partonic kinematics





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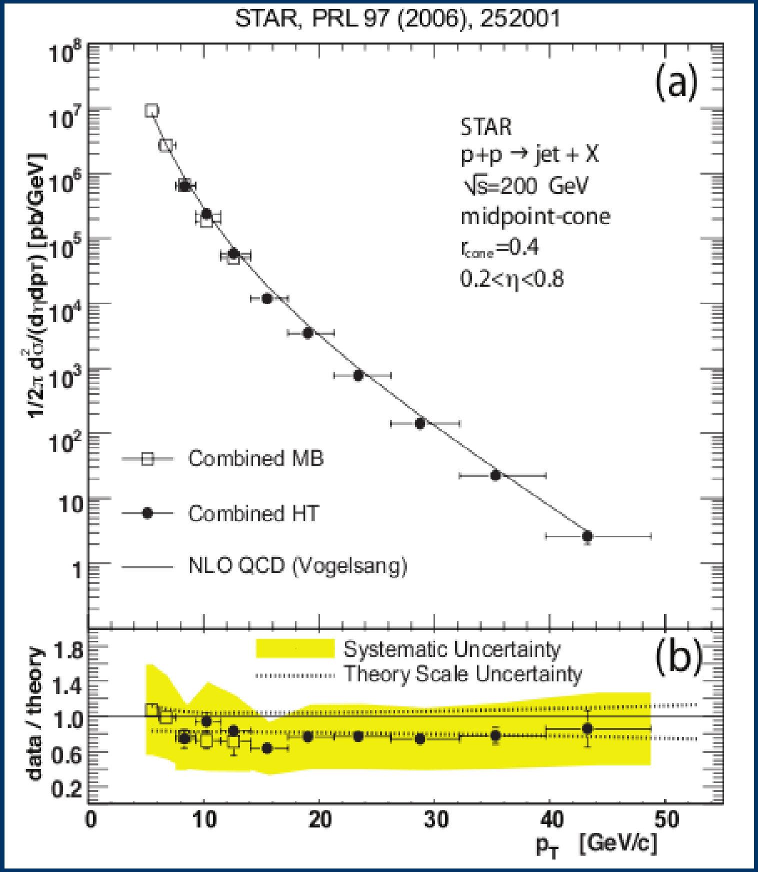
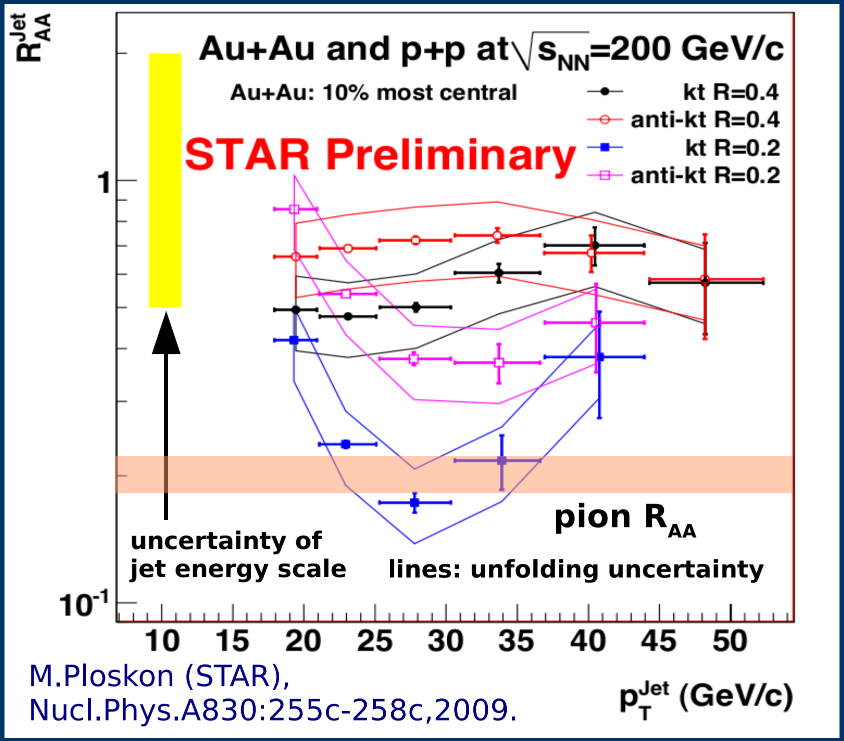
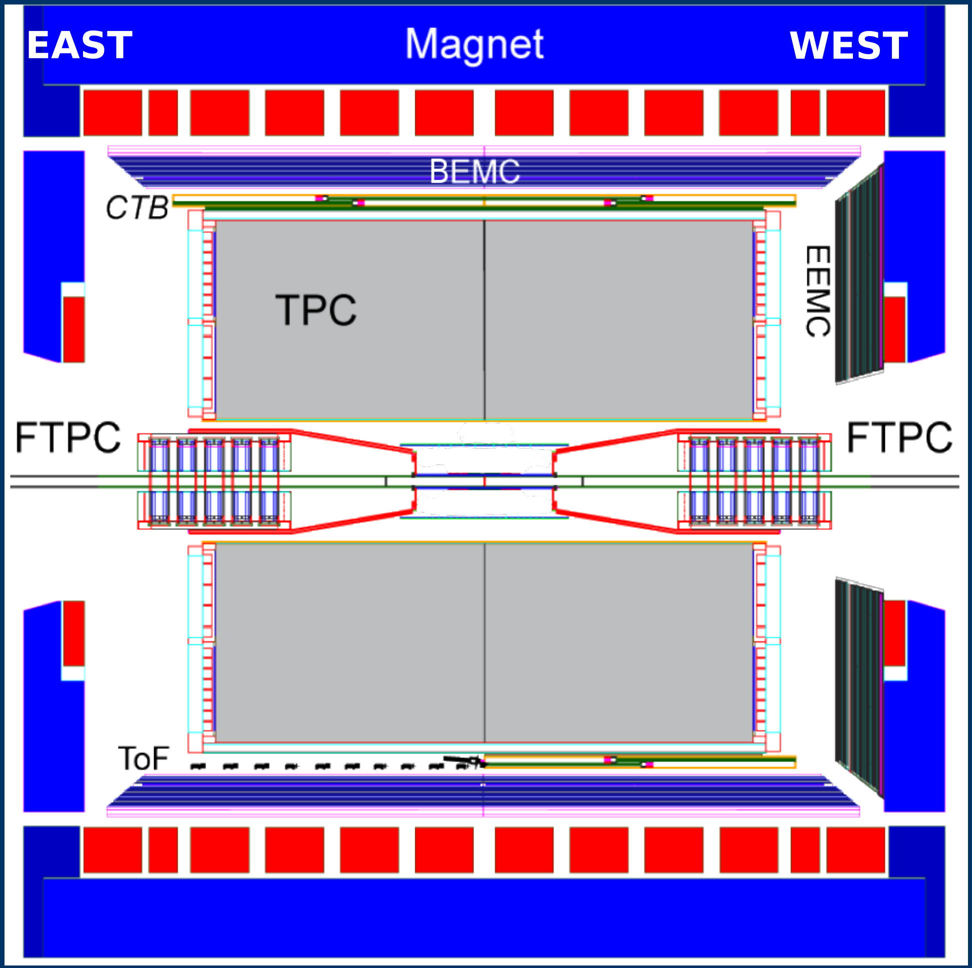




d+Au: estimate initial state effects

- di-jet correlations and jet p_T spectrum
- compare to p+p collisions
- possible effects due to modified PDF and parton rescattering in cold nuclear matter (CNM)

STAR experiment at RHIC



solenoidal magnetic field 0.5 T

detectors used (|η|<1, Φ: 2π):

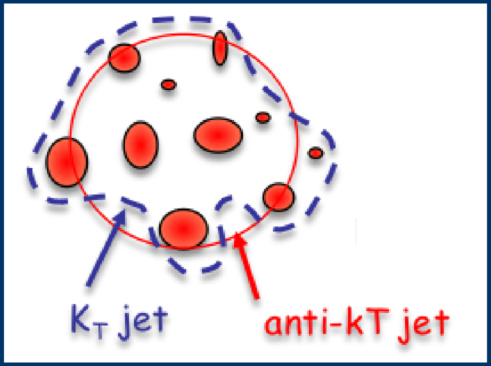
- Time Projection Chamber: tracking
- Barrel EM Calorimeter (BEMC):
  -neutral energy (towers 0.05x0.05)
  -trigger

“100% hadronic correction”: subtract matched track p_T off tower E_T: avoid double-counting (MIP, electrons, hadronic showers)

d+Au centrality: selected 20% highest multiplicity events using East FTPC

data used in this analysis: 200 GeV p+p & d+Au run 8 (2007/2008)

Jet reconstruction



recombination algorithms - FastJet package

Cacciari, Salam and Soyez, JHEP0804 (2008) 005, arXiv:0802.1188.

- $d_{ij} = \min(p_{Ti}^n, p_{Tj}^n)\,(\Delta\eta^2 + \Delta\varphi^2)/R^2$, $d_i = p_{Ti}^n$
- $\min(d_i, d_{ij})$: d_i -> new jet, d_{ij} -> merge i,j

- kt: n=2, clustering starts with low p_T particles
- anti-kt: n=-2: clustering starts with high p_T particles, less sensitive to background

Jet reconstruction

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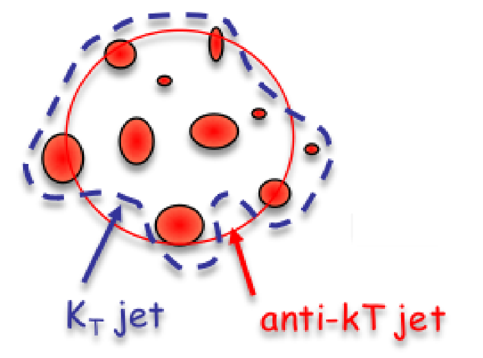

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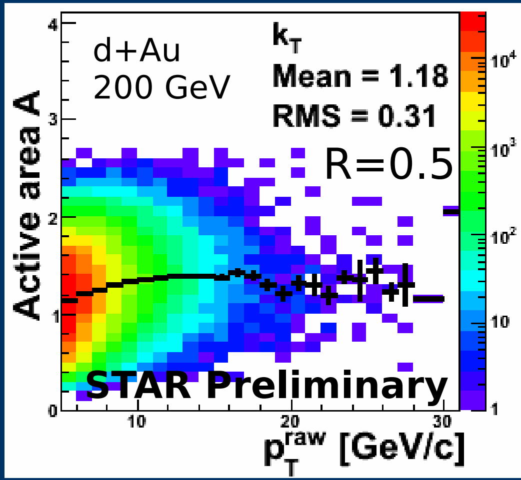
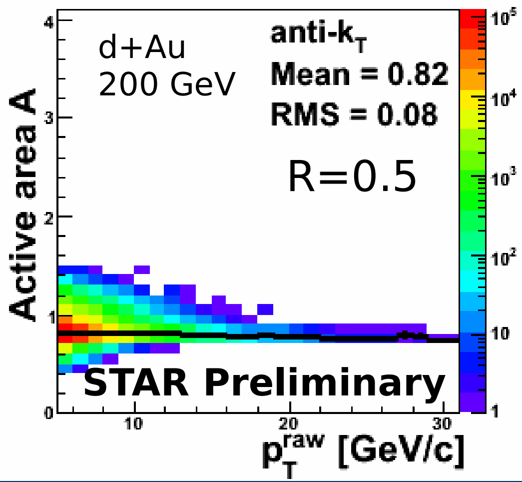
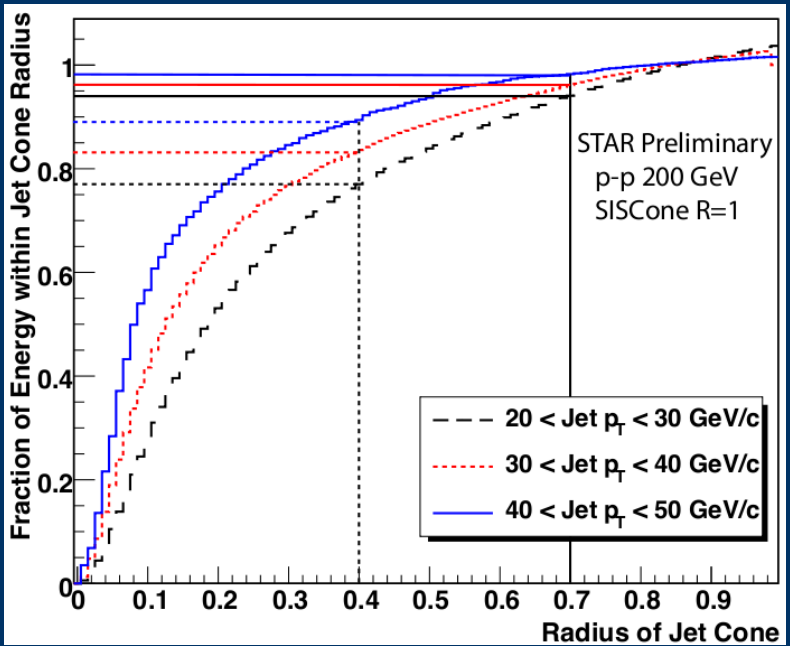
- R: resolution parameter
- active jet area A: using ghost particles



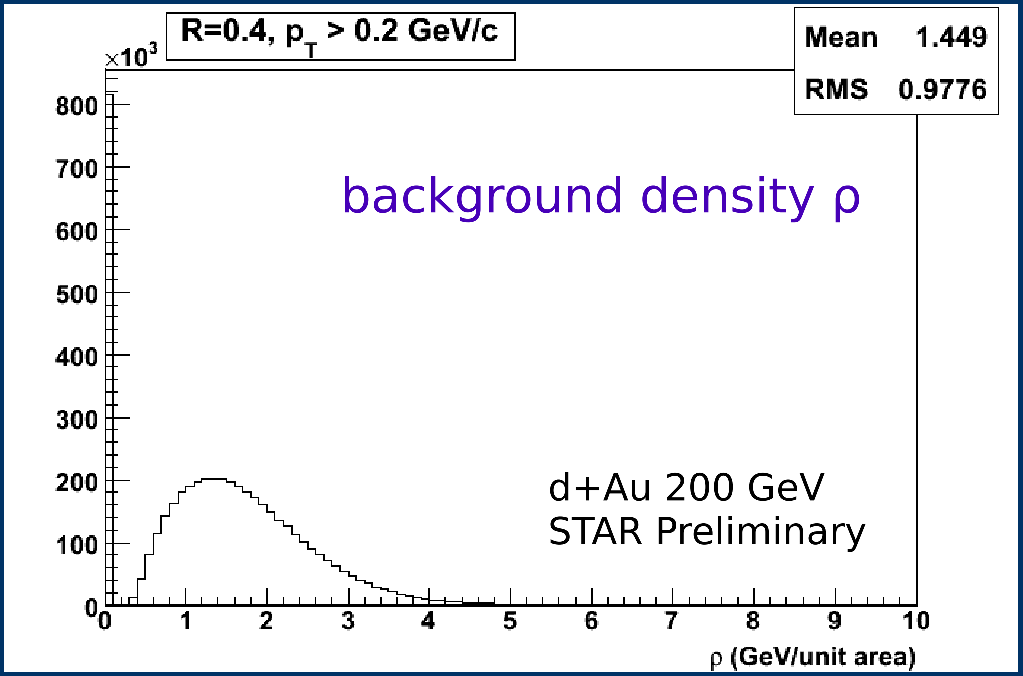




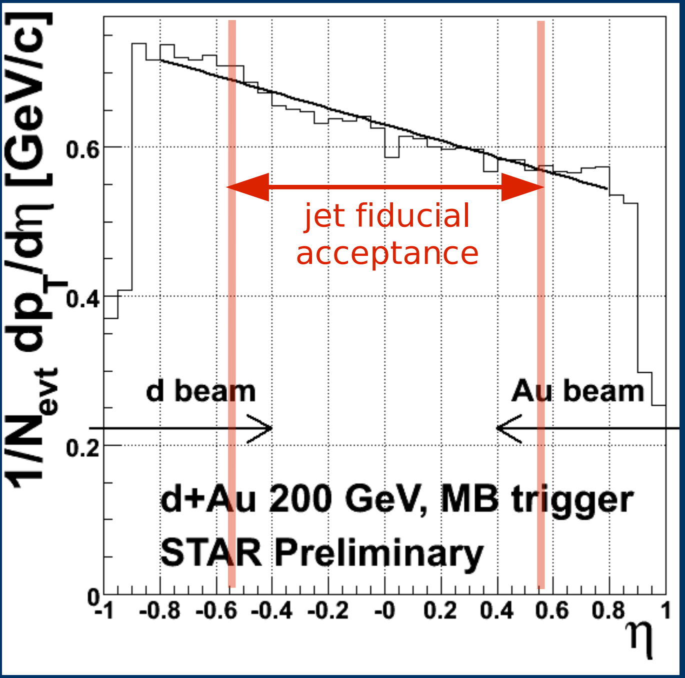
d+Au background

underlying event background

- reduction: lower R (0.4 or 0.5 rather than 0.7), p_T cuts (tracks/towers)
- estimation: background density constructed as ρ = median $\{p_T/A\}$ using kt algorithm
- subtraction: $p_{T,jet,true} = p_{T,jet,reconstructed} - \rho * A$



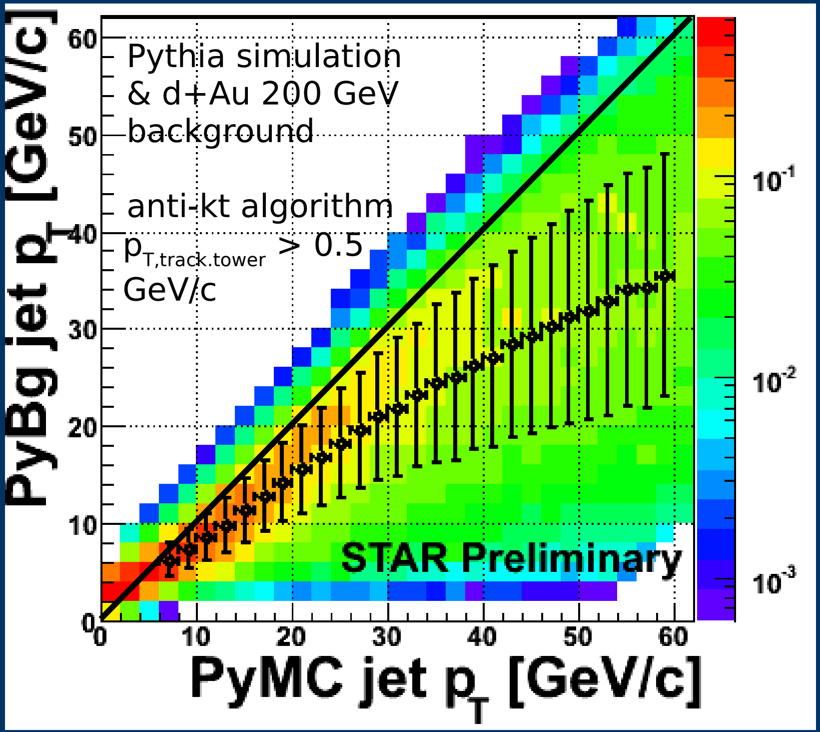
pseudorapidity dependence:



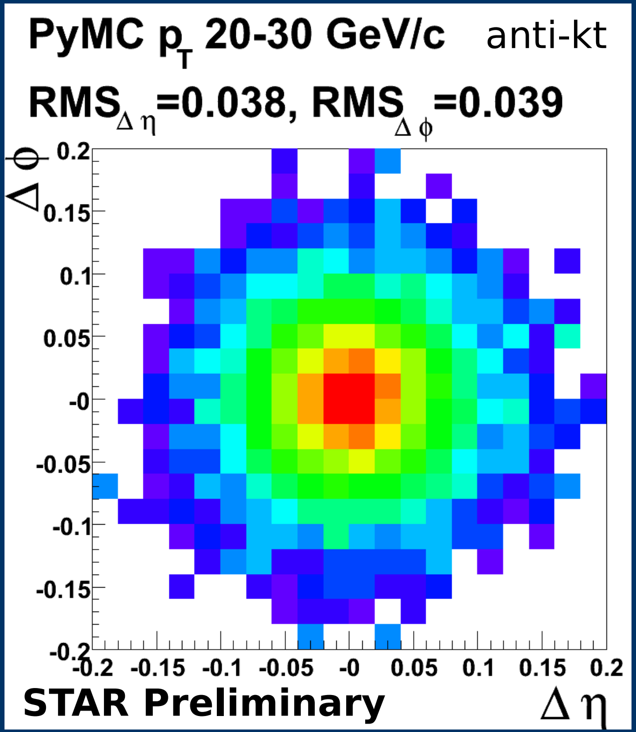
Pythia simulation

- Pythia 6.410, GEANT, STAR reconstruction software
- PyMC (particle level), PyGe (detector level)
- PyBg: reconstructed Pythia jet event inserted into d+Au event to estimate residual background effect (looking at matched jets: $\Delta R<0.2$)

jet p_T resolution: ~20%, shift due to K^0_L+n, dead towers, tracking efficiency, track+tower p_T cut

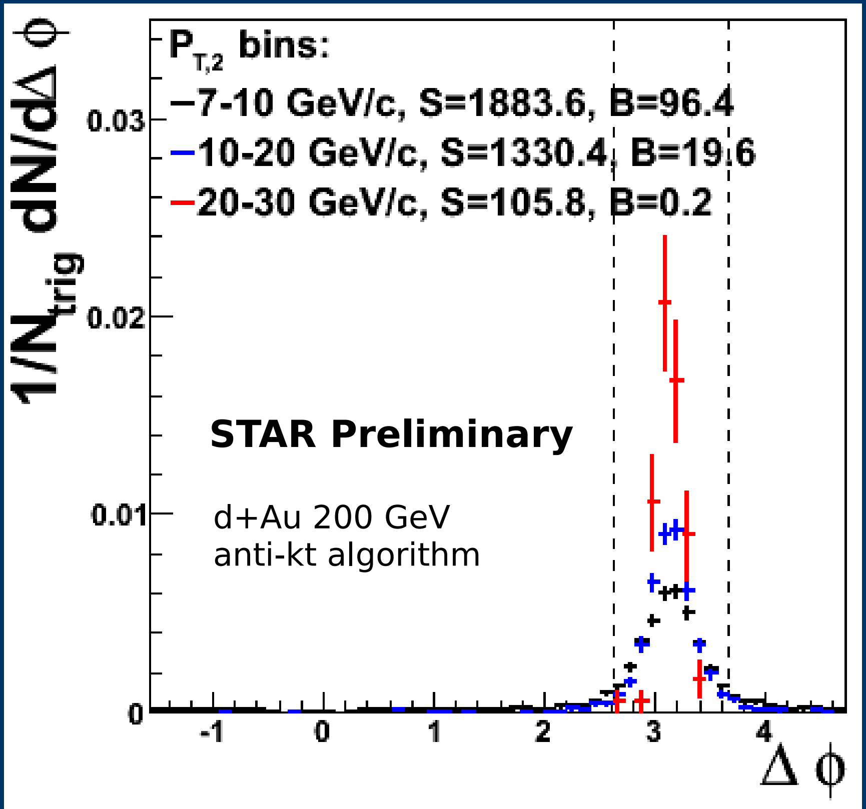


good angular resolution



Di-jets in d+Au collisions

- data used: High Tower (HT) trigger ($E_{T,tower}$ > 4.3 GeV)
- anti-kt, R=0.5, $p_{T,track/tower}$ > 0.5 GeV/c
- select two highest energy jets in event:
  - $p_{T,1} > p_{T,2}$
- use cut on $p_{T,2}$ to suppress background



clear back-to-back di-jet peak in ΔΦ

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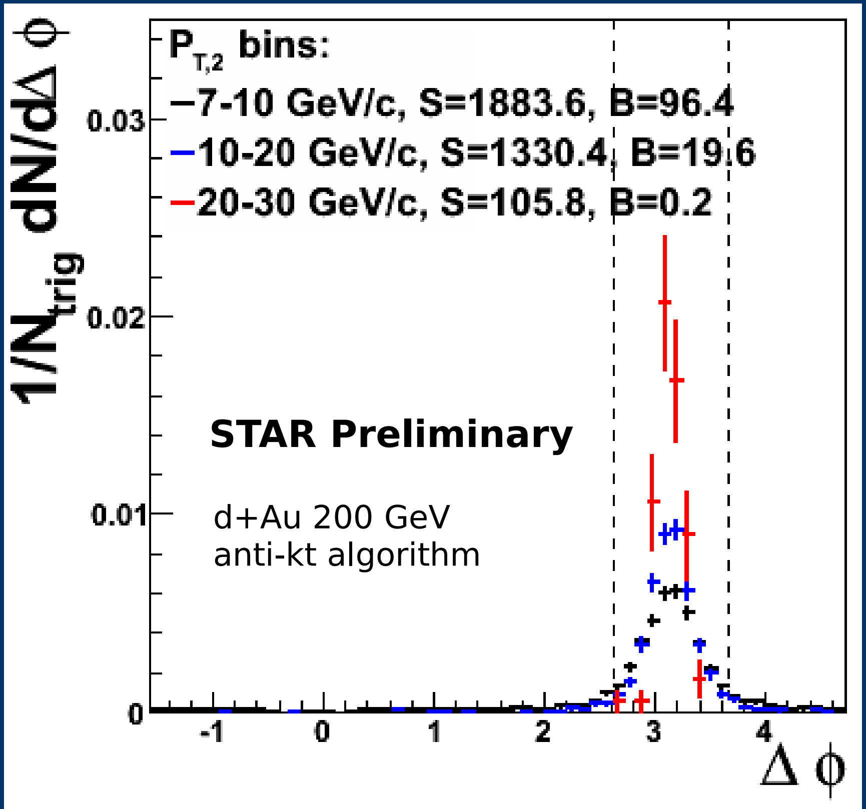
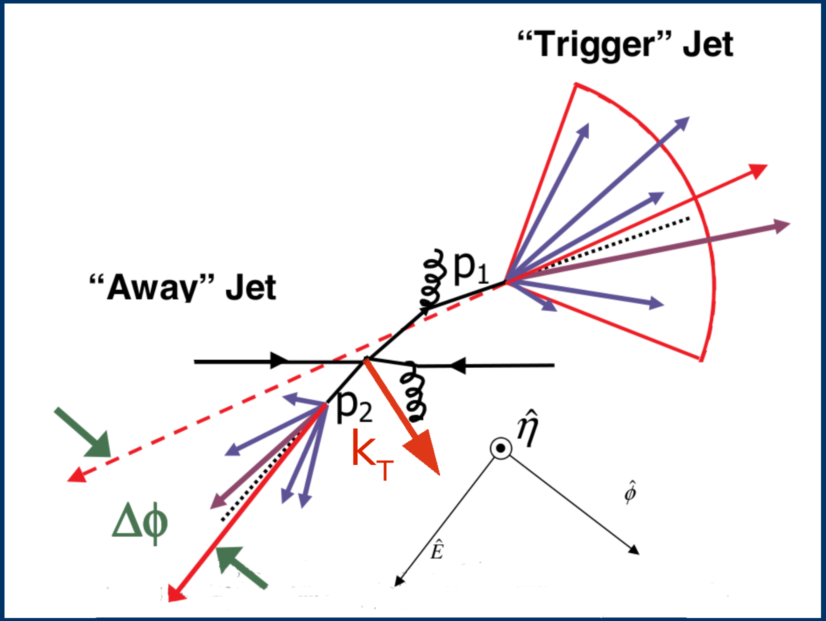
k_T effect (di-jet ΔΦ broadening):
intrinsic k_T + ISR,FSR (incl. CNM effects)





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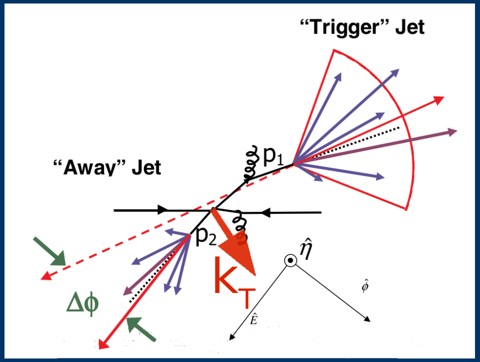
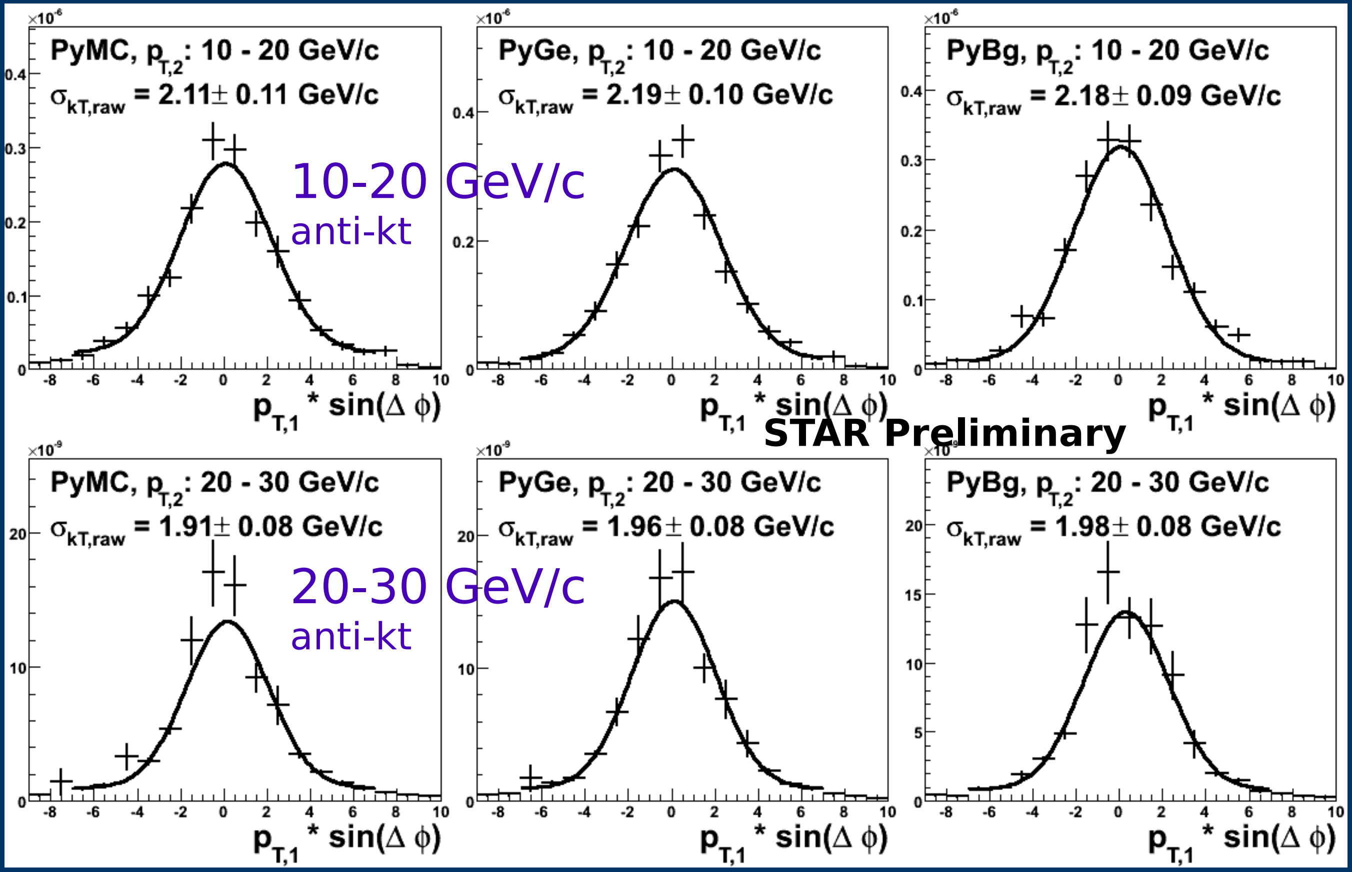
Measurement of k_T effect

- 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



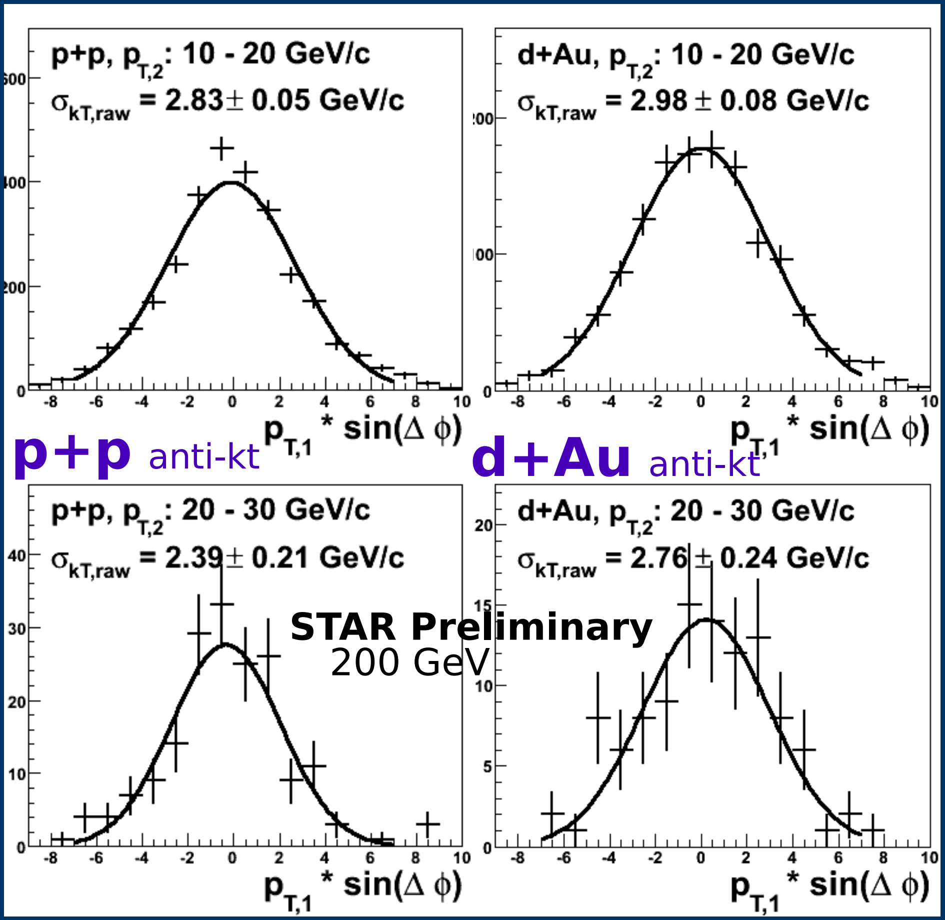
detector effects on k_T measurement:



...resulting detector effects are small, due to interplay of jet p_T and di-jet $\Delta\Phi$ resolutions

Do we see CNM effects in k_T?

- the same analysis technique in p+p and d+Au (run 8, HT trigger)



$\sigma_{kT,raw}$ (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 efficiency
- → expected to be less than 10%
- → largely correlated between p+p and d+Au

no strong Cold Nuclear Matter effect on jet k_T broadening seen

Jet p_T spectrum: d+Au

data used:

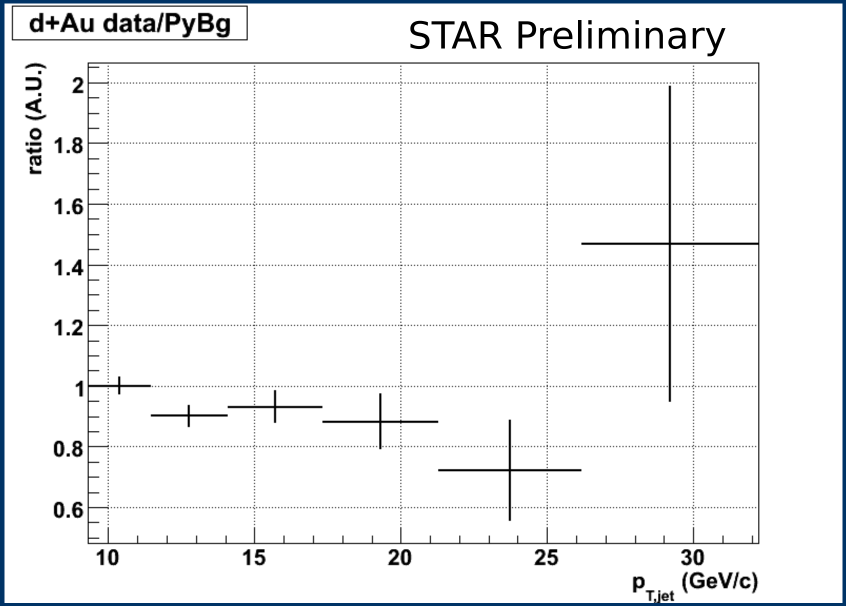
- 20% most central 200 GeV d+Au collisions
- minimum bias trigger
- 10M events after cuts
- p_T reach ~30 GeV/c

jets:

- anti-kt algorithm
- R = 0.4
- $p_{T,track/tower}$ > 0.2 GeV/c
- $|\eta_{jet}|$ < 0.55

bin-by-bin correction:

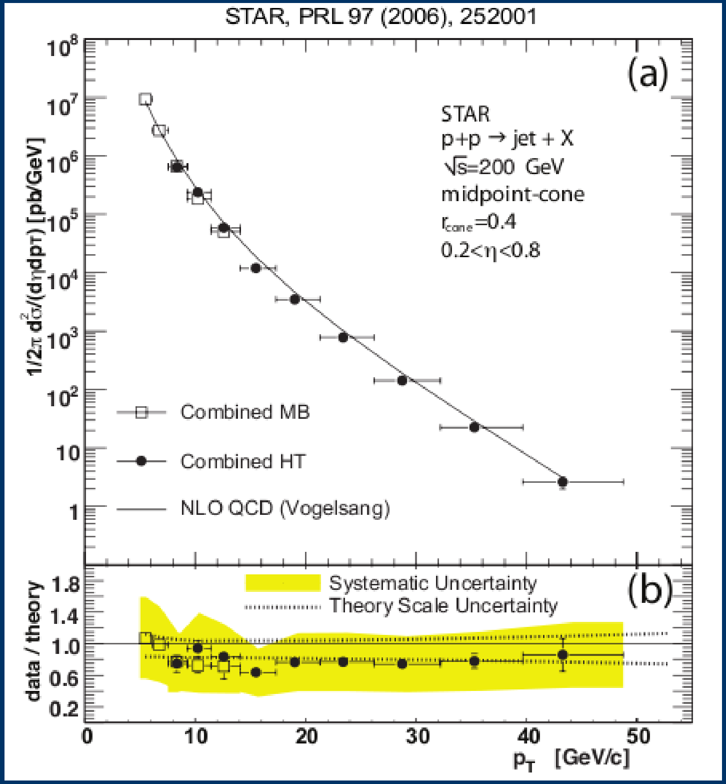
- ratio of jet p_T spectra PyMC/PyBg
- generalized efficiency:
  - efficiency of jet level cuts
  - p_T resolution
- applicable only if real data p_T spectrum and simulation (PyBg) have the same shape



Cross section & relation to p+p

compare to STAR p+p jet cross section:

- Mid Point Cone algorithm
- R = 0.4



number of binary collision scaling:

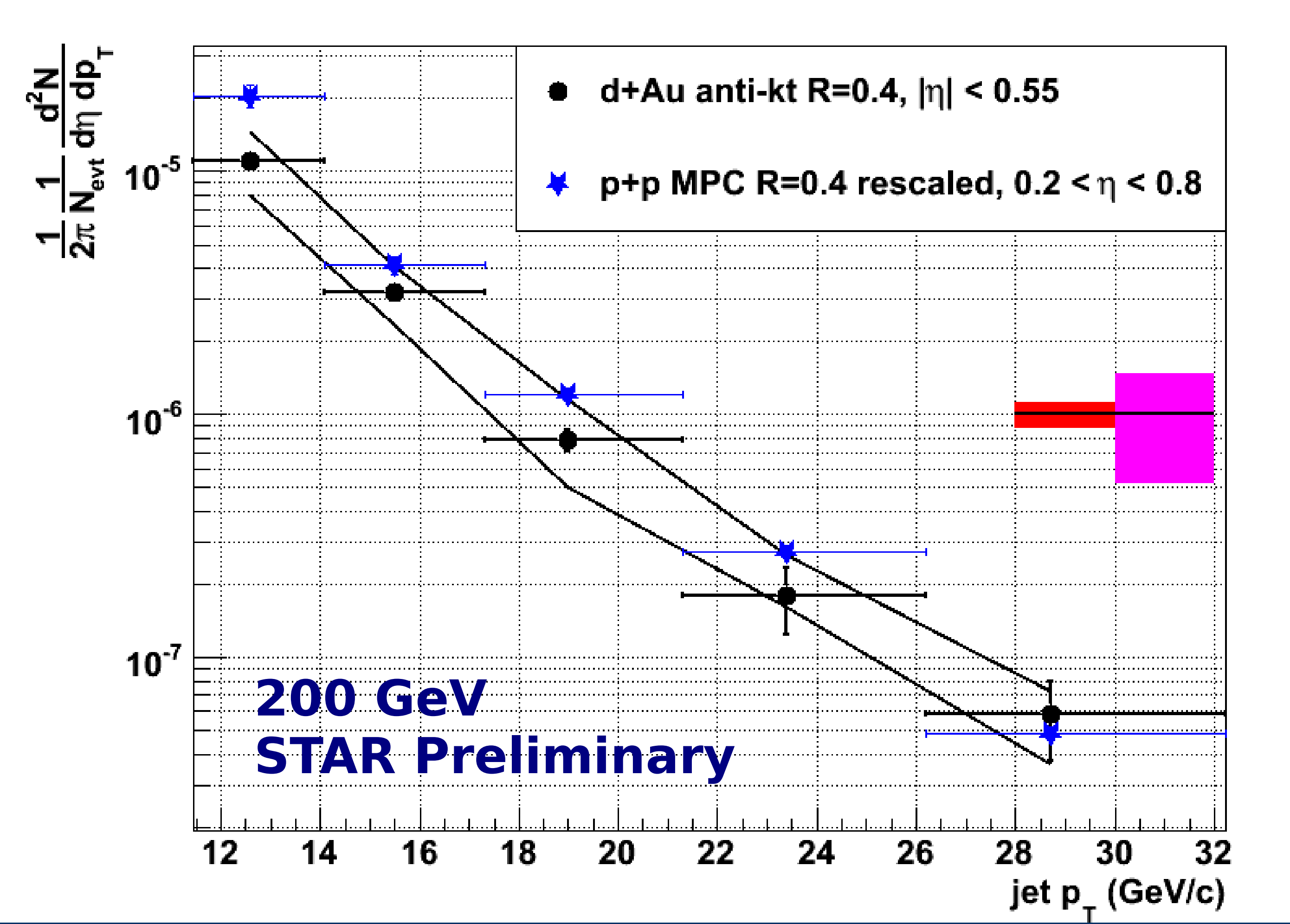
if there are no nuclear effects, hard processes scale according to $\langle N_{bin} \rangle$

for 20% most central run 8 d+Au collisions, $\langle N_{bin} \rangle = 14.6 \pm 1.7$ from MC Glauber

d+Au: jet yield normalised per event rescaling p+p to this level:
$Y_{jet,p+p\ (d+Au\ level)} = \sigma_{jet,p+p} / \sigma_{inel,p+p} * \langle N_{bin} \rangle$

$\sigma_{inel,p+p}$ = 42 mb is p+p inelastic cross section

d+Au jet p_T spectrum, p+p comparison



systematic errors:

black error band:
d+Au 5% jet energy scale uncertainty (mainly due to BEMC calibration, TPC tracking efficiency)

red box: $\langle N_{bin} \rangle$ 12% uncertainty

magenta box: p+p total normalization uncertainty (including jet energy scale)

note different η range (less than 15% effect)

- **d+Au: no significant deviation from N_{bin} scaled p+p**
- **further studies of systematics ongoing**

Outlook: towards jet R_{dAu}

- need to constrain the systematic uncertainties
  - improve understanding of jet energy scale
  - use run 8 p+p data as reference: most systematic uncertainties should cancel out
  - use the same jet finding algorithm for p+p

- use High Tower trigger data for d+Au
  - extend p_T reach to ~50 GeV/c

Conclusion

Di-jet measurement in 200 GeV d+Au and p+p collisions:

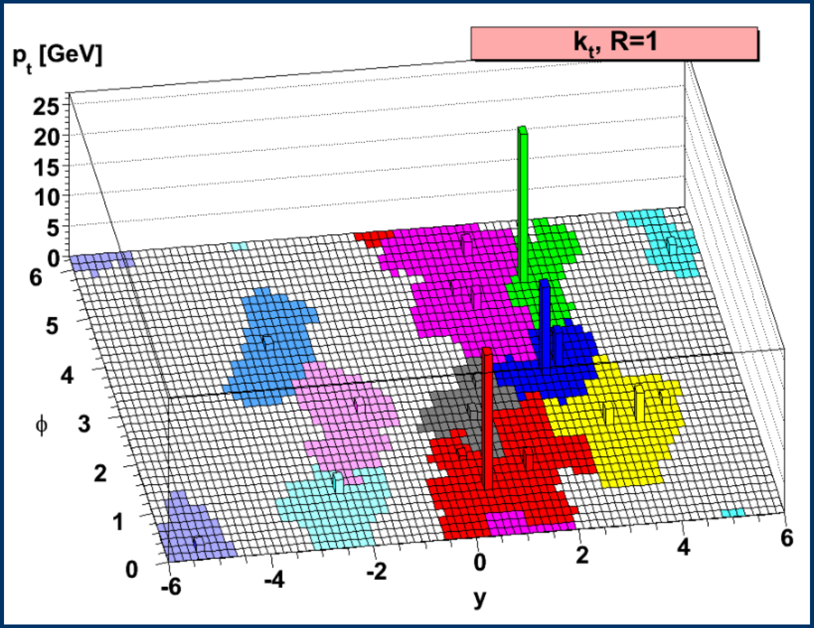
- no strong k_T broadening observed due to CNM effects

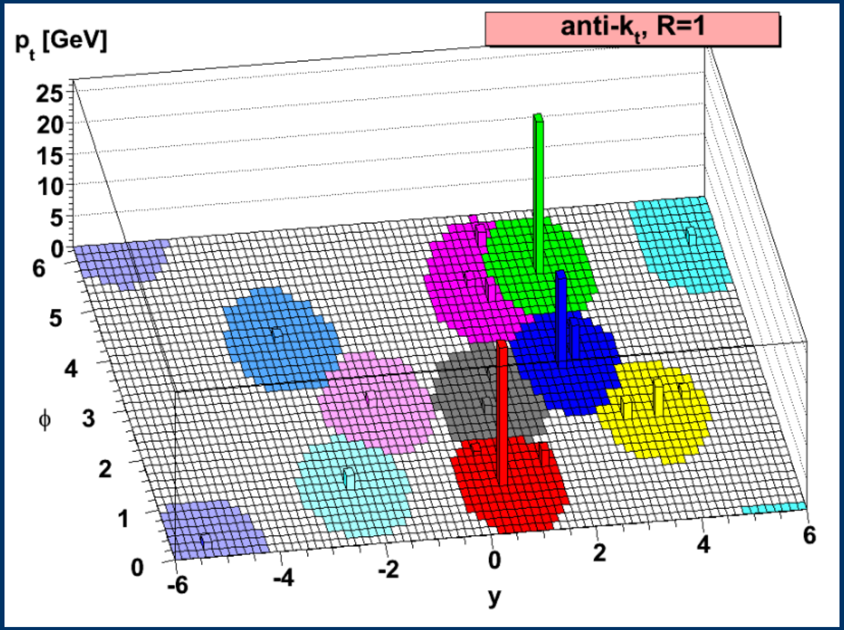
Inclusive jet p_T spectrum in 200 GeV d+Au collisions:

- no significant deviation from N_{bin} scaled p+p
- large systematic uncertainties
- High Tower trigger will allow to reach much higher p_T
- new measurement from run 8 p+p data will allow to constrain systematic uncertainties and construct R_{dAu} for jets

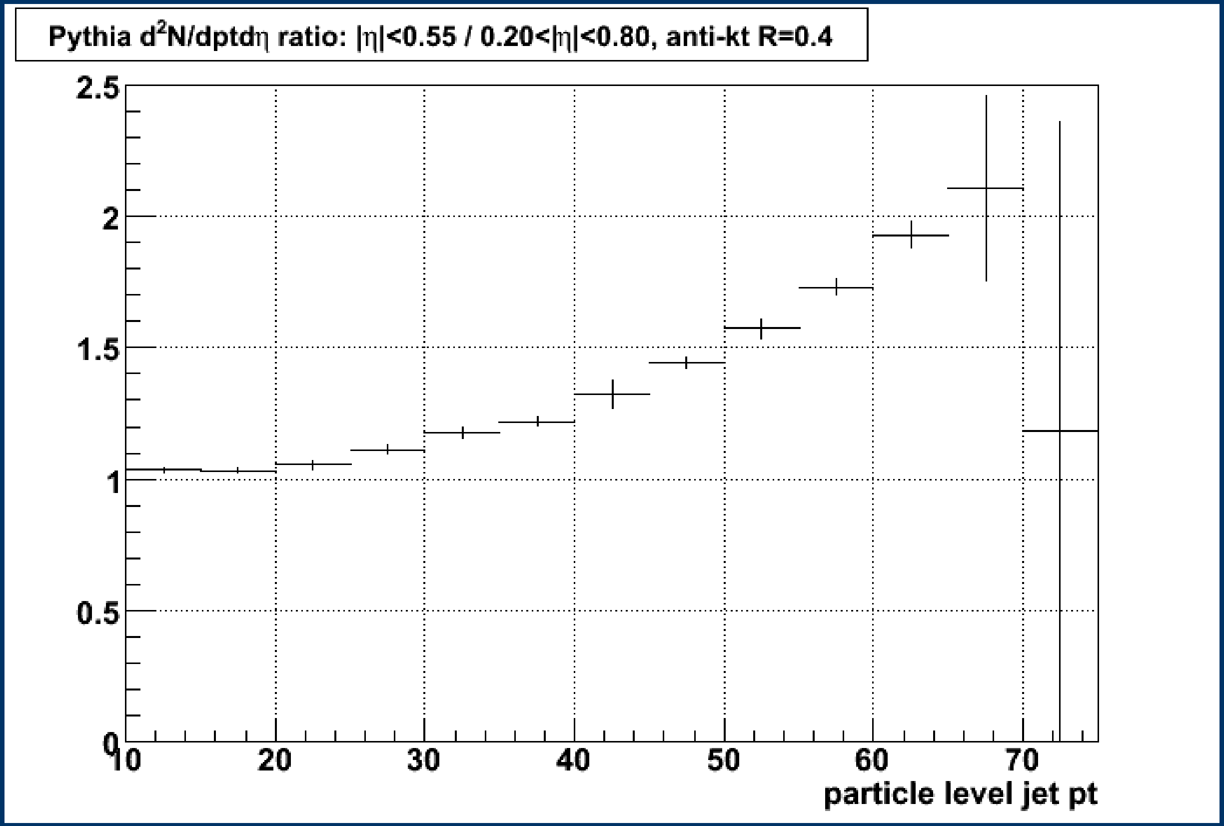
Backup

jet areas/shapes: kt, anti-kt





jet cross-section: eta dependence



a few % below 20 GeV
~15% effect at 30 GeV
significant effect at higher pt!

Recombination schemes

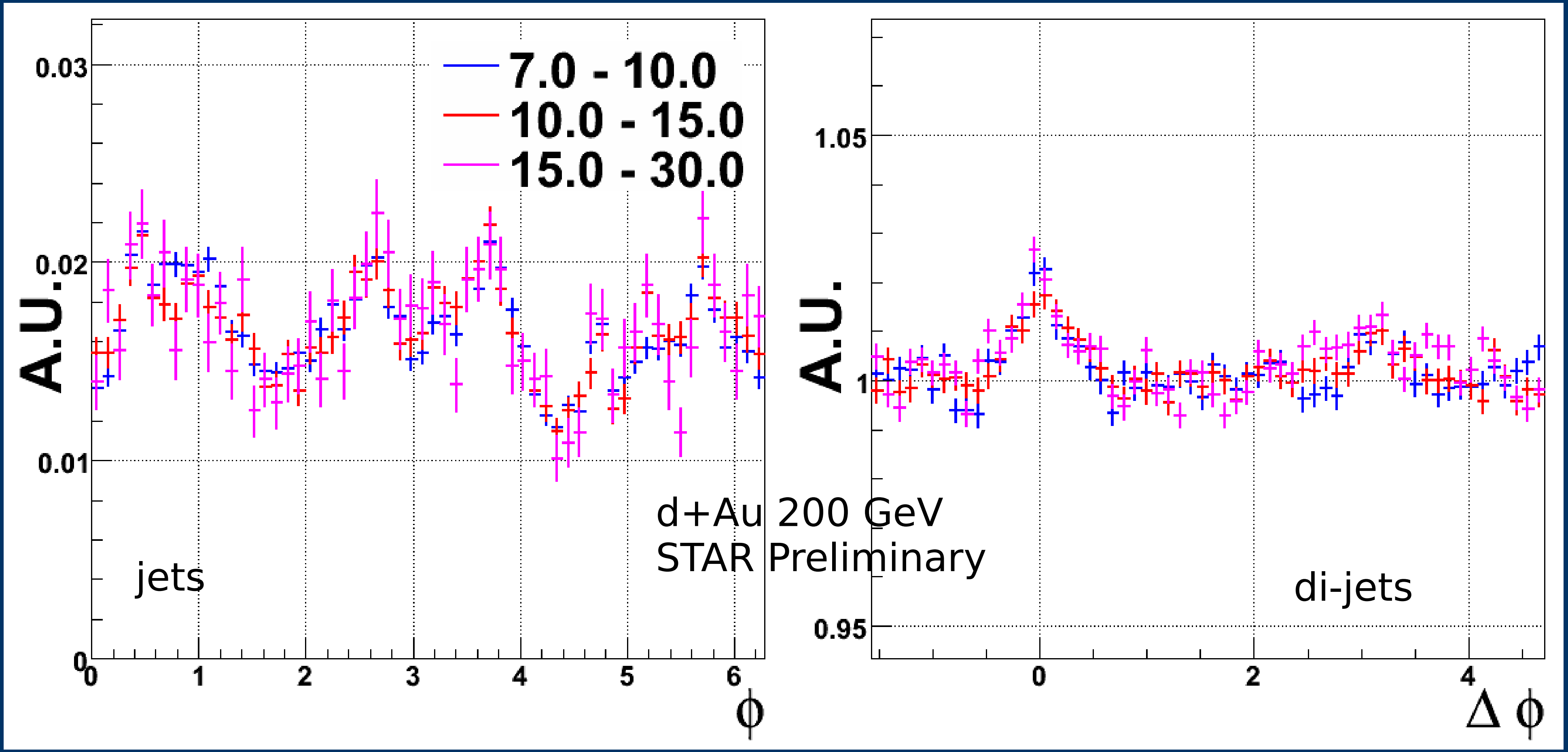
how are 4-momenta of 2 merged object summed?

we are using E scheme (FastJet default):
4-momenta are simply added
choice of mass of measured tracks, towers: zero
jet aquires mass

other possibilities:
p scheme: all objects mass-less & 3-momenta are summed

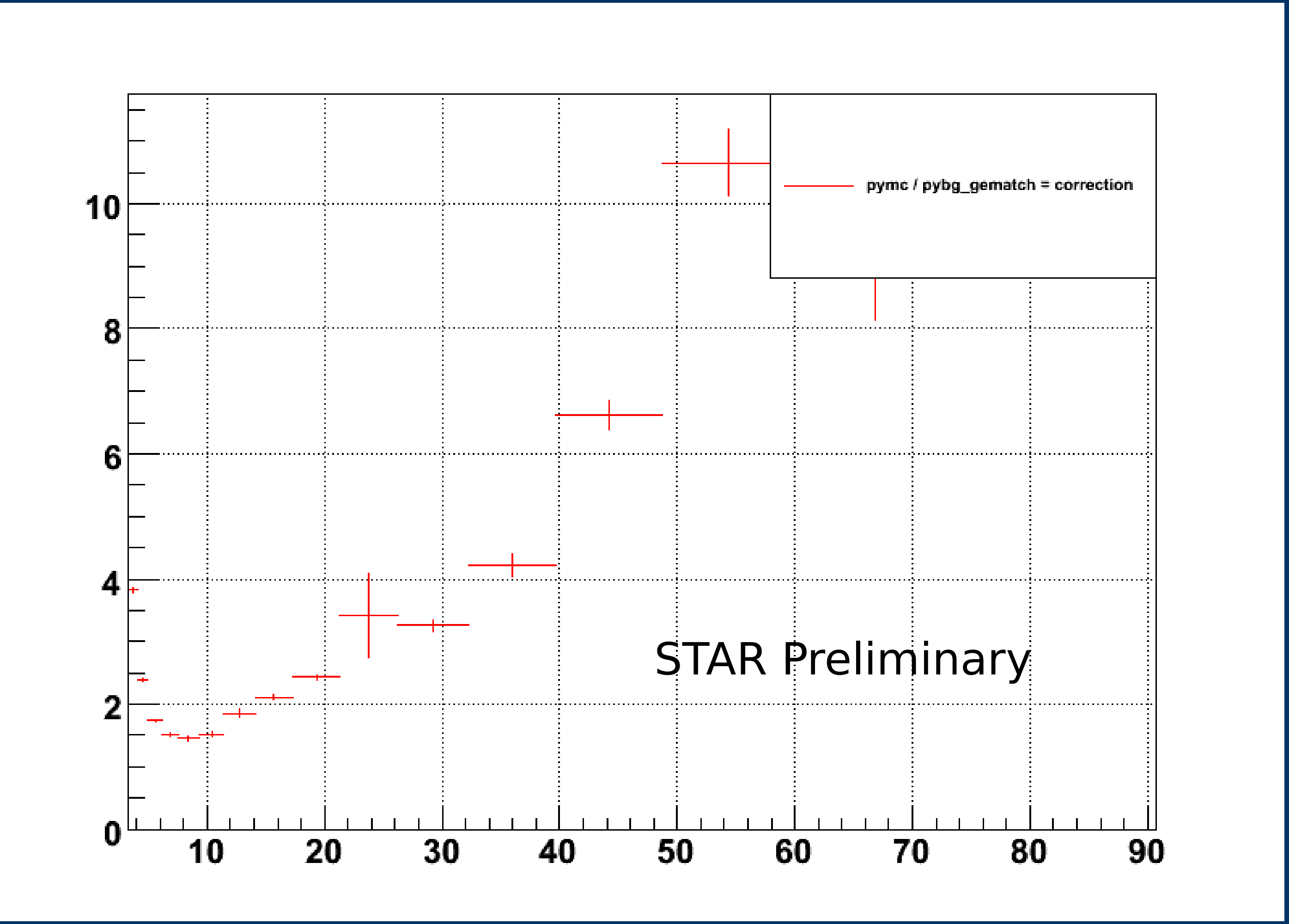
effect of these expected to be small compared to other systematic effects,
currently under study at STAR

Phi and ΔPhi acceptance



big effect on single jets, small effect on di-jets...

Correction factor



combination of jet cuts, tracking efficiency, p_T resolution...

Modified nuclear PDF

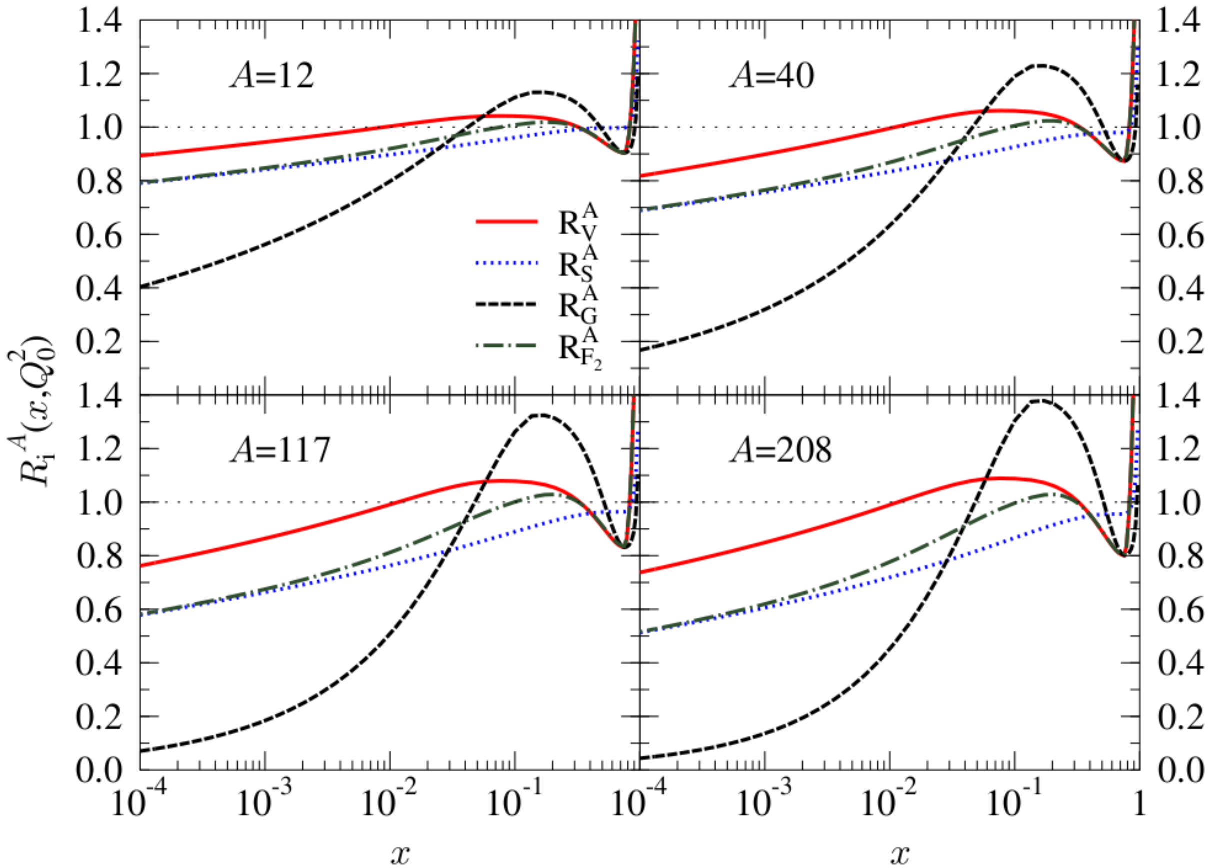
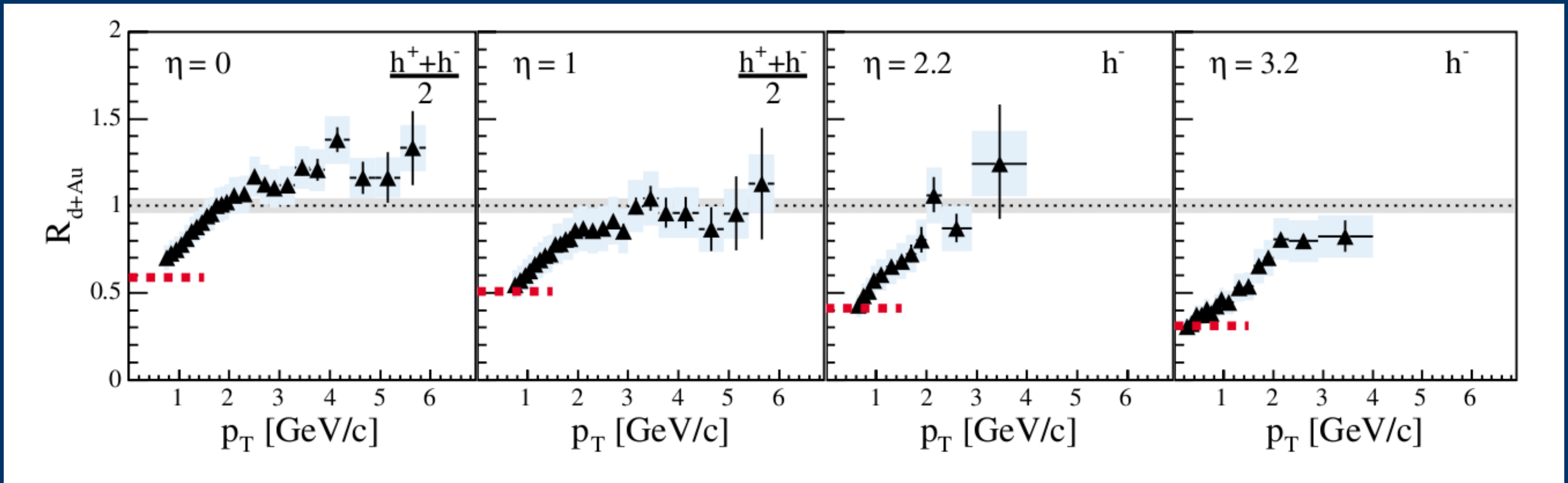


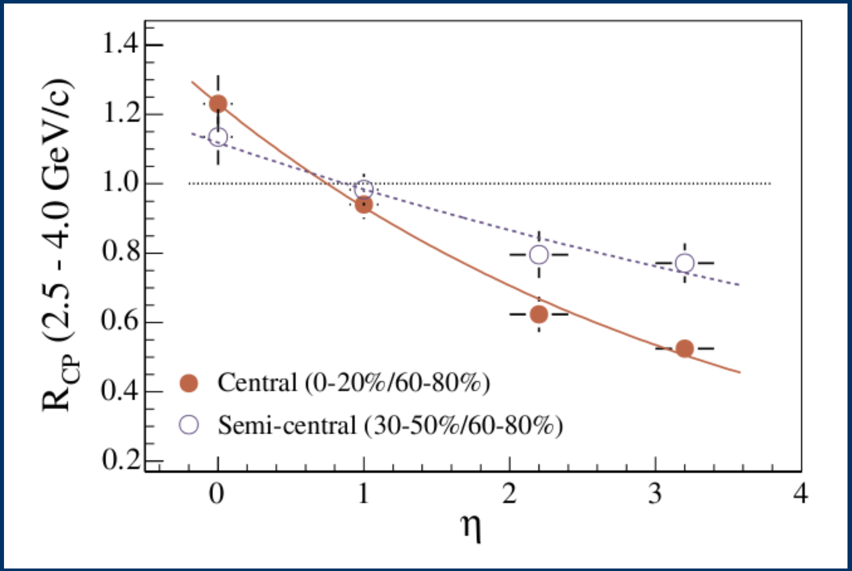
Figure 2: The nuclear modification factors R_V^A, R_S^A and R_G^A for C, Ca, Sn, and Pb at $Q_0^2 = 1.69\,\mathrm{GeV}^2$. The DIS ratio $R_{F_2}^A$ is shown for comparison.

K. J. Eskola, H. Paukkunen, C. A. Salgado, JHEP 0807:102,2008

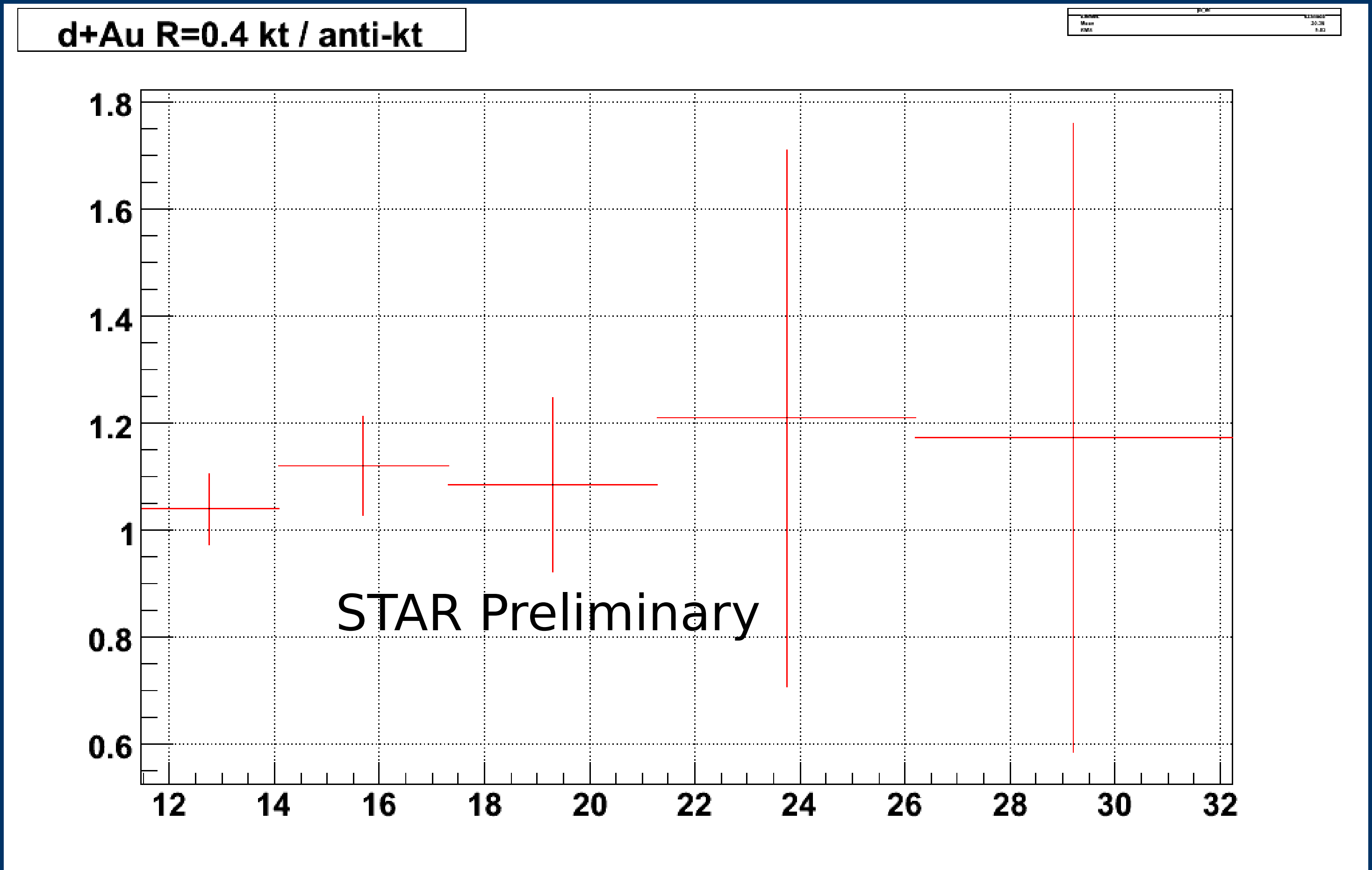
Single particle spectra

from BRAHMS Collaboration, Phys.Rev.Lett.93 242303 (2004)





anti-kt comparison to kt



kt ~10% higher, consistent with kt jets having slightly bigger area!