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

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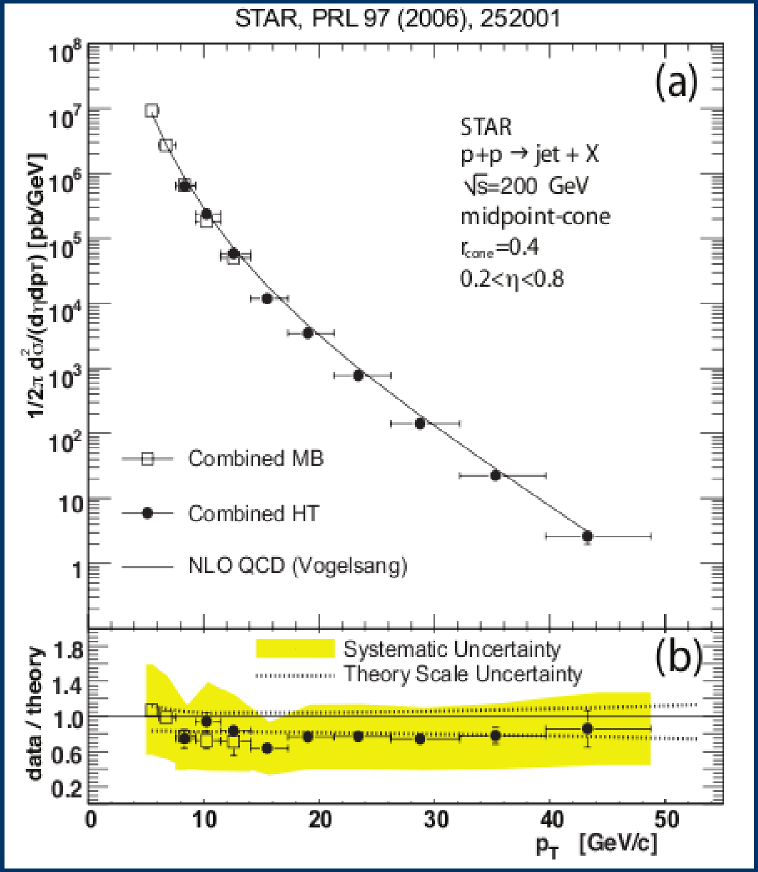
Outline

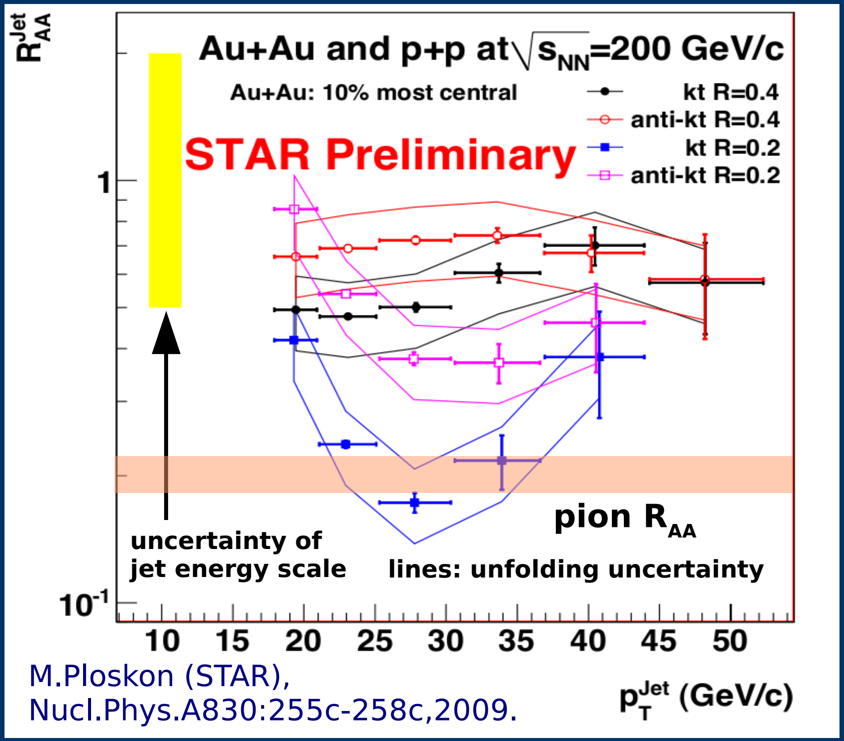
- motivation
- STAR experiment at RHIC
- jet reconstruction technique
- di-jets in p+p and d+Au collisions
- jet p_T spectrum from d+Au collisions

Motivation

jets:

- well calibrated probe (pQCD)
- access to partonic kinematics
- Heavy-Ion collisions: direct study of jet quenching





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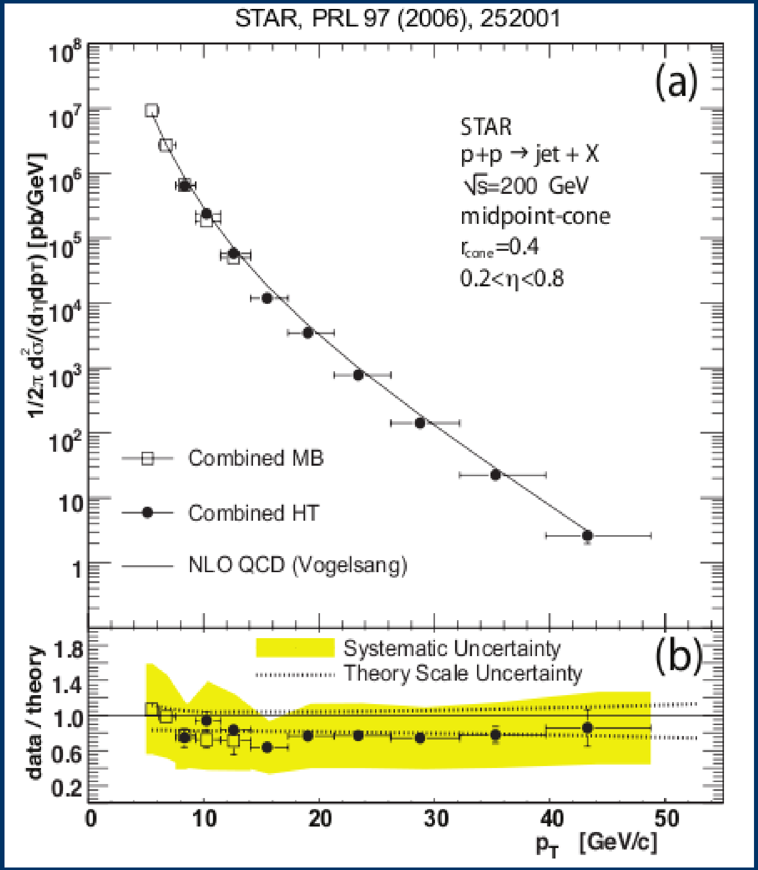
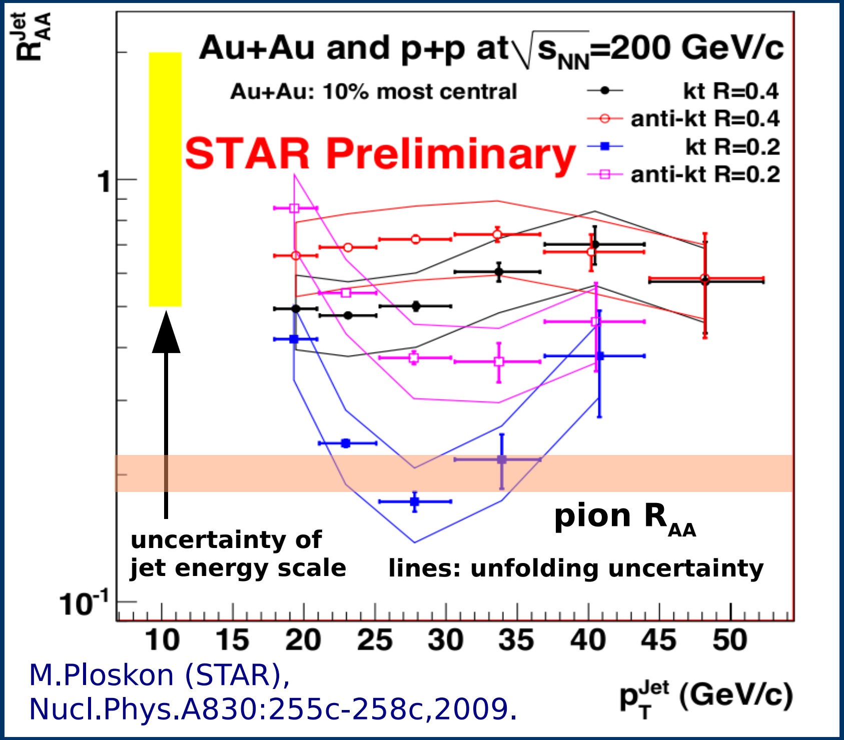
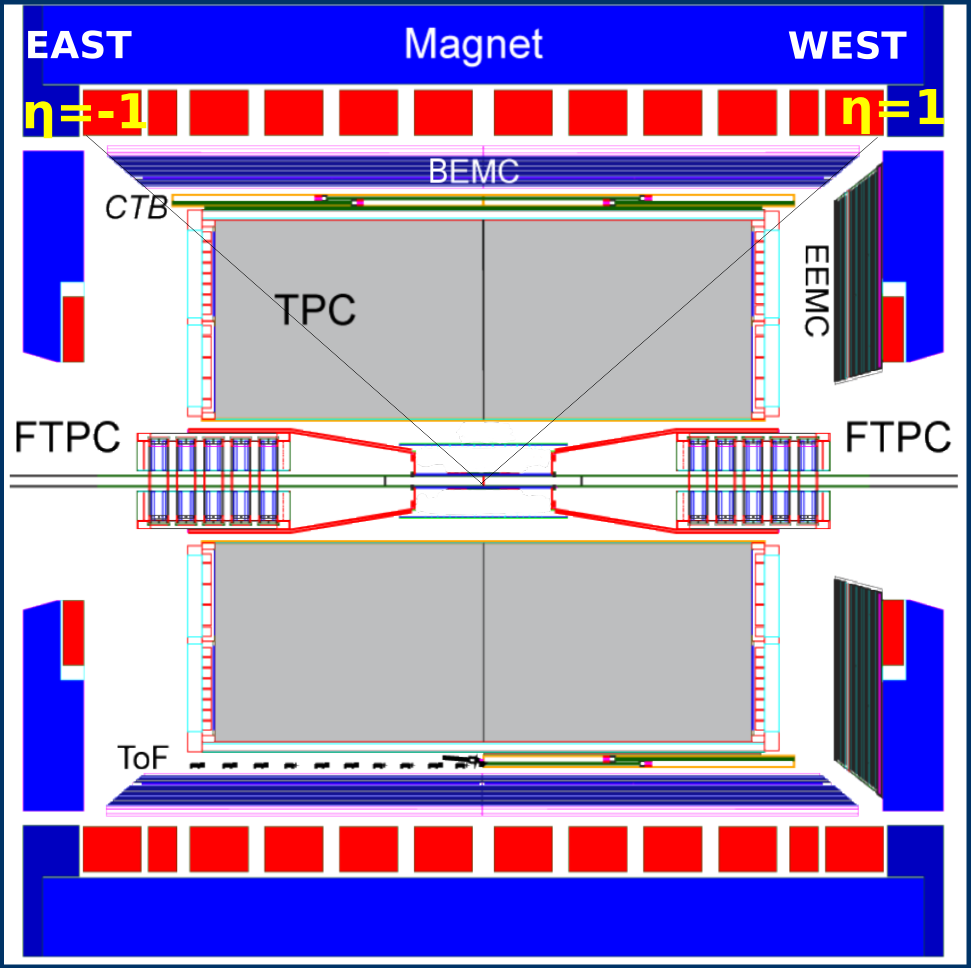




d+Au: estimate initial state effects

- 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)

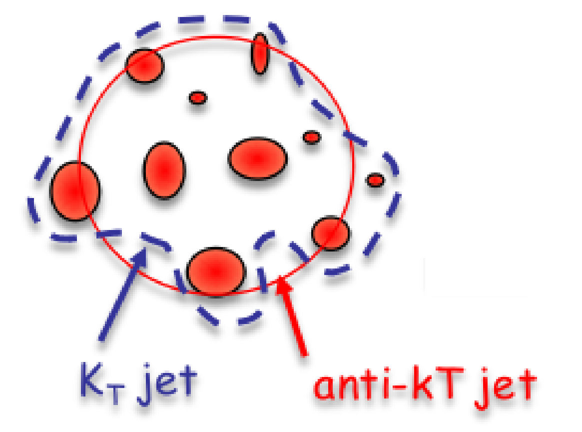
Jet reconstruction

recombination algorithms - FastJet package

Cacciari, Salam and Soyez, JHEP0804 (2008) 005.

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

- n=2: kt, n=-2: anti-kt
- R: resolution parameter
- recombination: E scheme with massless particles



kt algorithm:

- starts with low p_T particles
- sensitive to background!

anti-kt algorithm:

Cacciari, Salam and Soyez, JHEP0804 (2008) 063.

- starts with high p_T particles
- resilient w.r.t. soft radiation
- flexible w.r.t. hard radiation
- less sensitive to background!

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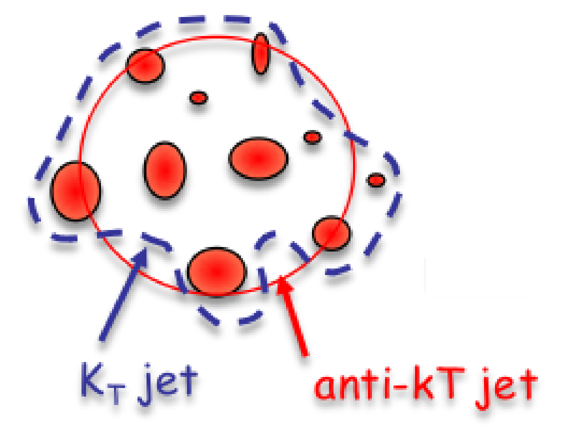

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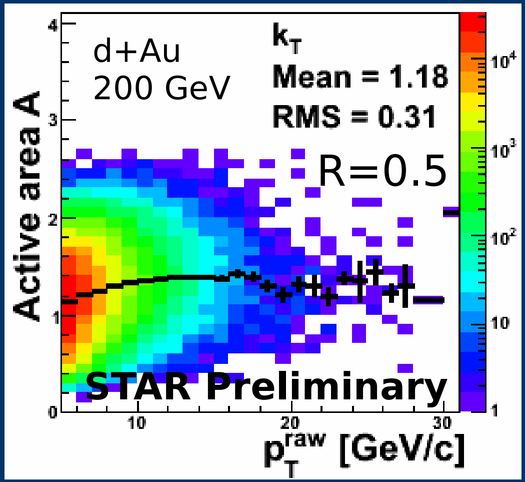
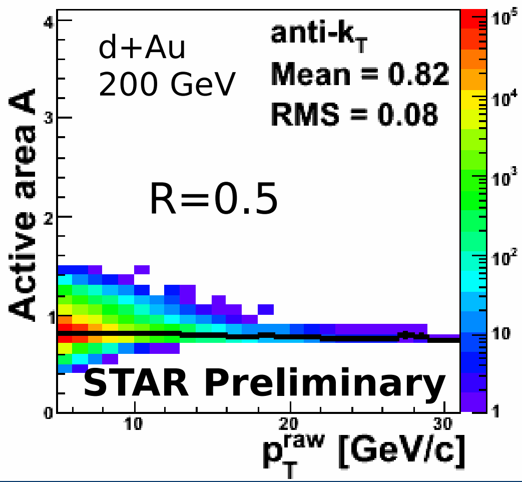
active jet area A: using ghost particles

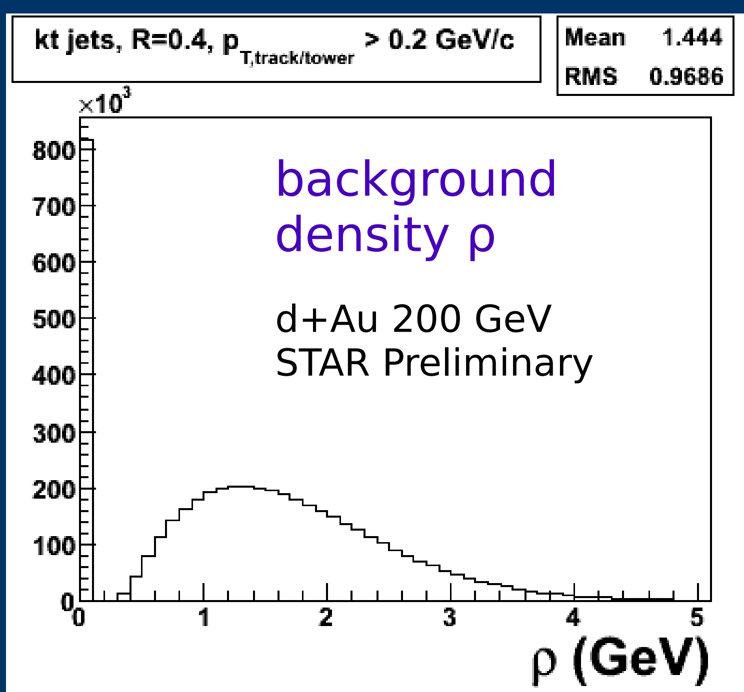




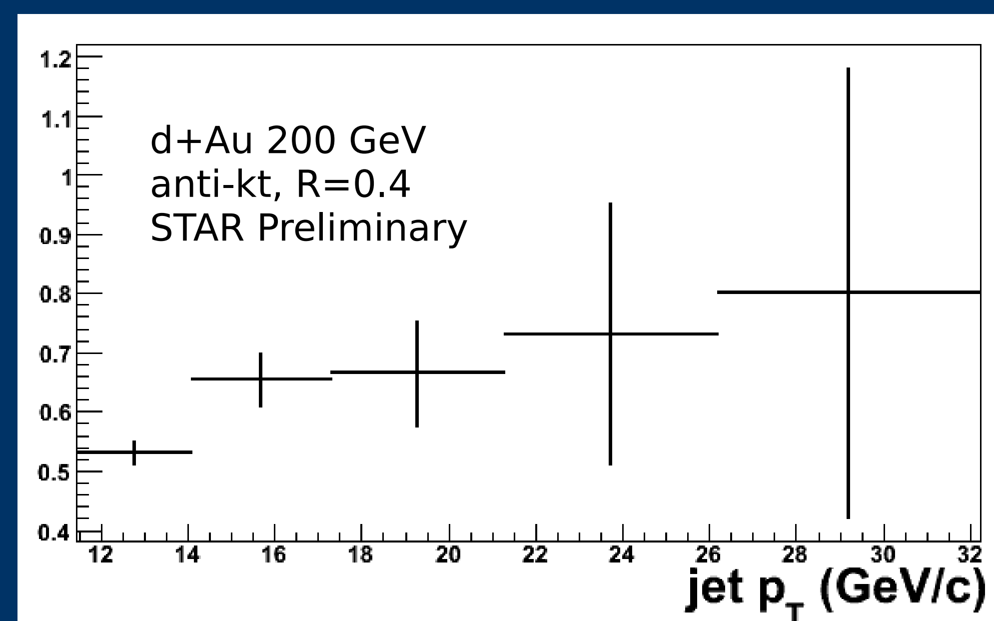
d+Au background

underlying event background

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



spectra ratio: bg-subtracted / raw



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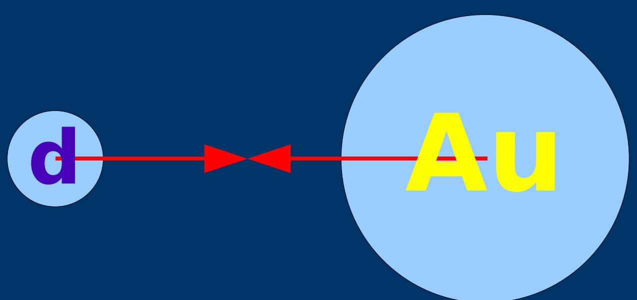
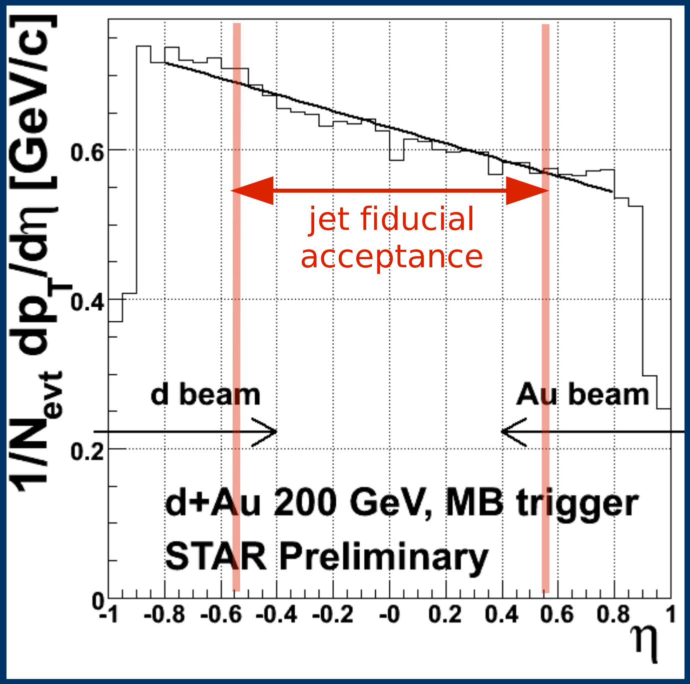


asymmetric collision

pseudorapidity dependence:



included in bg.subtraction

<2% effect on jet p_T spectrum: negligible systematic uncertainty!

Pythia simulation

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

jet p_T spectrum:

- very sensitive to Jet Energy Scale
- precise determination of tracking efficiency needed
- lowered the tracking efficiency in Pythia jet simulation to match the one from realistic detector simulation (“embedding”) for run 8

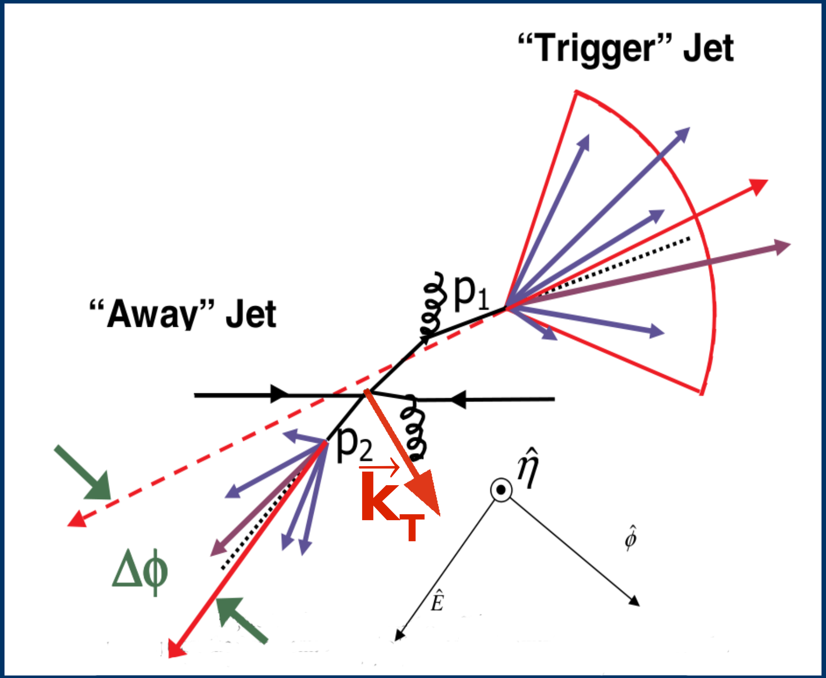
systematic uncertainty:

- run 8 tracking efficiency in jets under study now
- current worst case uncertainty is 10%
- taken this as the systematic uncertainty on the charged fraction of jets

k_T and di-jets in d+Au collisions

k_T effect (di-jet $\Delta\Phi$ broadening):

- intrinsic k_T + ISR,FSR (+CNM effects)
- radiation:
  - soft: Gaussian shape
  - hard(NLO): power-law tails
- can be measured through azimuthal component of $\vec{k}_T$



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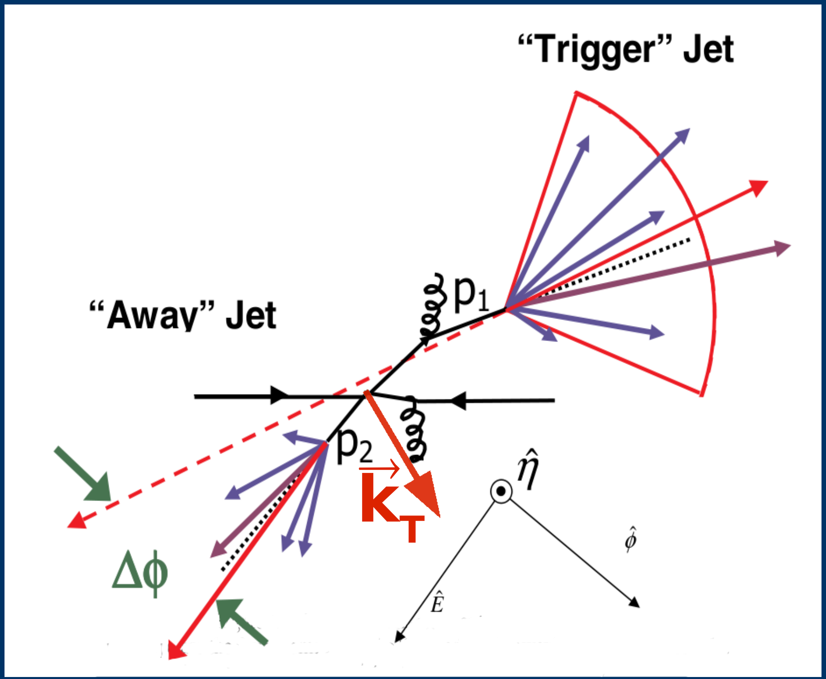
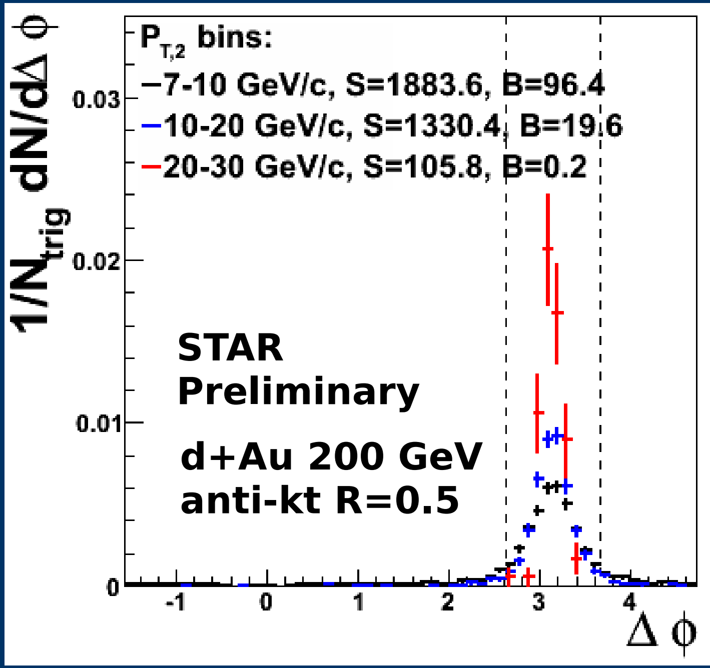


- data: High Tower (HT) trigger: $E_{T,tower}$ > 4.3 GeV
- anti-kt, R=0.5, $p_{T,track/tower}$ > 0.5 GeV/c
- 2 highest energy jets in event: $p_{T,1} > p_{T,2}$

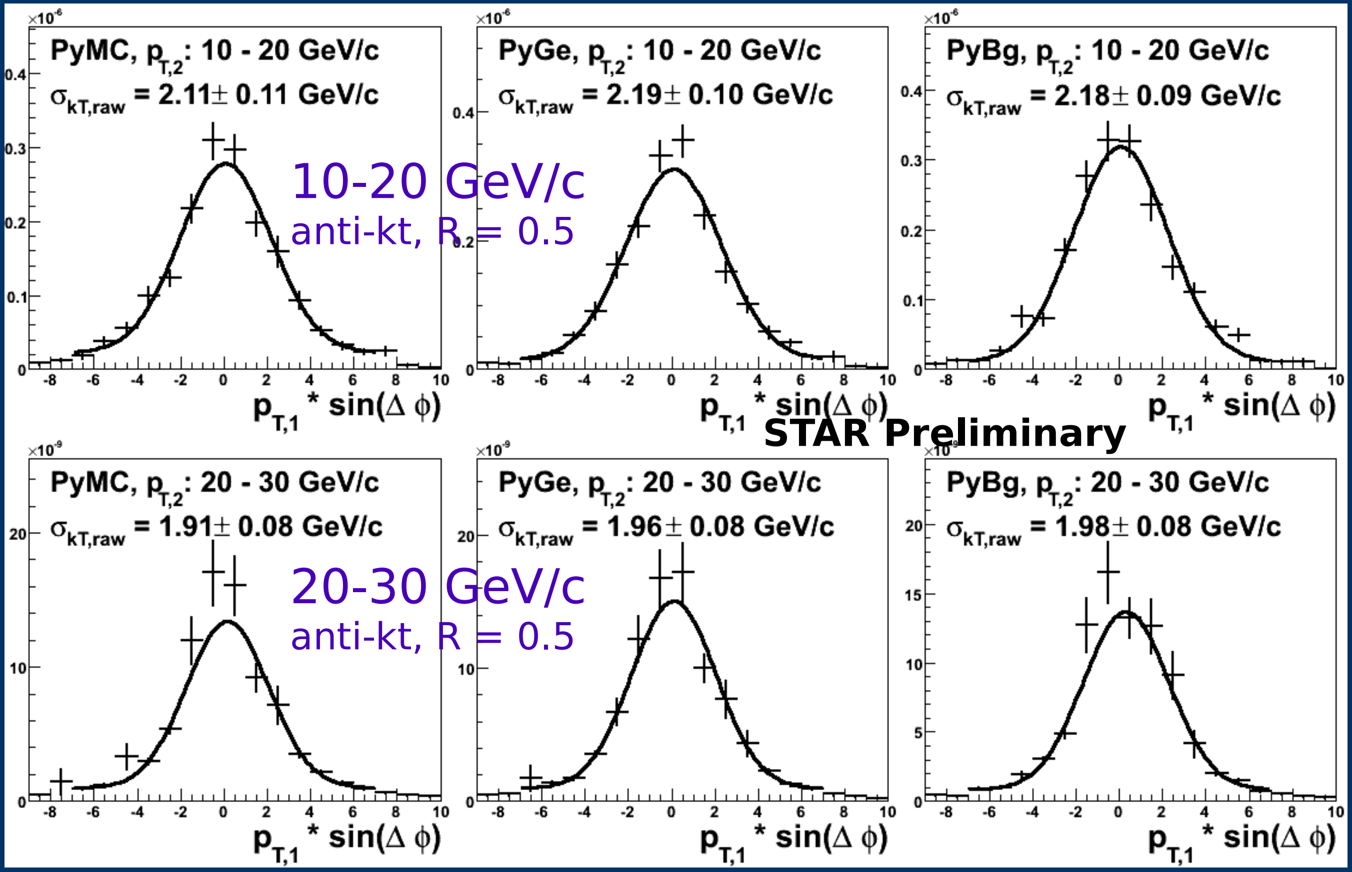


clear back-to-back di-jet peak

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
- sensitive mostly to intrinsic k_T and soft radiation

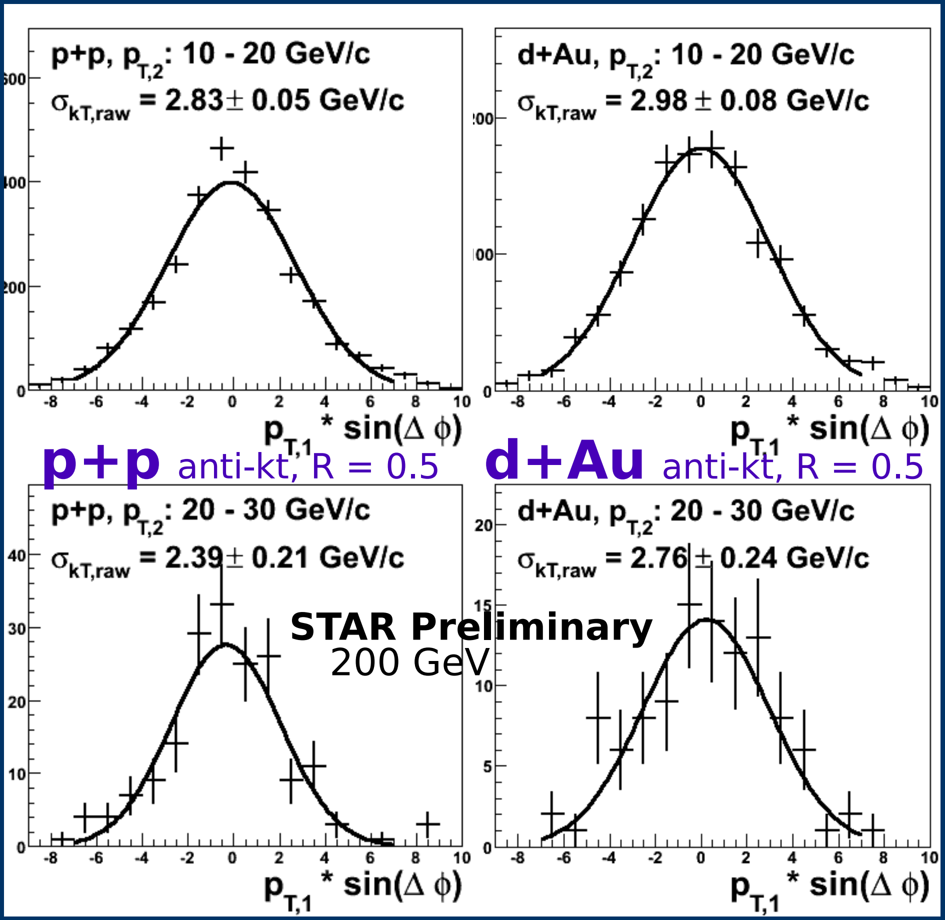
detector effects on k_T measurement:



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

Do we see CNM effects on k_T?

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



p_T – averaged values:

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

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

systematic uncertainties:

- neglecting detector effects
- BEMC calibration
- TPC tracking efficiency
- → in total expected to be less than 10%
- → evaluation under way...

no strong effect on jet k_T broadening seen

Towards jet p_T spectrum

200 GeV d+Au data:

- 20% most central collisions from minimum bias trigger data sample
- 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
- $|\eta_{jet}| < 0.55$

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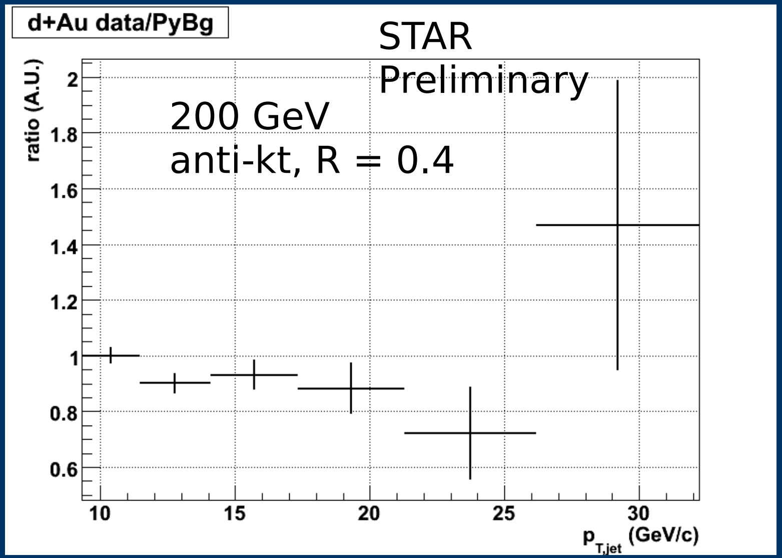
bin-by-bin correction:

- 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



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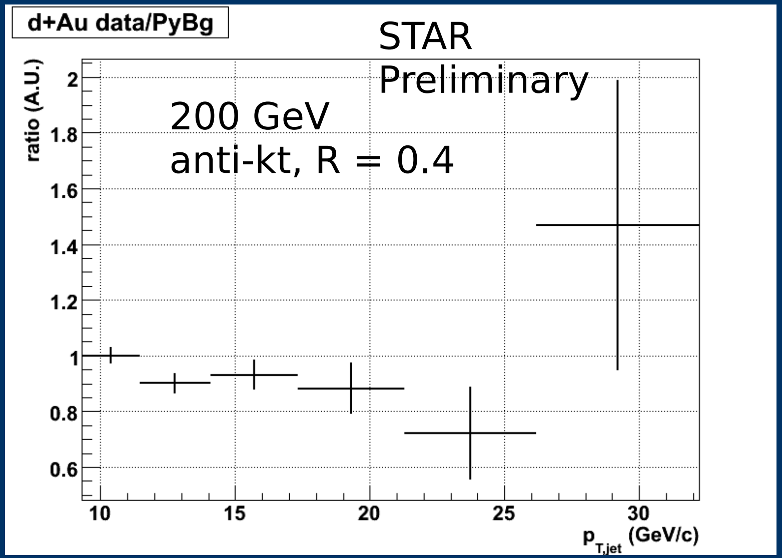


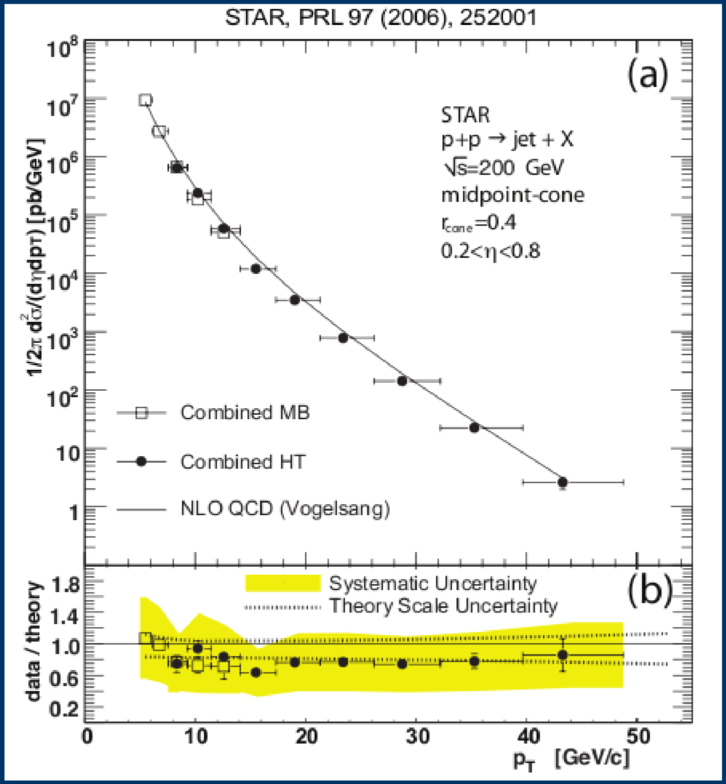
leading syst.uncertainty:
Jet Energy Scale (JES)

charged tracks: 10% uncertainty in TPC tracking eff. (will be less with jet embedding)
towers: 5% uncertainty in BEMC calibration
total uncertainty on average 7%

Jet 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:

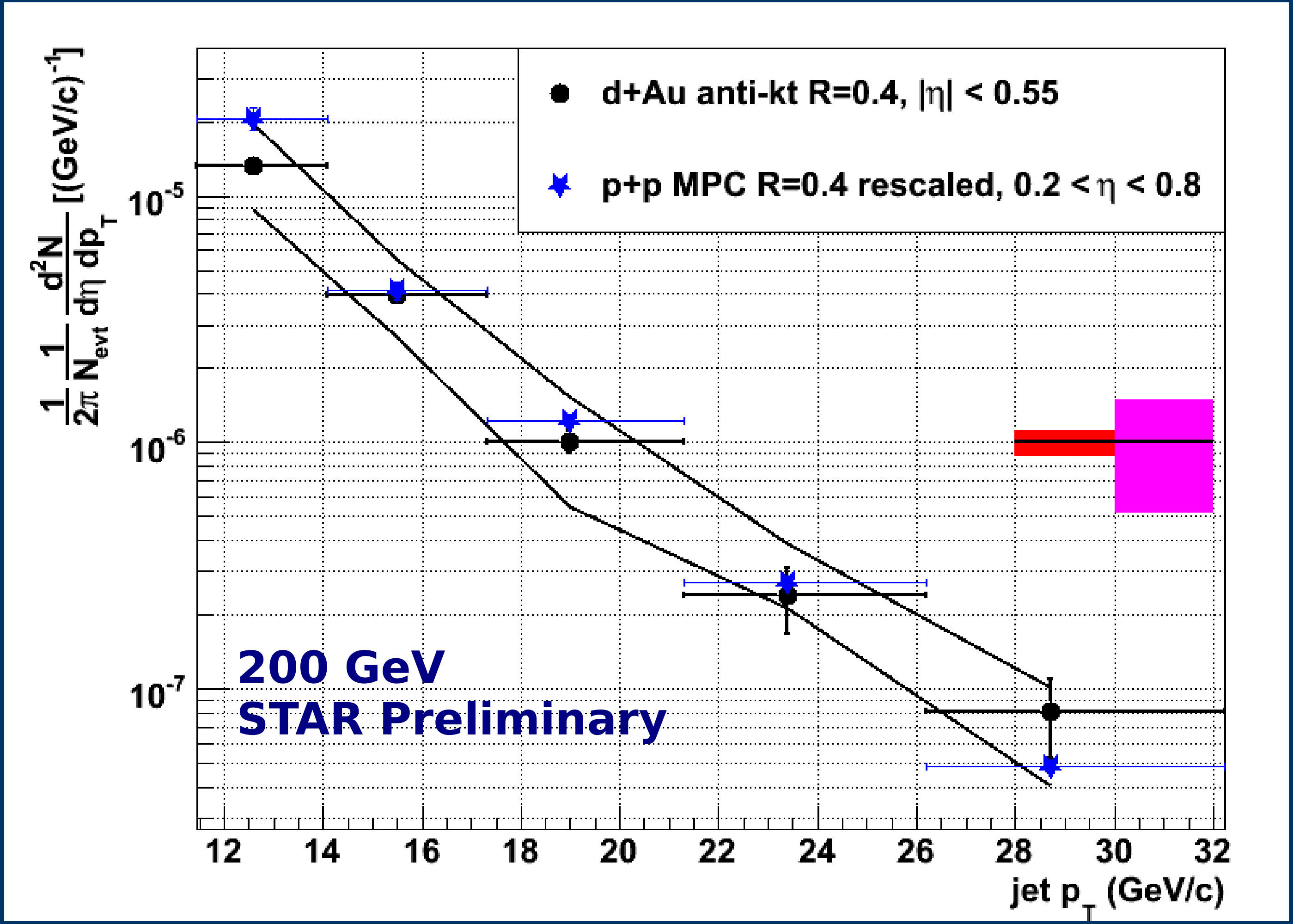
if there are no nuclear effects, hard processes scale according to $\langle N_{bin} \rangle$

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 JES uncertainty (TPC: 10%, BEMC: 5%)

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

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

note
- different η range
- different jet algorithm

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

Conclusion

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

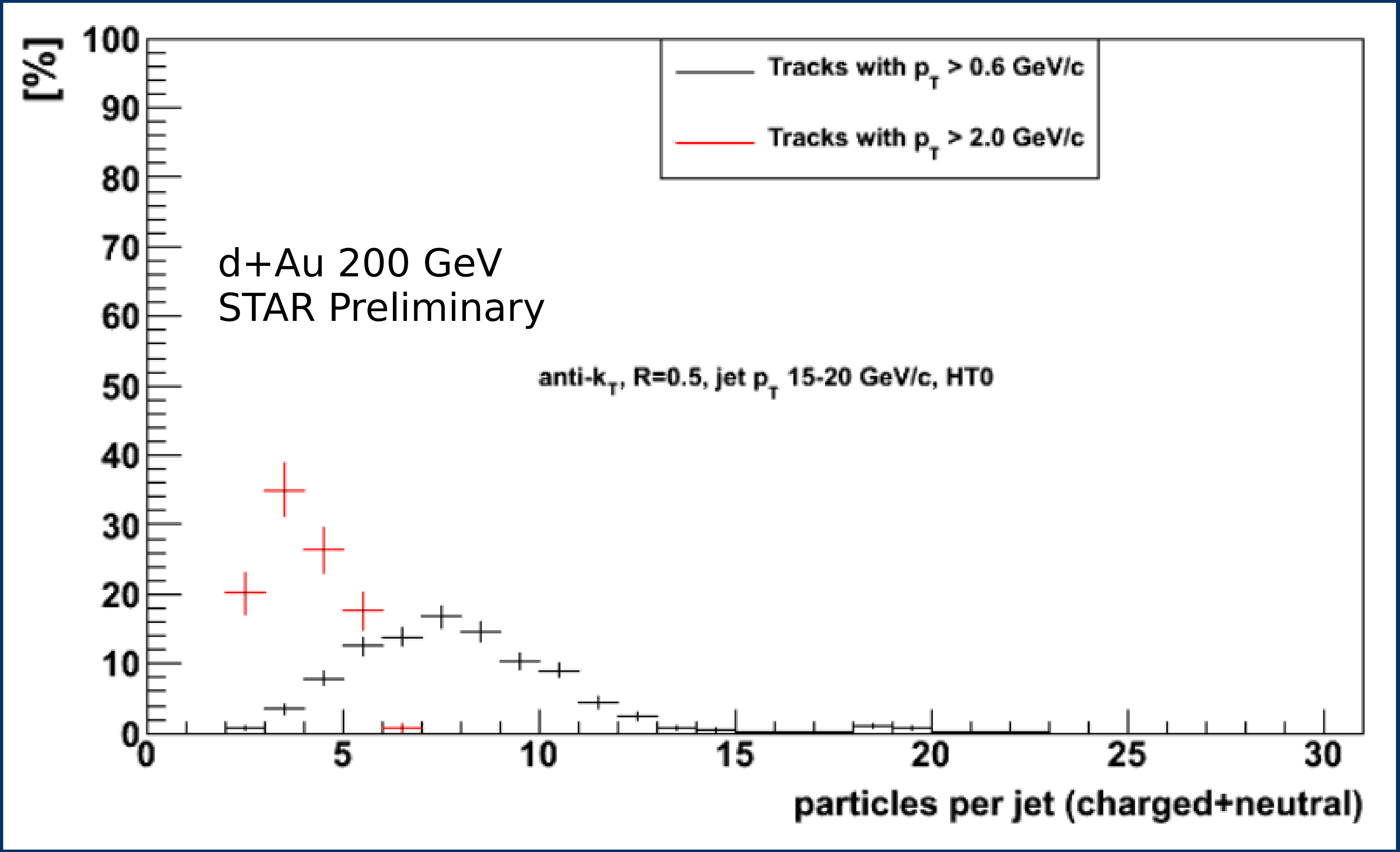
- no strong CNM effects on k_T broadening observed

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

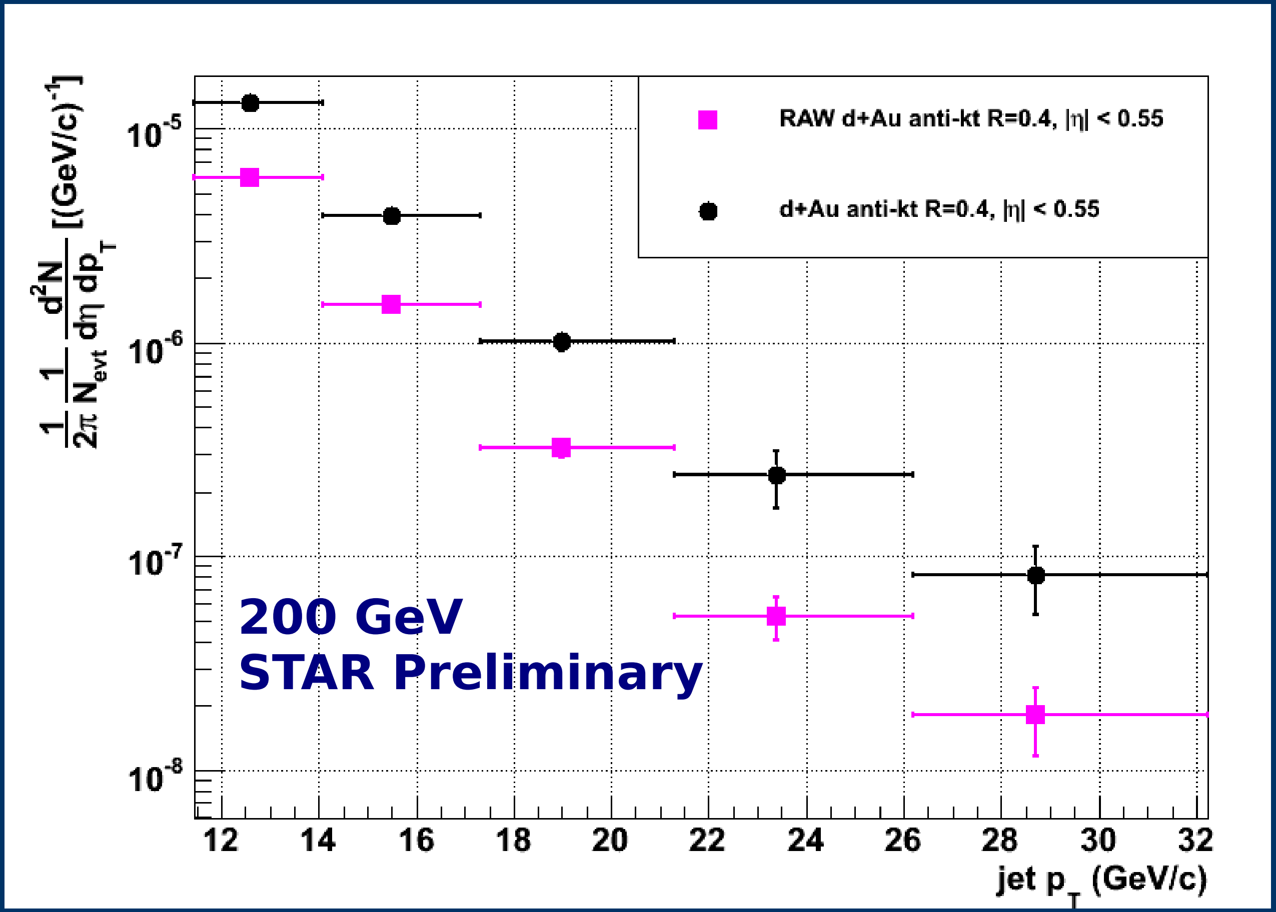
- no significant deviation from N_{bin} scaled p+p
- large systematic uncertainties
- improvements under way:
  - jet embedding
  - run 8 p+p data
- moving towards jet R_{dAu}

Backup

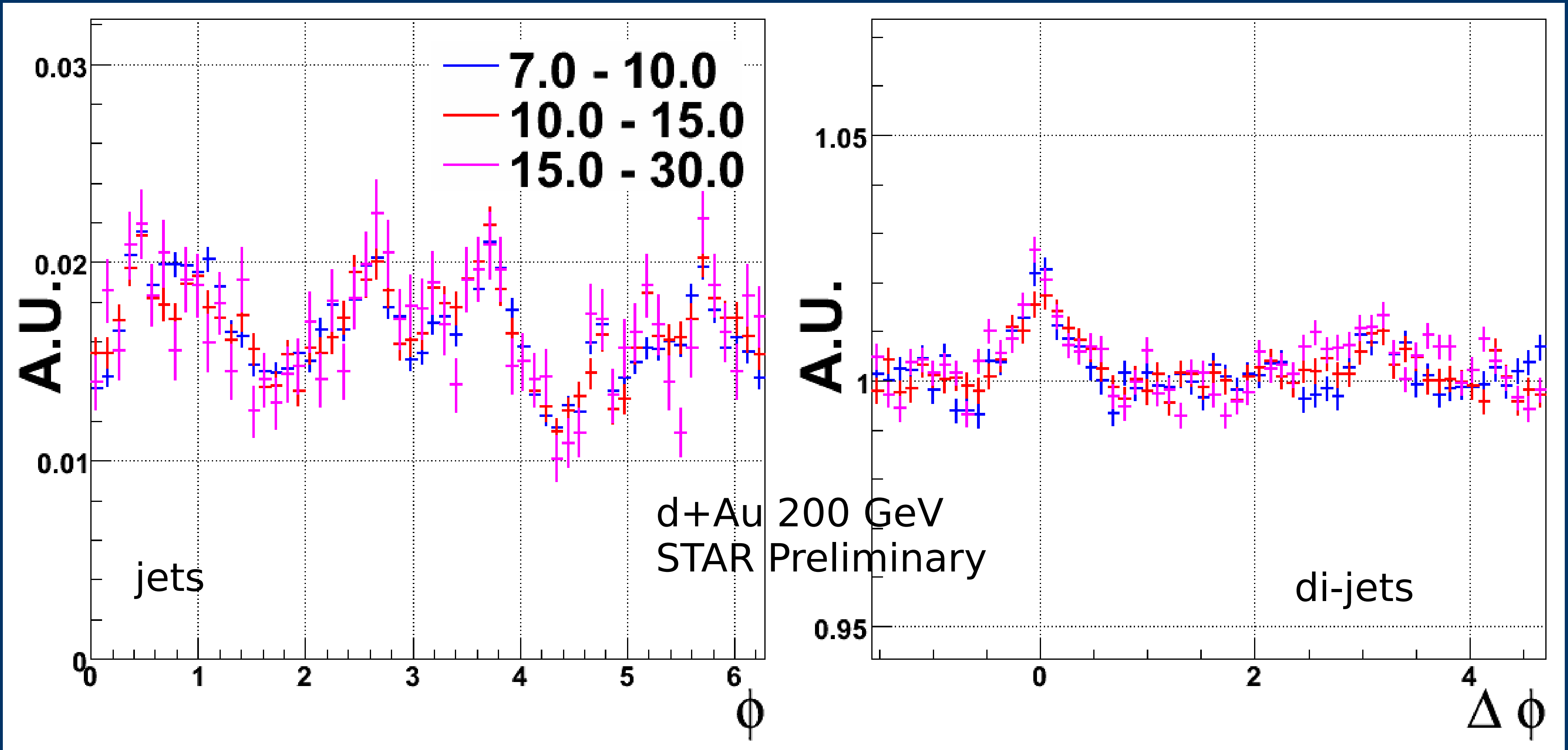
Number of particles per jet



Jet spectrum: effect of correction



Phi and ΔPhi acceptance



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

Modified nuclear PDF

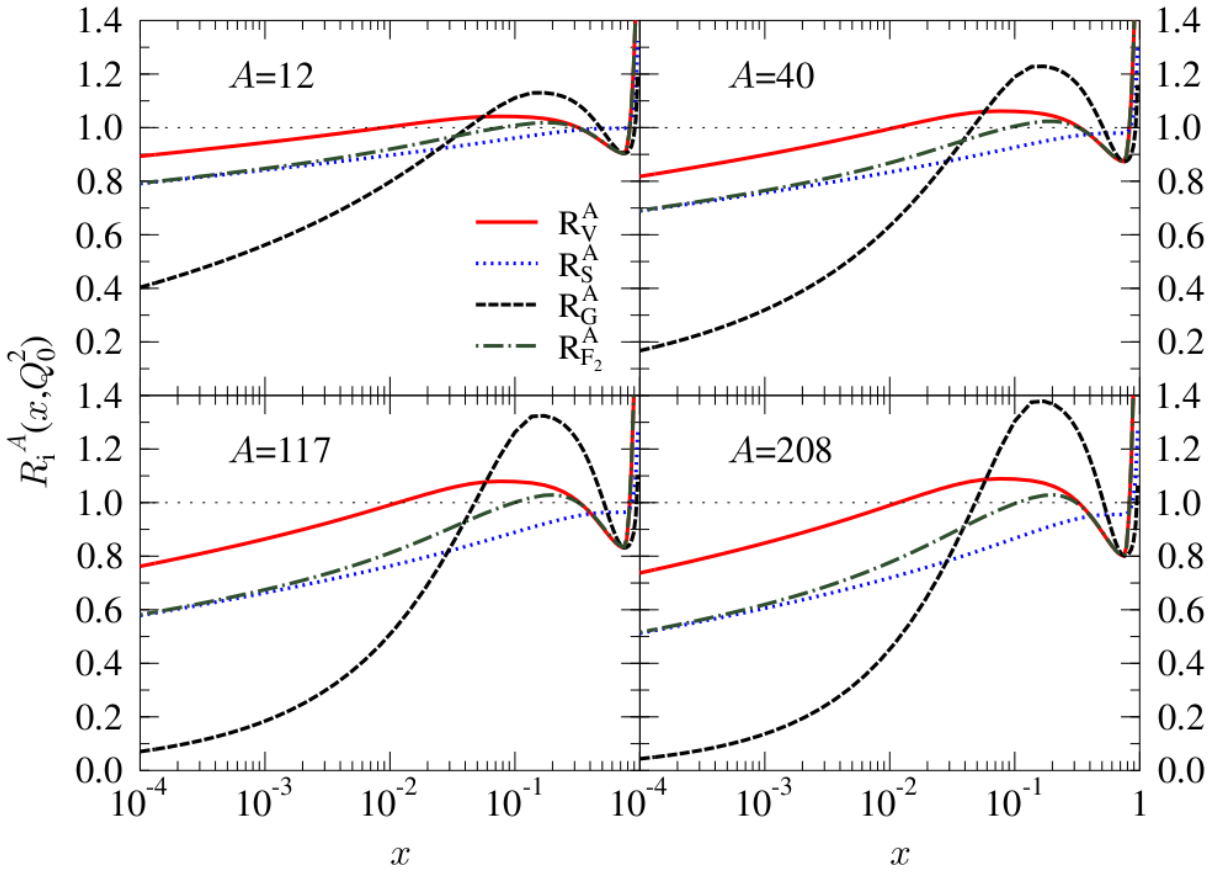
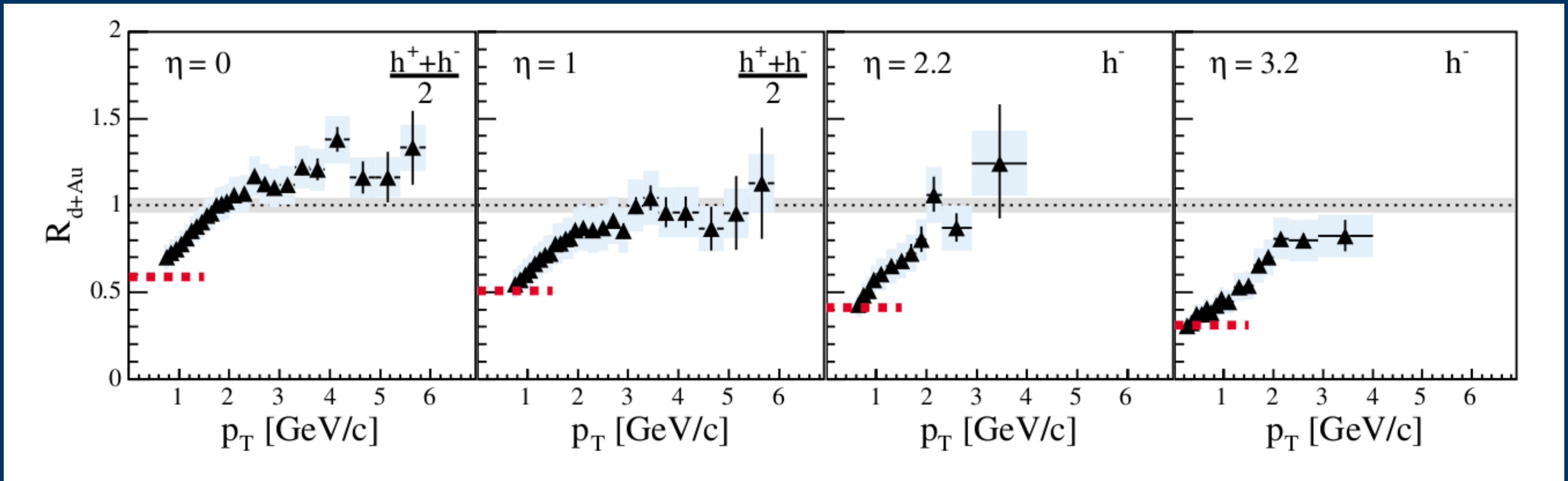


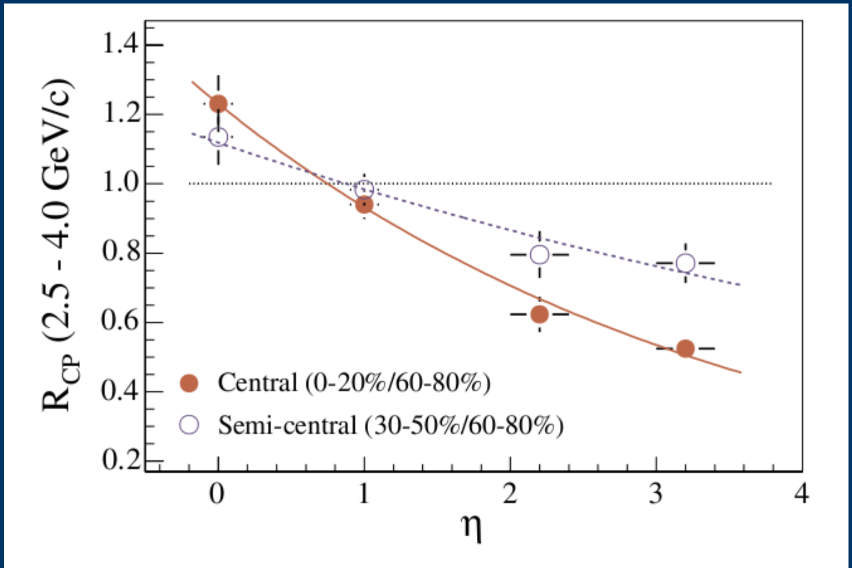
Figure 2: The nuclear modification factors R_V^A, R_S^A and R_G^A for C, Ca, Sn, and Pb at $Q_0^2 = 1.69\,\mathrm{GeV}^2$. The DIS ratio $R_{F_2}^A$ is shown for comparison.

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

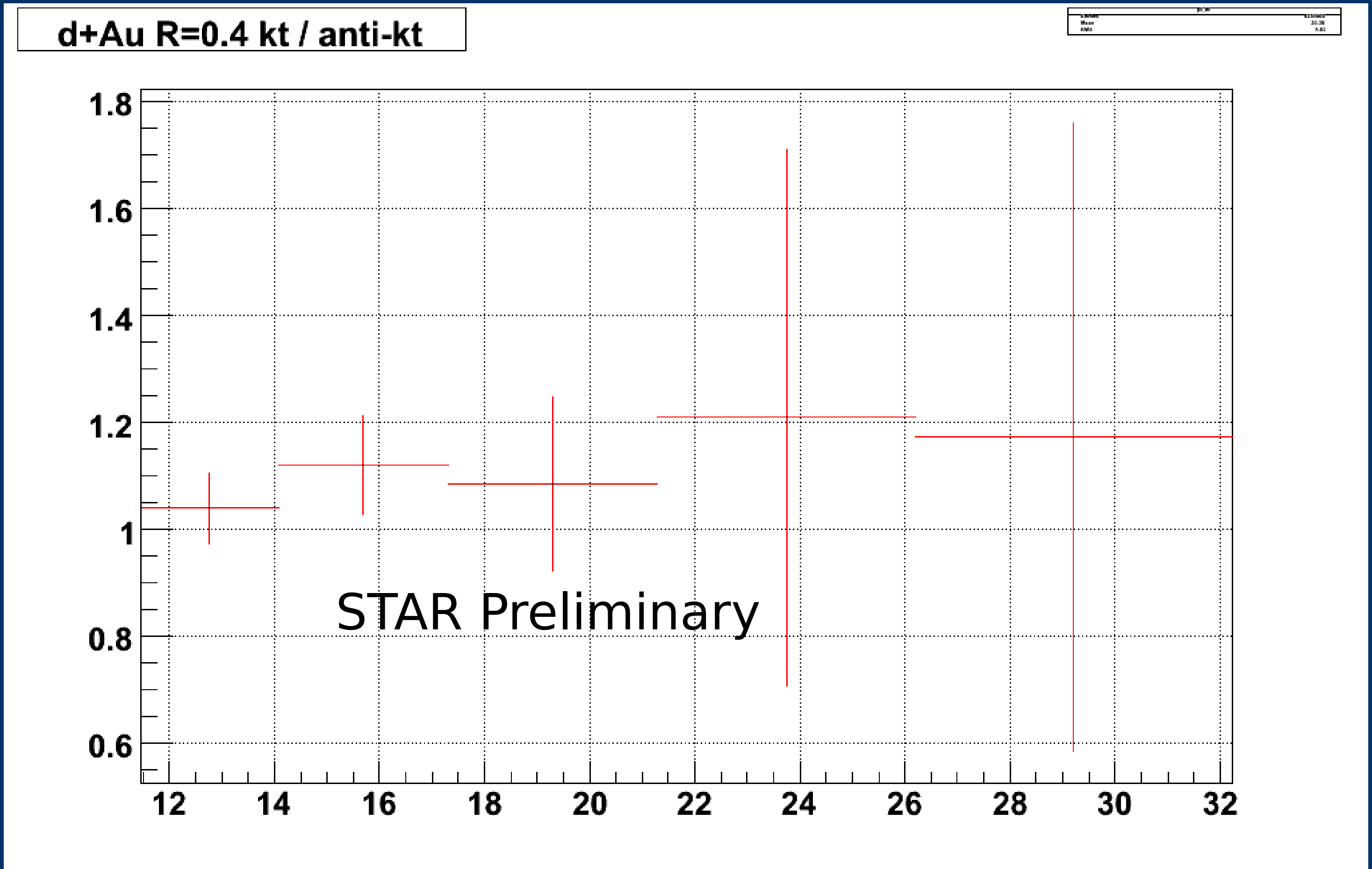
Single particle spectra

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





anti-kt comparison to kt



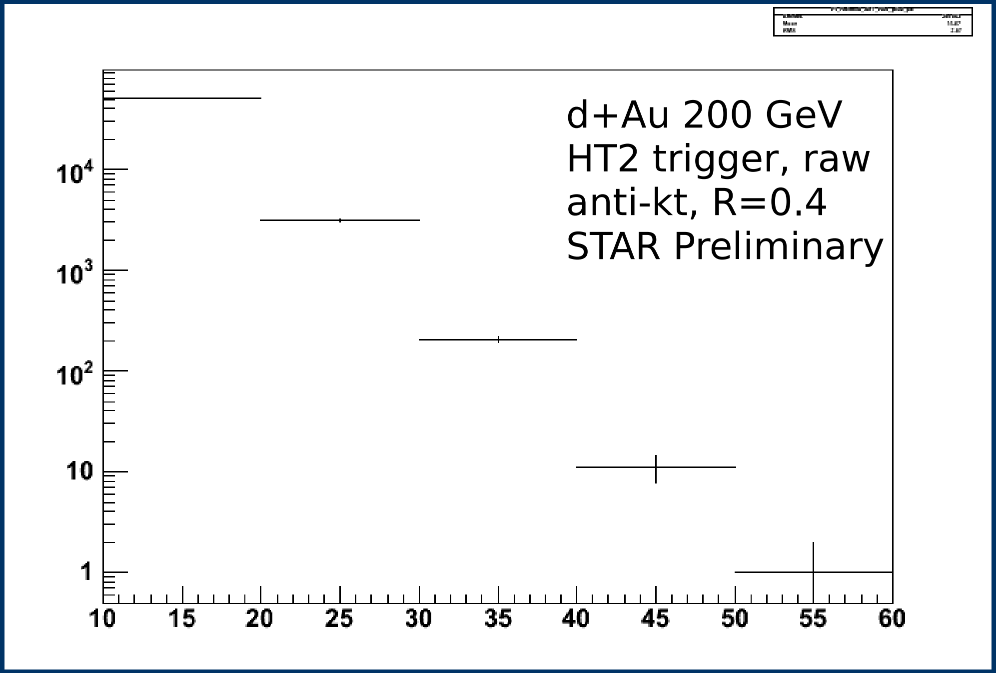
kt ~10% higher, consistent with kt jets having slightly bigger area!

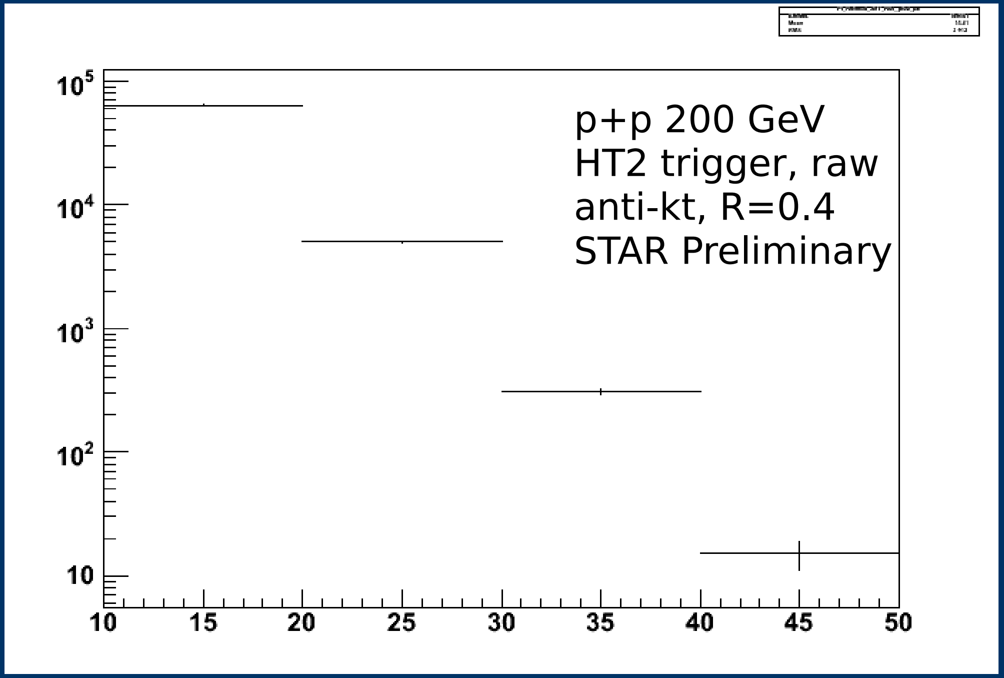
year 8 luminosities, raw HT spectra

note: no event (VertexZ), d+Au centrality cuts

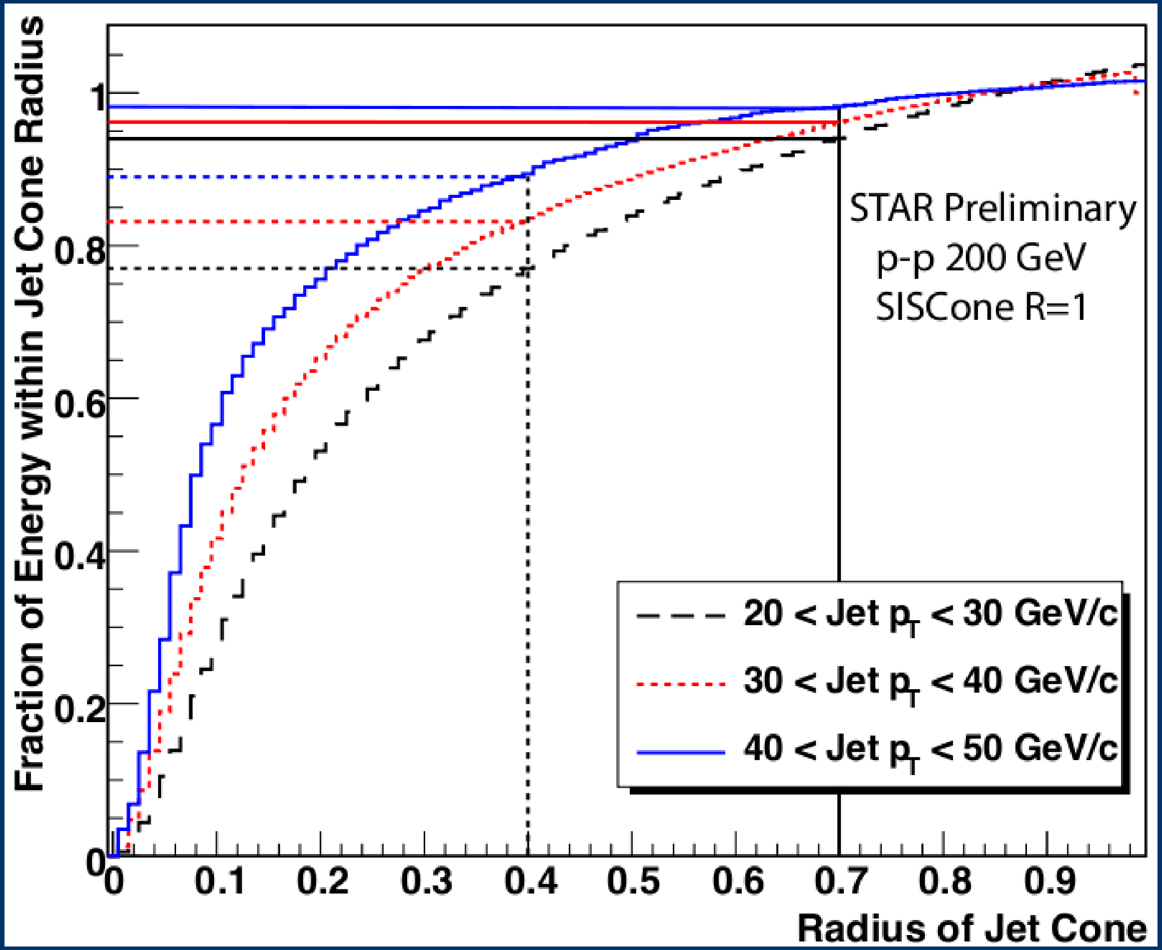
d+Au, HT trigger (bht2): 8 nb^-1 (p+p equvalent 3.2 pb^-1)

p+p, HT trigger (bht2): 2.7 pb^-1





resolution parameter



Effect of jet algorithm

different jet algorithms: same value of “R” doesn't mean result is the same
(as with JES uncertainty, small shift in jet p_T is huge shift in spectrum)

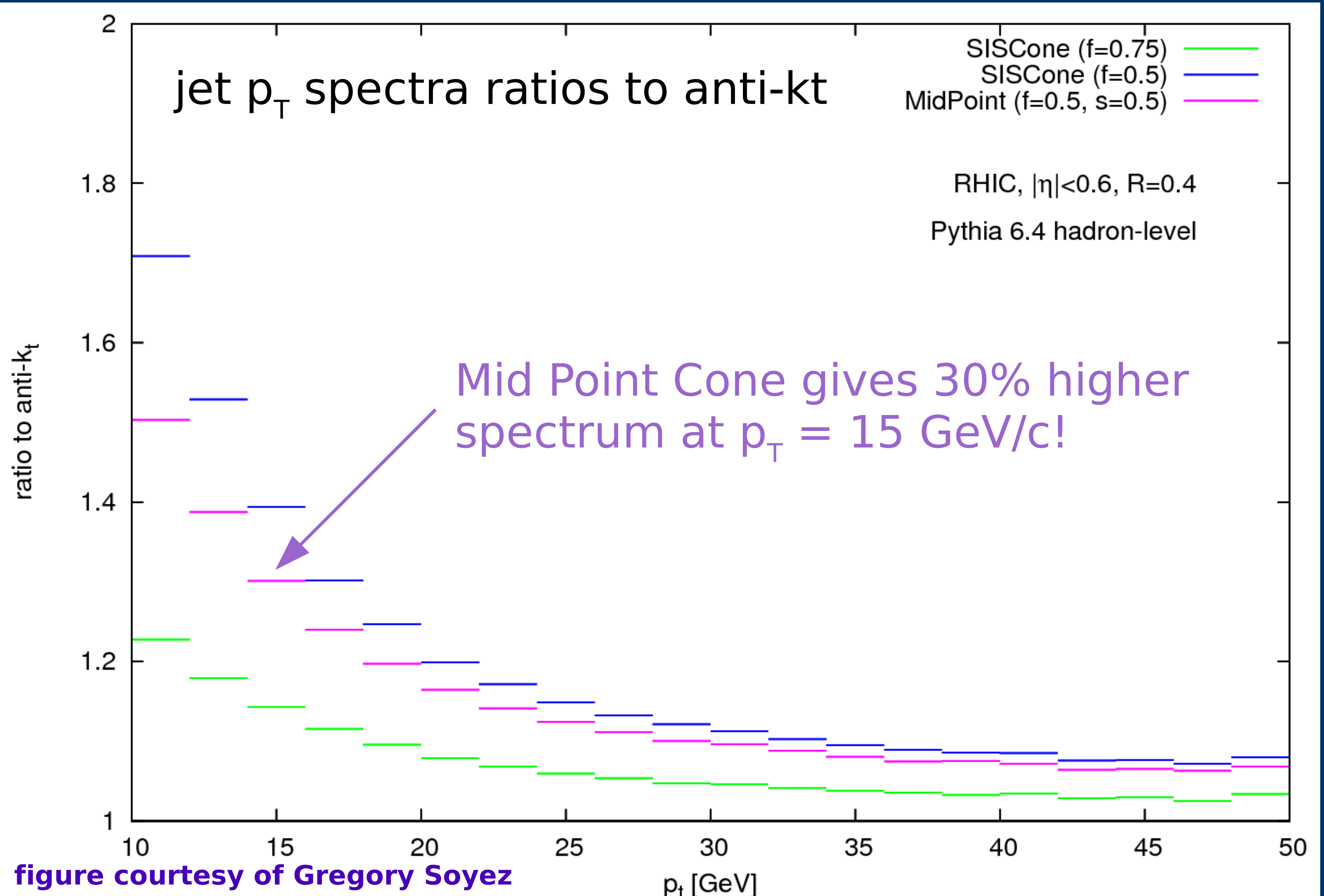
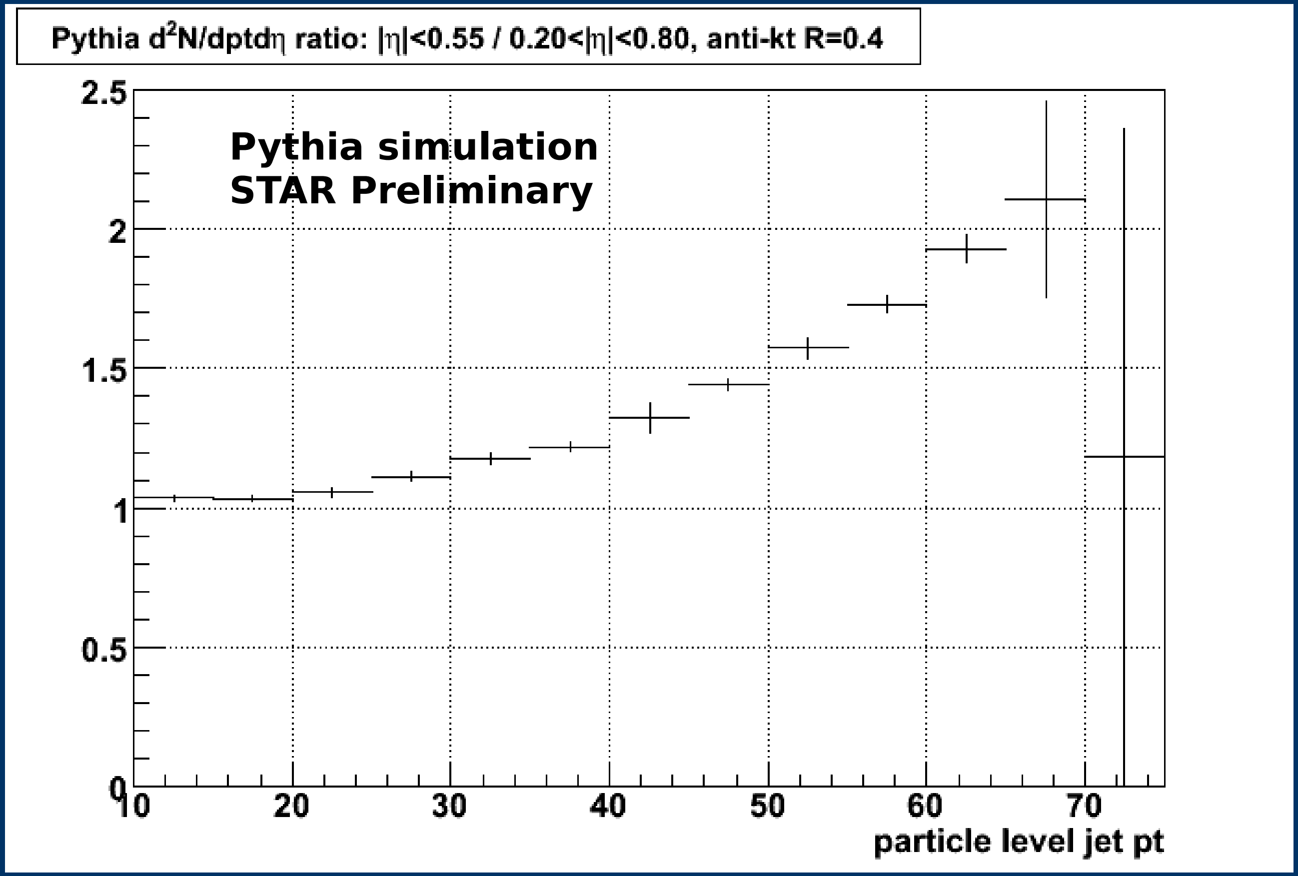


figure courtesy of Gregory Soyez

Pseudorapidity acceptance

jet dN/dη not flat: focusing towards η=0 for high jet p_T

|η|<0.55 vs 0.2<|η|<0.8: 50% effect at 50 GeV/c, negligible below 20 GeV/c:



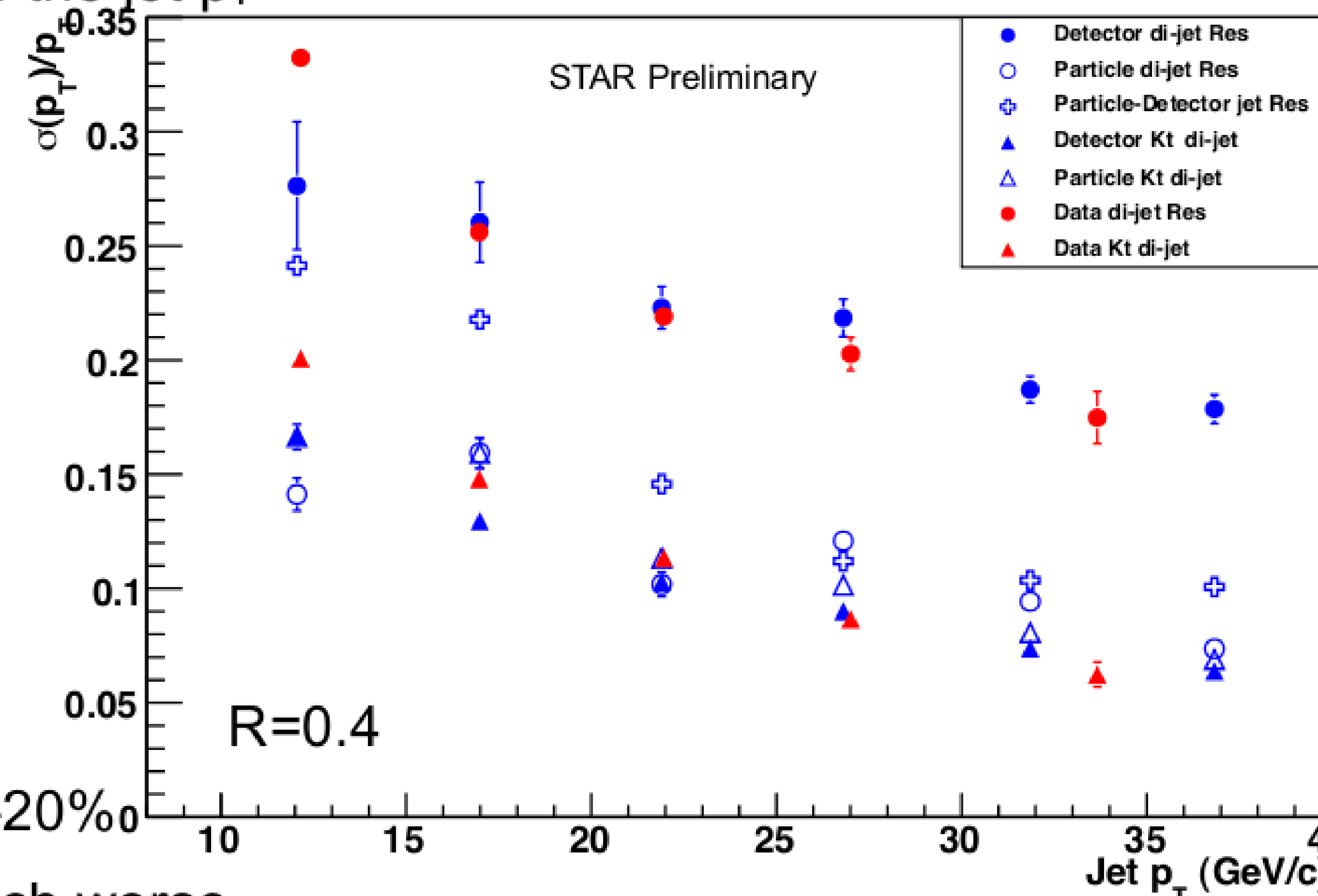
k_T and jet energy resolution

Study k_T, di-jet balance, and jet energy resolution

See talk by Jan Kapitan for more details on k_T

k_T and jet energy resolution interplay

- k_T measure involves the jet p_T



Study using PYTHIA

particle - pure PYTHIA

detector - PYTHIA +reconstruction

Allows to resolve detector effects from “physics”

- k_T - same at both levels
- di-jet particle ~ k_T
- Jet energy resolution 15-20%
- di-jet energy balance much worse
- Real data agrees with PYTHIA

Use PYTHIA to determine jet energy resolution